Economic growth implications for environmental quality indicators: A review and empirical analyses using a dynamic endogenous Environmental Kuznets Curve

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Abstract

Using a worldwide sample, this thesis examines the correlation between changes in environmental conditions and global economic growth, incorporating the growth rate of some control variables (population, financial development, merchandise trade, and regulations). One possible relationship is defined in the literature as the environmental Kuznets curve or EKC hypothesis. This hypothesis postulates an inverted-U association between some pollutants and economic output (Grossman & Krueger, 1991; Shafik, 1994).

To identify possible gaps in the hypothesis, this thesis uses a bibliographic mapping methodology to carry out a systematic literature review. It uses the Social Sciences Citation Index, an online academic citation database within the Thomson Reuters Web of Science™ platform from 1900 to 2017, and HistCite™ software to map the literature. From that, four research streams were identified: testing the basic EKC equation, critique of EKC, determinants of EKC, and review of EKC. An examination of more recent EKC literature (2005-2017) was also completed. The results suggest two new research streams, environmental indicators not previously considered and a new nexus of income and energy consumption. Also, fresh critiques of EKC and other factors affecting the EKC relationship were found in the more recent literature.

The second essay of this thesis analyses the impacts of global economic growth on the climate change phenomenon under a dynamic EKC context. I use changes in global CO_2 concentrations as a proxy for climate change in longitudinal panels of data from 177 countries from 1973 to 2013. I provide empirical evidence that global economic growth shows an inverted U-shape in relation to changes in CO_2 concentration using the ordinary least square (OLS) and fixed-effect panel conventional methods as well as the dynamic system generalized method of moments (GMM) methodology. The results were obtained by utilising the global environmental measure of CO_2 concentrations, a more representative indicator for analysing the EKC relationship.

Finally, the third essay seeks to empirically analyse the relationship between global economic growth and planetary boundary measurements. These planetary boundaries include global CO_2 concentration as a climate change proxy, threatened species as a biodiversity loss proxy, the total ozone as ozone depletion proxy, the mean of the surface ocean hydrogen ion concentration as ocean acidification proxy, and the global fertiliser consumption as biochemical cycles proxy. Under this integrated perspective, the EKC hypothesis is supported for climate change and ocean acidification panels using a dynamic system GMM approach. Meanwhile, biochemical cycles, ozone depletion and freshwater use, land change, and biodiversity loss boundaries do not support the existence of the EKC shape using the same methodology.

Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support and any other original research work used or reported in my thesis. The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

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Publications included in this thesis

No publications included.

Submitted manuscripts included in this thesis

No manuscripts submitted for publication.

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No other publications.

Contributions by others to the thesis

Both my advisors, Emeritus Professor Tom Smith and Professor Martina Linnenluecke, have contributed to the conception and design of the project, and the critical revision and edition of the multiple drafts included in this thesis.

Statement of parts of the thesis submitted to qualify for the award of another degree

None.

Research Involving Human or Animal Subjects

No animal or human subjects were involved in this research.

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CO_2 concentrations, gross domestic product, planetary boundaries, environmental Kuznets curve, conventional econometric methods, system generalized method of moments.

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List of Abbreviations

GHG	Greenhouse Gases
PB	Planetary Boundaries
EKC	Environmental Kuznets Curve
IPCC	Intergovernmental Panel on Climate Change
GMM	Generalised Method of Moments
OLS	Ordinary Least Squares
GDP	Gross Domestic Product
CO_2	Carbon Dioxide
ESRL	Earth System Research Laboratory
MT	Merchandise Trade
POP	Population
PR	Political Rights
CL	Civil Liberties
FD	Financial Development
ADF	Augmented Dickey-Fuller
CCO2	CO_2 concentrations
DWH	Durbin-Wu-Hausman
WDI	World Development Indicators

CHAPTER I

Introduction

Growing evidence suggests that greenhouse gas (GHG) emissions from human activities generate significant changes in climate conditions which affect economic well-being, productivity, and health (Deschênes & Greenstone, 2007; Hjort, 2016; Mendelsohn, Morrison, Schlesinger, & Andronova, 2000; Thao, Takagi, & Esteban, 2014). These conditions have raised significant concerns for economists looking at environmental issues and economic impact on the quality of the environmental (Dinda, 2004).

In that context, one line of research focused on an inverted U-shape relationship that may exist between environmental indicators and income output variables. This linkage is defined as the Environmental Kuznets Curve (EKC) and was debated for the first time by Grossman and Krueger (1991). They argued that environmental quality deteriorates during the early stages of economic development but after a certain tipping point quality starts to improve. During the first phase, economic growth requires more use of natural resources and therefore causes higher emissions and concentration of pollutants. This is because emitters are not able to pay for improving environmental standards. However, in the later stages and as income increases, the value of a healthy environment and more effective environmental regulations improve the environmental condition, resulting in a drop in emissions (Dinda, 2004).

Firstly, in chapter 2, this thesis seeks to analyse the EKC literature using a bibliographic mapping method of systematic review. Here, I identify the most cited publications, the main research streams, the relationship between these publications as well as gaps and future research on EKC theory. The review was limited to the 30 most cited articles, which were published from 1991 to 2004. The results suggest that EKC literature is divided into four main streams: (1) testing the basic EKC equation; (2) critiques of the EKC; (3) determinants of the EKC; and (4) review of the EKC.

Furthermore, a careful and detailed investigation was conducted to analyse the most recent EKC literature from 2004 to 2017. These publications exhibit similar trends to the ones found in the most cited articles, extending points (2) and (3) by identifying new econometric limitations and other factors affecting the EKC relationship. However, at the same time, the results suggest two additional streams (5) new environmental indicators, and (6) a new nexus: income and energy consumption. In this line of enquiry, the EKC research had a greater focus not only on methodological limitations and the estimations that new models made to address the main econometric gaps but also on the environmental indicators used to test the EKC relationship.

Consequently, the second study, presented in chapter 3, takes the methodological limitations presented in previous EKC estimations and a more appropriate environmental indicator to carry out empirical research with the aim of validating the presence of the EKC shape. The main econometric limitations detected follow the unidirectional assumption in the economic-environment relationship; the stochastic trend in the data and stationary; and the static specification in the EKC hypothesis.

Thus, this study includes an international sample of 177 countries between 1973 and 2013. It examines whether economic growth in these countries is associated in an inverted U-shape with changes in global CO_2 concentration levels. Authors suggest that one of the most contributed emitters for the greenhouse gases emission is the CO_2 emission (Akbostancı, Türüt-Aşık, & Tunç, 2009; Knight & Schor, 2014). In fact, the fifth announcement of the Intergovernmental Panel on Climate Change (IPCC) states that around 78% of the CO_2 emissions are produced from the fossil fuels combustion (IPCC, 2014).

Therefore, and considering the econometric limitations found in chapter 2, the study presented in chapter 3 uses the system generalised method of moments (GMM) to test the EKC shape, which covers the main econometric gaps unaddressed in the conventional techniques. Additionally, conventional methods such as ordinary least square (OLS) and fixed-effect panel model were used to check the differences in estimators.

Results using conventional methods support the EKC hypothesis as well as the findings under the system GMM approach. In particular, the coefficient resultant using system GMM techniques are similar to the Li, Wang, and Zhao (2016) study, which found evidence in favour of the EKC hypothesis using the same methodology but considering only one nation (China).

The present empirical study validates the EKC relationship in a worldwide sample that assumes there is one global EKC relationship. This suggests that countries with a low level of income belong to the initial stage of EKC; nations with middle-income levels are closer toward the peak of the curve's tipping point; and countries with a high level of income are located in the falling stage of the EKC. This places all of them under the assumption of invariance of the income-pollutant relationship (Dinda, 2004).

Furthermore, this study indicates that developed countries show the same patterns as the global sample. Nevertheless, states with low, upper-middle, and lower-middle levels of income do not show any EKC shape between economic output and changes in the global CO_2 concentration. This is because those countries are not capable of paying for environmental deterioration abatement with current levels of economic growth.

Based on the results of chapter 3, and in order to get an integrated perspective of global warming, the third study, showed in chapter 4, takes planetary boundaries (PB) to validate the EKC shape between the broader economy and comprehensive environmental quality measures. The PB is a relatively new concept introduced by Rockström et al. (2009b) who acknowledged a safe operating space for humanity with limits that could not be treated in isolation. Moreover, PB represent the control variables of the nine dimensions of global environmental change. These include climate change; ocean acidification; biodiversity loss; biochemical cycles of nitrogen and phosphates; land-system changes; global freshwater use; aerosol loadings; and chemical pollution.

The following study is different from the existing EKC literature. Most of the articles cover local pollutant and not a global pollutant to test the non-linear relationship between income and the environment. Additionally, they use methodologies that undressed all the main econometric limitations. Thus, due to the lack of evidence in this regard, the third study uses the same sample of chapter 3, composed of 177 countries around the world showing a global environmental view. The dependent variables are evaluated using seven different panels, whether for climate change, biodiversity loss, ozone depletion, ocean acidification, land used, freshwater use, or biochemical cycles. Rockström et al. (2009b) proposed measures for those seven dimensions and leave out two others: novel entities and atmospheric aerosol loading. Novel entities cover more than 100,000 substances as pollutants around the world, and therefore, it is impossible to measure each one of them. Therefore, novel entities boundary has not been determined yet (Raworth, 2012; Rockström et al., 2009b; Steffen et al., 2015). Moreover, the atmospheric aerosol loading is still complicated to define as a measurement. Thus, using these novel environmental measurements of seven ecological dimensions, the EKC hypothesis was empirically tested under a dynamic and endogenous context as the dynamic system GMM approach. Also, conventional econometric methods (OLS and fixed-effect panel model) have been utilized to test the same hypothesis in order to identify possible differences in coefficients.

Findings indicate that climate change and ocean acidification validate the existence of the non-linear relationship between the growth rate of the environmental indicator and the economic growth for 177 countries using a dynamic system GMM approach. In contrast, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change, and biodiversity loss do not support this non-linear association. In particular, biochemical cycles, ozone depletion, and freshwater use show a U relationship between their environmental measures and the economic growth using the same methodology. Land change exhibits a negative linear relationship, while biodiversity loss boundary reveals a positive linear association. Therefore, when an integrated perspective is considered as the planetary boundaries, the EKC is not supported for all environmental dimensions. Thus, not all dimensions support the issue that the economic growth increases together with environmental degradation, and then after a threshold, environmental quality starts to improve having less degradation.

The remainder of the thesis is organised as follows. The second chapter describes the systematic literature review of the EKC hypothesis through the bibliographic mapping method to identify the most cited publications and future research. Chapter three provides an EKC empirical analysis for a worldwide sample using dynamic econometric methodologies for the global CO_2 concentrations. Chapter four develops analyses for the planetary boundaries and the global economy implications under the EKC context, evaluating seven out of nine ecological dimensions. Finally, conclusions and future research are described in section 5.

CHAPTER II

A Systematic review for Environmental Kuznets Curve (EKC) literature

1. Introduction

The Earth has entered a new epoch, the Anthropocene[1], where humans are the dominant driver of changes and impacts on the human and natural systems (IPCC, 2014; Steffen et al., 2007). The influence of the exponential growth of human activities on the climate system is evident and could destabilise the biophysical system and therefore trigger significant environmental changes (Choi, Heshmati, & Cho, 2010; Rockstrom et al., 2009a) such as heat waves, droughts, flooding, cyclones and wildfires (IPCC, 2014).

A scientific group that includes the Intergovernmental Panel on Climate Change (IPCC), and the World Meteorological Organization has reached a consensus that climate change can be attributed to anthropogenic influence from industrial, agricultural, transport, and other human activities (Deschênes & Greenstone, 2007; IPCC, 2007; Tapia & Carpintero, 2013).

Economic literature has been debating climate change and its consequences on the global economy since the 1980s (Tapia & Carpintero, 2013). One hypothesis on the link between the economy and environmental quality is the environmental Kuznets curve, which started in the early 1990s.

Originally, the “Kuznets curve” (KC) was developed by economist Simon Kuznets (1955). Kuznets identified a historical relationship between a measure of inequality in the distribution of income and income growth during the 1940s. His hypothesis suggested an inverted U association between per capita growth and income distribution,

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[1] Anthropocene term has been introduced for the current geological epoch to emphasize the central role of humankind in geology and ecology (Steffen, Crutzen, & Mcneill, 2007).

meaning that as there was economic growth, economic inequality would initially increase, then decrease over time.

From the KC, the EKC concept was debated by Grossman and Krueger (1991) for the first time. They identified a non-linear relationship between income and precise measurements of environmental quality, proposing an inverted U association between these variables. Their theory suggested that the per capita gross domestic product (GDP) initially lead to greater environmental quality deterioration at low levels of income, but other factors may eventually cause an improvement in environmental quality with further economic development for two environmental measures: SO_2 and smoke (Grossman & Krueger, 1995; Selden & Song, 1994).

Since then, EKC literature has been extended by: testing different environmental indicators (local and global); identifying different explanations on why the EKC relationship is used; and applying different methodologies for EKC estimations.

Subsequently, it is necessary to have a clear understanding of how the EKC concept has been developed since the early 1990s. This chapter examines knowledge approaches and knowledge gaps in economic research on an inverted-U income-environment model. The bibliographic map and visualisation software *HistCite*™ were used for the analysis. In particular, this software was capable of providing a chronological map with the highly cited publications in a specific field of research (Linnenluecke, 2017). Specifically, this paper uses *HistCite*™ as a method to identify the origins and the structure of EKC literature, highlighting the highest cited publications for the business economic field and linkages between these publications.

The methodological steps used in this paper include: the data collection and data cleaning; manual additions to the dataset; and the citation statistics and bibliographic (Janssen, 2007; Janssen, Schoon, Ke, & Börner, 2006).

The results are given by a review which shows the main contributions of the highly cited EKC publications in the business economic field. Results suggest that EKC literature is subdivided into four streams: (1) testing the basic EKC equation; (2) critiques of the EKC; (3) determinants of the EKC; or (4) review of the EKC.

This paper extends both the critique and determinants streams of the EKC for future research. Furthermore, the study outlines new research streams and pathways for future research in the business economic studies that include (5) new environmental indicators, and (6) new nexus: income and energy consumption.

2. Research method

The bibliographic map methodology was used to identify the most influential articles on the Environmental Kuznets Curve (EKC) theory and their interrelations (Linnenluecke, Chen, Ling, Smith, & Zhu, 2017). The bibliographic map on the EKC hypothesis identified the origins and the structure the specific literature takes over time and highlighted the most cited works as well as citations between them (Janssen, 2007; Janssen et al., 2006). To get the data collection and analysis, the methodological steps outlined by Janssen (2007) and Janssen et al. (2006) were followed. These include data collection and data cleaning; manual additions to the dataset; and the citation statistics and bibliographic map. Other authors also have applied these steps into their systematics studies such as Linnenluecke et al. (2017) and Linnenluecke (2017).

The first step was a compilation of a comprehensive dataset of relevant publications and the references cited in each article. Publications were identified through a review of Boolean searches which used the Social Sciences Citation Index, an online academic citation database within the Thomson Reuters $Web\, of\, Science^{TM}$ platform (Linnenluecke, 2017). Using the $Web\ of\ Science^{TM}$ website, the search was conducted for publications with the term “Environmental Kuznets Curve” or “EKC” in the title, abstract, or keywords. Additionally, the searching was limited to publications classified as belonging to the area “business economics” and the document type “articles”. The time interval was not restricted. As a result, the search identifies all articles published from the origin of the EKC hypothesis in the early 1990s to 2017. The search identified a total of 493 records.

Once the data was obtained the 493 records were downloaded and imported into $HistCite^{TM}$ software (version 12.03.17) to be cleaned. For each article, the author(s) name(s); the title of the article; the name of the journal; citation detail (including volume, issue, page numbers); abstracts; keywords; and a full record of references cited were imported. The articles were then analysed by checking their title, abstract and keywords to determine whether to include or clean each one from the review analysis. In some cases, the full article was checked. As a result of the data cleaning, 214 records were removed with 279 records left in the dataset.

Following the Janssen (2007) and Janssen et al. (2006) methodological steps, the second stage was to incorporate relevant articles manually from records that were not included. That covered articles which did not meet the search criteria or were in publication sources not indexed in the $Web\ of\ Science^{TM}$ database. Likewise, a relevant record might not be included when limiting the search to the field of business economics. To identify those publications, the references cited by record collection within the dataset were used. That allowed us to identify those that had been cited by other articles but were not included in the data collection (Linnenluecke, 2017). The cited reference identified 24 additional publications (see Table 1) which were incorporated manually into the final review analysis (including two relevant working papers that are the highest cited papers of the EKC hypothesis).

In the same stage, it was necessary to unify the citation record due to inconsistencies in journal styles or incorrect spellings of author names. $HistCite^{TM}$ software cannot visualise the linkage in these inconsistencies with the correct citation. Consequently, with the manual additions, the final review analysis contained 305 records across 86 sources, published between 1991 and 2017 (cut off July 2017 which included online first articles published up to this point).

Table 1: Manual Additions for the dataset

No.	Author(s)	Publication Details	LCS	GCS	Reason for Manual Adding
1	Grossman and Krueger (1991)	NBER Working Paper Series (Working Paper No. 3914)	76	266	The publication does not refer to ‘Environmental Kuznets Curve' or ‘EKC’ but identify an inverted-U shape between income and environmental quality, which is the basis for future work on EKC hypothesis.
2	Shafik (1994)	Oxford Economic Papers	151	654	The publication does not refer to ‘Environmental Kuznets Curve' or ‘EKC’ but identify an inverted-U shape between income and environmental quality, which is the basis for future work on EKC hypothesis.

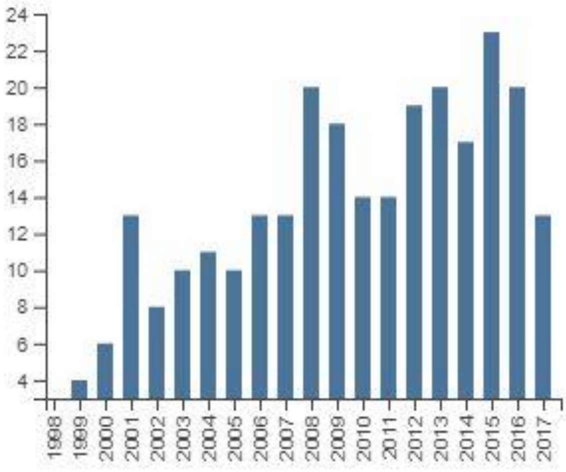
3	López (1994)	Journal of Environmental Economics and Management	40	175	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title, abstract or keywords.
4	Selden and Song (1994)	Journal of Environmental Economics and Management	130	732	Not captured in initial search
5	Arrow et al. (1995)	Science	76	615	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title. Also, it is a policy forum.
6	Holtz-Eakin and Selden (1995)	Journal of Public Economics	86	369	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title, abstract or keywords.
7	Selden and Song (1995)	Journal of Environmental Economics and Management	38	141	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title. Also, it is a policy forum.
8	Grossman and Krueger (1995)	The Quarterly Journal of Economics	172	1364	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title. Also, it is a policy forum.
9	Moomaw and Unruh (1997)	Environment and Development Economics	19	111	Not captured in initial search
10	Carson, Jeon, and McCubbin (1997)	Environment and Development Economics	21	82	Not captured in initial search
11	Vincent (1997)	Environment and Development Economics	25	99	Not captured in initial search
12	de Bruyn (1997)	Environment and Development Economics	25	78	Not captured in initial search
13	McConnell (1997)	Environment and Development Economics	27	94	Not captured in initial search
14	Ekins (1997)	Environment and Planning A	29	161	Not captured in initial search
15	Panayotou (1997)	Environment and Development Economics	47	234	Not captured in initial search
16	Cole, Rayner, and Bates (1997)	Environment and Development Economics	56	279	Not captured in initial search
17	Rothman (1998)	Ecological Economics	23	168	Not captured in initial search
18	Stern (1998)	Environment and Development Economics	31	129	Not captured in initial search
19	Schmalensee, Stoker, and Judson (1998)	The Review of Economics and Statistics	33	213	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve'

					or 'EKC' in the title, abstract or keywords.
20	Stokey (1998)	International Economic Review	53	252	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title, abstract or keywords.
21	Jones and Manuelli (2001)	Review of Economic Dynamics	20	54	The publication was not captured in the initial search as it does not refer to 'Environmental Kuznets Curve' or 'EKC' in the title, abstract or keywords.
22	Copeland and Taylor (2004)	Journal of Economic Literature	34	419	Not captured in initial search
23	Dinda (2004)	Ecological Economics	76	614	Not captured in initial search
24	Jalil and Mahmud (2009)	Energy Policy	20	242	Not captured in initial search

3. Results: Citation Statistic and Bibliographic Map

Figure 1 shows the yearly output of research on the Environmental Kuznets Curve (EKC) in the field of business economics published. In the early 1990s, little was known about the empirical relationship between the level of emissions or concentrations of environmental indicators with the economic outcome variables. One reason was the lack of data on air pollution in comparable basis for a sample of countries (Grossman & Krueger, 1991). However, since the EKC hypothesis spread in economic literature that global warming, through air pollutants, was associated with economic growth, scholars have extended the research to examine this relationship (Chua, 1999).

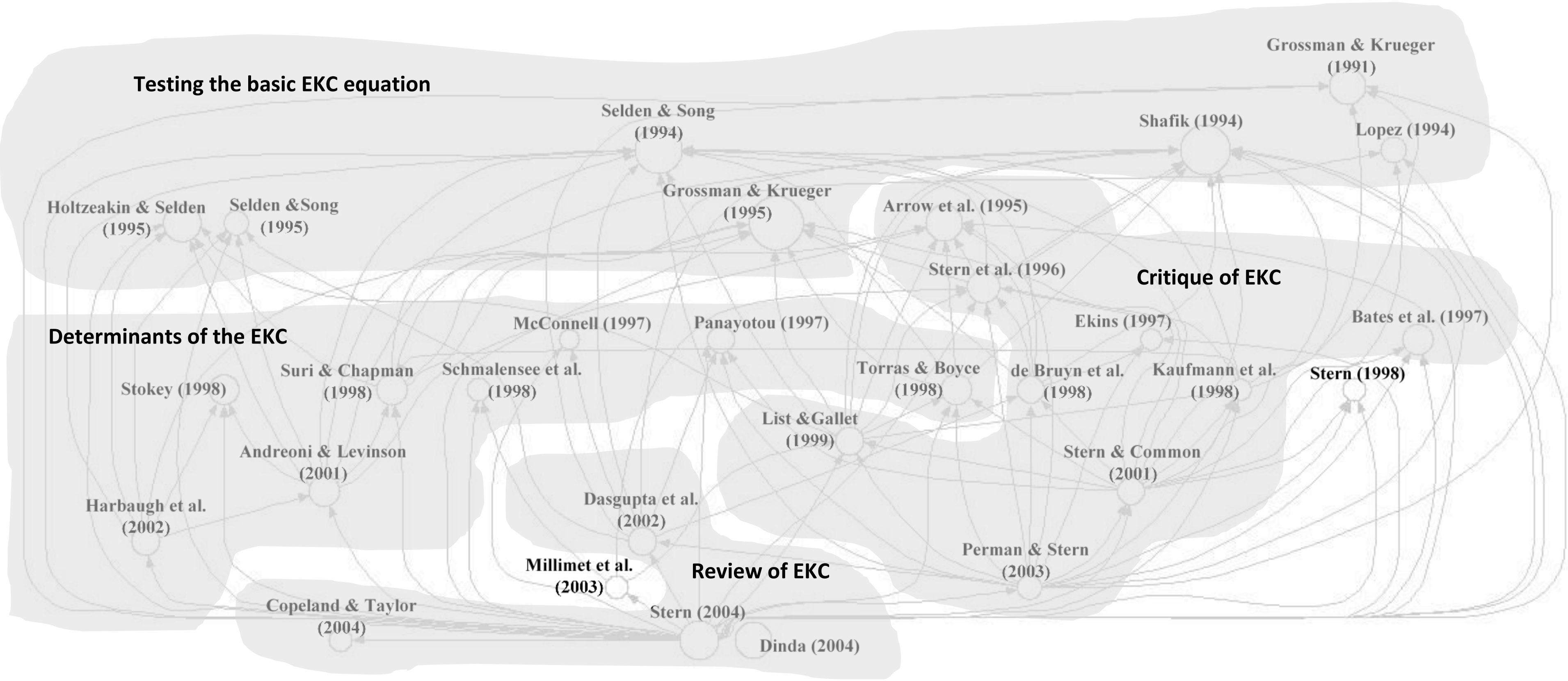
Figure 1: Total publications yearly



Source: results from Web of Science Core Collection between 1990-2017

The citation map generated with $HistCite^{TM}$ (see Figure 2) showed the most highly mentioned publications within the dataset along a timeline (left side of figure). Records are displayed as circles, and citation linkages in the dataset are represented as arrows. The size is one relevant aspect of the map because it represents the quantitative importance of a specific publication in the image. The bibliographic mapping allows the identification of knowledge development and knowledge gaps in a field; for example, the EKC hypothesis. The count and details for each node represents each of the most cited publication in Fig. 2 is provided in Table 2.

Figure 2: Approaches in Environmental Kuznets Curve Research



In this paper, the review was limited to the top 30 cited publications however there was no specific rule on how many records should appear in the analysis (Linnenluecke et al., 2017). In this case, the cut- off of the data set was set by the Local Citation Score (LCS), which referred to the number of each publication's citations in the dataset. This LCS was given by the number of citations ≥ 27.

Table 2: List with highly cited papers in the paper citation network

No.	Author(s) and Year	Journal/Publication Details	LCS	GCS
1	Grossman and Krueger (1991)	NBER Working Paper Series (Working Paper No. 3914)	76	266
2	Selden and Song (1994)	Journal of Environmental Economics and Management	130	732
3	López (1994)	Journal of Environmental Economics and Management	40	175
4	Shafik (1994)	Oxford Economic Papers	151	654
5	Arrow et al. (1995)	Science	76	615
6	Holtz-Eakin and Selden (1995)	Journal of Public Economics	86	369
7	Grossman and Krueger (1995)	Quarterly Journal of Economics	172	1364
8	Selden and Song (1995)	Journal of Environmental Economics and Management	38	141
9	Stern, Common, and Barbier (1996)	World Development	67	383
10	Cole et al. (1997)	Environment and Development Economics	56	279
11	McConnell (1997)	Environment and Development Economics	27	94
12	Panayotou (1997)	Environment and Development Economics	47	234
13	Ekins (1997)	Environment and Planning A	29	161
14	Stern (1998)	Environment and Development Economics	31	129
15	Schmalensee et al. (1998)	Review of Economics and Statistic	33	213
16	Stokey (1998)	International Economic Review	53	252
17	Torras and Boyce (1998)	Ecological Economics	60	319

18	de Bruyn, van den Bergh, and Opschoor (1998)	Ecological Economics	48	207
19	Suri and Chapman (1998)	Ecological Economics	56	267
20	Kaufmann, Davidsdottir, Garnham, and Pauly (1998)	Ecological Economics	28	100
21	List and Gallet (1999)	Ecological Economics	49	158
22	Stern and Common (2001)	Journal of Environmental Economics and Management	44	207
23	Andreoni and Levinson (2001)	Journal of Public Economics	58	197
24	Dasgupta, Laplante, Wang, and Wheeler (2002)	Journal of Economic Perspectives	50	338
25	Harbaugh, Levinson, and Wilson (2002)	Review of Economics and Statistic	50	228
26	Perman and Stern (2003)	Australian Journal of Agricultural and Resource Economics	37	143
27	Millimet, List, and Stengos (2003)	Review of Economics and Statistic	32	108
28	Copeland and Taylor (2004)	Journal of Economic Literature	34	419
29	Dinda (2004)	Ecological Economics	76	614
30	Stern (2004)	World Development	93	716

4. Approaches in Environmental Kuznets Curve Research

In this section, the main research streams regarding the Environmental Kuznets Curve (EKC) hypothesis are discussed (as shown in Fig. 2). The top of the figure reflected the early studies of the EKC hypothesis when it was debated for the first time. This is “Testing the basic EKC equation” research stream. At the bottom of Fig. 2 the later research stream, “Review of EKC” is shown.

Following the review and because the bibliographic mapping approach considers the highly cited articles, this essay also includes and summarises new research published from 2005 to 2017 into two of these streams (Critique of the EKC and Determinants of the EKC). That process identified two new streams (New environmental indicators, and the New Nexus: Income- energy consumption) in the EKC literature. Subsequently, new research directions that had not yet attracted many citations in the map were recognised. This might be useful for new research opportunities and pathways for future research.

4.1 Testing the basic EKC equation

In 1955, economist Simon Kuznets identified a historical inverted U-shaped relationship between levels of inequality and economic growth in the 1950s. This was known as the Kuznets Curve (KC). Based on KC, the Environmental Kuznets Curve (EKC) concept was debated for the first time in the early 1990s, giving rise to the first research stream at the top of Fig. 2. This concept says when per capita income increases with the environmental degradation and then exceeds a certain turning point, the level of environmental quality or pollutant emissions begin to decrease (Grossman & Krueger, 1991; Selden & Song, 1994; Shafik, 1994).

Among these early empirical analyses, we found the most relevant article in the EKC theory, the working paper ‘The environmental impacts of the North America Free Trade Agreement (NAFTA)’ by Grossman and Krueger (1991), which was then published in 1993. Grossman and Krueger (1991) studied how air quality varied with economic growth using the Global Environmental Monitoring System (GEMS)[2]. They evaluated three air pollutants in a cross-section of urban areas in 42 countries. Two of the environmental indicators, suspended particular matter (SPM) and SO_2, show an inverted U-shape when looked at with economic growth. That meant, the level of pollutant rose with per capita income at low concentrations and then declined with higher levels of per capita income.

Separately but at the same time as Grossman and Krueger’s research, the working paper ‘The World Bank’s 1992 World Development Report’ was published in 1994 (Shafik, 1994). It explored the same relationship in a sample of 149 countries for the period 1960-1990. Since different income levels were considered in the study, Shafik

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[2] GEMS is operated by United Nations Environment Programme in collaboration with the World Health Organization since 1976. The role of these organisations is to monitor closely the concentration of several pollutants in a cross-section of urban areas using standardised methods of measurement (Grossman & Krueger, 1991).

concluded most of the middle-income countries tended to improve their environmental quality, following the U-inverted income-environment relationship.

Selden and Song (1994) investigated the U-inverted linkage between economic development and four important air pollutants, SPM, SO_2, oxides of nitrogen (NO_x), and carbon monoxide (CO) for a cross-national data panel. They found that NO_x and SO_2 supported the existence of the EKC hypothesis. Selden and Song pointed out that the main reason for this relationship might be because as income grows, countries with a higher standard of living, more protect the environment. Thus, they live and demand the higher quality of habitat, throughout changes in the composition of the demand and supply, a higher level of education, and the environmental awareness of the political system.

Following the same context, Selden and Song (1995) and López (1994) use an alternative model to examine the income-environment relationship. Both papers used the neoclassical environmental growth model to provide a dynamic connection between pollution, abatement effort and economic development (Selden & Song, 1995).

Later, Grossman and Krueger (1995) retested and also reported an inverted U-shaped association between per capita gross domestic product (GDP) and additional dimensions of environmental degradation. The factors included: urban air pollution; the state of the oxygen regime in the river basin; faecal contamination of watersheds; and contamination of river basins by heavy metals.

Under this stream, Holtz-Eakin and Selden (1995) were the first to examine the inverted U-shape for economic development and carbon dioxide (CO_2) emissions as a global environmental measure. They used an uneven panel of 130 countries from 1951 to 1986. Holtz-Eakin and Selden suggested that as economies grew and wealth increased, the marginal propensity to emit (MPE) CO_2 diminished. They forecasted annual emissions growth and concluded the average growth rate of emissions would be 1.8% annually until 2025.

The basic EKC equation has been tested using different samples for different environmental indicators (local and global) which have shown evidence in favour of an inverted U-shape relationship.

4.2 Critique of EKC

The second stream of research, the *Critique of EKC* is on the right side of Fig. 2. The results obtained during different empirical analyses for estimating the basic EKC relationship not only depended on the environmental indicators but also the methodologies used for each estimation.

In 1995, Arrow et al. (1995) opened a new field on the EKC hypothesis with their critiques. Some relevant factors for appropriate interpretation of the inverted U-shaped relationship between income and environment were considered. They emphasised the income-environment link had been commonly tested for environmental indicators that involved local short-term costs, not for the accumulation of waste stock. In fact, the EKC relationship only seemed to be present in some environmental indicators (List & Gallet, 1999).

Cole et al. (1997) found local measures instead of global ones seemed to be part of this critique where the EKC relationship might not be present. The literature showed empirical EKC analyses with several environmental indicators (nitrogen dioxide (NO_2), SO_2, SPM, CO, nitrate, CO_2, total energy use, chlorofluorocarbons (CFCs) and halons, methane, municipal waste and traffic) (Cole et al., 1997). The authors found the EKC relationship only existed for local air pollutants while indicators with more global impacts increased monotonically with the income or had predicted tipping points at a high level of per capita income.

Apart from the critique testing some specific environmental indicators, the EKC hypothesis has several econometric gaps. Stern et al. (1996) called into question the simultaneity assumption between GDP and CO_2 emissions and identified the first, and one of the most critical, problems of EKC empirical analysis. They challenged the fact that the linkage between the environmental indicators and economic growth had a unidirectional causality from income to CO_2 emissions. They argued it was not enough to focus on keeping the relationship from the environment to the economic growth in the EKC hypothesis because the results obtained in these studies would be estimated as a single equation model that produce biased and inconsistent estimates.

Studies such as Cole et al. (1997), Ekins (1997), and Kaufmann et al. (1998) and more recent empirical research including Jaunky (2011), Shen (2006) and Omri, Daly, Rault, and Chaibi (2015) agreed with Stern et al. All these authors also referred to the need to consider the simultaneity assumption instead of unidirectional causality (which left out the premise of environmental indicator to income) for EKC estimations because early studies estimating the basic equation were unable to address it. Furthermore, Carson (2010) and Jaunky (2011) state that income should not be considered exogenous because a type of endogeneity may well exist (Carson, 2010; Jaunky, 2011). In other words, because the exogeneity assumption means the regressors are not related to the error process, the endogeneity assumption would violate the strict exogeneity, generating inefficient EKC estimates and may lead to spurious results.

New critiques have arisen regarding the stochastic trend in the data as econometric problems. Classical regressions in previous estimations assume that the variables considered in the model were stationary (Perman & Stern, 2003). Stern (2004) states: "(…) the EKC literature is econometrically weak. In particular, little or no attention has been paid to the statistical properties of the data used- such as serial dependence or stochastic trends in time-series" (p 2). As such, more recent studies ignored the possibility of the existence of unit roots in the data or the non-stationary in variables of interest that might cause spurious regressions (Jaunky, 2011).

Consequently, with the aim of working on improvements on the EKC early estimations, authors have developed new methodologies to test the income-environment connection process. For example, Cole et al. (1997) utilised the generalised least squares (GLS) methodology to correct heteroscedasticity and autocorrelations identified in the estimate reduced-form relationships.

Similarly, considering statistical particularities from previous studies, de Bruyn et al. (1998) used an alternative growth model for three types of emissions, including $\mathrm{CO_2}$ emissions, in four countries (Netherlands, UK, USA and Germany). Apart from the positive correlation between time patterns and economic growth identified, the study suggested emissions were associated positively with economic growth.

Others, such as Stern and Common (2001) with a large and global sample of sulphur, carried out the EKC estimation using first differences. This was due to these differences having much better statistical properties than level models. In particular, first differences reduce the serial correlation and remove the country effect showed in the level models (Stern & Common, 2001).

New appropriate techniques have also been developed to consider the other econometric limitations specifically for the stochastic trend of the data. The literature addressed the issue by using a co-integration econometric technique to test the EKC hypothesis (Esteve & Tamarit, 2012b; Jalil & Mahmud, 2009; Narayan & Narayan, 2010; Perman & Stern, 2003). However, Wagner (2008) argued the methodology ignored an additional econometric problem: cross-sectional dependence. In particular, the author stated that the cross-sectional dependence in the data invalidated the use of cointegration techniques. Furthermore, a more recent paper, using the approach of cointegration, identified that coefficients proved to be time dependent and therefore EKC is not time invariant. This meant these methodologies were not appropriate to analyse the EKC relationship (Apergis, 2016).

In particular, Shen (2006) used a simultaneous equation model of Two-Stage Least Squares (2SLS) Regression Analysis to address the exogeneity assumption under a single equation. The author identified that EKC only existed in water pollutants, instead of using a single polynomial equation where the relationship would be given in all pollutants except for SO_2. Moreover, Omri et al. (2015) conducted a study using the simultaneous-equation models with both time series data and panel data of the 12 Middle East and North Africa (MENA) countries from 1990-2012. Results also verified the existence of the EKC hypothesis.

Some additional factors have been considered inside this research stream. List and Gallet (1999) emphasised that if the turning points were at very high-income levels, the environmental benefit of economic growth might not occur. This would be a significant issue if the estimations were generalised as a global measurement. They also revealed that when additional variables were incorporated into the model, the estimated coefficients appeared to diminish in significance or not even show an inverted U-shape income-environment linkage.

The critique of EKC stream considers some relevant issues in EKC methodologies previously not utilised. Therefore, new approaches have been developed to address this issue in recent methodologies. For example, cointegration techniques to discuss the stochastic trends in the data, or simultaneous equations that have been used to consider the feedback between the two variables instead of a single equation model.

4.3 Determinants of the EKC

The third stream of research is *Determinants of the EKC*, which considers several different factors that affect or contribute to the EKC. They display some viable explanations of why the inverted U-shape relationship exists between an economic measure and some environmental indicators. We found the main determinants that explain the EKC, were:

1) the income elasticity of environmental quality demand;
2) an economy scale, technological and compositional effects;
3) international trade;
4) environment regulations; and
5) empirical factors for estimations.

Regarding the first determinant, McConnell (1997) conducted a study that focussed on the role of preferences and the income elasticity of demand for environmental degradation under the EKC context. Particularly, the study observed that some EKC relationships were consistent with the high-income elasticity of environmental quality demand. A more recent study (Guo, 2017) estimating the income-emissions relationship and the household income disparity and CO_2 emissions, referred to a positive indirect effect that household income inequality affected CO_2 emissions through household consumption.

The second factor, the scale, technological and compositional effects on economies under the EKC hypothesis, was proposed for the first time by Grossman and Krueger (1991). Their contention was more economic growth implied more input and therefore more natural resources, generating more environmental waste and emissions. According to this research, the previous process showed a scale effect that harmed the environmental quality but at the same time had a positive impact through a composition effect.

The composition effect was when the economy started to rise, the structure of the economy started to change and cleaner technologies to produce with less pollution became more prevalent (Grossman & Krueger, 1991). Under this context, Stokey (1998) studied long-run growth considering not only technology determinants but also household preferences to explain the inverted U-shaped income-environment relationship. He assumed that below the cut off economic activity only the dirtiest technology could be used and therefore, the economic growth would increase with the pollution until the threshold was crossed where cleaner technologies could be used.

Andreoni and Levinson (2001) suggest the EKC hypothesis could be derived directly from the technological link between consumption of a desired good and reduction of its undesirable by-product. That meant the EKC could be explained with increasing returns to scale in the abatement technology. While Lantz and Feng (2006) found technological change did not support the EKC relationship in a flexible model for the period 1970-2000.

The third determinant was international trade. According to Suri and Chapman (1998), the impact of the actual movement of goods between countries might be another factor affecting the EKC relationship. They quantified the effect of the trade of manufactured goods with the income-environment linkage in a pooled cross-country and time data series. Their results suggested that exports of manufactured goods by industrialised countries were an essential factor in producing the upwards slope in the EKC relationship, while the imports by industrialised countries have been for the downward slope fraction. The latter because these countries have been able to reduce commercial energy consumption by importing goods. More recent studies such as Ren, Yuan, Ma, and Chen (2014), Kasman and Duman (2015), and Kander et al. (2017) also examined international trade in their estimations and concluded that the trade openness was statistically significant in EKC estimations. In particular, Kander et al. (2017) found that the U-shape curve is reduced but does not disappear for both countries studied (Germany and Britain) when energy intensity without trade adjustments were considered.

Environment regulations were also identified as one of the main determinants affecting the EKC hypothesis. Apart from investigating the possible causal connections between changes in income distribution and changes in environmental quality, Torras and Boyce (1998) found that literacy, political rights and civil liberties have a significant effect on environmental degradation in countries with low-income. In the same vein, Panayotou (1997) examined policy intervention in the EKC analysis. He concluded that the quality of policies and institutions could make a reduction in the environmental degradation possible at a low-income level and accelerate the enhancement at the high-income level, helping to "flatten" EKC.

One year later, Stokey (1998) compared several regulatory schemes to see which was a more efficient path to contribute to the EKC relationship. The result suggested that tax and voucher schemes had advantages over direct regulations to regulate pollution. To extend the literature in this field of determinants, Markandya, Golub, and Pedroso-Galinato (2006) conducted their study to see if the implementation of air pollution regulations over time had any impact on the inverted-U shape. They concluded that environmental regulations to reduce environmental degradation could influence the shape of the EKC.

On the other hand, this stream included those factors that affected the empirical estimations of the EKC hypothesis. For instance, Harbaugh et al. (2002) carried out a study to examine the robustness of the EKC evidence. They considered the sensitivity to functional form to additional covariates besides income and changes in the countries, cities and years sampled. They concluded the estimations were highly sensitive to previous changes.

Meanwhile, M. Galeotti, Lanza, and Pauli (2006) evaluated its robustness with a different parametric setup and alternative data. They concluded that existing EKC evidence did not depend on the data and the alternative data supported the EKC hypothesis.

Under this stream, five main determinants have been identified in the highly cited publications. The main explanations to the EKC hypothesis or the main factors contributing the EKC relationships were: the income elasticity of environmental quality demand; the scale, technological and compositions effects of the economies; international trade; the environmental regulation; or the empirical factors for estimations. Currently, studies maintain the trend toward these determinants. However, new factors are being considered.

4.4 Review of the EKC

All articles in the fourth stream review the EKC hypothesis. These publications placed on the left side of Fig. 1 display a vast experiment examining the existence of the EKC hypothesis focused on micro and macro levels and their mixed results. In 2002, Dasgupta et al. (2002) reviewed the arguments and evidence about the position, shape and mutability of the EKC hypothesis. Similarly, in 2004, Copeland and Taylor (2004) carried out an extended critical review of the EKC, considering the theoretical and empirical basis for understanding how this evidence might contribute to policy debates. Dinda (2004) also included the methods utilised in the EKC estimations and the policy implications in her review, as did Stern (2004). In particular, Stern (2004) followed the development of the EKC concept in chronological order. A more recent study by Kijima, Nishide, and Ohyama (2010) also conducted a review of everything related to the EKC literature, showing static and dynamic models, theoretical models, and the background of the EKC hypothesis. There are a number of studies which are reviewing the EKC literature, showing all the methodologies applied, different samples utilised and all determinants explaining the EKC hypothesis.

5. Directions for current research

EKC literature has expanded since 2004. The focus seems to be under the same streams of research shown previously. To identify these patterns, a careful and detailed investigation of recent EKC publications from 2004 to 2017 were carried out. These publications revealed similar patterns that earlier research had found and focused mainly on the Critique of the EKC and Determinants of the EKC. Furthermore, they incorporated new trends such as New environmental indicators for EKC estimations and New Nexus: income-energy consumption.

It seems to appear that new determinants and factors have not been considered in previous EKC analyses as well as new methodological approaches to address the EKC estimations. Moreover, new environmental indicators with global impacts have been discussed into the more recent EKC studies, and some of them identify a new nexus of the EKC hypothesis, the income and energy consumption.

Therefore, the following section proposes four trends from recent research and provides a pathway to address future research.

5.1 New methodological critiques to the EKC

Additional critiques have arisen since 2004 in relation to the econometric gap in EKC estimations. This included criticism that in most of the early studies it was possible to find the incorporation of GDP and GDP^2 or even GDP^3 in the same regression in empirical analyses. This has been criticised in EKC theory because it may cause multicollinearity or collinearity problems among variables and consequently econometric limitations (Al-Mulali, Saboori, & Ozturk, 2015; Narayan & Narayan, 2010). Under the same stream, some researchers rejected the popular static EKC specification and instead took into account dynamic models with spatial dependence (Auffhammer & Carson, 2008). In this context, several studies have considered the estimation using dynamic panel data (Du, Wei, & Cai, 2012; Narayan, Saboori, & Soleymani, 2016).

Van Hoa and Limskul (2013) suggested that: “a more appropriate approach is to build plausible theoretical $\mathrm{GCO_2}$ dynamic single or simultaneous structural equation models that assume and test for the possibility of causality and reverse causality (endogeneity) of growth and $\mathrm{CO_2}$ emissions” (p 2). Consequently, they developed an adequate dynamic policy modelling to assess the reverse and directional causality between a pollutant ($\mathrm{CO_2}$ emissions) and the economic growth in Thailand under the EKC context. Others such as Du et al. (2012), and Ren et al. (2014) also pointed out the system dynamics method. This method could, through modelling, simulating and analysing, address issues of endogeneity, heteroscedasticity, and autocorrelation within variables of interest. In particular, Marrero (2010) and Ren et al. (2014) both developed a dynamics panel model using the system generalised method of moment (GMM).

Apart from the previous methodologies that are all parametric estimations, we can find studies that have developed non-parametric specifications to test the EKC hypothesis. For example, Azomahou, Laisney, and Van (2006) conducted a study of 100 countries in which they reject the polynomial functional form to lead the EKC in several studies. Similarly, Mills and Waite (2009) included a quantile regression and spatial filtering to reanalyse the data because the conventional regressions techniques failed. Their initial findings supported the EKC. Furthermore, the cross-correlation approach was also identified as a new method to test the existence of the EKC hypothesis. Narayan et al. (2016) carried out their study utilising this methodology for 181 countries. They found that if there was a positive cross-correlation between the current economic output and the lagged level of CO_2 emissions and a negative cross-correlation between the current economic output and the future level of CO_2 emission, then CO_2 will diminish with a high level of income over time.

5.2 New factors affecting the EKC hypothesis

Since the 1990s, several texts have incorporated new explanations to find additional determinants which contribute to the EKC hypothesis. For instance, Dinda (2005) included the ratio allocation of capital. He researched what happened when an economy utilised one part of the capital for commodity production (which caused environmental degradation), and the remaining part was used to improve the environment. This resulted in a change from insufficient to sufficient capital allocation for abatement measures as the base for the inverted U-shaped income-environment connection. This factor entered into the utility function as well as the production function, making Dinda’s paper different from previous literature, which did not consider the environment as a productive asset.

Another factor that has taken more relevance recently is financial development. Several studies have focused their research on incorporating this factor into EKC estimations. Among them, Tamazian and Rao (2010) conducted their study to examine links between economic development, environmental degradation, financial development and institutional quality. Their results provided evidence that supported the EKC hypothesis and confirmed the relevance of financial development and institutional quality on the environmental performance. Others (Jalil & Feridun, 2011; Ozturk & Acaravci, 2013) concluded financial development in China led to a reduction in environmental degradation.

To expand understanding on the financial development and environment connection, the literature has focused on foreign direct investment (FDI) as a new factor to test its impact on EKC relationship (He & Yao, 2017; Ren et al., 2014; Shahbaz, Nasreen, Abbas, & Anis, 2015; Zhu, Duan, Guo, & Yu, 2016). The results have been mixed. While He and Yao (2017) found a significant FDI influence on EKC hypothesis, Shahbaz et al. (2015) do not find relationship between FDI and CO_2 emissions.

Corruption was also considered a relevant factor in the EKC literature (Leitao, 2010). In particular, she contributed to theoretical literature that investigated the possibility of different paths for income-environment relationship because of corruption. In her study, Leitao supported the EKC hypothesis and suggested that the higher the level of corruption, then the higher level of income is for the turning point. That is, the point where countries made the transition to actively reduce levels of environmental degradation.

More recent research has identified tourism as another determinant affecting the EKC literature. Katircioglu (2014) showed the relationship between tourism development and CO_2 emissions were in long-term equilibrium. This was because tourist arrivals have a significant negative effect on CO_2 emissions. Similarly, Zaman, Shahbaz, Loganathan, and Raza (2016) investigated the long run and causal relationship between tourism indicators, energy consumption and the EKC hypothesis for 34 developed and developing countries. Their conclusions suggested a non-linear carbon-income relationship. Instead of this, they identified an EKC shape in the region and at the same time they concluded that tourism induced carbon emissions.

In a more specific field, the role of an enterprise's sustainability capability can also be incorporated into EKC context estimations. For example, Lapinskiene, Peleckis, and Nedelko (2017) focussed their study on sustainability scores as factor affecting the EKC hypothesis, which could influence the relationship between greenhouse gases (GHG) and economic measures. Results indicated that sustainable enterprises decrease GHG levels while also confirming the presence of the EKC relationship.

5.3 New environmental indicators for EKC estimations

Many empirical studies have extended the inverted U-shaped curve analysis on the EKC hypothesis and have tested several pollutants since the EKC was originally proposed, according to previously mentioned highly cited papers. The most studied pollutants include SO_2, total suspended particulates (TSP), smoke, NO_2, CO, CO_2 , oxygen regimes, fecal contamination, and heavy-metal contamination in rivers (Cole et al., 1997; Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995; Selden & Song, 1994). It should be clear that such empirical analyses using different pollutants might generate a partial EKC profile which may shift depending on the single pollutant. This is because pollutants differ in their sources as well as in their physical and chemical properties (V. Brajer, R. W. Mead, & F. Xiao, 2011).

Therefore, in addition to indicators already discussed, new environmental quality measurements have been considered in recent research to test the validity of the EKC hypothesis. For instance, McPherson and Nieswiadomy (2005) considered threatened birds and mammals to test the EKC hypothesis. Their results suggested a possible EKC shape. Similarly, Mills and Waite (2009) found evidence supporting the EKC. They used the proportion of species conserved to test the EKC validity using it as biodiversity factor. Baek and Kim (2013) found the same results in Korea using the level of energy consumption, fossil fuels and nuclear energy in electricity as environmental indicators to test their relationships with economic growth. While Romero, Cruz, and Barata (2017) identified an EKC shape using transport energy consumption in the European Union, others do not support using an ecological footprint (EF) as an environmental indicator for the EKC hypothesis (Caviglia-Harris, Chambers, & Kahn, 2009). They used an EF indicator because it represented the cumulative measurement of environmental degradation.

Since land is one of the most important elements in an ecosystem, as well as an important source of production and construction, land consumption is also an environmental indicator considered in the EKC perspective (Bimonte & Stabile, 2017). Bimonte and Stabile (2017) took account of this indicator as a proxy by the number of building permits issued annually by local authorities. In this scenario, results indicated a U-shaped relationship between income and environmental indicators and, therefore, they concluded that lifestyle development, as well as institutional and political factors, caused an adverse effect on the environment.

5.4 New nexus: income and energy consumption

There is a vast amount of analyses that focuses on the EKC relationship within a panel dataset and country level context, using different pollutant indicators. However, there has been a growing interest in examining the link between income-energy consumption which has been omitted in previous research. The energy use takes precedence because CO_2 emissions are mostly generated by the use of fossil fuels (Kasman & Duman, 2015). According to Soytas, Sari, and Ewing (2007), this variable should be included in EKC analysis. They tested the EKC relationship considering energy use and indicated that income has Granger cause with energy consumption, while carbon emissions do not. However, Caviglia-Harris et al. (2009) indicated that energy use was the main reason for the lack of an EKC relationship in their study. Developing this idea further, Kasman and Duman (2015) examined the dynamic correlation between carbon emissions, energy consumption and income, including additional variables such as trade openness and urbanisation. The results provided evidence for the EKC hypothesis under this structure.

6. Conclusions

This chapter carries out the mapping research method to analyse the EKC hypothesis since its origins and identifies the most influential publications in this area. It has established four main research streams to classify highly cited papers. These include (1) ‘Testing the basic EKC equation’, (2) ‘Critique to EKC’, (3) ‘Determinants of EKC’, and (4) ‘Review of EKC’. Each of these fields has been examined and reviewed in detail. Moreover, new trends of the EKC literature from 2004-2017 were added to this study. Among them, I found the ‘new environmental indicator’ and ‘new nexus: income and energy consumption’ trends. Also, it has extended the literature for two of the previous research streams ‘Critique of the EKC’ and ‘Determinants of the EKC’. In critiques, new methodological critiques that have been identified were discussed. For determinants, new factors affecting EKC explanations were considered.

Therefore, this study outlines knowledge gaps and future research directions that might possibly be used to extend the EKC literature in different contexts. The EKC research has had greater focus on methodological limitations and the estimations of new models which address the main econometric gaps as well as the environmental indicator utilised to test the EKC relationship. The latter refers to the emissions of certain environmental indicator resulting in an inverted-U behaviour between income and environment. On the other hand, the concentration of the same pollutant, which represents the accumulated factor, showed in some cases a monotonically relationship. In this context, one of the most relevant environmental quality indicators is given by CO_2, which is responsible for at least 78% of GHG emissions. CO_2 is a major cause of significant increases in the global temperature, which generates changes in climate and impacts natural and human ecosystems. Also, it has an indirect effect on the economy, though less productivity, poor health outcomes and lower production.

This paper also identifies the new nexus of income with energy consumption within new research trends. Energy use is directly related to CO_2 emissions, which is the main cause of climate change, as previously mentioned.

In conclusion, the prospect remains hopeful for EKC research with: greater focus on new econometric limitations; and new environmental measurements. These new fields show real promise for future research where new scholars must be more open to new methodologies to extend the EKC theory. Empirical analyses addressing the dynamic behaviour of the EKC and those focusing on the reverse causation are only some of the possible options to tackle the fundamental econometric gaps, as well as answer the real association between economic output and environmental quality measures.

CHAPTER III

Carbon Kuznets curve: A dynamic empirical approach for a panel data

1. Introduction

Excessive consumption of natural resources has led to economic development with associated population growth and changes in human behaviour and lifestyle. In turn, these have contributed to increased environmental degradation and harm. (Häyhä, Lucas, van Vuuren, Cornell, & Hoff, 2016). A lack of concern for the environment and the integrity of its ecosystems has resulted in global environmental change with natural cycles significantly impacted. This has been a catalyst for research into any link between the environment and the economic standards of communities being affected. (IPCC, 2014). Most studies have focused their attention on the Environmental Kuznets Curve (EKC) framework.

The EKC theory argues the level of environmental deterioration and per capita income follow an inverted-U relationship. This mirrors the Kuznets Curve theory on income inequality and per capita income (Dinda, 2004). What EKC says, is that levels of pollution increase together with economic output, but once the economic output reaches a particular turning point, environmental degradation starts to decrease while income levels increase. (Grossman & Krueger, 1991; Holtz-Eakin & Selden, 1995; Marrero, 2010).

Since its origins in the early 1990s, EKC theory has developed different contexts within its literature. These can be classified into six streams: (1) testing the basic EKC equation; (2) determinants of EKC; (3) critique of EKC; (4) review of EKC; (5) new environmental indicators; and (6) new nexus – energy consumption and income (all explained in the first essay of this thesis). In particular, determinants and critique of EKC have had more extended reviews by different authors (Al-Mulali, Saboori, et al., 2015;

Cole et al., 1997; Du et al., 2012; Lapinskiene et al., 2017; McConnell, 1997; Shen, 2006; Stokey, 1998; Tamazian & Rao, 2010; Torras & Boyce, 1998; Zaman et al., 2016).

The primary determinants affecting EKC explanations include: the income elasticity of environmental quality demand; the scale, technological and compositions effects on the economy; international trade; regulations; the ratio of allocation; financial development; corruption; and the most recent determinant – the role of an enterprise's sustainability.

On the other hand, the critique of EKC stream suggests that several conventional estimation methods have been used such as ordinary least square (OLS) and fixed-effect panel model. New approaches such as: co-integration techniques; simultaneous equations; and generalized method of moment (GMM), specifically the dynamic system GMM, have also been used. In particular, these new approaches have been used to cover the main econometric gaps unaddressed in conventional methods. These limitations of conventional methods refer to the unidirectional assumption in the economic-environment relationship; the stochastic trend in the data and stationary; and the static EKC specification.

New approaches have resulted in the EKC specification's environmental indicators having more consistent results. Short-term and local pollutants such as sulphur dioxide (SO_2), suspended particulate matter (SPM), carbon monoxide (CO), and nitrous oxides (NO_x) behave in a U-inverted shape in relation to economic output, which validates the EKC hypothesis (Dinda, 2004).

On the other hand, other authors have focused their attention on global indicators such as CO_2 and they have tested the EKC existence using this indicator. The results are being mixed. While some authors support the EKC hypothesis (Asghari, 2012; M. Galeotti, Manera, & Lanza, 2009; Holtz-Eakin & Selden, 1995), others employing the same global indicator do not validate the existence of this relationship (Ben Youssef, Hammoudeh, & Omri, 2016; Burnett, Bergstrom, & Wetzstein, 2013; Guo, 2017; Lantz & Feng, 2006). However, all these studies have included the CO_2 emissions as a factor to evaluate the inverted-U environment-income linkage and not been considered in concentration terms. CO_2 constitutes the largest portion of greenhouse gas (GHG) concentrations (78%) between 1970 and 2010 (IPCC, 2014).

This study seeks to fill the gap in the EKC literature by analysing the carbon Kuznets curve under a dynamic and endogenous context for a global view and under an income classification. In particular, from a methodology perspective, this paper is one of the first to apply system GMM estimations for a global sample of 177 countries for 43 years.

Similar to Li et al. (2016) who focus their study on China, this study finds evidence to support the EKC hypothesis, validating that in a global context and in developed countries, environmental deterioration and economic output follow an inverted-U shape. Applying the system GMM estimator, the coefficient resultants cover the different endogeneity forms: reverse causation; dynamic endogeneity; and unobservable heterogeneity between pollutants and economic output.

Also, this study expands the analysis using conventional methods and dynamic GMM approach towards a level of income by country. The results are mixed. Under the OLS and fixed-effect panel model, the EKC only exists for countries with high level of income. Countries with lower-middle, upper-middle and low levels of income show an inverted-U shape, but the squared economic growth is not significant for the changes in the global CO_2 concentrations. Then, employing a dynamic GMM approach, the results indicate that all levels – except a low level – of income follow an EKC relationship, showing the same behaviour as shown using the conventional methods.

The remainder of this paper is organised as follows. The second section provides the background of the EKC literature used in the first essay of this document. Section 3 describes the dataset, relevant variables and econometric model used. Section 4 presents the results from the empirical analyses and Section 5 concludes the paper.

2. Literature Review

Industrialisation has been accompanied by environmental problems (E. Choi et al., 2010). The consumption of natural resources on a global scale, driven by population growth, economic development and lifestyle changes has resulted in the degradation of the earth system in the last few years (Häyhä et al., 2016). Existing literature on modelling the effects of global environmental change on socio economic and economic productivity raises some real concerns. There has been evidence on how per capita income and economic growth may be affected by rising temperatures on both micro and macro levels (Burke, Hsiang, & Miguel, 2015; Dell, Jones, & Olken, 2012; Mendelsohn et al., 2000; Tol, 2009).

In a major advance, scholars extended the literature examining the relationship between the economic output and pollutants such as SO_2, SPM, CO and NO_x (Dinda, 2004; Grossman & Krueger, 1991, 1995; Selden & Song, 1994). The first results pointed out an inverted U-shaped relationship between these pollutants and income output, or the Environmental Kuznets Curve (EKC) hypothesis. The EKC hypothesis was debated for first time by Grossman and Krueger (1991) in their working paper on the environmental consequences under the North American Free Trade Agreement context. They refer to when the per capita income increases and exceeds a certain turning point the level of environmental quality or pollutant emissions begin to decrease. Since then, authors such as Selden and Song (1994), Selden and Song (1995), Grossman and Krueger (1995) and Holtz-Eakin and Selden (1995) have tested the basic EKC equation to validate an inverted U-shape relationship between economic output and environmental degradation.

Further research identified three key gaps or limitations in the econometric models analysing the EKC hypothesis. Firstly, Stern et al. (1996) called into question the environment-income simultaneity assumption. They argued an empirical examination under a single equation, with uni-directional causality might produce biased and inconsistent estimates. Stern et al advocated a bi-directional relationship between income and environment should be reflected instead. Since then, several other investigators have also shown their concerns for considering the simultaneity or reverse causation into their EKCs estimations (Cole et al., 1997; Ekins, 1997; Kaufmann et al., 1998). More recent studies such as Shen (2006), Carson (2010), Jaunky (2011) and Al-Mulali, Saboori, et al. (2015) critique the inverted U-shape of the income-environment linkage estimation because a causal relationship seemed to exist.

The second econometric limitation considered by some researchers (Jaunky, 2011; Perman & Stern, 2003; Stern, 2004) indicated that the current empirical analyses might cause spurious regressions. They focused on the stochastic trend in the data rather than the stationary trend used in the classic EKC model and argued it should be included in the EKC estimations. Finally, under the same stream of critique on EKC estimates, a third limitation was recognised. The popular static EKC specification was rejected and new dynamic models with spatial dependence started to be considered (Auffhammer & Carson, 2008; Du et al., 2012; Narayan et al., 2016).

Since then, with the aim to improve the econometric problems mentioned above, researchers have provided new methodologies to test the income-environment connection along the EKC estimation path. For example, there is the generalized least squares (GLS) model to correct autocorrelations among variables (Cole et al., 1997). The first differences model to reduce the serial correlation was put forward by Stern and Common (2001). A number of studies supported co-integration techniques to address the stochastic trends in the data (Apergis, 2016; Esteve & Tamarit, 2012b; Jalil & Mahmud, 2009; Narayan & Narayan, 2010; Perman & Stern, 2003). And the simultaneous-equation model to take account into the feedback from environmental degradation to economic measures was also proposed (Omri et al., 2015; Ren et al., 2014; Shen, 2006).

More recently, authors have used the system generalised method of moment (GMM) model to correct both the autocorrelation and reverse causality within the variables of interest for a dynamic panel (Du et al., 2012; Li et al., 2016; Marrero, 2010; Ren et al., 2014; Sirag, Matemilola, Law, & Bany-Ariffin, 2017). In particular, Du et al. (2012), Ren et al. (2014) and Li et al. (2016) focused their dynamic empirical analyses on China and its provinces, as Marrero (2010) did with 24 European countries. Sirag et al. (2017) carried out their study on a sample of 134 countries. They looked at low, middle and high-income groups and put emphasis on developing countries which were still below the optimal income turning point to reduce rates of environmental damage.

Furthermore, determinants or factors that were responsible for the inverted U-shape have been incorporated into EKC estimations. This has been with the purpose of providing validated explanations on why the inverted U-shape relationship between the environmental quality and economic output existed.

As mentioned in the first essay of this thesis, the main factors affecting EKC explanations may be divided into five categories. The first is the income elasticity of environmental quality demand, where the preferences of household play an important role under the EKC context (Guo, 2017; McConnell, 1997; Stokey, 1998). They refer to as income rise, they society has better standard of living, and therefore, is not willing to sacrifice the environment. As a result, people demand for better environment and contribute to change the structure of the economy to abatement the environmental degradation (Dinda, 2004).

The second category utilises the scale, technological and composition effects of the economies to explain the inverted U-shape income-environment relationship (Grossman & Krueger, 1991; Stokey, 1998).

International trade is the third determinant. Results from these investigations indicated that trade openness is statistically significant in the EKC shape (Kander et al., 2017; Kasman & Duman, 2015; Ren et al., 2014).

The fourth category looks at environmental regulation. Variables such as political rights and civil liberties have been used to see the effect on the environmental degradation (Torras & Boyce, 1998). The quality of policy intervention and different regulatory schemes on environmental degradation in the EKC analysis was also included in the EKC estimations (Markandya et al., 2006; Panayotou, 1997; Stokey, 1998).

Apart from the previous determinants, new publications have provided fresh explanations. For example, the ratio of allocation of capital proposed by Dinda (2005) and financial development included by Tamazian and Rao (2010), Jalil and Feridun (2011), and Ozturk and Acaravci (2013).

Ren et al. (2014), Shahbaz et al. (2015) and He and Yao (2017) use the foreign direct investment (FDI) factor to test financial development with the EKC hypothesis. Other factors such as corruption (Leitao, 2010), tourism (Katircioglu, 2014; Zaman et al., 2016) and the role of an enterprise's sustainability (Lapinskiene et al., 2017) have been also included in some studies.

Furthermore, environmental quality indicators have played a relevant role in EKC analyses and at the same time, become another limitation in empirical models. The income-environment link is commonly tested for short-term and local environmental indicators but not for global and accumulated indicators (Arrow et al., 1995).

Some authors focused their studies on global environmental measures such as CO_2 emissions to test the inverted U-shape income-environment link. The results have been mixed. For example, some examiners emphasised that when CO_2 emissions were used, the inverted U-shape income-environment relationship did not seem to be present (Agras

& Chapman, 1999; Asghari, 2012; Cole et al., 1997; Esteve & Tamarit, 2012a; G. Halkos & Tsionas, 2001; Tsurumi & Managi, 2010; K. Wang, 2012).

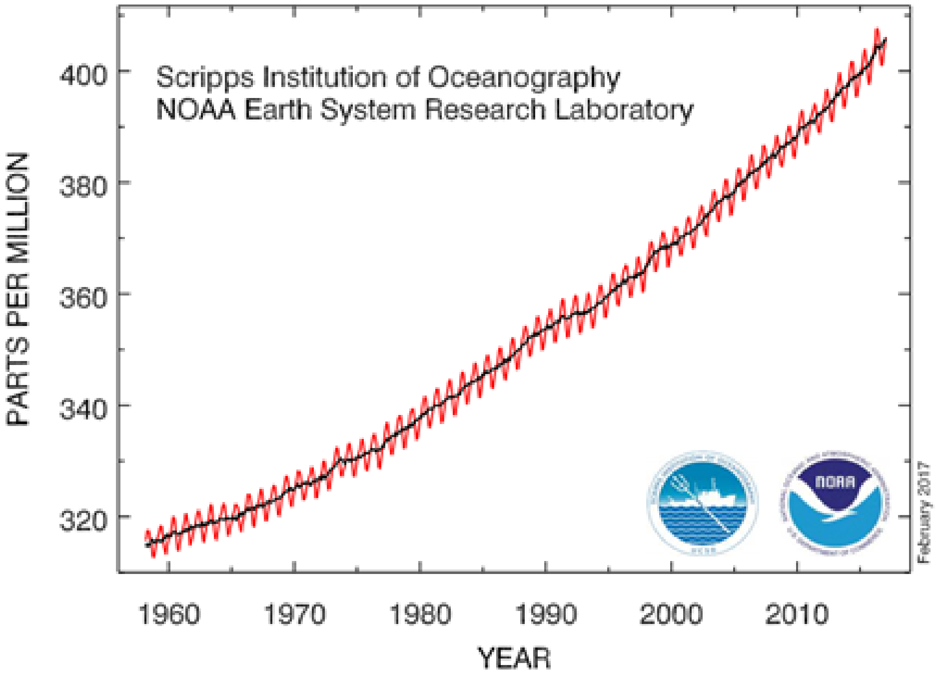
However, others support the EKC relationship between economic output and the same environment indicator (Ben Youssef et al., 2016; Bernard, Gavin, Khalaf, & Voia, 2015; Burnett et al., 2013; Guo, 2017; Martinez-Zarzoso & Maruotti, 2011; Rafiq, Salim, & Apergis, 2016). These investigations included CO_2 emissions as an environmental indicator rather than a global environmental quality measure as concentrations of CO_2 emissions.

2.1 Global environmental indicators

In a global context, the science has indicated that GHG concentrations, an anthropogenic contribution to the atmosphere via emissions from human activity as well as natural emissions, are the primary cause of global warming (Du et al., 2012; IPCC, 2007). According to the fifth report of the IPCC, GHG emissions mainly depend on the population, economic activity, lifestyle, energy use, land use patterns, technology and climate policy (IPCC, 2014). As a result, since the pre-industrial period, accumulated anthropogenic gas emissions have substantially increased in atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) (IPCC, 2014; Tapia & Carpintero, 2013). In its fourth report, the IPCC said GHG emissions had increased 1.6% annually. It predicted emissions would have increased by 25% to 90% in 2030 when compared to 2000 (IPCC, 2007).

Concerning environmental deterioration indicators, CO_2 emissions are considered the biggest cause of GHG emissions and therefore causing significant effects on a global scale (Akbostancı et al., 2009; Knight & Schor, 2014). CO_2 emissions from fossil fuels accounts for the largest portion (78%) of GHG emissions from 1970 to 2010 (IPCC, 2014; Stockholm Resilience Centre, 2015). These emissions have been increasing the global temperature since 1950, generating changes in climate and impacting the natural and built environments on all continents and the oceans (Brook, Ellis, Perring, Mackay, & Blomqvist, 2013; IPCC, 2014). According to Tucker (1995), historical data shows that at the beginning of the industrial revolution the earth's atmosphere contained a concentration around 280 parts per million (ppm) of CO_2. In 1994, those levels reached 360ppm. Current atmospheric concentrations of CO_2 have already reached 400ppm (Tapia & Carpintero, 2013; WWF, 2014) and will continue to rise (see figure 3).

Figure 3: Atmospheric CO_2 at Mauna Loa Observatory. Source: NOAA/ESRL and SIO (2017)



Note: The carbon dioxide data (red curve) measured as the mole fraction in dry air, on Mauna Loa constitute the longest record of direct measurements of CO_2 in the atmosphere. The black curve represents the seasonally corrected data.

In its fifth assessment, the IPPC found that around 40% of CO_2 emissions had remained in the atmosphere. The rest had been removed from the atmosphere and was stored in the earth and oceans. This implied that oceans absorbed around the 30% of CO_2 emissions, which in turn led to ocean acidification. In fact, the report stated that emissions would cause major warming and prolonged changes in the climate system such as heat waves and extreme precipitation. Rising sea level and biodiversity loss would also be caused by high CO_2 concentrations.

Consequently, this study seeks to analyse the carbon Kuznets curve throughout a dynamic panel model, using the system GMM method at a worldwide level. In addition, our study expands its examination not only for the global concentration of the CO_2 emissions, but also for a classification of countries under socioeconomic categories.

3. Methodology

3.1 Sample description

This section describes the data used to test the relationship between the level (or growth rate) of economic output (the gross domestic product or GDP) and the environmental indicator, or more specifically the global CO_2 concentration. The sample for this study is drawn from the World Development Indicators (WDI) by World Bank's 2016 report, which covered an unbalanced annual economic data from 177 countries. It analysed a 43-year period from 1973 to 2013. The National Oceanic & Atmospheric Administration (NOAA) was the primary data source for the worldwide environmental data. The countries used are listed in Table 3. The full dataset contains 49,568 observations. Additionally, countries were also classified according to income level of four groups: high, upper-middle, lower-middle, and low according to the World Bank's 2016 world development indicators. Data series are transformed with natural logarithm for estimation purposes.

Table 3: List of countries and level of income.

ID	Country	Level of income	ID	Country	Level of income
1	**Afghanistan**	Low	90	**Korea, Rep.**	High
2	**Angola**	Upper-Middle	91	**Kuwait**	High
3	**Albania**	Upper-Middle	92	**Lao PDR**	Lower-Middle
4	**United Arab Emirates**	High	93	**Lebanon**	Upper-Middle
5	**Argentina**	Upper-Middle	94	**Liberia**	Low
6	**Armenia**	Lower-Middle	95	**Libya**	Upper-Middle
7	**Antigua and Barbuda**	High	96	**St. Lucia**	Upper-Middle
8	**Australia**	High	97	**Sri Lanka**	Lower-Middle
9	**Austria**	High	98	**Lesotho**	Lower-Middle
10	**Azerbaijan**	Upper-Middle	99	**Lithuania**	High
11	**Burundi**	Low	100	**Luxembourg**	High
12	**Belgium**	High	101	**Latvia**	High

13	**Benin**	Low
14	**Burkina Faso**	Low
15	**Bangladesh**	Lower-Middle
16	**Bulgaria**	Upper-Middle
17	**Bahrain**	High
18	**Bahamas, The**	High
19	**Bosnia and Herzegovina**	Upper-Middle
20	**Belarus**	Upper-Middle
21	**Belize**	Upper-Middle
22	**Bolivia**	Lower-Middle
23	**Brazil**	Upper-Middle
24	**Barbados**	High
25	**Brunei Darussalam**	High
26	**Bhutan**	Lower-Middle
27	**Botswana**	Upper-Middle
28	**Central African Republic**	Low
29	**Canada**	High
30	**Switzerland**	High
31	**Chile**	High
32	**China**	Upper-Middle
33	**Cote d'Ivoire**	Lower-Middle
34	**Cameroon**	Lower-Middle
35	**Congo, Rep.**	Lower-Middle
36	**Colombia**	Upper-Middle
37	**Comoros**	Low
38	**Cabo Verde**	Lower-Middle
39	**Costa Rica**	Upper-Middle
40	**Cyprus**	High
41	**Czech Republic**	High
42	**Germany**	High
43	**Djibouti**	Lower-Middle
44	**Dominica**	Upper-Middle
45	**Denmark**	High
46	**Dominican Republic**	Upper-Middle
47	**Algeria**	Upper-Middle
48	**Ecuador**	Upper-Middle
49	**Egypt, Arab Rep.**	Lower-Middle
50	**Eritrea**	Low
51	**Spain**	High
52	**Estonia**	High
53	**Ethiopia**	Low
54	**Finland**	High
55	**Fiji**	Upper-Middle
56	**France**	High
57	**Micronesia, Fed. Sts.**	Lower-Middle
58	**Gabon**	Upper-Middle
59	**United Kingdom**	High
60	**Georgia**	Upper-Middle
61	**Ghana**	Lower-Middle
62	**Guinea**	Low
63	**Gambia, The**	Low
64	**Guinea-Bissau**	Low
65	**Equatorial Guinea**	Upper-Middle
66	**Greece**	High
102	**Morocco**	Lower-Middle
103	**Moldova**	Lower-Middle
104	**Madagascar**	Low
105	**Maldives**	Upper-Middle
106	**Mexico**	Upper-Middle
107	**Macedonia, FYR**	Upper-Middle
108	**Mali**	Low
109	**Malta**	High
110	**Myanmar**	Lower-Middle
111	**Montenegro**	Upper-Middle
112	**Mongolia**	Lower-Middle
113	**Mozambique**	Low
114	**Mauritania**	Lower-Middle
115	**Mauritius**	Upper-Middle
116	**Malawi**	Low
117	**Malaysia**	Upper-Middle
118	**Namibia**	Upper-Middle
119	**Niger**	Low
120	**Nigeria**	Lower-Middle
121	**Nicaragua**	Lower-Middle
122	**Netherlands**	High
123	**Norway**	High
124	**Nepal**	Low
125	**New Zealand**	High
126	**Oman**	High
127	**Pakistan**	Lower-Middle
128	**Panama**	Upper-Middle
129	**Peru**	Upper-Middle
130	**Philippines**	Lower-Middle
131	**Papua New Guinea**	Lower-Middle
132	**Poland**	High
133	**Portugal**	High
134	**Paraguay**	Upper-Middle
135	**Qatar**	High
136	**Romania**	Upper-Middle
137	**Russian Federation**	Upper-Middle
138	**Rwanda**	Low
139	**Saudi Arabia**	High
140	**Sudan**	Lower-Middle
141	**Senegal**	Low
142	**Singapore**	High
143	**Solomon Islands**	Lower-Middle
144	**Sierra Leone**	Low
145	**El Salvador**	Lower-Middle
146	**Serbia**	Upper-Middle
147	**Sao Tome and Principe**	Lower-Middle
148	**Suriname**	Upper-Middle
149	**Slovak Republic**	High
150	**Slovenia**	High
151	**Sweden**	High
152	**Swaziland**	Lower-Middle
153	**Seychelles**	High
154	**Syrian Arab Republic**	Lower-Middle
155	**Chad**	Low

67	**Grenada**	Upper-Middle	156	**Togo**	Low
68	**Guatemala**	Lower-Middle	157	**Thailand**	Upper-Middle
69	**Guyana**	Upper-Middle	158	**Tajikistan**	Lower-Middle
70	**Honduras**	Lower-Middle	159	**Timor-Leste**	Lower-Middle
71	**Croatia**	High	160	**Tonga**	Lower-Middle
72	**Haiti**	Low	161	**Trinidad and Tobago**	High
73	**Hungary**	High	162	**Tunisia**	Lower-Middle
74	**Indonesia**	Lower-Middle	163	**Turkey**	Upper-Middle
75	**India**	Lower-Middle	164	**Tanzania**	Low
76	**Ireland**	High	165	**Uganda**	Low
77	**Iran, Islamic Rep.**	Upper-Middle	166	**Ukraine**	Lower-Middle
78	**Iraq**	Upper-Middle	167	**Uruguay**	High
79	**Iceland**	High	168	**United States**	High
80	**Israel**	High	169	**St. Vincent and the Grenadines**	Upper-Middle
81	**Italy**	High	170	**Venezuela, RB**	Upper-Middle
82	**Jamaica**	Upper-Middle	171	**Vietnam**	Lower-Middle
83	**Jordan**	Upper-Middle	172	**Vanuatu**	Lower-Middle
84	**Japan**	High	173	**Samoa**	Lower-Middle
85	**Kazakhstan**	Upper-Middle	174	**Yemen, Rep.**	Lower-Middle
86	**Kenya**	Lower-Middle	175	**South Africa**	Upper-Middle
87	**Kyrgyz Republic**	Lower-Middle	176	**Congo, Dem. Rep.**	Low
88	**Cambodia**	Lower-Middle	177	**Zambia**	Lower-Middle
89	**St. Kitts and Nevis**	High	178	**Zimbabwe**	Low

3.2 Variables

3.2.1 Dependent variables

According to previous studies, the income-environment link was commonly tested for local short-term environmental indicators and not for stocks of waste or pollutant (Arrow et al., 1995; Dinda, 2004). This might result in the misinterpretation of the inverted U-shaped relationship between income and environment.

Moreover, the EKC relationship only exists for local air pollutants, while indicators with more global impacts increase monotonically with the income or have predicted tipping points at the high level of per capita income (Cole et al., 1997; Holtz-Eakin & Selden, 1995). Under this context, some authors use CO_2 emissions as a main source of GHG emissions to test the global impact of the EKC hypothesis (Agras & Chapman, 1999; Costantini & Monni, 2008; Du et al., 2012; Esteve & Tamarit, 2012a; Holtz-Eakin & Selden, 1995; Lindmark, 2002; Martinez-Zarzoso & Maruotti, 2011; Sephton & Mann, 2016).

To take account into the weak environmental data in previous estimations, this empirical analysis includes the accumulation of stock emissions together with a global indicator. Therefore, the dependent variable is given by the global CO_2 concentration which represents climate change worldwide. The environmental data is obtained from NOAA. The platform is provided by Earth System Research Laboratory (ESRL) from Global Monitoring Division. This involves atmospheric CO_2 trends data from Mauna Loa, Hawaii Observatory[3]. The observatory has continuously monitored and collected data related to atmospheric change since the 1950s. The NOAA ESRL website covers data with different frequencies and measurements of CO_2 concentrations. However, to evaluate the carbon Kuznets curve, this paper uses a worldwide trend average from annual data.

3.2.2 Independent variables

In line with previous studies which test the EKC hypothesis, the annual real (inflation-adjusted) GDP is used as the main independent variable to analyse its effect on the specific environmental indicator (Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995). The annual GDP by country is compiled from the World Bank's 2016 WDI for 178 countries. According to the World Bank, this variable represents the sum of gross value added by all resident producers in one economy, plus any product taxes and minus any subsidies not included in the value of the product. At the same time, data is in current $US and converted from domestic currencies utilising single year official exchange rates.

3.2.3 Control Variables

Ever since the empirical analyses of EKC hypothesis started, researchers have taken into account several control variables to test the EKC relationship that may affect environmental degradation. This carbon Kuznets curve analysis will not only depend on the independent variable of income and its squared value, but also on some control

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[3] See more at http://www.esrl.noaa.gov/gmd/obop/mlo/

variables. Consistent with the literature, Selden and Song (1994) included the population (POP) as a demographic variable to test the EKC hypothesis. They indicated that population density was expected to show a negative association with emissions because populated countries were likely to be less concerned about lowering per capita emissions.

Also, merchandise trade (MT) is incorporated as a proxy of international trade, representing an important determinant of environmental quality (Van Hoa & Limskul, 2013). Countries with a high level of income have more opportunities to reduce their emissions levels because they can move polluting industries on to other countries through trade. This is the pollution haven hypothesis (Cole, 2004; Dinda, 2004). Some studies found a negative association between this variable and environmental indicators (Cole, 2004), while others showed an insignificant linkage (Van Hoa & Limskul, 2013).

Political rights (PR) and civil liberties (CL) are also included as a proxy of regulation influence. These two variables were found to have a significant effect on environmental quality in low-income countries (Torras & Boyce, 1998). Following on from this, Tamazian and Rao's (2010) EKC analysis considered financial development (FD) as a significant factor affecting the income-environmental relationship. In this study, results found evidence in favour of the EKC hypothesis and confirmed the relevance of financial development on environmental performance. Tamazian and Rao, along with other academics (Jalil & Feridun, 2011; Ozturk & Acaravci, 2013), concluded that financial development in China led to a reduction in environmental degradation. All control variables are compilated from the World Bank's 2016 world development indicators for the 176 countries.

One of the main econometric limitations on EKC estimations is the possibility of non-stationary time series data (Stern, 2004). To avoid this vulnerability, non-stationary variables should be differentiated as many times as required to be converted into stationary data (Choi et al., 2010; Jaunky, 2011; Stern, 2004). To do so, the Fisher type unit root test[4] for a panel based on the augmented Dickey-Fuller (ADF) unit root test is conducted. This identifies the stationary in each panel of variables (Maddala & Wu, 1999). The Fisher type unit root test combines p-values with N independent ADF unit root test. As the number of panels is finite in each unit root analysis, the inverse chi-

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[4] The Fisher type unit root test for a panel assumes that all series are non-stationary under the null hypothesis against the alternative hypothesis that at least one series in the panel is stationary (Maddala & Wu, 1999)

squared (X^2) P test is used (Choi, 2001). Due to results indicate that variables CCO2 and GDP should be differentiated by the possibility of unit root for the panel, the first difference of each variable in our model were utilized to present a stationary behaviour (See Table 4).

Table 4: Fisher Type unit-root test results

	Level Variable	Differenced Variable
Name	P- Statistic X^2	P- Statistic X^2
CCO2	1.7054	3073.0988***
GDP	296.3078	3071.4439***
POP	759.9849***	690.3108***
FD	417.3928**	3865.3128***
MT	694.4889***	5412.6136***
PR	596.9235***	4978.4063***
CL	717.012***	5320.8529***

Note: The inverse chi-squared P test was utilised in this analysis to test the null hypothesis that all panels of one variable are non-stationary. The inverse X^2 test is applicable for finite number of panel and present a X^2 distribution with $2N$ degrees of freedom (Choi, 2001).

Therefore, variables definition can be found in Table 5 as follow.

Table 5: Variables defintions

Variables	ID	Definition
Dependent variable	$CCO2_t$	This variable is given by the index of the global CO_2 concentrations. In other words, the changes in the natural log of these concentrations over the time.
Independent variable	$GDP_{i,t}$	This variable can be interpreted as per-period growth rates in income for country-specific regions.
Control variable	$POP_{i,t}$	This variable represents the changes of the natural log of the total population by country (all residents regardless of legal status or citizenship).
Control variable	$FD_{i,t}$	This variable entails the changes in the natural log of the financial development by country (domestic credit to private sector as percentage of the GDP).
Control variable	$MT_{i,t}$	The variable indicates the changes in the natural log of the merchandise trade by country (as a share of GDP).

Control variable	$PR_{i,t}$	This variable is the changes in the natural log of the political rights index by country.
Control variable	$CL_{i,t}$	This variable represents the changes of the natural log of the civil liberties index by country.

3.3 Econometric Model

Once the time series data in the panel is stationary, the econometric model is introduced to address the research question regarding the validity of the carbon Kuznets curve for a global data panel of 177 countries using an environmental indicator worldwide.

To investigate whether an inverted U-shape between the global growth rate and the index of global $\mathrm{CO_2}$ concentration exists, the relationship will be given by:

$$CCO2 = f(GDP, GDP^2, X'_{i,t}) \tag{1}$$

Where the changes in global CO_2 concentration (CCO2*)* depends on the GDP, the GDP^2 , and some control variables (described above) commonly used in EKC studies to mitigate potential misspecification and biased estimation (Li et al., 2016). Following on from Li et al. (2016), this estimation includes the lag term of the environmental indicator in the carbon Kuznets curve to consider the dynamic effect of the econometric model. This is because the environmental quality changes cumulatively, and therefore, as a pollution indicator is likely to be correlated over time. Consequently, the model will be given by:

$$CCO2_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 CCO2_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{2}$$

Where, i represents the country and t the period, γ_i captures the country fixed effects (because of the country specific characteristics such as culture, structure climate, etc.), and the ε_{it} entails the disturbance term. Under the specification in Eq. (2), the EKC hypothesis is validated if $\alpha_2 > 0$ and $\alpha_3 < 0$, while the $\alpha_2 > 0$ and $\alpha_3 = 0$ reveals a monotonically positive linear relationship and the $\alpha_2 < 0$ and $\alpha_3 = 0$ indicates a monotonically negative linear relationship.

To identify whether evidence exists of a significant association between the growth rate of a panel of 177 countries, and the index of the global $\mathrm{CO_2}$ concentration, the equation two is estimated using two conventional econometric methods: the pooled ordinary least square (OLS) and fixed-effects estimation procedures. In particular, the OLS requires the GDP, GDP^2, and control variables to be orthogonal to the errors. That is, errors are normally independently and identically distributed with zero (0) mean and constant variance σ_ε^2, both over time and across countries (Schultz, Tan, & Walsh, 2010). On the other hand, the fixed-effects panel specification only produces consistent estimates when the strictly exogeneity assumption is considered (Schultz et al., 2010). The latter, assumes that the GDP, GDP^2, and control variables are orthogonal to past, present, and future CCO2. Therefore, they are time-invariant.

As it is highly likely the country-specific characteristics are exposed to reverse causation and dynamic endogeneity, the assumption of strict exogeneity is transgressed. In this context, commonly used estimates may produce biased and inefficient results because the existence of one or more source of endogeneity (such as dynamic endogeneity or reverse causation) between the EKC shape (Al-Mulali, Saboori, et al., 2015; Carson, 2010; Jaunky, 2011; Kaufmann et al., 1998; Li et al., 2016; Shen, 2006; Stern et al., 1996; Van Hoa & Limskul, 2013). Particularly, the reverse causation will also break the rigid exogeneity assumption of the fixed-effect method, as the regressor would be contemporaneously correlated with the error (Schultz et al., 2010).

To address biased results using pooled OLS and fixed-effects methodologies, the system GMM estimator propounded by Arellano and Bover (1995) and fully developed by Blundell and Bond (1998) is used. In doing this, the econometric model examines the dynamic relationship between the $CCO2_t$, the $GDP_{i,t}$, ${GDP_{i,t}}^2$, and some control variables in the sample of 177 countries to test the EKC hypothesis. In particular, this mechanism may deal with attend to estimations problems introduced by unobservable heteroscedasticity, simultaneity, and dynamic endogeneity. As a result, it produces unbiased and consistent estimates using the appropriate internal instrumental variables that are present within the existing dataset (Schultz et al., 2010).

The generalized method of moments (GMM) approach was brought to light for the first time by Hansen (1982) and then updated by Arellano and Bond (1991) using the difference GMM estimator. The idea behind the difference GMM estimator was to provide several lagged exploratory variables as instrument variables (IV). However, this method was criticised due to the weak of its instrumental variables (Li et al., 2016). This critique focused on that the lagged dependent variable considered in the model as IV is a still potentially endogenous (Marrero, 2010; Roodman, 2006). As a result, instead of the previous approach, the system GMM procedure followed a system of equations in both first-differences and levels status. Thus, this method presents more efficient estimators under particular circumstances (Li et al., 2016; Marrero, 2010; Schultz et al., 2010). Therefore, the system of equations will be given by:

$$CCO2_t = \alpha_1 CCO2_{t-1} + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \beta_k X_{i,t} + E_{i,t}$$

$$\Delta CCO2_t = \alpha_1 \Delta CCO2_{t-1} + \alpha_2 \Delta GDP_{i,t} + \alpha_3 \Delta {GDP_{i,t}}^2 + \beta_k \Delta X_{i,t} + \Delta E_{i,t} \qquad (3)$$

Where: $(t-1)$ is a one period lag operator; Δ represents the time-differencing operator; $CCO2$ is N x 1 vector of the global environmental quality measure across N observations; α_1 is given 1 x 1 vector scalar of the coefficient for the lag of the global CO_2 concentration measure, $CCO2_{t-1}$, across N observations; GDP is the growth rate of by country-specific across N observations; α_2 is a 1 x 1 vector of coefficient for the growth rate by country-specific; GDP^2 is the square of the GDP variable and the α_3 the 1 x 1 vector of coefficient for this variable; X is an N x Q matrix of the Q country-specific control variables across N observations: β is a Q x 1 vector of coefficients, β_k, for the Q country-specific control variables, and E is an N x 1 vector of error terms across N observations.

In summary, this study tested the inverted U-shape economic-environment relationship using pooled OLS regressions that were unable to address the different form of endogeneity such as unobservable heterogeneity, dynamic endogeneity, and simultaneity. Consequently, it estimated the relationship under the fixed-effect methodology, which focused specifically on one type of endogeneity, was the unobservable heterogeneity. Therefore, the system GMM dynamic model is used to correct all types of endogeneity, and thereby provide efficient and consistent estimates.

4. Results

This section starts by analysing the descriptive statistics of variables provided in Table 6. The table shows the description for the variables CCO2, GDP, GDP2 and control variables utilised in this study. In particular, CCO2 variable with 6,176 observations shows a degree of variation of 0.00071, while GDP 0.1497 for 6,291 observations and GDP2 0.7270 with the same number of observations. The control variables present a variability of 1.99 for POP, 0.9322 for FD, 0.5757 for MT, 0.7276 for PR and 0.6278 for CL.

Table 6: Descriptive statistic of the variables.

Variable	No of observations	Min	Max	Mean	Std. Dev
CCO2	6176	0.0036	0.0072	0.0046	0.0007
GDP	6291	-1.4198	1.3725	0.0593	0.1497
GDP2	6291	0.0000	2.0158	0.0259	0.0727
POP	6291	10.6273	21.0288	15.5143	1.9889
FD	5936	-7.4277	1.1383	-1.3143	0.9323
MT	6201	-3.0140	2.2891	-0.6295	0.5757
PR	6191	0.0000	1.9459	1.0536	0.7276
CL	6191	0.0000	1.9459	1.1114	0.6278

The notation is as defined in Table 5.

To examine whether the global GDP is related to the global CCO2 under inverted U-shape behaviour, models were tested using Stata14 (64bit) software. The baseline econometric technique was given by the pooled OLS estimation and used as the methodology to compare alternatives approaches.

The OLS estimations results reported in Column 2 of Table 7 were consistent with previous EKC analyses that argued evidence existed to support the inverted U-shape economic-environment relationship (Grossman & Krueger, 1995; Suri & Chapman, 1998). As such, the global CCO2 seems to have an increase with positive changes of the

GDP ($\alpha_2 = 0.0004$), and then decline for a higher level of economic growth, GDP2 ($\alpha_3 = -0.0006$), variable. However, as aforementioned, this estimation has a strict exogeneity assumption that is not accepted in this empirical analysis when the endogeneity presented within the model is considered.

Table 7. Global CO_2 concentration and GDP relation.

Regressor	OLS	Fixed-Effects	Dynamic Sys GMM
CCO2 (*t-1*)	0.8914***	0.8718***	0.6644***
GDP	0.0004***	0.0004***	0.00144***
GDP2	-0.0006***	-0.0007***	-0.0083***
POP	-0.0011***	-0.0027***	-0.0059***
FD	-0.000016	-0.000004	-0.00005***
MT	0.0005***	0.0005***	0.00091***
PR	-7.64e-06	-8.23e-06	-0.000047**
CL	-0.00003	-0.00003	0.00009***
Cons	0.0006***	0.00072***	0.0018***
No Instruments	N/A	N/A	539
No Groups	N/A	177	177
R^2	0.547	0.51 – 0.9540 - 0.5458	N/A
J-Statistics	N/A	N/A	175.42
Arellano-Bond AR (1)	N/A	N/A	-7.6063***
Arellano-Bond AR (2)	N/A	N/A	0.36576

The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively.

The table presents the resultant coefficient under three econometric approaches, OLD, fixed-effect panel and dynamic system for EKC analysis. The parameter estimates are produced using the two-step GMM procedure, with the inverse of the variance-covariance matrix of the moment condition as the weighting matrix. Following the line of Schultz et al. (2010) in their study of corporate governance and total return relation, this study utilised the same set of instruments for differenced and level equations. The instrument set for the differenced CCO2 variable is the lag 2 of the CCO2 (dependent variable), and lags 1 and 2 of the levels of the control variables. The instrument set for the CCO2 level equation is the lag 1 of the differenced CCO2, and lags 0 and 1 of the differenced control variables. The R^2 is reported for OLS estimation and the R^2 for the fixed-effects panel model includes the overall, within groups, and between groups, respectively. The J-Statistic test and the Arellano-Bond test are displayed for the system GMM estimation.

Consequently, the fixed-effect panel approach is estimated to correct the unobservable heterogeneity issue that may be present in the global CCO2 and GDP relation. The results of this estimation are displayed in Column 3 of Table 7. Using this technique, the economic variables GDP ($\alpha_2 = 0.0004$) and GDP2 ($\alpha_3 = -0.0007$) are significantly associated with the global CCO2 variable. The GDP variable presents a positive correlation with the CCO2, while GDP2 has a negative one, following the same patterns as the OLS method. This means that economic-environment linkage follows an inverted U-shape behaviour. These results are consistent with previous studies that utilise this approach to address the unobservable heterogeneity in country-specific characteristics (Selden & Song, 1994Suri & Chapman, 1998). However, this econometric technique only works for the unobservable heterogeneity issue. As previously mentioned, their results may be biased parameter estimates in the presence of dynamic endogeneity and reverse causation.

With the aim of verifying whether the model estimation requires a GMM approach instead of pooled OLS and fixed-effects estimation procedures, an endogeneity test is conducted for GDP and GDP2 measures. This is to assess the necessity of deviating from the pooled OLS approach. In particular, the Durbin-Wu-Hausman (DWH)[5] test for endogeneity is used on the variables mentioned above and the results are presented in Table 8.

Table 8: The Durbin-Wu-Hausman test for endogeneity of regressors

	GDP	GDP2
Wu-Hausman Test	8.93048***	5.85521**
P-value	0.0028	0.0156

Note: ** and *** denotes significance and the rejection of H_o at the 5% and 1% levels. The test is based on the global GDP and GDP2 on global CCO2 and control variables. Following the line of Schultz et al. (2010) to carry out this endogeneity test, lags of the differenced variables are utilised as instruments for both analyses. In particular, lags 1 of the differences CCO2 variable, lags 0 and 1 of the differenced control variables, and lags 1 of the differenced GDP measure are applied as instruments in this GDP endogeneity test. While, lags 1 of the differences CCO2 variable, lags 0 and 1 of the differenced control variables and lags 1 of the differenced GDP2 measure are employed to test the endogeneity in GDP2 variable.

Based on the results of Table 8, it is possible to infer that when GPD and GDP2 variables are used into the model, endogeneity is a significant concern. Both analyses reject the null hypothesis that regressors are exogenous, confirming that the OLS and fixed-effect coefficient-estimates are not consistent and produce biased results.

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[5] The DWH test statistic follows a chi-squared X^2 distribution with ρ degrees of freedom, where ρ is the number of regressors tested for endogeneity (Schultz et al., 2010). The null hypothesis is given by all regressor are exogenous and the rejection would indicate the presence of endogeneity.

Therefore, the results obtained from testing the endogeneity indicate that a dynamic panel specification that contains appropriate instrumental variables should be employed. In this line, as previously mentioned, the dynamic system GMM panel methodology was chosen because it provides more efficient instruments for the estimations.

The dynamic system GMM estimates for the EKC relationship using a two-step estimator are displayed in Column 4 of Table 7. According to Roodman (2006) and Schultz et al. (2010), the coefficients estimated under the two-step GMM estimator are more efficient and consistent in the presence of heteroscedasticity. At the same time, the serial correlation is robust to the potential unobservable heterogeneity, simultaneity and dynamic endogeneity presented in the panel dataset. Thus, under the two-step GMM estimator and similar to previous methodologies, the resultant coefficient, pooled OLS and fixed-effect, show an inverted U-shape between environmental and economic output. This approach estimated α_2 of 0.00144 and α_3 of -0.0083 being the GDP and GDP2 variables significantly influencing the global CCO2. I note that the coefficient of GDP is positive and the coefficient of GDP2 negative. The results are consistent with previous studies using the same econometric method (Li et al., 2016). In contrast to previous studies such as Marrero (2010) who justify that the results under conventional methods may shift when dynamic estimations are used, this study identified a different situation.

This essay argues that testing the basic EKC equation under conventional methods or econometric methods that tackle the dynamic endogeneity, unobservable heterogeneity and causality, result in the estimates behaving the same way. In other words, they lend support to the existence of an inverted U-shaped EKC for CCO2[6].

This study addresses the short-term and local impact environmental indicators used in different EKC empirical analyses where results are unbiased and inconsistent. This is because this study considers a global environmental quality measure, the global CCO2.

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[6] To check whether my findings identified are robust alternate environmental indicators (global CO_2 emissions and the CO_2 emissions by country) were used. The regressions were re-run under OLS, fixed-effect and dynamic system GMM approaches for both indicators. Consistent with my results (not tabulated), the estimations remain stable using the global CO_2 emissions for the three procedures, supporting the EKC hypothesis. On the other hand, using the CO_2 emission by country, the OLS and fixed effect show an inverted-U relationship between income-environment variables. However, under system GMM only GDP coefficient follows a positive association with the dependent variable.

Additionally, this study provides standard specification tests for each estimator and model. The Sargan J-Statistics[7] is displayed for system GMM estimates as well as the Arellano-Bond test[8] which is given by m_1 for Autoregressive Model (AR) of the first order (1) and m_2 for AR of the second order. The results are displayed in Table 8.

Under the two-step estimator for system GMM, the Sargan test supported the null hypothesis, and therefore, the moment conditions were correctly specified and not rejected at significant levels. Moreover, the secondary specification Arellano-Bond test showed there was no correlation in the error for the estimation with m_1 of –7.6063 (p>0.000), while m_2 reveals a 0.36576 (p>0.7145) as results for the second order. That means the full set of instruments applied in this regression are valid, which is consistent with previous studies.

Regarding control variables, the POP variable exhibits a negative and high significance association in relation with the dependent variable for the three estimation approaches. That is, $\alpha_4 = -0.0011$ for OLS, $\alpha_4 = -0.0027$ for fixed-effect, and $\alpha_4 = -0.0059$ for system GMM approach. By doing so, the population variables indicate that an increase a 1% of the variable produce a reduction of the environmental degradation in around 0.1% and 0.6%. On the contrary, the MT variable shows a positive and high significance in its coefficient in relation to the CCO2 indicator for the three estimation approaches; α_6= 0.00049 (OLS) α_6= 0.00048 (fixed- effect), and α_6= 0.00091 (system GMM). This is consistent with existing literature which found trade to be an important factor for EKC explanation. That can be explained because the export and import of manufactured goods are likely to be strong determinants on levels of energy consumption, which directly influence the CCO2 indicator (Dinda, 2004; Suri & Chapman, 1998).

Meanwhile, consistent with Torras and Boyce (1998), the analysis found that in general, the political rights (PR) variable only show significance with the CCO2 indicator for the system GMM procedure with a coefficient of -0.000047. The civil liberties (CL) variable followed the same pattern as PR for OLS and fixes-effect approaches, no significance a negative relationship with the dependent variables, while under system

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[7] The Sargan J-Statistic test follow a chi-squared distribution with degrees of freedom equal to the number of moment restrictions minus the number of parameters estimated under the null hypothesis that moment conditions are valid (Marrero, 2010; Schultz et al., 2010).

[8] The Arellano-Bond test follows an asymptotic normal distribution with the null hypothesis that there is no correlation of order v in the differenced errors, and where v is given by 1 for first order and 2 for the second order (Schultz et al., 2010).

GMM method the control variable shows a positive and highly significant relationship with the variable of interest (CCO2) with a coefficient of 0.00009

The results for financial development (FD) variables were mixed. The OLS and fixed-effect estimations report that FD had no significance for its negative relationship with CCO2. However, the estimations under system GMM (α_5= -0.000052) displayed a highly significant negative relationship between the FD and CCO2. These were consistent with Jalil and Feridun (2011) and Ozturk and Acaravci (2013), who considered FD positively influenced a reduction in environmental degradation.

The conventional methodologies plus the two-step robust system GMM estimation in equation 3, display the EKC relationship between one global environmental indicator and the contemporaneous economic output country-specific variable. However, the results capture a global view of accumulated degradation, and such a relationship might be too generalised, biased and inconsistent for certain countries.

Therefore, this next analysis estimates equation 3 by sorting the level of income in countries into four different levels (1) high, (2) upper-middle, (3) lower-middle and (4) low. All levels were tested under conventional methods and dynamic system GMM. The findings are different compared to the global EKC estimation. The results are reported in Table 9, Table 10, and Table 11.

The findings in Table 9 report that only countries with a high level of income showed evidence to support the inverted U-shape environment-income linkage. In contrast, countries with low, lower-middle and upper-middle level income did not show an EKC relationship between environment and economic variables.

Table 9: OLS Levels of income

Regressor	High	Low	Lower-Middle	Upper-Middle
CCO2 (*t-1*)	0.87071***	0.85869***	0.85566***	0.85836***
GDP	0.00044***	6.41E-05	0.00026***	0.00023***
GDP2	-0.0018***	-7.99E-05	-0.0003	-0.0003
POP	6.42E-06	0.00004***	0.00001**	0.00002***
FD	6.27E-05***	3.43E-07	3.43E-05*	0.00001
MT	8.35E-05***	0.00013***	9.68E-05***	0.00009***
PR	5.09E-06	-4.65E-05	-6.4E05	0.00002
CL	2.38E-06	-2.48E-05	6.98E-06	-6.4E-05
Cons	0.00066***	0.00022	0.00070***	0.00054***

R-squared	0.569	0.5755	0.542	0.5178
Adj R-squared	0.567	0.5717	0.5395	0.5153
Number of obs	1691	895	1490	1544

The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively.

Results reported in Table 10 using the fixed-effect panel model for EKC estimation indicate that only countries with high income levels produced an inverted U-shape relationship between the environment and income variables. The rest of socioeconomic categories only showed positive and significant correlation with the GDP variable and not with the GDP2.

Table 10 results find that countries with a low, lower-middle and upper-middle level of income have no EKC conduct between the variable of interest. The control variables under this methodology only have significance for countries with lower-middle and upper-middle socioeconomic classification.

For POP and MT variables, lower-middle countries have a positive linkage with the CCO2 indicator at the 10% level. Whereas the POP variable for upper-middle countries show a negative relation with CCO2 with a significance of 1% level, while MT follows a positive and high significance connection with the environmental variable.

Table 10: Fixed Effect Levels of income

Regressor	High	Low	Lower-Middle	Upper-Middle
CCO2 (*t-1*)	-0.2047***	-0.14741***	-0.16416***	-0.11007***
GDP	0.20154***	0.138086***	0.134203***	0.153479***
GDP2	-0.3212***	0.053350	-0.12972	0.053600
POP	-0.0049	0.022629	0.010708*	-0.06695***
FD	-0.0016	-0.00164	-0.00576	0.002339
MT	-0.0128	0.048794	0.033694*	0.058745***
PR	-0.0042	0.003611	-0.02230	-0.00201
CL	0.00282	-0.04408	0.005978	-0.01236
Cons	0.06428	-0.24154	-0.11842	1.100075***
R^2	0.077 - 0.015 - 0.069	0.051 - 0.01 - 0.032	0.044 - 0.11 - 0.026	0.055 - 0.029 - 0.006
No of groups	52	28	47	50
Number of obs	1718	912	1477	1562

The notation is as defined in Table 5.

***, **, * indicate significance at 1%, 5% and 10% levels respectively. The R^2 for the fixed-effects panel model reported includes the overall, within groups, and between groups.

In contrast, countries with high, lower-middle and upper-middle of income in the dynamic system GMM estimation (Table 11) follow an inverted U-shape between CCO2 and GDP variables. Countries with a low level of income show that when the economic growth is increasing, the environmental degradation also increases until a tipping point. In a higher level of income, the relationship becomes insignificant, being unable to reach an EKC shape as the other countries. Furthermore, the control variables FD and PR have no significance with the CCO2 variable for countries with low income. The CL variable does not have in countries with high level of income.

Table 11: Dynamic System GMM Levels of income

Regressor	High	Low	Lower-Middle	Upper-Middle
CCO2 (*t-1*)	0.60603***	0.58751***	0.58038***	0.58357***
GDP	0.00152***	0.00039***	0.00039***	0.00030***
GDP2	-0.0092***	-0.0001	-0.0020***	-0.0017***
POP	0.00013***	0.00059***	0.00017***	0.00026***
FD	0.00013***	0.00013	0.00025***	0.00021***
MT	0.00050***	0.00025***	0.00046***	0.00050***
PR	0.00008**	-0.0000	-0.0002***	-0.0002***
CL	-0.0000	0.00025*	-0.0001**	-0.0002***
Cons	0.00017	-0.0071***	0.00062**	-0.0008***
No Instruments	215	197	345	357
No Groups	52	28	47	50
Number of obs	1605	849	1421	1463

The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The parameter estimates are produced using the two-step GMM procedure, with the inverse of the variance-covariance matrix of the moment condition as the weighting matrix. Following the line of Schultz et al. (2010) in their study of corporate governance and total return relation, this study utilised the same set of instrument for differenced and level equations. The instrument set for the differenced CCO2 variable is the lag 2 of the CCO2 (dependent variable), and lags 1 and 2 of the levels of the control variables. The instrument set for the CCO2 level equation is the lag 1 of the differenced CCO2, and lags 0 and 1 of the differenced control variables.

When the dynamic system GMM approach is employed, 215 instruments are utilised for estimations with high income, 197 with low income, 345 with lower-middle income, and 357 with upper-middle income.

In summary, the GMM results show that when accounting for endogeneity in the EKC regressor, all causal relations between the CCO2 indicator and economic output exist and are highly significant.

However, when the level of income is used, the EKC shape is attributable to countries with a high, lower-middle and upper-middle level of income. The causal relations between these variables disappear for countries with low income.

Furthermore, it can be seen that the past CCO2 factor is considered positive and significant for the dependent variable CCO2, for global and income level estimations under both OLS and system GMM. Subsequently, the coefficients of the lagged dependent variable indicate that CCO2 indicators are positively serially correlated, justifying the essay of a dynamic EKC specification, consistent with Marrero (2010) and Li et al. (2016). Meanwhile, the fixed-effect estimation presents a highly significant negative association at the 1% level.

5. Conclusions

This study provides a novel econometric method to validate the EKC hypothesis in a global sample of 177 countries for 43 years, with different levels of income, and the global CO_2 concentration which represents worldwide climate change. This research uses a dynamic system GMM approach to cover the main econometric gaps which have been unaddressed as well as employing conventional approaches such as OLS and fixed-effect methodologies. These limitations, which may produce biased and inconsistent parameter estimates, include the unobservable heterogeneity, the dynamic endogeneity, and the existing causality in income-environment connection. Therefore, three estimations were conducted to see the differences between the coefficient resultants employing the three methodologies mentioned (OLS, fixed-effect, and system GMM). Findings employing OLS methodology were consistent with previous studies that used the same method validating the inverted U-shape for income-environment connection (Grossman & Krueger, 1995; Suri & Chapman, 1998). Factors contributing to the EKC shape are given by merchandise trade, as a proxy of trade openness, and population by country. These findings are consistent with Suri and Chapman (1998) and Ren et al. (2014) and show a high degree of significance. That means the actual movement of goods between countries has a positive and significant effect on the EKC relationship.

Then, to correct the unobservable heterogeneity a fixed-effect panel model was employed. The results came to the same conclusion as the OLS method. Global CO_2 concentration and economic growth by country observed an EKC behaviour. Factors such as population, financial development and merchandise trade were positive and significantly related to the global CO_2 concentration.

Finally, with the aim to cover the three econometric limitations present in conventional methods, the system GMM was the most appropriate methodology to produce consistent results (Li et al., 2016; Schultz et al., 2010). The findings consistently exhibited an inverted U-shape relationship between changes of global CO_2 concentrations and the economic growth by country in a global view and for developed countries.

In particular, this essay provides an appropriate technique to address all endogeneity forms during the empirical analysis of validating the EKC hypothesis for a large sample.

CHAPTER IV

Planetary Boundaries: An environmental measurement for a dynamic EKC relationship

1. Introduction

Planetary boundaries (PB) are a relatively new phenomenon representing control variables of nine dimensions of global environmental change. These include: climate change; ocean acidification; biodiversity loss; biochemical cycles of nitrogen and phosphates; land-system changes; global freshwater use; aerosol loadings; and chemical pollution. Introduced by Rockström et al. (2009b), the concept proposes a safe operating space for humanity with limits that cannot be treated in isolation.

Although there is little acknowledgement of planetary boundaries, since 2011, some firms have begun to incorporate this concept into their corporate reports (Bjørn, Bey, Georg, Røpke, & Hauschild, 2016). Moreover, investment companies may influence the performance of other industries such as mining and manufacturing (Gifford, 2004). By leveraging their investment capital, they might catalyse capital investment from high-emission toward low-emission climate resilient developments (UNEP, 2014).

Under this context, this chapter seeks to evaluate the existence of the Environmental Kuznets Curve (EKC) hypothesis in a group of 177 nations using their economic growth, control variables (population, financial development, merchandise trade, political rights, and civil liberties), and the growth rate of seven of the nine global environmental dimensions. According to Rockstrom et al. (2009a) and Steffen et al. (2015) seven out of these nine boundaries provide measures to quantify a particular environmental damage. Thus, this study considers these seven dependent variables for validating the EKC hypothesis within seven different panels of data between 1973-2013.

As discussed in Chapters 2 and 3, the EKC hypothesis is explained by a non-linear relationship between economy and environmental degradation. The literature refers to an inverted U-shaped between these two subjects, where environmental quality decreases with economic growth and then starts to improve with a higher economic growth rate (Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995; Shafik, 1994).

Since each environmental indicator has specific sources and characteristics, the EKC analysis might generate a particular profile depending on the index (Brajer, Mead, & Xiao, 2011). This chapter, in line with Chapter 3, considers one global environmental integrated dimension to examine the existence of a global EKC. The dimensions included in this study are: climate change (global CO_2 concentrations); biochemical cycles (global fertiliser consumption); ozone depletion (the annual mean of total ozone); ocean acidification (the mean surface ocean hydrogen ion concentrations); freshwater use (the global water withdrawal); land use (the global agricultural land area); and biodiversity loss (global threatened species).

This chapter conducts a dynamic system Generalized Method of Moments (GMM) together with conventional methods such as Ordinary Least Squares (OLS) and fixed-effect. Thus, the main econometric limitations in EKC under conventional econometric approaches are addressed. They are the: unidirectional assumption in the economic-environment relationship; stochastic trend in the data and stationary; and static EKC specification. In particular, the system GMM approach utilises a system of equations, one differenced equation, and one level equation. Accordingly, the methodology used in this thesis seeks to employ instruments correctly specified for both equations to obtain unbiased results for EKC estimates. Moreover, this econometric approach is compared with conventional methods such as Ordinary Least Squares (OLS) and fixed-effect to identify possible significant differences.

As mentioned, due to the availability of data and measuring instruments, this chapter suggests results for seven out of nine boundaries. Climate change and ocean acidification dimensions support the EKC shape using system GMM specification. In fact, their estimates do not change when conventional methods such as OLS and fixed-effect are used. In keeping with Chapter 3, the results suggest that the environmental degradation measurement is consistent with the EKC hypothesis which states that environmental degradation increases with economic growth until a tipping point, where it starts to improve with higher economic growths.

In contrast, biochemical cycles, ozone depletion and freshwater use, land change, and biodiversity loss boundaries do not support the existence of the EKC shape using a system GMM methodology. Particularly, biochemical cycles, ozone depletion and freshwater use, exhibit a U-shape relationship between income and environment variables. On the other hand, land change boundary exhibits a negative linear effect between economic growth and its environmental measure. The biodiversity loss boundary is the dimension more influenced by others. Its results exhibit a positive linear association between the economic variable and the environmental measure, being significant under the system GMM and conventional methods. These findings explain an increase in environmental degradation for any economic growth.

The remainder of the chapter is organised as follows. The second section is the literature review of the third study of this thesis. Section three provides the methodology of the study which includes variables and econometric models for each of the seven boundaries evaluated. Section four exhibits the results for the proposed models. Section five gives an overview of the robustness analysis, which incorporates the econometric methods and results for each boundary considering their possible interactions. Conclusions of this chapter are also described in Section 5.

2. Literature Review

Economic literature, its link with the environment, and its consequences on the global economy have been extensively studied since the 1980s (Tapia & Carpintero, 2013). Most of these studies have reached a consensus that the climate change process is attributed to anthropogenic influence from industrial, agricultural, transport, and other human activities (Deschênes & Greenstone, 2007; IPCC, 2007; Tapia & Carpintero, 2013). Similarly, a more recent report given by the Intergovernmental Panel on Climate Change (IPCC)[9], an organisation that provides a clear scientific view on the current state of climate change and possible environmental and socio-economic impacts, states that most global environmental change since 1950s had been generated by humankind (IPCC, 2014).

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[9] The IPCC is an organisation established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) (IPCC, 2014)

Global environmental change is explained as both biophysical and socio-economic changes which are altering the structure and functioning of the Earth system. These changes include disruptions globally such as: land use and land cover; urbanisation; globalisation; coastal ecosystem; atmospheric composition; river flow; nitrogen cycle; carbon cycle; physical climate; marine food chains; biological diversity; population; economy; resource use; energy; transport; communications; and more (Steffen et al., 2015).

In the pollution-economic growth nexus, one of the most ground-breaking and most studied hypotheses in scientific literature is the EKC. As it has been previously mentioned, the EKC was debated for the first time early in the 1990s by Grossman and Krueger (1991) in their working paper "The environmental impact of the North America Free Trade Agreement (NAFTA)". This hypothesis describes an inverted U-shape between economic output and some environmental quality indicators. That means, during the early stage of economic development the environmental quality deteriorates, and then as the economy grows, the environmental condition starts to improve over time (Grossman & Krueger, 1991, 1995; Selden & Song, 1994; Shafik, 1994).

Chapter 2 of this thesis conducted a systematic literature review using citation mapping with the most influential publications (the most cited 30 papers). It shows literature on the EKC hypothesis has followed six different streams of research since its beginnings. They are:

1. "Testing the basic EKC equation" (Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995; López, 1994; Selden & Song, 1995; Selden & Song; Shafik, 1994);
2. "Determinants of the EKC" (Andreoni & Levinson, 2001; Harbaugh et al., 2002; McConnell, 1997; Panayotou, 1997; Schmalensee et al., 1998; Stokey, 1998; Suri & Chapman, 1998; Torras & Boyce, 1998);
3. "Critique of EKC" (Arrow et al., 1995; Cole et al., 1997; de Bruyn et al., 1998; Ekins, 1997; Kaufmann et al., 1998; List & Gallet, 1999; Perman & Stern, 2003; Stern & Common, 2001; Stern et al., 1996);
4. "Review of EKC" (Copeland & Taylor, 2004; Dasgupta et al., 2002; Dinda, 2004; Stern, 2004) and then applying a detailed examination into the more recent publication (from 2005 to 2017); two additional research streams were also identified:

5. “new environmental indicators”; and
6. “new nexus: energy-economy”.

Most of these studies carried out their analyses using cross-section and panel methodologies across countries (Kaufmann et al., 1998; Stern & Common, 2001; Torras & Boyce, 1998).

With the aim of explaining the aforementioned inverted U-shape between income and environment, studies under the determinants of EKC research stream seek to find factors which help justify this relationship. These include: the income elasticity of environmental quality demand; economy sale, technological and compositional effect; international trade; environmental regulations; and some empirical factors such as the sensitivity of indicators or methodologies used which contribute to explain the EKC shape.

In more recent years, the focus on finding new factors affecting the income-environment connection are given by the ratio allocation of capital, financial development and more specifically, foreign direct investment, corruption, tourism, and the enterprise’s sustainability capability.

On the other hand, with respect to the contaminants utilised within the EKC literature, the most influential pollutants include: SO_2, SPM, smoke, NO_2, CO, CO_2, oxygen regimes, fecal contamination, deforestation, and heavy-metal contamination in rivers (Bhattarai & Hammig, 2001; Chua, 1999; Culas, 2007; Dinda, Coondoo, & Pal, 2000; Galeotti et al., 2006; Grossman & Krueger, 1995; Holtz-Eakin & Selden, 1995; Roca, Padilla, Farre, & Galletto, 2001; Stern et al., 1996).

Other newer measures such as threatened bird and mammal species (McPherson & Nieswiadomy, 2005) and the percentage of national protected areas (Bimonte, 2002) have been used as an environmental quality indicator to test the EKC hypothesis. However, as each indicator has its sources as well as physical and chemical properties, the use of different indicators might generate a partial EKC profile, depending on the single pollutant, and therefore produce biased results (Brajer et al., 2011).

Consequently, several studies have contributed to the new environmental indicators research stream, using indicators under indices structure to estimate the EKC relationship. These studies have constructed new measures with the aim of addressing more components of the environmental quality deterioration into one indicator. For example, Jha and Murthy (2003) conducted their study using an index, including both different degraders and pollutants to capture a more comprehensive notion of environmental degradation. The results derive the precise shape of the global EKC.

Halkos and Tzeremes (2009) used the environmental efficiency measure through a ratio of good efficiency performance (using a good output) to a bad efficiency measure (using a bad production) to estimate the EKC shape relationship between environment and economy. Their findings indicate that there is no EKC type relationship, suggesting that the heterogeneity across countries seems to be a difficulty to testing the EKC hypothesis.

Then, both Bagliani, Bravo, and Dalmazzone (2008) and Caviglia-Harris et al. (2009) utilised the known Ecological Footprint (EF) index to examine the environment-economy connection. In particular, this index considers six external environmental impacts that include the carbon, grazing land, forest, fishing grounds, cropland, and built-up-land footprints to measure how much nature we have and how much nature we use (Böhringer & Jochem, 2007; Mori & Christodoulou, 2012; Singh, Murty, Gupta, & Dikshit, 2009; WWF, 2014).

Although the EF seems to be a comprehensive measure to explain environmental degradation, new approaches have emerged from an integrated perspective of assessing global sustainability (Linnenluecke, Meath, Rekker, Sidhu, & Smith, 2015). In this context, not only evaluating different environmental footprints but also combined with satisfying certain environmental limits, a new framework was developed – ‘planetary boundaries’ (PB).

PB, launched by Rockström et al. (2009b), defines a safe operating space for humanity to develop and thrive and determine how humans and human systems will be impacted by transgressions of these boundaries (Hörisch, Ortas, Schaltegger, & Álvarez, 2015).

Unlike other previous global sustainability indices, PB provides a viable and meaningful form of assessment that makes possible studies of cross-firm, cross-sector and cross-country (Whiteman, Walker, & Perego, 2013). Therefore, this approach might be a more integrated way to measure the environmental deterioration for measuring the EKC shape between environment and economic output.

2.1 Planetary boundaries

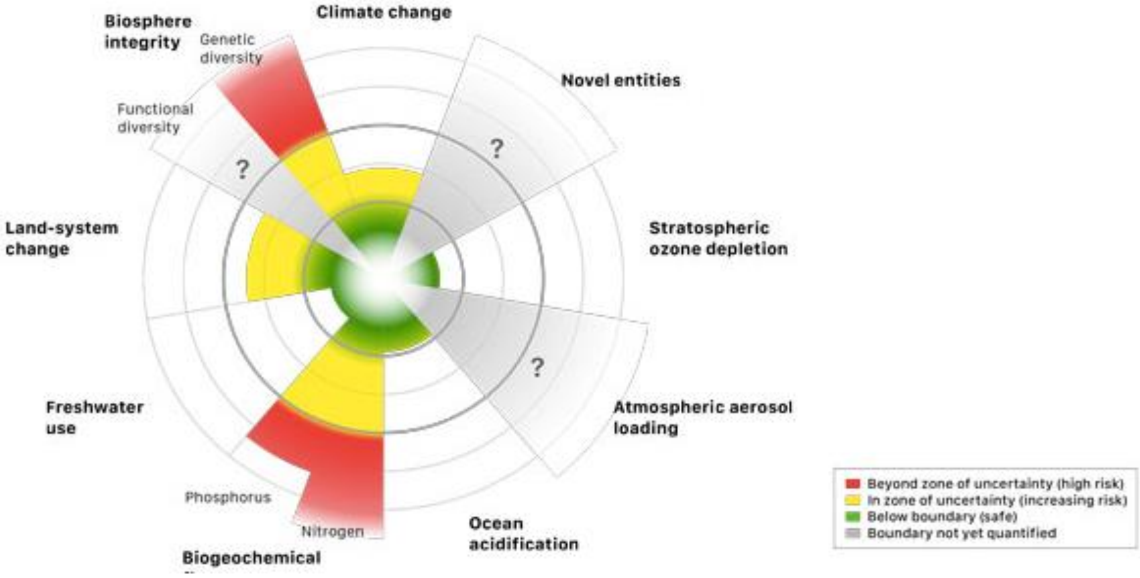
The concept of ‘planetary boundaries’ was addressed by a group of 29 leading Earth system experts from Johan Rockström at the Stockholm Resilience Centre, Stockholm University. During the early 21st century, experts faced one of the largest political problems for humanity regarding how to protect the Earth system and build stable institutions that guarantee a safe transition and co-evolution of natural and social networks on a planetary scale (Biermann, 2012). To initiate such a safe operating space for society, they set levels (or points) linked to critical global scale processes beyond which humanity should not proceed (Steffen et al., 2011). Since its publication, PB have stimulated the work of scientists that influences business and policy agendas (WWF, 2014).

These level (or points) include nine key priorities and thresholds with a global perspective of how close humanity is to exceeding the Earth systems (Rockström et al., 2009b). At the same time, most of these thresholds can be defined by critical values for one or more control variables (Rockstrom et al., 2009a). The nine PB (Figure 4) cover:

1. climate change;
2. change in biosphere integrity (biodiversity loss);
3. stratospheric ozone depletion;
4. ocean acidification;
5. changes in biochemical cycles (including nitrogen and phosphorus levels into the ocean);
6. land-system changes;
7. global freshwater use;
8. anthropogenic global change which provides for aerosol loadings; and
9. chemical pollution (Linnenluecke, Birt, Lyon, & Sidhu, 2015).

A more recent study (Steffen et al., 2015) involved an updated version of PB which says biodiversity integrity is now rescoped and focusing on the function of ecosystems and biological diversity. Moreover, Steffen et al. (2015) introduced novel entities to tackle environmental releases of toxic chemical pollutants and claim that safe levels of four PB have already been exceeded. These include climate change, change in biosphere integrity (biodiversity loss), land-system change, and changes in biogeochemical flows, particularly nitrogen levels.

Figure 4: Nine Planetary Boundaries (Steffen et al., 2015)



The green part represents the proposed safe operating space for nine planetary boundaries. The red colour indicates an estimate of the current status for each variable. It is possible to see that the boundaries in three of these systems have already been crossed. They are biodiversity loss, climate change and nitrogen cycle (Rockstrom et al., 2009a).

2.1.1 Climate change

Over the last 60 years, climate changes have impacted natural and human systems on all continents and oceans (IPCC, 2014). One of the most relevant consequences is the fact that the global temperature has risen since 1950 due to atmospheric greenhouse gas (GHG) concentrations (Brook et al., 2013) and most importantly from increased CO_2 emissions from fossil fuel use (Stockholm Resilience Centre, 2015). Fossil fuel used plus industrial processes have contributed about 78% of the total GHG emissions between 1970 and 2010 (IPCC, 2014). The issue is that these GHGs generated by human activities has trapped enough infrared energy in the lower atmosphere to warm the surface of the earth. Studies show an average global surface temperature rise of about 0.8°C since the pre-industrial period (Steffen et al., 2011).

Under this context, Rockström et al. (2009b) proposed a dual approach for assessing climate change boundary: atmospheric CO_2 concentration ppm (parts per million by volume) and energy imbalance at earth's surface, W m^{-2} (watts per meter squared). They assigned boundary values of 350ppm for the concentration of CO_2 in the atmosphere and +1.0 Wm^{-2} for radiative forcing (Biermann, 2012). In fact, considering these measures, studies show that current levels of these variables already exceed these levels. Atmospheric CO_2 stands at around 400ppm, and current radiative forcing stands at +2.3 W m^{-2} (1.1-3.3 W m^{-2}), respectively (Steffen et al., 2015).

The fact is, even if atmospheric GHG concentrations are held at current levels, temperatures would continue to climb. Even temperature increases that are below 2°C (which is the stated goal of governments worldwide) would represent significant risks for humankind and natural systems (WWF, 2014). Human assets and business activities might suffer the physical effects of rising temperatures including more frequent weather extremes (storms or drought) and sea-level rises because of CO_2 emissions (Chichilnisky & Heal, 1998; Linnenluecke, Birt, et al., 2015).

2.1.2 Changes in biosphere integrity

Although species extinction is caused by a natural process that would occur without human intervention, the primary causes of the biodiversity loss are anthropogenic activities such as land development, overexploitation, species translocations and introductions, and pollution (Lande, 1998). In this sense, Rockström et al. (2009b) introduced biodiversity loss as one of the PB to provide ecological functions that support biophysical subsystems of the Earth.

Due to the impossibility of providing an exact boundary measure to this PB, Rockstrom et al. (2009a) proposed the use of an extinction rate indicator. For this, they assign an uncertainty range of no more than ten extinctions per million species years (E/MSY).

In recent years, Steffen et al. (2015) suggested a dual approach to explain two critical roles of the biosphere. The first approach determines the capabilities of life to continue coevolving with the ecosystem. The second approach represents genetic diversity and provides the capacity of the ecosystem to persist in the long-term relative to changes. It is related to the Earth's natural system functioning through the value, range, distribution and abundance of different species.

2.1.3 Stratospheric ozone depletion

Since 1980, the worldwide ozone loss has been identified, studied, and analysed (Middlebrook & Tolbert, 2000). The effects of ozone loss can be seen through the existence of the Antarctic ozone hole. This hole exists where massive ozone loss has been observed annually since 1970 (Middlebrook & Tolbert, 2000; Smith et al., 1992; Solomon, Garcia, Sherwood, & Wuebbles, 1986).

The natural role of the stratospheric ozone is to absorb damaging ultraviolet (UV) radiation from the sun and provide a protective barrier to the planet. This barrier is essential for life to exist on Earth as exposure to UV radiation is a major cause of mutation and cancer in humans, animals, and plants (Solomon, 1999).

This PB is given by ozone concentration (O_3) measured in Dobson Units[10] (DU), and its boundary determined to be no lower than 275DU or <5% decrease in column ozone levels (Rockström et al., 2009b). A clear example of crossing the threshold is the Antarctic ozone hole. It shows that the O_3 concentration decreased to around 200DU (Steffen et al., 2015). However, recent evidence shows that the minimum ozone concentration has been remained constant for about 15 years after the phasing out of ozone-depleting substances such as chlorofluorocarbons (CFCs) (Stockholm Resilience Centre, 2015).

2.1.4 Ocean acidification

The PB ocean acidification and climate change are directly linked to the emission of CO_2. Climate change is caused by GHG emission, mostly CO_2 as mentioned previously, while the ocean acidification is controlled by the increased concentration of atmospheric CO_2 (Harrould-Kolieb & Herr, 2012).

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[10] Dobson Units were invented by the English scientist George M.B. Dobson in 1927. They're used for measuring the column amount of ozone by measuring the amount of UV light absorbed by the atmosphere (Middlebrook & Tolbert, 2000)

These substantial CO_2 emissions into the atmosphere are partially absorbed (roughly 30%) by the oceans, causing an increase in ocean acidification (IPCC, 2014; Turley & Findlay, 2016). Although the amount has been controlled, the absorption generates large-scale changes in seawater chemistry by reducing the ocean pH and increasing the amount of bicarbonate in seawater (Gattuso, Mach, & Morgan, 2013). This process may cause a conversion (or in fact destruction) of coral reefs to form algal-dominated systems which have considerable effects on marine life (Nordhaus, Shellenberger, & Blomqvist, 2012). It could also have a consequential impact on seafood staples around the world ("Why Ocean Acidification is a Climate Change Indicator," 2016).

With the aim of quantifying this PB, Rockström et al. (2009b) proposed the carbonate ion concentration as a measurement of oceanic acidification. It is measured by the average global surface ocean saturation state concerning aragonite, known as Ω_{arag}. They stated that the aragonite saturation state should remain above 80% of the pre-industrial value as a reference. Evidence shows the current amount of this PB is around 84% of the pre-industrial value (Steffen et al., 2015).

2.1.5 Changes in biochemical cycles

The following PB includes the Nitrogen and Phosphorous cycles. Both elements are classed as nutrients. Nitrogen (N) and phosphorous (P) are essential for the continuation of Earth’s natural systems functioning (Elser et al., 2007). Increasing N and P flows at a regional and global scale may generate undesired change not only in terrestrial ecosystems but also in the marine ecosystem (WWF, 2014).

Originally, Rockström et al. (2009b) formulated control variables for N and P, but without excluding the possibility that these boundaries should be separated. They assigned P to determine the quantity of phosphorous absorbed into the oceans and N to the amount of N_2 extracted from the atmosphere for anthropogenic activities. The current status of the phosphorous level is 8.5-9.5Mt/year, which is measured against 11Mt/year as the proposed boundary. Human activities remove approximately 121Mt/year of N_2 from the atmosphere, against a recommended limit of 35Mt/yr. (Steffen et al., 2011; WWF, 2014).

The Nitrogen Loss Indicator developed for the Convention on Biological Diversity represents roughly all nitrogen pollution generated from all sources within a country or region. Thus, such as food production, its consumption as well as the use of energy are sources of pollution (WWF, 2014). According to evidence, scholars have noticed that nitrogen produced by humanity has exceeded the natural level (Whiteman et al., 2013). Accelerations by using it in industrial fertilisers can have negative consequences such as the: enrichment of chemical nutrients in land-based and water ecosystems; reduction of oxygen content in coastal areas; and some acidification in soils and freshwater (Nordhaus et al., 2012). For its part, the extra burden of an increased phosphorous level because of industrial fertilisers might also generate consequences on land and in freshwater and seawater. An example, as seen in France, was an excessive growth of green algae blooms in sea water and coastlines (Whiteman et al., 2013), detrimental to the survival of aquatic life in the affected regions, due to fertiliser.

2.1.6 Land-system change

While the concentration of GHG in the atmosphere seems to have the more significant impact on climate change, variations in land use and surface cover (agriculture) also might alter the climate patterns (Pielke, 2005; Pielke et al., 2002). In that regard, Rockström et al. (2009b) have noted that the replacement of forest areas with cropland and settled landscapes had occurred at roughly 0.8% annually in the last 5 decades as well as it has been estimated that between 30% and 50% of the world's land surfaces have been transformed by humankind (Pielke, 2005).

Under this context, it has been suggested PB of no more than 15% of the global ice-free land surface utilized for agricultural land (Rockström et al., 2009b). Currently, this measure shows a current value at around 11% (Steffen et al., 2015).

2.1.7 Global freshwater use

This boundary is established by the water use by humans in km^3 per year. This is mainly due to the alteration in river flows, extracting water for irrigation and capturing rainfall for agriculture, industrial and household use (Raworth, 2012).

Humanity is altering river flows as well as patterns and timing of vapour flows. Studies have estimated that around 25% of world river watersheds run dry before arriving at the ocean because of human use (Rockström et al., 2009b).

The boundary measurement given by Rockström et al. (2009b) consists in the amount of 4,000km^3 of fresh water consumed by humans per year, and the current value is given to be 2,600km^3. Recently, this measure was enhanced by Steffen et al. (2015), who incorporated the term of environmental water flow (EWF). EWF is defined as the level of river flows based on different hydrological features of the river watersheds.

Given that water represents an essential resource, corporations are looking for sustainability in the use of freshwater (Whiteman et al., 2013). To do otherwise could generate water scarcity and have considerable effects on critical sectors such as thermal electricity generation, mining and oil and gas (Caldecott & McDaniels, 2014).

2.1.8 Chemical pollution

The primary cause of environmental air pollution is generated by human activities, mostly from industrial facilities (Kampa & Castanas, 2008). There are two reasons why chemical pollution is considered a PB. Firstly, it is due to the impact on the physiological development and demography of living beings (Rockström et al., 2009b). Secondly, it is because it acts as a slow variable with repercussions for other planetary boundaries (Rockström et al., 2009b).

Currently, there are more than 100,000 substances classed as pollutants around the world, and it is almost impossible to measure each of them (Rockström et al., 2009b; Steffen et al., 2015). For this reason, the boundary of these substances released and propagated through industrial production and waste disposal (radioactive compounds, organic compounds and heavy metals) still has not been determined (Raworth, 2012).

2.1.9 Atmospheric aerosol loading

Aerosols are well-known as having serious implications for human health due to considerable polluted micro-particles emitted into the air. In fact, around 7.2 million deaths are caused by exposure to aerosol pollutants (Steffen et al., 2015). In addition to health issues, Rockström et al. (2009b) considered atmospheric aerosol loading as a critical process in global climate change, with particular potential effects on climate systems. Although it is still complicated to define a measurement for this, recent research has studied the south Asian monsoon season to determine a regional boundary with a control variable called Aerosol Optical Depth (Steffen et al., 2015).

2.2 Boundaries Interactions

Although the planetary boundaries (PB) exhibit unique features and measures, they might move the safe level of one or more limits (Rockström et al., 2009b). For example, the forecasting of land to be in drought because of a lack of induced water by the safe crossing level of the climate change boundary, may cause adverse effects on the availability of the land for agricultural use. Consequently, this may displace the land use threshold to a lower level.

Extracting information from Table 1, provided by Rockström et al. (2009b) in their paper "*Planetary Boundaries: Exploring the safe operating space for humanity",* the boundaries might be influenced by the slow variable as follow:

> "Atmospheric aerosol loading: disruption of monsoon systems. Human health effects. Interacts with climate change and freshwater boundaries".
>
> "Biochemical cycles. P: avoid a major oceanic anoxic event (including regional), with impacts on marine ecosystems. N: slow variable affecting the overall resilience of ecosystems via acidification of terrestrial ecosystems and eutrophication of coastal and freshwater systems."
>
> "Global freshwater use: primarily slow variable affecting moisture feedback, biomass production, carbon uptake by terrestrial systems and reducing biodiversity."
>
> "Land-system change: primarily acts as a slow variable affecting carbon storage and resilience via changes in biodiversity and landscape heterogeneity."

> “Rate of biodiversity loss: slow variable affecting ecosystem functioning at continental and ocean basin scales. Impact on many other boundaries – C storage, freshwater, N and P cycles, land systems.” (p.8)

Under this context, Steffen et al. (2015) also refer to this interaction analysis and suggest that two boundaries – climate change and biosphere integrity – have a high integration, as well as being regulated by the other barriers.

In addition to the purely biophysical interactions, Nilsson and Persson (2012) discuss the boundaries interactions due to policy responses. For this analysis, they consider the boundaries of climate change, freshwater use, land system change, and biodiversity loss. For example, better use of freshwater and land for agricultural use may have some negative impacts on the biodiversity loss and climate change. An increase in forest cover can provide positive effects on climate mitigation by the natural process of carbon dioxide being extracted from the atmosphere and held in solid or liquid form in the biomass for energy. Thus, this would increase the green water, giving more availability of the freshwater use in some areas (Nilsson & Persson, 2012).

2.3 Planetary Boundaries approaches

Due to the concept of PB involving distinct dimensions of environmental pollution and the critical thresholds that should not be crossed (Hörisch et al., 2015), countries and corporations have been subject to both government and market pressures. The latter to adopt a corporate environmental strategy that redefines the pathways of human development in the future by diminishing the damage caused to the earth’s system (Coulson & Dixon, 1995). For example, carbon-intensive production processes have already been limited by regulatory changes, and there are similar potential changes in regulations on the use of chemicals in medicine, agriculture, consumer goods and new technologies. There are also calls for more restrictive government regulations concerning the number of permissible microparticles emitted into the atmosphere (Linnenluecke, Birt, et al., 2015).

One recent study by Bjørn et al. (2016) conducted a review examining the ecological limits references in corporate sustainability reports from 2010 to 2014 for a selection of companies. In this context, the PB concept was one of the references evaluated. The article noticed that PB references in company reports only started appearing in 2011, which is interesting considering its publication in 2009. Since 2011, the number of references has increased, but it is still not significant because companies and countries used more generic ecological terms for limits than those related to specific components of environmental issues.

Some examples of studies that have approaching the PB concepts into the business economic field are: Hörisch et al. (2015); Linnenluecke, Birt, et al. (2015); Linnenluecke, Meath, et al. (2015); Dearing et al. (2014); Häyhä et al. (2016); Hepburn, Beinhocker, Farmer, and Teytelboym (2014); Fang, Heijungs, and De Snoo (2015); and Galaz et al. (2012).

Hörisch et al. (2015) particularly addressed PB in their research by analysing survey data from the largest companies in five industrialised countries. Empirically they tested the impact of implementing sustainability management tools (STMs) on crucial dimensions of environmental performance. They used PBs as dimensions of environmental issues. They concluded that the implementation of effective corporate environmental and sustainability management practices could help companies diminish their negative impacts on the environment.

On the other hand, Linnenluecke, Birt, et al. (2015) discussed the implications of changes in planetary boundaries as environmental issues for asset impairment. They focused on the climate change variable because this has represented more significance in discussing the increased risk of impairment of fossil fuel assets. They looked at accounting standards on impairment, reviewing the practices of the top 10 metals and mining firms in Australia. They concluded that one of the companies already exhibited concerns regarding impairment and climate change. However, as this study is one of the initial studies on this matter, it remains on the research agenda to evaluate more extensively the effects of global environmental change.

Consequently, there have been multiple calls to develop businesses that better respect PBs (Hörisch et al., 2015). Given this, Linnenluecke, Meath, et al. (2015) examined the disinvestment in fossil fuels among Australian companies under planetary boundaries framework. This examination incorporated corporate social responsibility and ethical investment and discusses the science behind this disinvestment. They conclude that a correlation between policies and organisational responses leads to more significant action on climate change.

Another strand of the literature (Galaz et al., 2012) analyses the PBs and provides four interrelated global governance challenges and possible ways to address them. These challenges are the:

- interaction between Earth system science and global policies;
- capacity of international institutions to deal with planetary boundaries;
- role of international organisations in dealing with PB; and
- latest position of global governance in framing social-ecological innovations.

There is, however, significantly limited research that investigates how a corporation's actions affect and are affected by, each of these nine PB mentioned above (Whiteman et al., 2013). Under the same context, Häyhä et al. (2016) provides a sight to operationalise the PBs toward the national levels of decision-making. This paper proposes a framework which considers the biophysical, socio-economic, and ethical in global dimensions to translate the PB into national or regional implementation.

3. Methodology

3.1 Sample description

This section discusses the data applied in this study to test the implications of economic output (the growth rate) on seven PB (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land use, and biodiversity), considering a global EKC context for 177 economies around the world. As seven out of the nine ecosystems proposed by Steffen et al. (2015) provide measures, the samples for this study depend on the data for each boundary studied. That means, seven compilated databases are constructed for seven different unbalanced longitudinal samples, each one for 177 countries from Asia, Europe, North and Latin America, Southeast Asia and Africa (see Table 12). The full dataset for panels of climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land use contain 5,043 country-yearly observations between 1973 and 2013 under conventional econometric analyses and 4,766 observations under dynamic system Generalized Method of Moments (GMM) specification. The biodiversity loss panel includes 2,171 observations for conventional methods and 1,965 for system GMM analysis.

Table 12: List of countries for PB analyses

ID	COUNTRY						
1	Afghanistan	51	Spain	101	Latvia	151	Sweden
2	Angola	52	Estonia	102	Morocco	152	Swaziland
3	Albania	53	Ethiopia	103	Moldova	153	Seychelles
4	United Arab Emirates	54	Finland	104	Madagascar	154	Syrian Arab Republic
5	Argentina	55	Fiji	105	Maldives	155	Chad
6	Armenia	56	France	106	Mexico	156	Togo
7	Antigua and Barbuda	57	Micronesia, Fed. Sts.	107	Macedonia, FYR	157	Thailand
8	Australia	58	Gabon	108	Mali	158	Tajikistan
9	Austria	59	United Kingdom	109	Malta	159	Timor-Leste
10	Azerbaijan	60	Georgia	110	Myanmar	160	Tonga
11	Burundi	61	Ghana	111	Montenegro	161	Trinidad and Tobago
12	Belgium	62	Guinea	112	Mongolia	162	Tunisia
13	Benin	63	Gambia, The	113	Mozambique	163	Turkey
14	Burkina Faso	64	Guinea-Bissau	114	Mauritania	164	Tanzania
15	Bangladesh	65	Equatorial Guinea	115	Mauritius	165	Uganda
16	Bulgaria	66	Greece	116	Malawi	166	Ukraine
17	Bahrain	67	Grenada	117	Malaysia	167	Uruguay
18	Bahamas, The	68	Guatemala	118	Namibia	168	United States
19	Bosnia and Herzegovina	69	Guyana	119	Niger	169	St. Vincent and the Grenadines
20	Belarus	70	Honduras	120	Nigeria	170	Venezuela, RB
21	Belize	71	Croatia	121	Nicaragua	171	Vietnam
22	Bolivia	72	Haiti	122	Netherlands	172	Vanuatu
23	Brazil	73	Hungary	123	Norway	173	Samoa
24	Barbados	74	Indonesia	124	Nepal	174	Yemen, Rep.
25	Brunei Darussalam	75	India	125	New Zealand	175	South Africa
26	Bhutan	76	Ireland	126	Oman	176	Congo, Dem. Rep.
27	Botswana	77	Iran, Islamic Rep.	127	Pakistan	177	Zambia
28	Central African Republic	78	Iraq	128	Panama	178	Zimbabwe
29	Canada	79	Iceland	129	Peru		
30	Switzerland	80	Israel	130	Philippines		
31	Chile	81	Italy	131	Papua New Guinea		
32	China	82	Jamaica	132	Poland		

33	Cote d'Ivoire	83	Jordan	133	Portugal
34	Cameroon	84	Japan	134	Paraguay
35	Congo, Rep.	85	Kazakhstan	135	Qatar
36	Colombia	86	Kenya	136	Romania
37	Comoros	87	Kyrgyz Republic	137	Russian Federation
38	Cabo Verde	88	Cambodia	138	Rwanda
39	Costa Rica	89	St. Kitts and Nevis	139	Saudi Arabia
40	Cyprus	90	Korea, Rep.	140	Sudan
41	Czech Republic	91	Kuwait	141	Senegal
42	Germany	92	Lao PDR	142	Singapore
43	Djibouti	93	Lebanon	143	Solomon Islands
44	Dominica	94	Liberia	144	Sierra Leone
45	Denmark	95	Libya	145	El Salvador
46	Dominican Republic	96	St. Lucia	146	Serbia
47	Algeria	97	Sri Lanka	147	Sao Tome and Principe
48	Ecuador	98	Lesotho	148	Suriname
49	Egypt, Arab Rep.	99	Lithuania	149	Slovak Republic
50	Eritrea	100	Luxembourg	150	Slovenia

3.2 Variables

3.2.1 Dependent variable

As it is mentioned in the third chapter of this thesis, commonly used environmental performance indicators to test the income-environmental link correspond to local short-term measures which might result in the misinterpretation of the EKC relationship (Arrow et al., 1995; Dinda, 2004). These studies have included environmental indicators such as SO_2, SPM, smoke, NOx, and CO which have been consistent with the EKC shape (Dinda, 2004). On the other hand, based on previous studies, the EKC only exists for the local pollutant, while indicators with more global impacts increase monotonically with economic output variables (Cole et al., 1997; Holtz-Eakin & Selden, 1995).

As a result, and with the aim of considering a global impact, several studies incorporated the primary source of greenhouse gases (GHG) emissions to validate the EKC, CO_2 emissions (Agras & Chapman, 1999; Du et al., 2012; Holtz-Eakin & Selden, 1995; Sephton & Mann, 2016). However, these studies have not included an integrated perspective on global environmental change, which covers a comprehensive and long-term impact on the world as are the PB. For this reason, this essay takes account into a global view through the PB as environmental performance indicators.

Seven out of nine boundaries proposed by Rockstrom et al. (2009a) and Steffen et al. (2015) provide measures to quantify a particular environmental damage. Thus, this study considers these seven dependent variables for validating the EKC hypothesis, which was analysed within seven different panels of data.

The environmental data for the first PB (climate change) is obtained from the National Oceanic & Atmospheric Administration (NOAA) platform, which is provided by Earth System Research Laboratory (ESRL) from Global Monitoring Division. This platform involves atmospheric CO_2 trends data from Mauna Loa, Hawaii Observatory[11], that has continuously monitored and collected data relating to atmospheric change since the 1950s. The NOAA ESRL website covers data with different frequencies and measurements of CO_2 concentrations. However, to evaluate the climate change boundary contribution on EKC hypothesis, the seasonality corrected[12], average worldwide annual trend for CO_2 concentrations is employed as the first dependent variable within the first panel. Although the variable has availability from 1960 to 2015, this study considered a horizon between 1973 and 2013 to validate the EKC approach.

In the case of the biodiversity loss boundary, the environmental data is drawn from the world's central authority on the conservation status of species, the International Union for Conservation of Nature (IUCN)[13]. This association provides taxonomic, conservation status, and distribution information on plants and animals. Notably, it compiles the Red List of Threatened Species[14], which catalogues the relative risk of extinction for categories of critically endangered, endangered, and vulnerable species (IUCN, 2017). Therefore, to examine this boundary, the number of threatened species was used as a dependent variable for the period 1996 to 2013 because of the data availability.

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[11] See more at http://www.esrl.noaa.gov/gmd/obop/mlo/

[12] See at NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/)

[13] See at http://www.iucnredlist.org/

[14] IUCN Red List involves species such as mammals, birds, reptiles, amphibians, fishes, molluscs, other inverts, and plants.

For the third PB evaluated, ozone depletion, the environmental data was obtained from the British Antartic Survey[15], Natural Environment Research Council. This website provides ozone observation data made at the:

- Halley station in Antarctica, from 1956;
- Faraday station in Antarctica, from 1964 (then Vernadsky from 1996);
- King Edward Point station in South Georgia, from 1971 (until 1982); and
- Rothera station in Antarctica, from 1996.

However, to analyse the ozone depletion environmental indicator under an EKC context, only Halley station was considered. Notably, this station supplies the provisional monthly mean value of the total ozone at the station as well as the annual mean as measurements, which in turn was utilised as a proxy of the ozone depletion to construct the dependent variable for the third panel evaluated.

The fourth PB assessed was ocean acidification. In this regard, the environmental data is obtained from the Knoema[16] online platform. This website drew the data from two sources: the LSCE/IPLS[17] in France and the IPCC fifth assessment report. The global indicator of the mean surface ocean hydrogen ion concentration was utilised by the platform, and thus for this study, as a dependent variable to represent the acidification of the oceans. The data is available since 1960, however, to evaluate the EKC impact on this global environmental indicator, the panel considered the period 1973 to 2013.

Due to the fertiliser products cover nitrogen, potassium, and phosphate, the global fertilier consumption was utilised as the dependent variable and a proxy of the biochemical cycles boundary for this EKC analysis. What this consumption represents in a million tonnes is based on the International Industry Association (IFA)[18] dataset, which deliveries data from 1960 to 2013 (with 1961 and 1962 as a base year) on this issue.

The global freshwater use boundary is obtained from the Center for Environmental System Research of the University of Kassel. This variable represents in thousand cubic kilometres (km^3) is given by the sum of irrigation, domestic, manufacturing and

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[15] See at https://www.bas.ac.uk/

[16] See at https://knoema.com/

[17] Laboratoire des sciences du climat et de l'environnement (LSCE) and Institute Pierre Simon Laplace (IPSL)

[18] See at https://www.fertilizer.org/

electricity water withdrawal, which was utilised as a dependent variable within this panel. This environmental information is available since 1900, however, as this study considers a narrow horizon, the data obtained is from 1973 to 2010.

On the other hand, the global agricultural land area was employed as the dependent variable and a proxy of the land change boundary panel. This variable represented in square kilometres (km^2) values were obtained from the World Development Indicator (WDI) from the World Bank data collection source. The availability of this variable is from 1961 to 2015, however, to validate the EKC relationship using this boundary as environmental performance worldwide, the period 1973 to 2013 was considered. Some previous researchers have used similar variables to test the EKC hypohtesis (Bhattarai & Hammig, 2001; Chiu, 2012; Culas, 2012). However, these studies have focused their analsysis on specific countries or areas rather than a global EKC using a global environmental performance, or well they have not considered the possible correlation between environemntal indicators.

3.2.2 Independent variable

This chapter aligns with the third chapter of this thesis and previous estimations for EKC approach, which utilises the annual real (inflation adjusted) GDP as the leading independent variable to analyse the effects between economic variables and environmental performance indicators (Grossman & Krueger, 1991, 1995; Holtz-Eakin & Selden, 1995). As the second essay does, the annual GDP by country represents in current $US is drawn from the World Development Indicator (WDI) provided by the World Bank. This variable is defined as the sum of gross value added by all resident producers in one country, together with product taxes minus any subsidies not included in the cost of the product. With the aim of identifying the long-term effect such as the GDP, the GDP squared is included as an independent variable within the seven estimates panels.

3.2.3 Control Variables

The second chapter of this thesis explains the main streams of research within the EKC literature. One of them is the determinants of the EKC, or in other words, the factors justifying an inverted U-shape relationship between environment and economic variables. Under this context, the EKC literature together with the second study of this thesis has included several control variables in identifying these possible explanations.

Therefore, for the seven panel analysed in this study, the first control variable considered is the population (POP) by country as a demographic variable. The POP has also been included in previous studies to determine whether the level of population, rural population or the population growth rate are related to the EKC shape explanation (Selden & Song, 1994; Bhattarai & Hammig, 2001; Culas, 2007; Koop & Tole, 1999; Lantz & Feng, 2006; S. Wang, Fu, & Zhang, 2015).

The second control variable considered is the merchandise trade (MT) by country as a proxy of the international trade, which is also one of the explanations why the income-environment relationship presents an inverted U-shape. In particular, trade liberalisation allows developed countries to transport their “dirty” industries to other developing countries, also known as the pollution haven hypothesis (Cole, 2004). Some authors using the international trade as a covariate are: Cole (2004); Jalil and Mahmud (2009); Kearsley and Riddel (2010); Lehmijoki and Palokangas (2010); Van Hoa and Limskul (2013); and Kasman and Duman (2015).

Financial development (FD) is the third control variable incorporated within this EKC global validation as many researchers have considered it in previous studies (Jalil & Feridun, 2011; Ozturk & Acaravci, 2013; Tamazian & Rao, 2010). In particular, there are two hypotheses concerning financial development. One states that financial development leads to deteriorating environmental quality (Sadorsky, 2010; Zhang, 2011). The second refers to financial development improving the environmental quality condition (Jalil & Feridun, 2011; Tamazian & Rao, 2010).

Ozturk and Acaravci (2013) present three interpretations of why the first hypothesis should be enforced. First of all, the development of the stock market allows listed companies to reduce the financing cost, increase the funding channels, spread the operational risk and maximise the asset/liability structure. By doing so, these corporations get new installations and projects, which would, in turn, contribute to increasing CO_2 emissions through more energy consumption in their company's operations. Secondly, the financial development calls for increasing the foreign direct investment which enhances the economic growth rate and thus raising the level of pollution. Finally, when the financial development is more efficient, the consumers begin to get new and more sources of financing to purchase houses, vehicles, and articles of the white line, which imply further congestion and pollution.

For the second hypothesis, Ozturk (2013) mentions a possible explanation. That is, the financial development might increase energy consumption efficiency and enhance a company's performance, and thus reduce the level of energy use and pollution. Moreover, Tamazian and Rao (2010) state that the financial development provides the opportunity to use new technologies with clean and environmental-friendly company operations. As a consequence, these technologies might improve global environmental quality.

To capture the political approaches within the global EKC model, the political rights (PR) and civil liberties (CL) indices were also considered as possible determinants contributing to the inverted U-shaped income-environment association. These indices have been previously tested by Torras and Boyce (1998) and Lin and Liscow (2013) in EKC estimates.

According to FreedomHouse (2015), the PR index evaluates the electoral process, political pluralism and participation, and the functioning of government (FreedomHouse, 2015). The CL index measures the freedom of expression and belief, associational and organisational rights, the rule of law, personal autonomy and individual rights. Both indices vary between one (the highest degree of freedom) and seven (the least) (Lin & Liscow, 2013). The historical data of the ratings by country were drawn from FreedomHouse in 2015 from 1973 to 2015.

All the control variables mentioned above were compiled for the 177 countries from the World Development Indicators 2016 (WDI) provided by the World Bank between 1973 and 2013.

One of the main econometric limitations proposed by authors testing the environment-income relationship is the non-stationary characteristic in time series data (E. Choi et al., 2010; Marzio Galeotti, Manera, & Lanza, 2008; Jaunky, 2011; Perman & Stern, 2003; Romero-Avila, 2008; Stern, 2004). This means that variables don't have a covariance with constant mean and variance, or in another case, strict stationery which involved all factors having identical distribution in any sample from the data. Instead, they are referred to as the unit root, or stochastically trending variables (Perman & Stern, 2003). For that, some authors recommend differentiating the variables as many times as the variables required, to be converted into stationary data to avoid this vulnerability in the EKC validation.

One way to tackle this issue is by using the Fisher Type Unit Root Test[19] for a panel based on the augmented Dickey-Fuller (ADF) unit root test. According to Table 13, results indicate that the variables such as the global CO_2 concentration; global fertiliser consumption; worldwide freshwater withdrawal; global mean surface hydrogen ion concentration; and the global number of threatened species (as proxies of the climate change, biochemical cycles, freshwater use, ocean acidification, and biodiversity boundaries) plus the Gross Domestic Product (GDP), present the possibility of unit root for their panels. The global provisional annual mean of the total ozone, global agricultural (as proxies of the ozone depletion and land use boundaries, respectively), and control variables do not show non-stationary behaviour. Therefore, to conduct the models and econometric analysis the variables were differentiated, and thus, the first difference of each one is used which present a stationary behaviour.

Table 13: Fisher Type unit-root test results for PB analyses

	Level Variable	Differenced Variable
Name	P- Statistic X^2	P- Statistic X^2
CCO2	4.0771	542.1791***
FERTILISER	265.8862	2785.6878***
FRESHWATER	289.1546	5654.0091***
OZONE	906.8634***	1.18+4***
OCEAN	0.1569	1984.2889***
LAND	1190.5467***	4851.1664***
BIODIVERSITY	15.7315	1237.5251***
GDP	365.0725	3292.0305***
POP	707.9051***	4136.49***

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[19] The null hypothesis of the Fisher Type Unit Root test assumes that all series are stationary against the alternative hypothesis which says that at least on series is the panel is stationary (Maddala & Wu, 1999)

FD	413.2455**	3991.8702***
MT	693.3135***	5959.8487***
PR	609.0607***	4527.0409***
CL	620.5875***	5000.0185***

Note: The inverse chi-squared P test was utilised in these analyses to test the null hypothesis that all panels of variable are non-stationary. The inverse X^2 distribution with $2N$ of freedom (Choi, 2001)

Therefore, basing on the previous unit root test the variables definitions are given by the Table 14 as follows:

Table 14: Variables definitions for PB analyses

Variables	ID	Definition
Dependent variable Panel 1	$CCO2_t$	This variable is given by the changes of the natural log of the global CO_2 concentrations. In other words, the changes in these concentrations yearly.
Dependent variable Panel 2	$Fertiliser_t$	This variable is given by the changes in the natural log of the global fertilizer consumption yearly.
Dependent variable Panel 3	$Ozone_t$	This variable is given by the changes in the natural log of the annual mean of the total ozone.
Dependent variable Panel 4	$Ocean_t$	This variable can be interpreted as the changes in the natural log of the annual mean of the surface ocean hydrogen ion concentration.
Dependent variable Panel 5	$Freshwater_t$	This variable is given by the changes in the natural log of the global sum of irrigation, domestic, manufacturing and electricity water withdrawal yearly.
Dependent variable Panel 6	$Land_t$	This variable is given by the changes in the natural log of the global agricultural land area yearly.
Dependent variable Panel 7	$Biodiversity_t$	This variable is given by the index of the biodiversity loss. This means the changes in the natural log of the number of threatened species yearly.
Independent variable	$GDP_{i,t}$	This variable can be interpreted as per-period growth rates in income for country-specific regions. It is given by the changes in the

		natural log of the Gross Domestic Product (GDP) levels.
Control variable	$POP_{i,t}$	This variable represents the changes in the natural log of the total population by country yearly (all residents regardless of legal status or citizenship).
Control variable	$FD_{i,t}$	This variable entails the changes in the natural log of the financial development by country yearly (domestic credit to private sector as percentage of the GDP).
Control variable	$MT_{i,t}$	The variable indicates the changes in the natural log of the merchandise trade by country yearly (as a share of GDP).
Control variable	$PR_{i,t}$	This variable is the changes in the natural log of the political rights index by country yearly.
Control variable	$CL_{i,t}$	This variable is the changes in the natural lag of the civil liberties index by country yearly.

3.3 Econometric Models

Since the time series data in the seven panels are stationary and we have the variables definition, a set of econometric boundaries models will be introduced. Thus, the research question of whether the inverted U relationship between some global and long-term environmental indicators and the economic growth rate of 177 countries exist as a global EKC, and whether specific factors such as population, financial development, merchandise trade, political rights, and civil liberties might explain this behaviour.

To validate the previous research question, the possible relationships between the variables for the set of the seven boundaries panels are given by:

$$PB_t = f(GDP_{i,t}, GDP^2{}_{i,t}, X'_{i,t}) \tag{4}$$

Where, PB represents the environmental degradation indicator under boundaries context and it is given by the changes of the global indicator for each of the seven boundaries: climate change (CCO_2), biochemical cycles (Fertilizer), ozone depletion (Ozone), ocean acidification (Ocean), freshwater use (Freshwater), land use (Land), and biodiversity (Biodiversity). These PB will depend on the GDP, the GDP2 to measure the effect to long-term, and some control variables (described in the variables section). Particularly, the control variables are commonly used in EKC estimates to mitigate potential misspecification and biased estimation (Li et al., 2016).

Additionally, and following the line of some researchers (Agras & Chapman, 1999; Anderson & Cavendish, 2001; G. Halkos & Tzeremes, 2009; Lee, Chiu, & Sun, 2009; Li et al., 2016; Roman-Aso & Valles-Gimenez, 2016; Song, Zheng, & Tong, 2008), the econometric models include the lag term of the environmental indicator, or in other words, the lag of the boundary analysed to consider the dynamic effect. This lagged term aims to examine the impact that these global environmental indicators change cumulatively, and therefore, they are likely to be correlated over time.

Therefore, the econometric models where the proxies were used to explain each PB behaviour are given by the seven following equations:

$$CCO2_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 CCO2_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{6}$$

$$Fertiliser_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Fertiliser_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{7}$$

$$Ozone_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Ozone_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{8}$$

$$Ocean_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Ocean_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{9}$$

$$Freshwater_t = \alpha_1{+}\alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Freshwater_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{10}$$

$$Land_t = \alpha_1{+}\alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Land_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{11}$$

$$Biodiversity_t = \alpha_1{+}\alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Biodiversity_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{12}$$

Where, the i represents the country, t the period, γ_i captures the country fixed effects (because of the country-specific characteristics such as culture, structure climate, etc.), and the ε_{it} entails the disturbance term. Under the specifications in Eqs. (6) – (12), the conventional methods such as the Ordinary Least Squares (OLS) and fixed-effect estimates procedures are carried out to validate the hypothesis of the global EKC hypothesis. The assumption is confirmed if $\alpha_2 > 0$ and $\alpha_3 < 0$, while the $\alpha_2 > 0$ and $\alpha_3 = 0$ reveals a monotonically positive linear relationship and the $\alpha_2 < 0$ and $\alpha_3 = 0$ indicates a monotonically negative linear relationship. Mainly, the OLS procedure requires that GDP, GDP2, and control variables to be orthogonal to the errors of the model for the first set of models. That means the errors normally are independently and identically distributed with mean 0 and constant variance σ_ε^2 over time and across countries (Schultz et al., 2010). This might be solved using a fixed-effect econometric approach.

On the other hand, the fixed-effect procedure will produce consistency in results whether a strict exogeneity assumption is considered. That is, the GDP, GDP2, and control variables are orthogonal to past, present and future PB evaluated for each model. In other words, they have to be time-invariant to the boundaries analysed.

However, as it is likely to be at the forefront of the dynamic endogeneity and simultaneity issues because of the country-specific characteristics, the strict exogeneity assumption under fixed-effect procedure is violated. The dynamic endogeneity exists because the regressor would be contemporaneously correlated with the error (Schultz et al., 2010). Whereas, there is a widespread awareness that the conventional estimates produce biased results in the EKC estimates because the reverse causation between environmental indicators and economic output variables (Al-Mulali, Saboori, et al., 2015; Al-mulali, Weng-Wai, Sheau-Ting, & Mohammed, 2015; Carson, 2010; Jaunky, 2011; Kaufmann et al., 1998; Li et al., 2016; Shen, 2006; Stern et al., 1996; Van Hoa & Limskul, 2013).

Thus, with the aim of considering these econometric limitations presented in conventional approaches, the Durbin-Hausman (DWH) test for evaluating endogeneity issues is applied. The null hypothesis given by all regressors are exogenous, and the rejection would indicate the existence of endogeneity. Whether the results verify the presence of the endogeneity issues such as the unobservable heterogeneity, dynamic endogeneity, and simultaneity, the system GMM estimator might be conducted additionally.

Under system GMM procedure, the econometric proposal is given by a system of equations as follows:

$$PB_t = \alpha_1 PB_{t-1} + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \beta_k X_{i,t} + E_{i,t}$$

$$\Delta PB_t = \alpha_1 \Delta PB_{t-1} + \alpha_2 \Delta GDP_{i,t} + \alpha_3 \Delta {GDP_{i,t}}^2 + \beta_k \Delta X_{i,t} + \Delta E_{i,t} \tag{20}$$

Where: $(t-1)$ is a one time-lag factor; Δ represents the time-differencing factor; PB is N x 1 vector of the measures of the PBs evaluated (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land use, and biodiversity) across N observations; α_1 is given 1 x 1 vector scalar of the coefficient for the lag of the PB evaluated, PB_{t-1}, across N observations; GDP is the growth rate of by country-specific across N observations; α_2 is a 1 x 1 vector of coefficient for the growth rate by country-specific; GDP^2 is the square of the GDP variable and the α_3 the 1 x 1 vector of coefficient for this variable; X is an N x Q matrix of the Q country-specific control variables across N observations: β is a Q x 1 vector of coefficients, β_k, for the Q country-specific control variables, and E is an N x 1 vector of error terms across N observations.

In summary, this chapter seeks to validate the inverted U relationship between environmental variables under the PB context and an economic variable as the economic growth rate. The latter using different econometric approaches, from conventional methods such as OLS and fixed-effect model to system GMM procedure, and thus cover possible different endogeneity issues.

4. Results

Table 15 shows the descriptive statistics of the PB measures, GDP, GDP2, and control variables. The number of observations, the mean, standard deviation, minimum and maximum values of all variables in the dataset are presented in this table. The analysis of this table entails all boundaries considered in this study have a number of 5,649 of observations, except the biodiversity boundary which, because of the lack of data available, presents 2,449 observations. The higher deviation of these boundaries is given by the ozone and biodiversity boundaries and the lowest one by the climate change dimension.

The average growth rate for GDP is 0.057 with a maximum of 1.372 and a minimum value of -1.419. The mean of the growth rate squared is 0.027 with a maximum of 2.015 and a minimum of 0.00000000026. The volatility of GDP and GDP2 variables are 0.1563 and 0.075 respectively.

The highest variability in control variables is presented in the Financial Development (FD) variable, and the lowest one is given by the Population (POP). The mean of control variables is 0.018 for POP, 0.027 for FD, 0.009 for MT, -0.0081 for PR, and -0.0078 for CL.

Table 15: Descriptive statistics of variables

Variables	No of Observations	Mean	Std. Dev.	Min	Max
GDP	5649	0.057	0.153	-1.42	1.373
GDP2	5649	0.027	0.075	2.60e-10	2.016
CCO2	5649	0.005	0.0006	0.004	0.006
FERTILISER	5649	0.018	0.04	-0.081	0.092
OZONE	5649	-0.004	0.065	-0.146	0.16
OCEAN	5649	0.004	0.001	0	0.005
FRESHWATER	5649	0.010	0.026	-0.051	0.069

LAND	5649	0.005	0.022	-0.01	0.133
BIODIVERSITY	2449	0.04	0.061	0	0.235
POP	5649	0.018	0.016	-0.063	0.176
FD	5258	0.027	0.256	-6.579	7.083
MT	5539	0.009	0.157	-1.321	1.569
PR	5527	-0.0081	0.166	-1.253	1.792
CL	5527	-.00078	0.139	-1.1	1.253

Note: The notation is as defined in Table 14.

The correlation matrix for all variables included in the dataset are reported in Appendix 1. The correlation between the economic growth rate and the economic growth rate squared is positive and highly significant. The relation between GDP and all control variables, except Political Rights (PR), is negative, which has high significance. The GDP2 only shows a negative correlation for Financial Development (FD) and PR. Ozone Depletion (Ozone) and Land Use (Land) are negatively associated showing a high significance. Whereas, Climate Change (CCO2), Biochemical cycles (Fertiliser), Ocean acidification (Ocean), and Biodiversity (Biodiversity) present a positive significant relationship with economic growth in the sample. The rest of the correlations are in Appendix 1.

With the aim of examining the relationship between economic growth and a globally integrated perspective of the environmental degradation on a worldwide sample, OLS, fixed-effect, and system GMM approaches were tested to validate the existence of the global EKC. The results are reported by PB, considering the three econometric procedures.

Table 16 provides the OLS estimates for the seven boundaries analysed. The results are reported as follow: Climate Change (CCO2) in Column 2, Biochemical Cycles (FERTILISER) in Column 3, Ozone Depletion (OZONE) in Column 4, Ocean Acidification (OCEAN) in Column 5, Freshwater Use (FRESHWATER) in Column 6, Land Change (LAND) in Column 7, and the results for Biodiversity Loss (BIODIVERSITY) are presented in Column 8.

Findings for CCO2 are consistent with previous studies supporting an inverted U relationship between economic-environment, and more specifically consistent with studies examining the relationship between global measure as CO_2 emissions and economic growth (Agras & Chapman, 1999; de Bruyn et al., 1998; Du et al., 2012; Esteve

& Tamarit, 2012b; Holtz-Eakin & Selden, 1995; Jalil & Feridun, 2011; Martinez-Zarzoso & Maruotti, 2011; Omri et al., 2015; Sephton & Mann, 2016).

These results suggest that environmental degradation – specifically the climate change dimension – increase in the early stages of economic growth, and then, after a tipping point, declines with a higher economic growth rate. Thus, the global CCO_2 growth rate increases significantly with 1% rise of GDP (α_2 = 0.00057), and then decreases with 1% rise of GDP2 (α_3= -0.00017) at the 10% level of significance. Moreover, the OCEAN panel reveals an inverted U-shape between the economic growth rate and the OCEAN variable as CCO2. However, in this case, the non-linear relationship has no significance.

Under the same specification, FERTILISER and FRESHWATER show that the relationship with the economic growth rate is in a U-shape. However, this association is not statistically significant for either of them. On the other hand, LAND and BIODIVERSITY panels show a linear behaviour for their dependent variables. While LAND and OZONE keep going down when economic growth increase, BIODIVERSITY tends to keep going up with 1% economic growth rate. However, as with the previous boundaries, these two boundaries under OLS estimates do not present any significance.

Table 16: Planetary Boundaries and Economic Growth relation under OLS specification

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.7805***	0.2388***	-0.5774***	0.40763***	-0.17858***	0.04149***	0.04562**
GDP	0.00059***	-0.00185	-0.04526***	0.0003***	-0.01335***	-0.009***	0.11419***
GDP2	-0.00017*	0.02213**	-0.00137	-0.00006	0,00806	-0.00549	0,01609
POP	-0.00065**	0.03733	-0.22222***	-0.00288***	0.02346	0.03221*	0.0119
FD	0.00001	0,00017	0.00614**	-0.00005	0,00231	-0.0034***	-0.01842***
MT	0.00065***	-0.02367***	-0.03434***	0.00048***	-0.01342***	-0.01053***	0.08989***
PR	0.00000	-0.00052	0.01268***	0,0001	-0.0017	-0.00531***	0,00534
CL	-0,00006	0,00419	-0.02687***	0.00017*	0.00367	-0.00169	-0.02544**
Cons	0.00101***	0.01443***	-0.00085	0.00218***	0.01147***	0.00459***	0.03309***
R^2	0.6773	0.0585	0.3575	0.1873	0.0411	0.0130	0.0966

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under the OLS approach for EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension. The R^2 is reported for OLS estimation

Then, to correct the possible unobservable heterogeneity issues into each dataset to test the EKC shape for seven planetary boundaries, the fixed-effect panel procedure was tested. The findings are provided in Table 17 as follow: Climate Change (CCO2) is shown in Column 2, Biochemical Cycles (FERTILISER) in Column 3, Ozone Depletion (OZONE) in Column 4, Ocean Acidification (OCEAN) in Column 5, Freshwater Use (FRESHWATER) in Column 6, Land Change (LAND) in Column 7, and Biodiversity Loss (BIODIVERSITY) is presented in Column 8. The results show the same patterns as under OLS estimates. Climate change and ocean acidification panels follow an inverted U-shape between economic and environmental variables, being only statistically significant for the CCO2 variable with a coefficient of 0.00056 for GDP and -0.00021 for GDP2. That means the coefficients for the economic growth 0.0005 imply that a 1% increase in the growth rate of the GDP increases the global CO_2 concentrations by 0.005%. These CCO2 results are consistent with previous literature using the same methodology (Duarte, Pinilla, & Serrano, 2013; Lapinskiene et al., 2017; Lapinskiene, Peleckis, & Radavicius, 2015; Lin & Liscow, 2013; Neequaye & Oladi, 2015; T. Selden & D. Song, 1994; Suri & Chapman, 1998).

Consistent with OLS estimates, the fixed-effect approach for biochemical cycles, ozone depletion, freshwater use, land change, and biodiversity panels does not support the EKC hypothesis. Biochemical cycles (FERTILISER) and freshwater use (FRESHWATER) dimensions follow a U shape in relation with the economic variable; however, this association does not have significance for both panels. On the other hand, ozone depletion (OZONE) and land change (LAND) keep going down with a 1% increase in economic growth rate when BIODIVERSITY keeps going up, having not significant coefficients under OLS specification.

According to the EKC literature, conventional estimates do not consider the different endogeneity issues. Therefore, with the aim of proving that the proposed models require a system GMM approach instead of OLS or fixed-effect methodologies, the Durbin Wu-Hausman endogeneity test was conducted for the seven boundaries.

These tests are used to examine the possible endogeneity concerning the variables GDP and GDP2 on the different dependent variables (CCO2, FERTILISER, OZONE, OCEAN, FRESHWATER, LAND, and BIODIVERSITY). The results are reported in Appendix 1 for the seven environmental dimensions.

Table 17: Planetary Boundaries and Economic Growth relation under fixed-effect panel specification

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.76493***	0.23256***	-0.5803***	0.39212***	-0.18085***	0.03507**	0.03919*
GDP	0.00059***	-0.00154	-0.0491***	0.00028***	-0.01352***	-0.00859***	0.12197***
GDP2	-0.0002**	0.02194*	-0.01303	-0.00017	0,00834	-0.00321	0.04454
POP	-0.00193***	0,10035	-0.38158***	-0.00549***	0,04995	0.04435	-0.11341
FD	0,00001	0,00006	0.00527*	-0.00002	0,00234	-0.00316***	-0.01643***
MT	0.00065***	-0.02374***	-0.03681***	0.00046***	-0.01361***	-0.0102***	0.0935***
PR	0.00000	-0.00043	0.01221*	0,0001	-0.00164	-0.00524***	0,0044
CL	-0.00006	0,00363	-0.02638***	0.00017*	0,00359	-0.00187	-0.02716**
Cons	0.0011***	0.01338***	0.00253	0.00228***	0.01102***	0.00432***	0.03399***
No Groups	177	177	177	177	177	177	177
R^2	0.6512-0.96-0.6761	0.0562-0.2519-0.0579	0.3633-0.0106-0.3561	0.1731-0.6976-0.1853	0.0419-0.0026-0.0409	0.0108-0.3296-0.0128	0.1023-0.000-0.0951

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under the fixed-effect panel approach for a global EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension (PB). The R^2 is reported for the fixed-effects panel model and includes the overall, within groups, and between groups, respectively.

Findings for climate change, biochemical cycles, ozone depletion, ocean acidification, and biodiversity loss panels reject the null hypothesis that regressors are exogenous, confirming that the conventional approaches coefficient is not consistent and might produce biased results.

Consequently, the presence of endogeneity indicates that dynamic system GMM panel specifications might be used. Whereas, the result of the freshwater use and land change panels reveal that the null hypothesis may only be rejected for the analyses of GDP measure, while the GDP2 report is not dismissed, and the models do not present endogeneity issues. Consequently, the dynamic system GMM estimates – using a two-step estimator[20] – were conducted for the seven boundaries and displayed in Table 18 as follows. In Column 2 climate change; in Column 3 biochemical cycles; in Column 4 ozone depletion; in Column 5 ocean acidification; in Column 6 freshwater use; in Column 7 land change; and in Column 8 a biodiversity loss panel.

Findings under the system GMM specification show high significance for the seven panels analysed at the 1% level. Climate change and ocean acidification dimensions indicate an inverted U-shape between environmental indicators and GDP variables as the conventional methods, confirming the existence of a global EKC for both panels. CCO2 panel shows coefficients of 0.00195 for GDP and -0.00425 for GDP2, while OCEAN panel shows coefficients of 0.00047 for GDP and -0.00043 for GDP2. That means a 1% increase of economic growth produces a rise of 0.2% in climate change panel and 0.05% in ocean acidification panel, and then these two panels start to decrease at 0.4% for climate change and 0.04% for ocean acidification, separately. The results are consistent with previous evidence using the same econometric methodology, validating the EKC shape between environment and income variables (Li et al., 2016).

As the system GMM results, biochemical cycles, ozone depletion, and freshwater use boundaries follow a U shape between their environmental indicators and the economic growth rate at the 1% level. Particularly, FERTILISER has a coefficient of -0.0207 for GDP and 0.2569 for GDP2. Moreover, the coefficients that support the same behaviour for ozone depletion panel are given by -0.1389 for GDP and 0.1068 for GDP2. That means a 1% increase of economic growth produced a 13.89% improvement in

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[20] Coefficients under two-step estimator are more efficient and consistent in presence of heteroscedasticity. Moreover, the serial correlation is robust to the potential unobservable heterogeneity, simultaneity, and dynamic endogeneity (Roodman, 2006; Schultz et al., 2010).

environmental degradation (negative association with dependent variable). This starts to deteriorate at the 10.68% rate (positive association with dependent variable). These results are in line with Giovanis (2013) who validated a U shape using proxies of ozone depletion as the environmental indicator. Similarly, freshwater use boundary exhibits estimates of -0.04159 for GPD and 0.01463 for GDP2 to justify a U shape.

On the other hand, land change and biodiversity loss dimensions perform a monotonical relationship with the economic growth at the 1% level. When economic growth increases 1%, the LAND variable decreases 1.28% considering GDP, and decreases 1.36% considering GDP2, not being in line with previous studies using similar environmental indicators in their EKC estimations (Bhattarai & Hammig, 2001; Culas, 2007, 2012). Whereas, a 1% increase of economic growth produce an increase of 20.67% in biodiversity loss indicator when the GDP is considered, and an increase of 67.78% when GDP2 is analysed, rejecting the EKC hypothesis. As a result, the biodiversity loss results are not in line with previous studies using similar environmental indicators as the number of threatened species to test the EKC relationship (McPherson & Nieswiadomy, 2005).

In general, changes in control variables follow mixed results for the seven boundaries considering the three econometric specifications. Particularly, changes in population (POP) shows a negative and significant effect on the dependent variables for climate change, ozone depletion, ocean acidification panels under the OLS method. Under fixed effect and system GMM methods, the negative association is for the three panels and the biodiversity loss dimensions.

However, the same variable tends to increase the environmental indicator significantly for the freshwater use panel under OLS and system GMM approaches and land change panel under system GMM. These results are in line with previous literature such as T. Selden and D. Song (1994) who state that this relationship is presented because more people per square km produce more emissions because of the consumption of fossil fuels and less concern about lowering environmental indicator emissions.

Changes in financial development (FD) follow the same patterns for the three specifications in the seven boundaries. However, under the system GMM analysis, the factors are more statistically significant. For instance, ozone depletion and freshwater use dimensions show a positive relationship when the FD increases by 1%. That means that the environmental indicators tend to deteriorate with a positive growth rate of 1% in

Table 18: Planetary Boundaries and Economic Growth relation under system GMM specification

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.60931***	0.30035***	-0.53991***	0.37124***	-0.18752***	0.01322***	0.04228***
GDP	0.00195***	-0.0207***	-0.13894***	0.00047***	-0.04159***	-0.01278***	0.20675***
GDP2	-0.00425***	0.25694***	0.10675***	-0.00043***	0.14633***	-0.01361***	0.67812***
POP	-0.00558***	0,03636	-0.70706***	-0.01048***	0.16034***	0.0251*	-0.11523***
FD	0.0000	0,00114	0.003***	-0.00008***	0.00321***	-0.00307***	-0.01193*
MT	0.00124***	-0.03991***	-0.0685***	0.00061***	-0.03051***	-0.01222***	0.12193***
PR	-0.00003*	-0.00084	0.01355***	0.00013***	0,00021	-0.0059***	0,0003
CL	0.00007***	-0.00285***	-0.03313***	0.00025***	0.00207**	-0.00081**	-0.02346*
Cons	0.0019***	0.00758***	0.01088***	0.00247***	0.00864***	0.00526***	0.03189***
No Instrument	485	485	484	471	485	485	41
No Groups	177	177	177	177	177	177	177
J-Statistics	175.13	175.93	175.61	175.53	176.26	175.08	171.62
Arellano-Bond AR (1)	-10.272***	-12.037***	-12.249***	-11.604***	-12.11***	-10.997***	-11.47***
Arellano-Bond AR (2)	-2.2729**	-11.056***	8.0346***	-11.022***	2.9626***	-1.6867*	-1.0586

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under dynamic system GMM approach for EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension (PB). The GMM parameter estimates are generated using the two-step procedure, with the inverse of the variance-covariance matrix of the moment condition as the weighting matrix (Schultz et al., 2010). The instrument set for the differenced equations is the lag 2 of the dependent variables, and lags 1 and 2 of the control variables. While, the instrument set for the level equations is the lag 1 of the differenced dependent variables, and lags 0 and 1 of the differenced control variables. The J-Statistic test and the Arellano-Bond test are displayed for the system GMM estimation.

financial development, being consistent with studies such as Sadorsky (2010) and (Zhang, 2011) who also identify an environmental deterioration when FD increase..

On the other hand, this variable presents a negative relationship between the dependent variables ocean acidification, land change, and biodiversity loss panels under the system GMM method. That means that the environmental quality improves with a 1% increase of FD, being consistent with the literature supporting that it contributes to decreasing the environmental degradation because of the cleaner investment (Jalil & Feridun, 2011; Tamazian & Rao, 2010).

Although changes in merchandise trade (MT) have different effects depending on the boundary evaluated, the variable is highly significant at the 1% level for the seven boundaries under the three econometric methodologies. The behaviour patterns for each environmental dimension is shared under the three specifications. A 1% increase of the MT for climate change, ocean acidification and biodiversity loss panels result in a rising effect on the CCO2, OCEAN, and BIODIVERSITY variables using the three econometric procedures. The higher effect is produced on the biodiversity loss dimension which increases around 12% under the system GMM when the MT increases by 1%.

The findings are in line with Chapter 3 of this thesis, and therefore, with previous literature. They justify the relationship because the export and import of manufactured goods increases the level of energy consumption and therefore the environmental indicators concentrations (Dinda, 2004; Suri & Chapman, 1998).

On the other hand, the same control variable shows a negative relationship between the dependent variables of biochemical cycles, ozone depletion, freshwater use, and land change. That means MT might contribute to improve environmental degradation.

Regarding regulation variables, political rights (PR) and civil liberties (CL) reveal some significant correlations under the system GMM approach. In particular, PR shows a negative correlation with dependent variables of climate change, biochemical cycles, and land change, but a positive correlation for the ozone depletion panel, being significant at the 1% level. On the other hand, CL follows a negative correlation with dependent variables of biochemical cycles, ozone depletion, land change, and biodiversity loss panel and a positive correlation in climate change, ocean acidification, and freshwater use panels.

The positive value of the PB (*t-1*) coefficients imply that the growth rate of the planetary boundary examined is correlated each year positively at the 1% level. Whereas, the negative value represents that the growth rate of the boundary evaluated is correlated negatively each year. The boundary with higher correlation with the past value is climate change. The CCO2 variable indicates a 60.9% correlation under system GMM approach, while the lowest correlation is the land change boundary, which is negatively associated with past value at around -1.32%.

In addition to previous estimations, standard specification tests were conducted under system GMM estimates; the results are provided in Appendix 2. The tests include the Arellano-Bond test[21] for autocorrelation, which is given by m_1 for Autoregressive Model (AR) of the first order (1) and m_2 for AR of the second order. The null hypothesis suggests that there is no autocorrelation to the differenced residuals. On the other hand, the Sargan test[22] examines the set of instruments used and states a null hypothesis where the moment conditions are valid. Thus, these tests provide evidence to conclude that the instruments used and applied under system GMM regressions are valid, producing unbiased and consistent results.

The Sargan test demonstrates that the moment conditions are correctly specified for the seven boundaries, the instruments are consistent for the climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change, and biodiversity loss panels. Similarly, the Arellano-Bond postestimation suggests there is no autocorrelation for differenced residual in first order AR (1) for the seven panels, while in the second order AR (2) the biodiversity loss panel does not reject the null hypothesis.

In summary, testing seven out of nine environmental dimensions under econometric models, such as the system GMM procedure, and covering all endogeneity types, the EKC hypothesis is supported for climate change and ocean acidification dimensions. Biochemical cycles, ozone depletion, and freshwater use boundaries that justify a U shape between environment-income. Land change instead decreases monotonically with economic growth, while biodiversity loss dimension increases monotonically with it. In

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[21] The Arellano-Bond test follows an asymptotic normal distribution (Schultz et al., 2010).

[22] The Sargan J-Statistic test follow a chi-squared distribution with degrees of freedom equal to the number of moment restrictions minus the number of parameters estimated (Marrero, 2010; Schultz et al., 2010)

general, these findings present the same characteristics using conventional methods, however, there is no significance in the majority of them.

5. Robustness analyses

In addition to the previous set of econometric models, robustness analyses were conducted to evaluate the EKC hypothesis, considering possible PB interactions proposed by Rockström et al. (2009b). The relationship of these seven boundary panels, considering their interactions will be given by:

$$PB_t = f(GDP_{i,t}, GDP^2{}_{i,t}, Interactions_t, X'_{i,t})$$

Where the PB represents the environmental indicator for each boundary panel which depends on the GDP, GDP2, control variables, and interactions between PBs. According to Rockström et al. (2009b), the climate change boundary is possibly influenced by land change and freshwater use dimensions. The biochemical cycles boundary would have an interaction with biodiversity loss (BIODIVERSITY). Ozone depletion would not show any connection with other boundaries, and therefore its results correspond to the same findings provided in the previous set of models. Ocean acidification possibly depends on the biochemical cycles (FERTILISER) and climate change (CCO2) dimensions. Others, such as freshwater use and land change, might be affected by biodiversity loss and biochemical cycles boundaries. The biodiversity loss dimension, which is the boundary with more interactions, might have influences from land change, freshwater use, and biochemical cycles.

Additionally, the proposed econometric models include a lag term of the dependent variable (environmental quality dimension) to consider its dynamic effect. In this way, it is possible to examine the changes in these environmental dimensions cumulatively.

Therefore, the set of models are given by the seven following equations:

$$CCO2_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 CCO2_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Land_t + \alpha_{11} Freshwater_t + \gamma_i + \varepsilon_{i,t} \tag{13}$$

$$Fertiliser_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Fertiliser_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Biodiversity_t + \gamma_i + \varepsilon_{i,t} \tag{14}$$

$$Ozone_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Ozone_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \gamma_i + \varepsilon_{i,t} \tag{15}$$

$$Ocean_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Ocean_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Fertiliser_t + \alpha_{11} CCO2_t + \gamma_i + \varepsilon_{i,t} \tag{16}$$

$$Freshwater_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Freshwater_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Fertiliser_t + \alpha_{11} Biodiversity_t + \gamma_i + \varepsilon_{i,t} \tag{17}$$

$$Land_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Land_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Fertiliser_t + \alpha_{11} Biodiversity_t + \gamma_i + \varepsilon_{i,t} \tag{18}$$

$$Biodiversity_t = \alpha_1 + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \alpha_4 Biodiversity_{t-1} + +\alpha_5 PR_{i,t} + \alpha_6 CL_{i,t} + \alpha_7 POP_{i,t} + \alpha_8 FD_{i,t} + \alpha_9 MT_{i,t} + \alpha_{10} Fertiliser_t + \alpha_{11} Freshwater_t + \alpha_{12} Land_t + \alpha_{12} CCO2_t + \gamma_i + \varepsilon_{i,t} \tag{19}$$

Where, the i represents the country, t the period, γ_i captures the country fixed effects, and ε_{it} entails the disturbance term.

For equations (13) to (19) the conventional methods OLS and fixed effect model may be carried out to validate the EKC hypothesis. The assumption is confirmed if $\alpha_2 > 0$ and $\alpha_3 < 0$, while the $\alpha_2 > 0$ and $\alpha_3 = 0$ reveals a positive linear relationship and the $\alpha_2 < 0$ and $\alpha_3 = 0$ indicates a negative linear relationship. For these specifications, OLS estimates require GDP, GDP2, control variables, and PB interactions be orthogonal to the errors of the models. That means errors are normally independently and identically distributed with mean 0 and constant variance σ_ε^2 over time and across countries (Schultz et al., 2010).

The previous econometric limitation presented in the proposed OLS model might be solved using a fixed-effect procedure. However, the fixed-effect method will produce consistency in results whether a strict exogeneity assumption is considered. That is, the GDP, GDP2, control variables, and PB interactions are orthogonal to past, present and future PB evaluations – in other words, they have to be time-invariant to the boundaries analysed.

Due to country specific characteristics that violate the strict exogeneity assumption plus possible reverse causation between variables under EKC context, both conventional methodologies may produce biased results (Al-Mulali, Saboori, et al., 2015; Al-mulali, Weng-Wai, et al., 2015; Carson, 2010; Jaunky, 2011; Kaufmann et al., 1998; Li et al., 2016; Shen, 2006; Stern et al., 1996; Van Hoa & Limskul, 2013). For that, the Durbin-Hausman (DWH) test is conducted for GDP as well as GDP2 measures in seven panels. All regressors that give the null hypothesis are exogenous, and the rejection would indicate the existence of endogeneity. Whether the results verify the presence of endogeneity issues such as the unobservable heterogeneity, dynamic endogeneity, and simultaneity, the system GMM estimator will be also be conducted.

Mainly, the system GMM methodology follows a system of simultaneous equations – the first differences equation and the levels equation – which by considering certain conditions, would result in more efficient than difference GMM estimators (Li et al., 2016; Schultz et al., 2010). This method can overcome estimations problems introduced by unobservable heteroscedasticity, simultaneity, and dynamic endogeneity (Schultz et al., 2010).

Therefore, the system of equations for the set of models will be given by:

$$PB_t = \alpha_1 PB_{t-1} + \alpha_2 GDP_{i,t} + \alpha_3 {GDP_{i,t}}^2 + \delta_k Interacitions_t + \beta_k X_{i,t} + E_{i,t}$$

$$\Delta CCO2_t = \alpha_1 \Delta CCO2_{t-1} + \alpha_2 \Delta GDP_{i,t} + \alpha_3 \Delta {GDP_{i,t}}^2 + \delta_k \Delta Interactions + \beta_k \Delta X_{i,t} + \Delta E_{i,t} \tag{21}$$

Where: $(t-1)$ is a one time-lag factor; Δ represents the time-differencing factor; PB is N x 1 vector of the PB measures evaluated (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land use, and biodiversity) across N observations; α_1 is given 1 x 1 vector scalar of the coefficient for the lag of the PB evaluated, PB_{t-1}, across N observations; GDP is the growth rate of country-specific across N observations; α_2 is a 1 x 1 vector of coefficient for the growth rate by country-specific; GDP^2 is the square of the GDP variable and the α_3 the 1 x 1 vector of coefficient for this variable; Interactions is a N x Z matrix of the Z PBs interacting with the PB evaluated across N observations; δ is a Z x 1 vector of coefficients, δ_k; X is an N x Q matrix of the Q country-specific control variables across N observations; β is a Q x 1 vector of coefficients, β_k, for the Q country-specific control variables, and E is an N x 1 vector of error terms across N observations.

With the aim of examining the dynamic relationship (EKC shape) between economic growth and a global environmental integrated perspective (PB context) and considering their possible interactions, three econometric methodologies (OLS, fixed-effect, and system GMM) were conducted.

The OLS estimates are reported in Table 19 for the seven environmental dimensions examined (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change, and biodiversity loss). The results indicate that when PB interactions are considered, only the climate change panel shows an EKC shape between economic growth and the changes of the CO_2 concentrations with coefficients of 0.00049 for GPD and -0.00015. In contrast, biochemical cycles, ozone depletion, freshwater use, and land use panels exhibit a negative linear association with their dependent variables. Indeed, this relationship is significant for the GDP measure for the four dimensions. On the other hand, ocean acidification and biodiversity loss reveal a positive linear relationship with their environmental quality measure, showing

Table 19: Planetary Boundaries and Economic Growth relation under OLS specification with interactions

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.80145***	-0.21848***	-0.5774***	0.22084***	-0.30157***	0.33701***	0.03723*
GDP	0.00049***	-0.01758***	-0.04526***	0.000005	-0.0468***	-0.00197***	0.14054***
GDP2	-0.00015*	-0.00733	-0.00137	0.0001	-0.0117	-0.00022	0.01815
POP	-0.00043	-0.02667	-0.22222***	-0.00087	-0.00732	-0.00183	0.03219
FD	0.00001	-0.00168	0.00614**	-0.00004	-0.00119	-0.00041***	-0.01478***
MT	0.00056***	-0.02286***	-0.03434***	0.00022***	-0.03071***	-0.0002	0.11819***
PR	-0.00002	-0.00106	0.01268***	0,00005	-0.00208	-0.00003	0,00518
CL	-0.00003	-0.00504	-0.02687***	0.00023***	0.00813*	0.00022	-0.02376**
LAND	-0.00458***						0.48394***
FRESHWATER	-0.00129***						0.33389***
BIODIVESITY		0.1823***			-0.00315	0.07536***	
FERTILISER				0.64763***	-0.0262	-0.00366***	0.33055
CCO2				0.00437***			
Cons	0.00096***	0.01619***	-0.00085	-0.00024**	0.01822***	-0.00163***	0.01969***
No Groups	N/A	N/A	N/A	N/A	N/A	N/A	N/A
R^2	0.7226	0.1362	0.3575	0.3105	0.1325	0.7367	0.2018

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under the OLS approach for EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension. The R^2 is reported for OLS estimation.

significance only for the biodiversity panel. Therefore, all boundaries, except the climate change dimension do not support the existence of the EKC hypothesis for a global sample under OLS approach. The results are consistent with previous studies which did not identify an EKC shape in their analysis (Kaufmann et al., 1998).

When the OLS method is applied, control variables present different effects on dependent variables depending on the boundary analysed. For instance, the POP variable only presents significance for the ozone depletion panel with a negative impact on the OZONE variable (with a coefficient of -0.2222). Moreover, FD shows significance for the ozone depletion panel but with a positive relationship with its dependent variable. The same variable reveals a negative association between dependent variables for the land change and biodiversity loss boundaries, being highly significant in both cases. The latter is consistent with the literature that explains financial development in countries might contribute to improving the environmental quality due to cleaner investments (Jalil & Feridun, 2011; Tamazian & Rao, 2010).

The merchandise trade (MT) is a significant variable for almost all boundaries analysed. Climate change, ocean acidification, and biodiversity loss dimensions have a positive relationship between MT and their dependent variables (CCO2, OCEAN, and BIODIVERSITY). Whereas, biochemical cycles, ozone depletion, and freshwater use boundaries show a negative association between MT and their variables of interest. That means, when the relationship is positive, MT leads to deteriorating the environmental quality, while when the association is negative it might contribute to improving the degradation.

When CL is analysed four boundaries exhibit significance. Ozone depletion and biodiversity loss indicate a negative association with factors of -0.02687 and -0.02376, respectively. While, ocean acidification and freshwater use support a positive relationship between CL, OCEAN and FRESHWATER variables.

Then, to correct the possible unobservable heterogeneity issue in each dataset panel, a fixed effect specification was conducted. The coefficients for each environmental dimension are reported in Table 20. Findings follow a similar pattern that OLS estimates for each boundary. Climate change supports the existence of an inverted U-shape between income and environment variables. Others such as biochemical cycles, ozone depletion, freshwater use, and land change boundaries show a negative relationship between the

Table 20: Planetary Boundaries and Economic Growth relation under fixed-effect panel specification with interactions

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.78969***	-0.21492***	-0.5803***	0.21972***	-0.30124***	0.33488***	0,03037
GDP	0.0005***	-0.01899***	-0.0491***	-0.00001	-0.05065***	-0.00213***	0.15116***
GDP2	-0.00017*	-0.01088	-0.01303	0,00008	-0.02522*	-0.00084	0.05175*
POP	-0.00147***	-0.09531	-0.38158***	-0.0018	0.01971	-0.00707	-0.04158
FD	0.00001	-0.00197	0.00527*	-0.00004	-0.0021	-0.00046***	-0.01203**
MT	0.00056***	-0.02405***	-0.03681***	0.00022***	-0.03258***	-0.00022	0.12401***
PR	-0.00002	-0.00099	0.01221*	0.00005	-0.00201	-0.00001	0.00397
CL	-0.00003	-0.00515	-0.02638***	0.00024***	0.00888*	0.00024	-0.02559**
LAND	-0.00454***						0.48342***
FRESHWATER	-0.00128***						0.3541***
BIODIVESITY		0.18234***			0,00134	0.07524***	
FERTILISER				0.6374***	-0.02739	-0.00347***	0.36263
CCO2				0.00436***			
Cons	0.00103***	0.01738***	0.00253	-0.00017	0.01824***	-0.00153***	0.01932***
No Groups	177	177	177	177	177	177	177
R^2	0.6996-0.9637-0.7219	0.1365-0.0661-0.1352	0.3633-0.0106-0.3561	0.2921-0.9403-0.3116	0.1405-0.0009-0.1317	0.7394-0.4891-0.73678	0.2105-0.0023-0.2005

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under the fixed-effect panel approach for a global EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension (PB). The R^2 is reported for the fixed-effects panel model and includes the overall, within groups, and between groups, respectively.

economic variable and environmental indicators. The biodiversity loss dimensions under fixed effect specification – as the OLS specification reveals – shows a positive correlation between economic growth and the BIODIVERSITY variable. This justifies that economic growth contributes to deteriorating the environment thereby increasing the growth rate of the number of threatened species. Control variables under the fixed-effect panel model indicate that the POP variable has a negative association with CCO2 and OZONE variables. This is similar to results under OLS specification. FD, MT, PR and CL follow the same patterns as the OLS procedure.

As it is mentioned in the previous section, conventional methods such as OLS and fixed effect panel specifications do not cover all different endogeneity issues presented in EKC examinations. Therefore, the Wu-Hausman endogeneity test is conducted for the seven panel boundaries to confirm the presence of endogeneity on dependent variables. If the endogeneity issues are identifying for these panels, then the system GMM approach might be carried out for the seven panel environmental dimensions.

Results are displayed in Table 21 for all boundaries analysed. When PB interactions are considered within the analyses, the endogeneity tests indicate that studies for GDP measure present endogeneity presence. The analyses for GDP2 measures indicate the presence of endogeneity for all environmental dimensions except freshwater use.

The reports for these two measures reject the null hypothesis that all regressors are exogenous, confirming that conventional coefficients are not consistent and might produce biased results. As a result, the system GMM approach might be using to solve the main econometric limitations identify for EKC analyses.

Table 21: Durbin Wu-Hausman test for endogeneity of regressors for PB with interactions

Panel		Wu-Hausman Test	P-value
Climate Change			
	GDP	21.3610	0.00000
	GDP2	11.93840	0.00060
Biochemical Cycles			
	GDP	5.30727	0.02130
	GDP2	12.94350	0.00030
Ozone			

	GDP	68.86010	0.00000
	GDP2	4.38050	0.03640
Ocean Acidification			
	GDP	19.0558	0.00000
	GDP2	74.23130	0.00000
Freshwater Use			
	GDP	13.47430	0.00020
	GDP2	0.35240	0.55280
Land Use			
	GDP	329.37900	0.00000
	GDP2	209.79600	0.00000
Biodiversity			
	GDP	21.8085	0.0000
	GDP2	14.9606	0.0001

Note: ** and *** denotes significance and the rejection of H_0 at the 5% and 1% levels. The test is based on the GDP and GDP2 on each PB (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change and biodiversity loss) and control variables. The analyses include as instruments the lags of the differenced variables. In particular, each PB panel considers the lag 1 of the differences dependent variables, lags 0 and 1 of the differenced control variables, and lag 1 of the differenced GDP measure for the GDP endogeneity test, while the lag 1 of the differences dependent variables, lags 0 and 1 of the differenced control variables and lag 1 of the differenced GDP are used in the endogeneity test for GDP2 measure.

The dynamic system GMM results, using the two-step estimator, are displayed in Table 22 for the seven boundaries examined. When the system GMM approaches are conducted, including the PB interactions, three different behaviours are identified for the integrated environmental perspective.

Climate change supports the results under conventional methods and for the model without PB interactions. That validates the EKC shape. In contrast, ozone depletion and ocean acidification support a U shape between economic growth and their environmental indicator (OZONE and OCEAN). Therefore, these findings are not consistent with results when conventional methods are used.

Biochemical cycles, freshwater use, and land change panels reveal a negative association between GDP and GDP2 on dependent variables for these boundaries, with high significance in all cases. Whereas, the biodiversity loss panel is consistent with the fixed

Table 22: Planetary Boundaries and Economic Growth relation under system GMM specification with interactions

Regressor	Climate Change	Biochemical Cycles	Ozone Depletion	Ocean Acidification	Freshwater Use	Land Change	Biodiversity Loss
PB (*t-1*)	0.69269***	-0.01567***	-0.53991***	0.31671***	-0.21956***	0.28857***	-0.06451***
GDP	0.00157***	-0.04356***	-0.13894***	-0.00012***	-0.14425***	-0.0037***	0.39564***
GDP2	-0.00311***	-0.09359***	0.10675***	0.00098***	-0.13066***	-0.00457***	0.110113***
POP	-0.00421***	-0.23658***	-0.70706***	-0.00753***	0.54315***	-0.01309***	-0.1298724***
FD	0.00001*	-0.00583***	0.003***	-0.00007***	-0.0035***	-0.00065***	0.006
MT	0.00104***	-0.05204***	-0.0685***	0.00029***	-0.06883***	0.00024***	0.1997***
PR	-0.00004***	0.00073	0.01355***	0.00013***	0.00357	0.00018**	-0.01064
CL	0.00008***	-0.00015	-0.03313***	0.00023***	0.01588***	-0.00014	-0.03795***
LAND	-0.00065***						0.147912**
FRESHWATER	-0.00407***						0.71807***
BIODIVERSITY		0.15501***			0.08001***	0.00028***	
FERTILISER				0.00321***	-0.1392***	0.07266***	0.5471***
CCO2				0.4281***			
Cons	0.00153***	0.02146***	0.01088***	0.00059***	0.01631***	-0.0015***	-0.00022
No Instruments	489	291	484	476	293	293	51
No Groups	177	177	177	177	177	177	177
J-Statistics	1.755.898	175,0281	175,6082	176,113	174,3561	175.396	163.405
Arellano-Bond AR (1)	-10.968***	-12.617***	-12.249***	-11.639***	-9.3696***	-11.944***	-6.5359***
Arellano-Bond AR (2)	-4.2329***	-12.276***	8.0346***	-11.19***	-0.055895	-11.157***	-4.5589***

Note: The notation is as defined in Table 5. ***, **, * indicate significance at 1%, 5% and 10% levels respectively. The table presents the resultant coefficient under dynamic system GMM approach for EKC analysis. The term of $PB_{(t-1)}$ represent the lag value of dependent variables for each environmental dimension (PB). The GMM parameter estimates are generated using the two-step procedure, with the inverse of the variance-covariance matrix of the moment condition as the weighting matrix (Schultz et al., 2010). The instrument set for the differenced equations is the lag 2 of the dependent variables, and lags 1 and 2 of the control variables. While, the instrument set for the level equations is the lag 1 of the differenced dependent variables, and lags 0 and 1 of the differenced control variables. The J-Statistic test and the Arellano-Bond test are displayed for the system GMM estimation.

effect panel results, justifying a positive linear relationship between economic growth and the changes in threatened species worldwide.

Control variables such as POP and MT present high significance for the seven panels analysed. For that, the demographic variable shows a negative relationship with dependent variables for all boundaries, except for the freshwater use dimension. On the other hand, the international trade variable exhibits a positive effect on dependent variables for climate change, ocean acidification, land change and biodiversity loss panels, while a negative relationship is identified for the environmental indicator of biochemical cycles, ozone depletion, and freshwater use dimensions.

The only environmental quality dimension that does not show any significant connection with financial development is biodiversity loss. The rest reveal either a significant positive effect (climate change, ozone depletion) or a negative association (biochemical cycles, ocean acidification, freshwater use, and land change). The positive relationship between the dependent variables of these panels shows that the financial development contributes to declining environmental quality, which is consistent with previous findings (Dasgupta et al., 2002).

As a consequence, considering seven boundaries, the EKC only exist under the climate change boundary, while the rest of the environmental dimensions do not support the existence of an inverted U-shape between income-environment for a global sample of 177 countries around the worlds.

6. Conclusions

Some factors must be considered when evaluating global environmental change and the effects caused by growth of the global economy. Interestingly, the novel framework ‘planetary boundaries’ proposed by Rockström et al. (2009b) evaluates this global environmental change covering nine different dimensions: climate change, biodiversity loss, ozone depletion, ocean acidification, biochemical cycles, land-system, freshwater use, chemical pollution and aerosol loading. Thus, this approach allows carrying out a viable and meaningful form of assessing cross-firm, cross-sector and cross-country data.

Notably, this study has provided the examination of the growth rate of seven out of the nine boundaries to test the effects of economic growth on them in a global sample of 177 countries. These environmental dimensions include climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change, and biodiversity loss which provide measures.

As suggested by the Environmental Kuznets Curve (EKC) hypothesis, the level or growth rate of the environmental indicator is expected to rise with the economic growth of many economies, and thus contribute to global environmental warming. However, once the economic growth reaches a tipping point the growth rate of environmental dimensions should be to decrease, improving environmental conditions.

Hence, a dynamic system GMM approach is utilised to validate the existence of the EKC hypothesis using the seven environmental dimensions and some control variables. This methodology is compared with conventional econometric models (OLS and fixed-effect panel) which present some econometric limitations such as unobservable heterogeneity, dynamic endogeneity, and reverse causation.

Although numerous studies have examined the EKC shape using different environmental indicators and different econometric models, they have not considered an integrated environmental perspective together with an econometric approach that allows covering all common critiques in previous EKC estimates.

Under this context, our estimated results state that the climate change and ocean acidification boundaries indicate that the EKC shape exists when the changes in CO2 concentrations and the mean surface ocean hydrogen ion concentrations are factored into the analysis. The rest of the boundaries (biochemical cycles, ozone depletion, freshwater use, land change and biodiversity loss) do not support the existence of the EKC hypothesis.

CHAPTER V

Conclusions

The goal of this thesis is to examine the EKC literature through a bibliographic mapping systematic review to recognise the following elements: the most cited publications; the main streams of research; potential gaps; and future research in the EKC theory. Consequently, using the main critiques identified as one of the EKC research streams, the second study evaluates the existence of an EKC relationship using the growth rate of one global environmental indicator as the CO_2 concentration. Subsequently, due to the fact that global environmental change covers more than a unique environmental indicator, a third study tries to validate the existence of an EKC using novel framework which covers seven different ecological dimensions as planetary boundaries do.

The first study presented in chapter 2 uses a mapping research method to analyse EKC literature since its origins and it identifies the most cited publications on the topic. Based on this systematic review, and considering the highly cited articles, four main research streams were identified. These include (1) testing the basic EKC equation, (2) critique to EKC, (3) determinants of EKC, and (4) review of EKC. Additionally, new trends in EKC literature from 2004 to 2017 were added to this study. These trends consist of the new environmental indicator and new nexus: income and energy consumption research streams. During the same period, the EKC literature was extended by new publications in two of the research streams: the critique of the EKC and determinants of the EKC. These research streams outlined knowledge gaps and future research directions that might be used in different contexts. EKC research has had a more significant focus on methodological limitations and estimations of new models. This addressed the main econometric gaps as well as the environmental indicator utilised to test the EKC relationship.

Consecutively, the second study shown in chapter 3, evaluates the global EKC with changes in CO_2 concentration as the environmental measurement. While CO_2 emissions have been previously utilized to test the EKC hypothesis, there are no studies that consider the accumulation of one determined pollutant, even more, if we bear in mind that the CO_2 is the more significant cause of the greenhouse gases emission, and therefore, the main factor of the climate change phenomenon worldwide. This issue is addressed in one of the new research streams of the EKC literature, New environmental Indicators, where the more recent EKC studies are looking for a more appropriate environmental indicator to conduct their EKC analysis. Moreover, due to the critique of EKC estimates research stream, proposed by the first study which detects several inconsistences in the EKC coefficients resultants, the second study intents to cover all the main econometric limitations. These limitations include the simultaneity between variables of interest, the stochastic trend in the data, and the static EKC specification. Thus, it uses the system generalized method of moments (GMM) approach for a worldwide sample of 177 countries with different levels of income. This econometric approach is conducted together with conventional methodologies (ordinary least square and fixed-effect panel model) to analyse possible differences between the estimated parameters. Particularly, system GMM intends to cover most of these econometric gaps in testing EKC hypothesis (Li et al., 2016; Ren et al., 2014). For example, the unobservable heterogeneity; the dynamic endogeneity; and the existing causality between income-environment connections.

Furthermore, in order to understand the main factor affecting this possible inverted-U shape between income and environment, some control variables were incorporated into the model. Population as a demographic variable, financial development as a financial variable, the merchandise trade as international trade variable, political rights and civil liberties as regulation variables.

Findings share the interpretations under different econometric methods. The use of the OLS methodology is consistent with previous studies using the same methods (Grossman & Krueger, 1995; Suri & Chapman, 1998), thereby validating the inverted U-shape for income-environment connection. Subsequently, in order to correct the unobservable heterogeneity presented in the global panel of 177 countries, the fixed-effect panel model is employed. The results follow the same patterns as the OLS estimate using a global measurement as the global CO_2 concentration. Finally, in order to cover the simultaneity and unobservable heterogeneity issues in the EKC empirical test, the system GMM indicates that the estimates are consistent. As conventional techniques do, they exhibit an inverted U-shape relationship between changes in global CO_2 concentration and economic growth by countries in a global view and for developed countries.

As control variables implications, and joying previous studies, the estimates conclude that population, financial development, merchandise trade, political rights, and civil liberties are highly significant to the global environmental indicator evaluated under a dynamic system GMM approach. An increase in the growth rate of the population, financial development, and political rights contributes to decrease environmental degradation. The advance in financial systems might produce cleaner technological investments and contributes to improve the environmental quality as more restrictive policy regulations do. In contrast, the growth rate of international trade and civil liberties might deteriorate the environmental condition because manufacturing businesses from developed countries start to move on areas with fewer regulations as undeveloped countries.

Consequently, and understanding how different environmental dimensions affect the global economy or how the global economy affects the environment over time, the EKC hypothesis is evaluated under global environmental dimensions. For this purpose, the third study seeks to conduct an empirical analysis of the ECK relationship using a comprehensive sample of the seven planetary boundaries. This study incorporates seven of the nine boundaries due to the complexity involved in the measurement of novel entities and atmospheric aerosol loading. In fact, the measurement for these two boundaries mentioned above has not been defined yet (Rockstrom et al., 2009a). Therefore, the environmental dimensions examined involve climate change; biodiversity loss; ozone depletion; ocean acidification; biochemical cycles; land-system; and freshwater used. All the dimensions were applied on a global sample composed of 177 countries.

Subsequently, and tackling the main econometric limitations identified in previous EKC estimates, the third study uses a system GMM approach as the second study does. Therefore, the results, considering a dynamic model and covering all endogeneity issues, reveal that climate change and ocean acidification validate the existence of an inverted-U shape between the economic growth and the growth rate of their environmental measure. The latter is consistent with the literature of planetary boundaries which states that both boundaries are associated with the emissions of CO_2. That is to say, environmental quality decrease with the economic growth rate of 177 countries, and then improve with the economic growth after reaching a threshold.

Other environmental dimensions such as biochemical cycles, ozone depletion, and freshwater use show a U shape between income and environment. That is, the growth rate of environmental indicator decreases with the increase in the economic growth of 177 countries, and then it starts to rise with the economic growth after a tipping point. Otherwise, biodiversity loss increases monotonically with the economic growth, while the growth rate of the land change decreases monotonically with the economic growth rate.

Therefore, when an appropriate econometric procedure is utilized for one global environmental, the EKC is supported, while an integrated perspective is considered, only dimensions associated with the CO_2 pollutant validate the EKC.

Despite the significant results, this thesis has some limitations; most importantly the availability of the environmental data by country. The access to environmental information regarding accumulated pollution is limited. Moreover, using the short-term of the environmental indicators as the emissions by country, the results might provide differences. However, if the CO_2 indicator is analysed in terms of accumulation, that actually produces climate change, the results can be useful for providing international cooperation to tackle the environmental problems.

Conversely, when an integrated perspective is considered, covering seven different ecological dimensions, the results are mixed giving four possible associations between income and environment. They are an inverted-U shape, U shape, positive linear, and negative linear. In conclusion, the dynamic econometric approach addressed in this thesis (system GMM) can cover all endogeneity issues; however, this methodology does not allow to include all boundaries in one model, as structural equation modelling might be.

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Appendix 1

Correlation Matrix

	GDP	GDP2	POP	FD	MT	PR	CL	CCO2	FERTILISER	OZONE	OCEAN	FRESHWATER	LAND	BIODIVERSITY
GDP	1													
GDP2	0.05***	1												
POP	-0.03**	0.03**	1											
FD	-0.06***	-0.09***	-0.01	1										
MT	-0.33***	0.08***	-0.03**	0.04***	1									
PR	0.01	-0.01	0.01	0.01	0.01	1								
CL	-0.02*	0.02	0.02	-0.04***	0.002	0.31***	1							
CCO2	0.06***	-0.05***	-0.12***	0.05***	0.05***	0.02	-0.05 ***	1						
FERTILISER	0.05***	-0.04***	0.02*	0.002	-0.07***	-0.001	0.004	-0.12***	1					
OZONE	-0.06***	-0.01	-0.02*	0.003	-0.08***	0.01	-0.03 *	-0.003	0.13***	1				
OCEAN	0.06***	-0.03**	-0.07***	0.02*	0.04***	0.03**	0.01	0.50***	0.14***	0.04***	1			
FRESHWATER	-0.02	0.03**	0.02*	0.02	-0.04***	-0.001	0.02	-0.14***	0.09***	0.22***	0.15***	1		
LAND	-0.06***	-0.001	0.01	-0.04***	-0.06***	-0.05***	-0.03 **	-0.22***	-0.14***	0.08***	-0.38***	0.12***	1	
BIOSIVERSITY	0.22***	0.04*	-0.01	-0.06***	0.14***	-0.001	-0.06 ***	0.15***	0.25***	-0.13***	0.17***	0.02	0.19***	1

Note: This table sets out Pearson's correlations coefficients for all variables that will be considered in the seven panel regressions (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land use, and biodiversity loss). This is using global environmental indictors and country-specific characteristic of 177 countries in the period between 1973 and 2013 for all panels, expecting the biodiversity loss panel which considers a period from 1996 to 2013. * Correlation is significant at the 1% level; ** Correlation is significant at the 5% level; ***Correlation is significant at the 10% level.

Appendix 2

Durbin Wu-Hausman test for endogeneity of regressors for PB

Panel	**Wu-Hausman Test**	**P-value**
Climate Change		
GDP	19,2075	0,0000
GDP2	8,3958	0,0038
Biochemical Cycles		
GDP	218,9140	0,0000
GDP2	40,6189	0,0000
Ozone		
GDP	68,8601	0,0000
GDP2	4,3805	0,0364
Ocean Acidification		
GDP	23,5885	0,0000
GDP2	844,9225	0,0000
Freshwater Use		
GDP	19,3950	0,0000
GDP2	1,7999	0,1798
Land Use		
GDP	34,1777	0,0000
GDP2	0,1683	0,6816
Biodiversity		
GDP	9,7596	0,0018
GDP2	4,3023	0,0382

Note: ** and *** denotes significance and the rejection of H_0 at the 5% and 1% levels. The test is based on the GDP and GDP2 on each PB (climate change, biochemical cycles, ozone depletion, ocean acidification, freshwater use, land change and biodiversity loss) and control variables. The analyses include as instruments the lags of the differenced variables. In particular, each PB panel considers the lag 1 of the differences dependent variables, lags 0 and 1 of the differenced control variables, and lag 1 of the differenced GDP measure for the GDP endogeneity test, while the lag 1 of the differences dependent variables, lags 0 and 1 of the differenced control variables and lag 1 of the differenced GDP are used in the endogeneity test for GDP2 measure.