Essays on the effect of globalisation on environmental performance and sustainable development

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Resumo

Os efeitos das alterações climáticas são mais do que uma ameaça para o futuro, são uma realidade com a qual a sociedade já tem de lidar nos dias de hoje. A presente tese foca-se na análise da influência da globalização no cumprimento das metas ambientais e do desenvolvimento sustentável. Através do crescente desenvolvimento tecnológico e integração das economias, os países são hoje mais conectados do que alguma vez foram. Contudo, existem inúmeros desafios ambientais e económicos associados à globalização. Estes desafios aumentam a degradação ambiental e instigam condições de trabalho precárias em países com rendimentos mais baixos que produzem bens para países desenvolvidos. Com o propósito de analisar o efeito da globalização no meio ambiente e no desenvolvimento sustentável das economias, a presente tese realiza seis ensaios, organizados em três partes. A primeira parte tem como objetivo analisar empiricamente o comportamento da cada medida e dimensão da globalização no desempenho ambiental, considerando economias com características distintas, como o nível de rendimento, desenvolvimento e globalização, a conjuntura regulatória, económica, política e social. Esta primeira parte compreende três ensaios de forma a cumprir o objetivo descrito anteriormente. Através da utilização de estimadores de dados em painel com frequência anual, os principais resultados sugerem evidência empírica para o comportamento distinto de cada medida e dimensão da globalização sob características distintas das economias. Diante disto, as estratégias ambientais devem ser delineadas considerando as características especificas de cada economia, em vez de serem implementadas diretrizes transversais para um grupo de países ou para o fenómeno da globalização como um todo. Enquanto isso, é necessário debater estratégias que desencorajem o benefício económico que as economias desenvolvidas e de alto rendimento retiram da crescente degradação ambiental nos países em desenvolvimento e de rendimento mais baixo.

Promover o desenvolvimento sustentável e atingir a meta do carbono líquido-zero exige que os decisores políticos projetem e implementem políticas e diretivas eficientes. Para isto, é crucial fornecer uma análise detalhada e realista do desempenho ambiental. Desta forma, compreender as lacunas que poderão ser necessárias de colmatar e as melhorias que são necessárias introduzir na avaliação do desempenho ambiental motivou a segunda parte da presente tese. Assim, a segunda parte tem como objetivo fornecer um extenso e detalhado levantamento da literatura e uma análise crítica de um dos métodos mais utlizados para avaliar o desempenho ambiental, nomeadamente a Curva Ambiental

de Kuznets (*Environmental Kuznets Curve - EKC*). Este ensaio fornece uma revisão detalhada da literatura existente, na qual é descrito o período e os países em análise, as variáveis analisadas na relação Curva Ambiental de Kuznets, as variáveis adicionais que são incluídas, as abordagens realizadas, a relação obtida, e o cálculo do ponto de viragem. Além disso, identifica lacunas e propõe melhorias na aplicação da Curva Ambiental de Kuznets. Este ensaio revela que os decisores políticos devem estar cientes da sensibilidade e volatilidade dos resultados da Curva Ambiental de Kuznets. Os resultados deste método devem ser usados apenas como orientação para a projeção e implementação de políticas, mas não como um indicador decisivo por si só.

A eficiência energética e as finanças climáticas são ferramentas cruciais para promover o desenvolvimento sustentável e cumprir as metas ambientais. Esta evidência definitivamente motivou a terceira parte desta tese. Assim, a terceira parte tem como objetivo principal analisar a papel da globalização como determinante da eficiência energética, financiamento climático e desenvolvimento sustentável. Dois ensaios foram desenvolvidos para cumprir o objetivo descrito. Vários estimadores de dados em painel foram aplicados, nomeadamente o Modelo Autorregressivo com Desfasamento Distribuído (*Autoregressive Distributed Lag*), a Regressão Linear com Erros Padrão Corrigidos para Painel (*Panel Corrected Standard Errors*) e a Regressão com Erros Padrão de Driscoll-Kraay (*Regression with Driscoll-Kraay standard errors*). A robustez dos resultados foi executada através da aplicação de especificações diferentes dos modelos e do uso do modelo de Regressão Aparentemente não Relacionada (*Seemingly Unrelated Regression*). Os principais resultados da terceira parte desta tese sugerem que os países com maior consumo de energia *per capita* podem estar a priorizar o benefício económico no lugar da qualidade ambiental. Importa também salientar que os resultados sugerem que o financiamento climático mais do que um mecanismo de preservação ambiental para os países desenvolvidos, promove melhorias no padrão de vida da sociedade nestes países. De acordo com isto, o desenvolvimento humano revela-se como um determinante do fluxo do financiamento climático. Acordos ambientais internacionais permitem maior transparência e compromisso, mas é crucial estabelecer metas ambientais específicas e garantir o seu cumprimento. A implementação de penalizações para as economias que não cumprem as metas estabelecidas pode desencorajá-las de tomar decisões priorizando a maximização do lucro em vez da qualidade ambiental.

Palavras-chave

Degradação Ambiental; Crescimento Económico; Globalização de jure e de facto; Curva Ambiental de Kuznets; Finanças Climáticas; Desenvolvimento Sustentável; Índice de Eficiência; Entrada de Capital Estrangeiro

Resumo Alargado

As alterações climáticas são um desafio transversal a todos os países do mundo. Sem o devido controlo, as alterações climáticas irão acarretar consequências devastadoras, tanto para as economias como para as vidas humanas. Desta forma, a necessidade de cumprir os acordos ambientais internacionais levou os países a trabalhar em conjunto, evidenciando a crescente globalização e o fato de que os países estão hoje mais conectados do que nunca. Esta crescente globalização promove a integração económica e o avanço tecnológico, mas também incita a desigualdade de rendimento e condições de trabalho desfavoráveis. Estes fatos constituem a principal motivação para o desenvolvimento desta tese, que tem como principal objetivo fornecer evidência empírica sobre os efeitos que têm resultado da crescente globalização no ambiente, bem como em mecanismos como a eficiência energética e o financiamento climático. Incorporado neste objetivo principal, a presente tese ambiciona contribuir para o progresso da análise do desempenho ambiental. Para abordar esses desafios, esta tese é composta por três partes. Na primeira analisaram-se detalhadamente os efeitos da globalização na degradação ambiental. A segunda parte foca-se na análise crítica de um dos métodos mais usados para analisar o desempenho ambiental. E por fim, na terceira analisaram-se mecanismos de mitigação e adaptação às alterações climáticas. Para alcançar estes objetivos, as três partes que constituem esta tese acomodam seis ensaios.

Na primeira parte, procedeu-se a uma análise detalhada de como cada dimensão e medida da globalização se comporta, e consequentemente influencia o desempenho ambiental perante características distintas das economias (como nível de rendimento, desenvolvimento, globalização, contextualização política e outros). Para um melhor entendimento da complexidade do fenómeno da globalização e dos seus impactos perante características distintas das economias, foram realizados três ensaios. Para tal, utilizou-se um estimador Driscoll-Kraay com uma abordagem autorregressiva de desfasamento distribuído para capturar a dinâmica de curto e longo prazo. Nestes três ensaios foi utilizada uma estrutura de dados anuais em painel. No primeiro ensaio, para um conjunto de 25 países da União Europeia. No segundo ensaio, para dois conjuntos de países, nomeadamente 32 países desenvolvidos e 26 em desenvolvimento. E no terceiro ensaio, para um conjunto de 23 países africanos.

Os resultados da primeira parte desta tese evidenciam os efeitos distintos que a globalização tem sobre o meio ambiente perante características diferenciadas das

economias. Cada dimensão e medida da globalização tem efeitos diferentes tanto de natureza como de magnitude no meio ambiente. Desta forma, os resultados indicam que as estratégias ambientais devem ser delineadas tendo em consideração o nível de rendimento, desenvolvimento e globalização, e o contexto regulatório, económico, social e político das economias. Para além disso, é necessário debater sobre estratégias que desencorajem as economias desenvolvidas e de alto rendimento de beneficiarem economicamente do aumento da degradação ambiental nos países em desenvolvimento e de baixo rendimento.

Os resultados obtidos nos primeiros três ensaios desta tese motivaram o desenvolvimento da segunda e da terceira parte. Estes resultados evidenciam que é crucial fornecer uma avaliação realista do desempenho ambiental de forma que os decisores políticos implementem políticas eficientes em direção ao desenvolvimento sustentável. E ainda, que os países em desenvolvimento enfrentam significantes necessidades financeiras no que diz respeito ao investimento necessário para atingir as metas ambientais. Desta forma, na segunda e terceira parte são abordados os principais desafios da análise do desempenho ambiental através da hipótese da Curva Ambiental de Kuznets (*Environmental Kuznets Curva – EKC*) e da implementação de mecanismos e ferramentas de mitigação da degradação ambiental.

Os formuladores de políticas ocupam um papel central na luta contra as alterações climáticas. Desta forma, é imprescindível fornecer estudos robustos do desempenho ambiental para que possam servir de base ao desenvolvimento de políticas e diretrizes eficazes. Esta é a principal motivação para a segunda parte desta tese, que é composta por um ensaio. Através deste ensaio, pretende-se fornecer uma ferramenta útil aos formuladores de política relativamente à interpretação dos resultados obtidos através de um dos métodos mais utilizados para analisar o desempenho ambiental. Para isso, desenvolveu-se um extenso e detalhado levantamento da literatura da Curva Ambiental de Kuznets com o objetivo de nomeadamente, descrever a evolução da sua aplicação, identificar os fatores que influenciam a sua validação, e ainda identificar lacunas e propor progressos na aplicação deste método.

O levantamento da literatura sobre a Curva Ambiental de Kuznets, que serviu de base para a análise crítica desenvolvida neste ensaio, consiste na compilação de mais de 200 artigos científicos de 1998 até 2022, dos quais é apresentada a informação individual dos países analisados, das variáveis incluídas na análise, das metodologias utilizadas, a relação obtida, entre outras. Os resultados sugerem que um dos principais desafios da análise do desempenho ambiental através da hipótese da Curva Ambiental de Kuznets é a sensibilidade desta abordagem no que diz respeito à sua especificação/processo econométrico, nomeadamente o tipo de análise (análise em painel ou serie temporal), a metodologia aplicada e as variáveis incluídas. Além disso, os resultados sugerem a necessidade de integrar informação de outras áreas de investigação, bem como de ferramentas de mitigação da degradação ambiental. Este capítulo salienta que os decisores de políticas devem estar cientes da volatilidade e sensibilidade associada aos resultados obtidos através da análise da Curva Ambiental de Kuznets.

Progredir em direção ao desenvolvimento sustentável requer garantir as necessidades presentes sem comprometer a capacidade de satisfazer as necessidades das futuras gerações. Desta forma, o desenvolvimento sustentável pressupõe que as economias continuem a crescer, contudo, sem aumentar a degradação ambiental. No entanto, o cumprimento das metas de desenvolvimento sustentável requer elevado investimento. O que consequentemente desperta grandes desafios globais, principalmente para as economias em desenvolvimento em que existe escassez de capital. Perante um objetivo que é global, cumprir as metas de desenvolvimento sustentável, as economias desenvolvidas concordaram em fornecer apoio financeiro às economias em desenvolvimento para enfrentar os desafios das alterações climáticas, não só para a mitigação da degradação ambiental, mas também para estratégias de adaptação aos efeitos já sentidos.

Estas evidências representam a principal motivação para o desenvolvimento da terceira parte desta tese, a qual pretende analisar o papel da globalização no desenvolvimento sustentável e em dois mecanismos de mitigação da degradação ambiental. A terceira parte é constituída por dois ensaios. O primeiro ensaio foca-se na eficiência energética e no desenvolvimento sustentável. Enquanto o segundo é focado no financiamento climático como mecanismo de mitigação e adaptação às alterações climáticas, e ainda de progresso do desenvolvimento humano. Em ambos os ensaios foi utilizada uma estrutura de dados anuais em painel, sendo que no primeiro ensaio analisaram-se países intensivos em consumo de energia, e no segundo analisou-se um grupo de países em desenvolvimento. Para tal, foram aplicados modelos Autorregressivos com Desfasamento Distribuído (*Autoregressive Distributed Lag - ARDL*), Regressão Linear com Erros Padrão Corrigidos para Painel (*Panel Corrected Standard Errors - PCSE*) e Mínimos Quadrados Generalizados Factíveis (*Feasible Generalized Least Squares - FGLS*). No segundo ensaio, a robustez dos resultados foi comprovada pela aplicação de uma Regressão Aparentemente não Relacionada (*Seemingly Unrelated Regression - SUR*).

Os resultados do primeiro ensaio da terceira parte mostram que a globalização promove a eficiência energética e o desenvolvimento sustentável, contudo, apenas nos países com maiores níveis de globalização. Nos países com níveis inferiores de globalização, apenas promove o desenvolvimento sustentável. Além disso, os resultados sugerem que o consumo de energia renovável pode estar a desacelerar o desenvolvimento sustentável nos países intensivos em consumo de energia. Este é, na verdade um resultado inquietante, perante o qual as estratégias de penetração das renováveis devem ser restruturadas. Os resultados do segundo ensaio revelam que o financiamento climático é uma ferramenta eficaz para mitigar a degradação ambiental e também para promover o desenvolvimento humano. Contudo, a entrada de capital estrangeiro nos países em desenvolvimento para além de aumentar a degradação ambiental, restringe o desenvolvimento humano. Este resultado sugere que o capital é direcionado para atividades e indústrias intensivas em emissões. Deste modo, são necessárias políticas de controlo da pegada ecológica da entrada de capital estrangeiro que desincentivem as economias desenvolvidas de beneficiarem do relaxado contexto regulatório e da necessidade de crescimento económico dos países em desenvolvimento. Essas políticas devem ser complementadas com o fortalecimento do contexto regulatório nos países em desenvolvimento.

As alterações climáticas são transversais a todos os países, o que quer dizer que independentemente de a poluição ser produzida nos países desenvolvidos ou nos em desenvolvimento, terá a mesma contribuição para o problema global. No geral, a presente tese fornece evidências empíricas que devem ser consideradas pelos formuladores de políticas, para potencializar o canal da globalização no cumprimento das metas do desenvolvimento sustentável e dos acordos ambientais internacionais. Tal como, para promover mecanismos de mitigação e de adaptação da degradação ambiental como a eficiência energética e o financiamento climático. Além disso, fornece evidência para a realização de análises do desempenho ambiental mais robustas. Estas evidências refletem o que tem ocorrido até ao presente e fornecem conhecimento essencial à formulação de políticas eficiente. No entanto, a tecnologia está em constante progresso e os agentes económicos em constante adaptação. É imprescindível desenvolver novas tecnologias, adotar novos comportamentos, fortalecer regras e metas, e adicionar penalizações ou incentivos para que as economias se sintam encorajadas em dar primazia aos objetivos ambientais e ao futuro sustentável. Se a presente tese, e os seis ensaios nela incorporados, contribuir para o progresso das economias como um todo em direção ao desenvolvimento sustentável, o seu maior objetivo será cumprido.

Abstract

More than a threat to the future, climate change is a reality that needs to be dealt with today. The main focus of this thesis is the analysis of the influence of globalisation on the achievement of sustainable development goals. Countries around the world have become more connected than ever due to advancing technology and economic integration. However, globalisation gives rise to diverse ecological and economic challenges, leading to environmental damage and inducing substandard working conditions in emergent nations that produce goods for more developed ones. To address some of these challenges, in this thesis, six analyses organised into three main parts were performed. The first aims to empirically analyse the effect of each dimension and measure of globalisation on environmental performance, considering economies' distinct contexts, such as level of income, degree of development, level of globalisation, regulatory structure, and economic, political, and social frameworks. Three essays were included in the first part of the thesis to address the objective stated above. Panel data estimators for an annual frequency were used, and the main findings suggest that each dimension and measure of globalisation behaves differently under distinct economies' features. In light of this, environmental strategies should be delineated according to the specific features of the economies instead of implementing transversal directives for both a group of economies and globalisation as a whole. A debate is needed on strategies that discourage developed and high-income economies from economically benefiting from increasing environmental degradation in developing and low-income countries.

An all-embracing environmental performance assessment is crucial for policymakers to design and implement the most efficient policies and directives to achieve sustainable development and the net-zero carbon goal. Understanding the gaps that might need to be overcome, and the improvements that might need to be made in environmental performance assessment, motivated the second part of this thesis. Thus, the second part of this thesis aims to provide a survey of the literature and a critical analysis of one of the most popular methods used to assess environmental performance, the Environmental Kuznets Curve (EKC). This essay goes further by first presenting a detailed review of the literature that describes the time period and countries under analysis, the variables of the EKC relationship analysed, additional variables included, approaches performed, the relationship obtained, and if the turning point is calculated. Secondly, it identifies gaps and proposes improvements to the EKC hypothesis assessment. This essay highlights that policymakers should be concerned about the volatility of the EKC outcomes. The use

of the EKC outcomes as guidance on policy design and implementation, but not as a decisive indicator, is recommended.

Energy efficiency and climate finance are crucial tools to achieve sustainable development and the net-zero carbon goal. This evidence motivated the third part of this thesis. The main objective of this third part is to analyse globalisation as a driver of energy efficiency, climate finance, and sustainable development. Two essays were written to achieve this objective. Diverse empirical methods were applied, such as the Autoregressive Distributed lag model, both Panel-Corrected Standard Errors and Feasible Generalized Least Squares, and the Driscoll-Kraay estimator. The robustness of the results has been confirmed by using different models' specifications and by employing a Seemingly Unrelated Regression method. The main findings of the third part of this thesis highlight that economic benefit might have been prioritized over environmental quality in the higher energy consumers per capita countries. At the same time, climate finance is an environmental preservation mechanism for developing countries, but further than that, it induces improvements in the standard of living. In concordance with that, human development is suggested as a substantial determinant of climate finance flow. Strengthening regulation and implementing environmental protection directives are indispensable to accomplishing the established environmental goals, as well as founding specific goals and mainly accomplishing them. International agreements allow transparency and the commitment to a shared interest. Implementing penalties for the economies that do not comply with the agreed treaty might discourage these economies from making decisions that maximize their profit over environmental quality.

Keywords

Environmental Degradation, Economic Growth, Globalisation *de jure* and *de facto*, Environmental Kuznets Curve, Climate Finance, Efficiency Index, Sustainable Growth, Foreign Capital Inflow

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Acronyms list

AF	Adaptation Finance/Funds
AMG	Augmented Mean Group
APEC	Asia Pacific Economic Cooperation
ARDL	Autoregressive Distributed Lag
ASEAN	Association of Southeast Asian Nations
BIC	Brazil, India and China
BOD	Biochemical oxygen demand
BRIC	Brazil, Russia, India and China
BRICS	Brazil-Russia-India-China-South Africa
CCE	Common Correlated Effects
CCEMG	Common Correlated Effects Mean Group
CCR	Canonical Cointegrating Regression
CD	Cross-sectional Dependence
CF	Climate Finance/Funds
CIPS	Second-Generation unit root test
CO	Carbon Monoxide
CO_2	Carbon dioxide
COD	Chemical oxygen demand
COP	Conference of Parts
CRR	Cox, Ross and Rubinstein
CS	Cross-Sectional
CUP-BC	Continuously Updated Bias-Corrected
CUP-FM	Continuously Updated Fully Modified
DAC	Development Assistance Committee
DFE	Dynamic Fixed Effect
DF	Driscoll-Kraay
DOLS	Dynamic Ordinary Least Square
EC	Energy Consumption
ECCP	European Climate Change Programme
ECM	Error correction mechanism
EF	Ecological Footprint
EFFI	Efficiency Index
EKC	Environmental Kuznets Curve
ETS	Emissions Trading System
EU	European Union
FCI	Foreign Capital Inflow
FD	Financial Development
FDI	Foreign Direct Investment
FE	Fixed effects
FGLS	Feasible Generalized Least Squares
FMOLS	Fully Modified Ordinary Least Square
FOC	First Order Conditions
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GDP	Gross Domestic Product

GFCF	Gross Fixed Capital Formation
GHG	Greenhouse Gas
GLS	Generalized Least Squares
GMM	Generalized Method of Moments
GRP	Gross Regional Product
GSP	Gross State Product
GVA	Gross Value Added
HDI	Human Development Index
HGC	High globalized countries
HGCF	High globalized counties *de facto*
HGCJ	High globalized counties *de jure*
ICT	Information and Communications Technology
IDA	Index decomposition analysis
IEA	International Energy Agency
IGVA	Industry Gross Value Added
IR	Impulse Response
ISEW	Index for Sustainable Economic Welfare
IV	Instrumental Variable
LGC	Low globalized countries
LGCF	low globalized counties *de facto*
LGCJ	low globalized counties *de jure*
LMDI	Log Mean Divisia index
LMIC	Lower-middle-income Countries
LPOLSM	Local Polynomial Smoothing Model
LSCV	Least-Squares Cross-Validation
LSDV	Least square dummy variable
LSDVC	Least Square Dummy Variable Corrected
MENA	Middle East and North African
MF	Mitigation Finance/Funds
MG	Mean Group
MMQR	Method of Moments of Quantile Regression
MT	Million tonnes
Mtoe	Millions of tonnes in oil equivalent
NARDL	Nonlinear Autoregressive Distributed Lag
NEA	Northeast Asian countries
NH_4	Ammonium
NO_2	Nitrous Oxide
NSEA	Northeast and Southeast Asian
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OLG	Overlapping Generations
OLS	Ordinary Least Square
OPEC	Organization of Petroleum Exporting Countries
PCA	Principal Component Analysis
PCSE	Panel Corrected Standard Errors
PDOLS	Panel Dynamic Ordinary Least Square
PHH	Pollution Haven Hypothesis
PLS	Panel Least Squares
$PM_{2.5}$	Particulate Matter (2.5 micrometres)

PMG	Pooled Mean Group
PR	Personal Remittances
PVAR	Panel Vector Autoregressive Model
PSTR	Panel Smooth transition Regression
R&D	Research and Development
RE	Random effects
RES	Renewable Energy Sources
SAR	Spatial Autoregressive Model
SARAR	Spatial Autoregressive Model with Spatial Autoregressive
SDGs	Sustainable Development Goals
SDM	Spatial Durbin Model
SEA	Southeast Asian countries
SEM	Spatial Error Model
SF6	Sulphur Hexafluoride
SFE	Static Fixed Effect
SGVAR	Semi-Parametric Global Vector Autoregressive Model
SLM	Spatial Lag Model
SO2	Sulphur Dioxide
SOC	Second Order Conditions
STSM	Structural time series modelling
SUR	Seemingly Unrelated Regression
SYS-GMM	System Generalized Method of Moments
Sys2Step	Two-Step Dynamic System Generalized Method of Moments
TFP	Total Factor Productivity
TO	Trade Openness
TSLS/2SLS	Two-stage Least Squares
TY	Toda–Yamamoto
UAE	United Arab Emirates
UK	United Kingdom
UMIC	Upper-middle-income Countries
UNSD	United Nations Statistical Division
US	United States
USA	United States of America
VA	Value Added
VAR	Vector Autoregressive Model
VECM	Vector Error Correction Model
VIF	Variance Inflation Factors
VOC	Volatile Organic Compounds
WCED	World Commission on Environment and Development
WWCC	Wavelet Window Cross Correlation
2SGMM	Two-step Dynamic Generalized Method of Moments

Chapter 1

Introduction

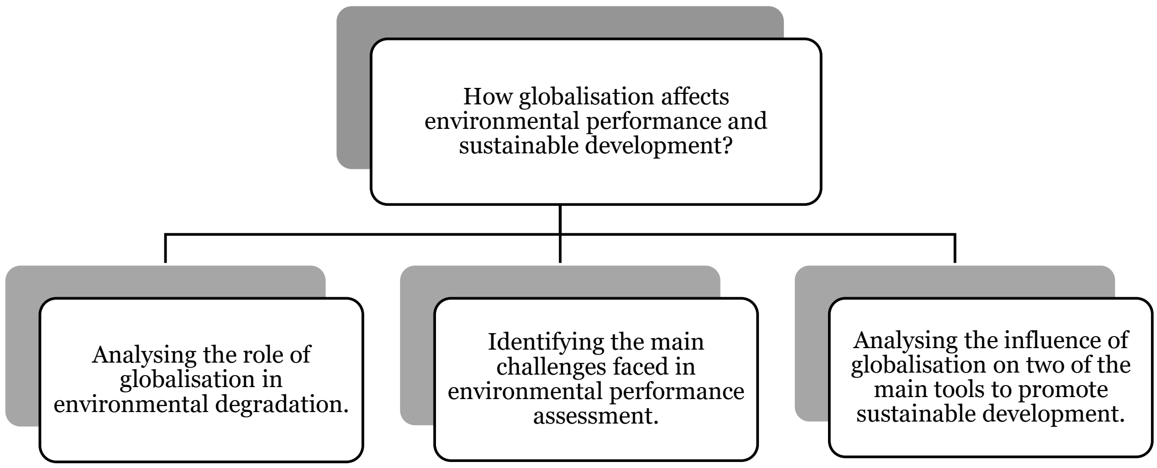
Global warming is the most significant challenge humanity has faced so far. Without appropriate control, this phenomenon will have devastating consequences on human life, economies, and the environment. These consequences will be far-reaching and long-lasting. Academics and policymakers have discussed the issue of climate change at great length. The Conference of Parties (COP) from the United Nations frequently reviews climate change adaptation and mitigation strategies. Acknowledging the need to act against global warming, world leaders reached a consensus in the Paris Agreement of 2015 and agreed to work together to mitigate this phenomenon. This partnership by people from different countries sharing ideas and knowledge, and governments working together cooperatively, is a clear example of globalisation.

Countries worldwide have become more connected than ever through rising technological improvements and economic integrations. Globalisation is considered, by many, the key to defining the economic development and future of the planet (Intriligator, 2004). However, globalisation induces income inequality and substandard working conditions in lower income countries that produce goods for more affluent ones. Environmentalists assert that globalisation induces economic activities and the production of goods, which leads to environmental damage (Rahman, 2020)[1]. Globalisation gives rise to diverse environmental and economic challenges. Considering the urgent need to meet international environmental agreements, developed nations have established ambitious environmental targets. However, these targets require huge investment needs not afforded by all nations. These facts have inspired the development of this thesis, which is focused on the role of globalisation in achieving the Sustainable Development Goals (SDGs). Throughout the development of this thesis, certain SDGs are addressed: Goal 8 - decent work and economic growth, Goal 10 – reduced inequalities, Goal 12 - responsible consumption and production, and Goal 13 – climate action.

The main objective of this thesis is to provide evidence, mainly empirical, about the role of globalisation in both environmental degradation and sustainable development. In other words, this thesis aims to evaluate the effects of each measure and dimension of

[1] The APA 6th edition (American Psychological Association, 2010) citation style been used throughout this thesis.

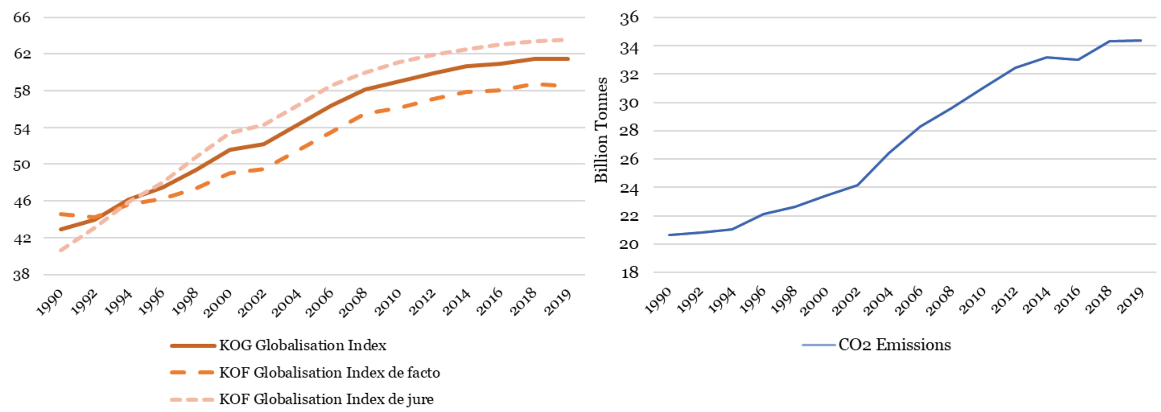
globalisation has had on Carbon Dioxide (CO_2) emissions, energy efficiency and climate finance. It also addresses the main challenges of the environmental performance assessment and the challenges that the economies have been facing to accomplish the SDGs, namely comparative advantages between economies, and investment needs to mitigate and adapt to climate change consequences. This thesis consists of three main parts accommodating six analyses. Briefly, the first part consists of exploring the role of globalisation on environmental performance under economies' distinct features. The second part addresses the challenges of evaluating environmental performance, and the third part discusses the impact of globalisation on sustainable development tools. Figure 1.1 summarises the structure of this thesis.



Notes: Own elaboration.
Figure 1.1 – Thesis' summarised structure and objectives

The most recent econometric techniques were applied, and different groups of countries were analysed to accomplish the objective of this thesis. The techniques were selected with the research objective and the features of the collected data in mind. Panel data techniques were used on an annual basis to obtain as many observations as possible. The long-term relationship between the variables under analysis was also considered to guarantee robust outcomes. According to the research objective of each essay, data availability determines the main selection criteria of the countries studied throughout this thesis. The empirical evidence of this thesis intends to cover all the regions of the globe, from developed to developing economies, high- to low-income, and high- to low-globalised. The choice of each group of countries analysed has been explained in each chapter.

In order to further explain the facts that inspired and motivated the development of this thesis, some statistics related to globalisation and environmental degradation are presented below, and a brief contextualisation of the literature is provided as follows. Environmental degradation and globalisation follow a very close temporal path. Figure 1.2 shows the evolution of world globalisation and CO2 emissions over the same period.

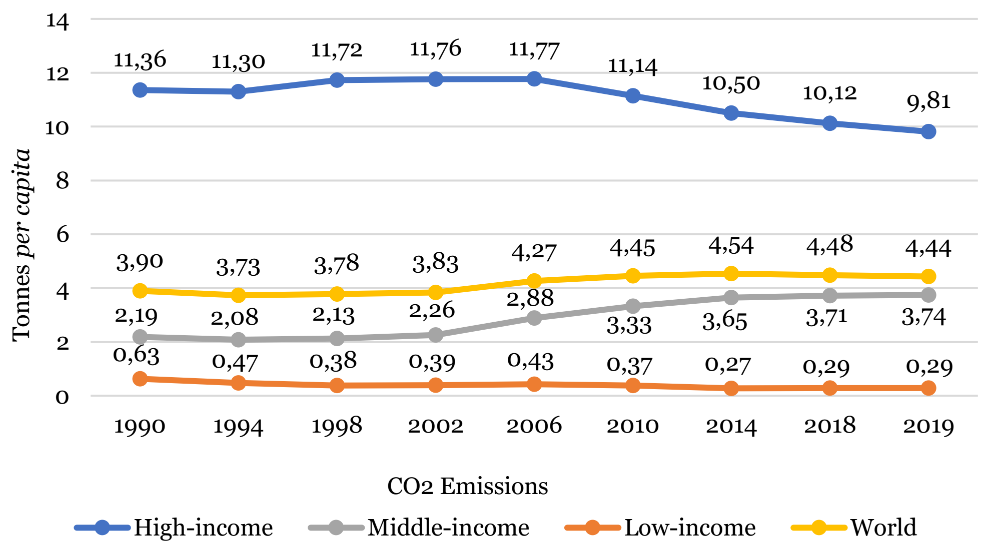


Notes: Own elaboration. Data source: KOF Swiss Economic Institute[2] and World Bank's World Development Indicators database (Accessed on 17 May 2023).

Figure 1.2 – World average of KOF Globalisation Index (general index, *de facto* and *de jure*) and World average of CO2 emissions

Looking at Figure 1.2, from 1990 to 2019, world globalisation increased by 43.2% and CO2 emissions by 66.5%. Over the years, different regions have gone through different development processes and industrialization phases. The different stages of economic development are reflected in the volume of CO2 emissions released, which suffer fluctuations. Currently, middle-income countries are the most significant contributors to the world´s CO2 emissions, with the highest amount of CO2 released. However, when considering the size of the population of each region, high-income economies are the ones that are above the world average for tonnes of CO2 emissions released per habitant. Figure 1.3 reveals the evolution of CO2 emissions per capita measured in tonnes for the world, high-, middle-, and low-income economies from 1990 to 2019.

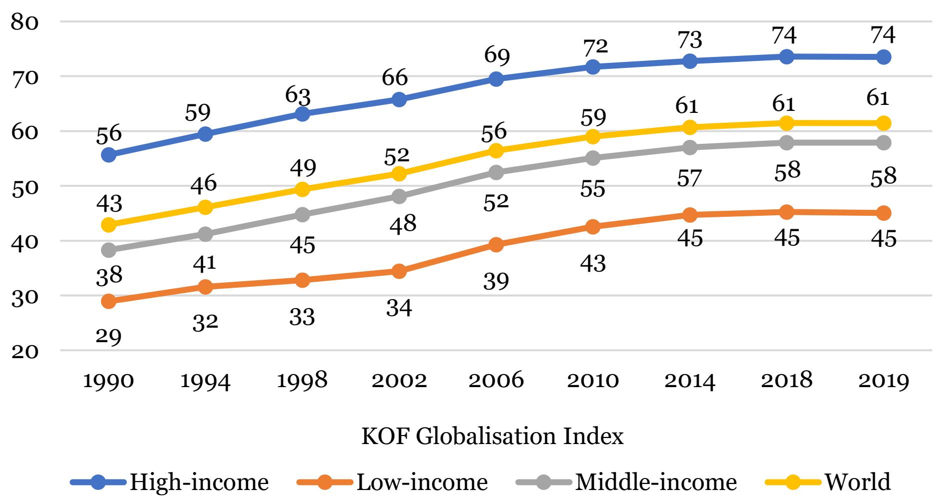
[2] https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html



Notes: Own elaboration. Data source: World Bank's World Development Indicators database (Accessed on 17 May 2023).

Figure 1.3 – Carbon Dioxide Emissions tonnes per capita

Also, regarding the level of globalisation, the high-income economies are above the world mean, while middle- and low-income ones are below. Figure 1.4 reveals the evolution of the level of globalisation for the world, high-, middle-, and low-income economies from 1990 to 2019.



Notes: Own elaboration. Data source: KOF Swiss Economic Institute (Accessed on 17 May 2023).

Figure 1.4 – KOF Globalisation Index

Although the world's environmental degradation and globalisation temporal paths follow similar trajectories, a closer look at the countries categorised by income levels reveals that each group of countries has a specific environmental degradation and globalisation relationship.

There has been no consensus among academic researchers regarding the relationship between globalisation and environmental degradation (Rafindadi & Usman, 2019). The juxtaposition of globalisation regarding environmental performance is interesting. On the one hand, it mitigates environmental degradation by facilitating the importation of clean technology or improving global ecological awareness (Shahbaz, Shahzad, & Mahalik, 2018). On the other hand, it induces trade openness and transportation of goods and enables the relocation of pollutant production (Bilgili, Ulucak, Koçak, & İlkay, 2020). Efforts have been made to improve the measurement of this complex phenomenon of globalisation, which has resulted in a revised version of the standard globalisation index, the KOF globalisation index (Gygli, Haelg, Potrafke, & Sturm, 2019). The analysis of the two measures of each dimension of globalisation facilitates an understanding of globalisation's diverse influence on environmental performance. Furthermore, the revised version provides insights that allow policymakers to design effective policies for each measure of each dimension of globalisation. This thesis aims to add to that contribution.

This thesis consists of six essays inspired and motivated by the facts described up to this point. These six essays are focused on three main objectives, as thereafter described. The first three essays of this thesis (Chapters 2, 3, and 4) are focused on the analysis of the role of each dimension and measure of globalisation in environmental degradation. Although the relationship between globalisation and environmental performance is addressed in the literature (see, e.g., Potrafke, 2015), it is considered a neglected variable in environmental research. In that way, analysing the effects that result from each dimension and measure of globalisation is a quite a novel topic.

Globalisation is a complex phenomenon, and the main purpose of the three first essays of this thesis is to fully explore how each dimension and measure of globalisation behaves and affects environmental performance under economies' distinct features (e.g., level of income, development, globalisation, regulation, politician contextualisation, and others). In other words, the first of the three main objectives of this thesis focus on providing a clear understanding of the scientific knowledge regarding the various impacts of each dimension and measure of globalisation. In light of this, Chapter 2 of this thesis aims to fill this gap by analysing the effects of globalisation in developed, high-income and high-globalised countries. These countries are considered politically and economically integrated with unified foreign and security policies. Chapter 2 is focused on a group of 25 European Union (EU) economies. The Schengen agreement between EU (free circulation of citizens) can be considered a form of globalisation legislation. Chapter 2 aims to provide an answer to the following central research questions:

(i) Is the level of globalisation compromising the environment?
(ii) What are the dimensions of globalisation that are most beneficial and harmful to the environment?
(iii) Do the *de jure* and *de facto* measures of globalisation influence the environment differently?

An appropriate model was needed to answer these questions considering the properties of the data collected. The Autoregressive Distributed Lag (ARDL) approach with a Driscoll-Kray estimator was chosen to distinguish short- and long-term effects. The analysis was carried out from 1990 to 2016. A group of 25 EU economies was categorised into high and low *de facto* and *de jure* globalised. Then, four models were estimated to analyse the effect of globalisation on CO2 emissions, considering the four different levels of globalisation.

The main findings of Chapter 2 indicate that the role of globalisation on environmental performance is not static. Answering the central questions of this chapter, the level of globalisation impacts environmental performance. The political dimension of globalisation primarily benefits the environment, while the social and economic ones mostly hamper it. Additionally, the *de facto* and *de jure* measures have different effects in nature and magnitude. The highest EU globalised economies are mostly influenced by the *de jure* measure, while the lowest ones are by the *de facto* measure. This means that the highest globalised economies invest more in research and the development of technologies, policies, and treaties, while the lowest globalised are more likely to be technology adopters. The relevance of analysing the measures of globalisation was supported, and it provides insight to policymakers to develop and implement specific and more effective policies. Furthermore, this essay contributes that besides the EU countries having common policies and directives, the level of globalisation inside this group of countries affects the impact of globalisation on environmental performance.

Once the consequences of globalisation on environmental performance in countries with similar economic, political, and social features were analysed, Chapter 3 innovates by analysing and comparing the effects of globalisation in countries with entirely distinct features. Thus, Chapter 3 considers two groups of countries: 32 developed and high-income economies and 26 developing and middle-income ones. Apart from the level of development and income, these two groups of countries also have distinct regulatory, economic, social, and political contexts. Therefore, these two groups of countries are considered in order to explore how globalisation influences the environment of developed, high-income, and high-globalised countries, and with strict regulation economies, compared with developing, middle-income, less globalised, and with permissive regulation ones. In contrast to the analysis developed in Chapter 2, the group of developed economies in this chapter does not follow common policies and directives and has distinct geographic locations.

Chapter 3 of this thesis further assesses the Environmental Kuznets Curve (EKC) hypothesis. The assessment of this hypothesis makes it possible to capture the effects of globalisation not only on environmental performance but also the influence on the relationship between environmental degradation and economic growth. Therefore, this essay intends to answer the following research question:

(iv) How does globalisation affect environmental performance in developed and developing countries?

The principal analysis in this essay is accomplished through an ARDL model with a Driscoll-Kraay estimator analysing the data from 1995 to 2017. When the phenomenon is studied in the long-run, it becomes vital to understand the most immediate and persistent adjustment dynamics over time. Therefore, this essay employs modelling capable of accommodating different adjustment dynamics over time.

The results of Chapter 3 answer the research question; globalisation essentially improves environmental quality in developed countries and chiefly drives environmental degradation in developing ones. In other words, globalisation generally has a beneficial effect on the environment of developed countries and a harmful effect on the environment of developing ones. Regarding the assessment of the EKC hypothesis, developed countries produce an inverted U-shaped curve, while developing ones reveal a U-shaped relationship; that is, in developed countries, environmental degradation firstly increases over economic growth and then starts to decrease. In developing countries, the opposite occurs. The findings also suggest that developed economies become service-oriented while developing ones become carbon-intensive. The comparative analysis of developed economies over developing ones reveals a beneficial effect of economic globalisation *de facto* on the environment in developed countries and a harmful effect in developing countries in the long-run, which could indicate that developed countries relocate polluting industries to developing countries. This relocation occurs mainly due to the permissive environmental regulations of developing countries. The permissive regulation in developing economies is suggested by the absence of influence of political globalisation there.

To fully accomplish the first objective of this thesis and comprehensively explore the effect of globalisation, it only remains to analyse a group of low-income and low-globalised economies. The wealthy mainly focus on economic costs and benefits, and the environmental costs of development are mainly incurred by the poor (Hao, Chen, & Zhang, 2016). African countries are considered highly susceptible and vulnerable to the impact of climate change, and consequently, problems of air quality, poverty, and infectious diseases are increasing in these countries (Zaidi & Saidi, 2018). Furthermore, in these economies, concerning the industrialisation path, severe climate change consequences, poor access to energy, and severe economic and governance conditions are a reality. Considering this, Chapter 4 focuses on analysing a group of 23 African economies. This chapter goes further by analysing the phenomenon of globalisation, corruption and energy poverty. Therefore, this essay was undertaken to answer the research question:

(v) What is the environmental impact of globalisation on African countries where corruption is perceived to be prevalent?

To answer this research question, a regression of environmental degradation was estimated as a function of each dimension and measure of globalisation, economic growth, renewable and non-renewable energy consumption, corruption, and energy poverty. Considering the characteristics of the data collected, the ARDL model with the Driscoll-Kraay estimator was applied, and both short- and long-run effects were explored using annual data from 1999 to 2017.

The results reveal that the effect on the environment of each *de jure* and *de facto* dimension differs in nature and/or magnitude. In the short-run, globalisation *de facto* is more evident, while globalisation *de jure* is more prevalent in the long-run. Political globalisation *de jure* is the most pronounced influence in the African countries under analysis, and it improves environmental quality and decreases environmental degradation. Political globalisation *de jure* consists of international organisations and treaties. Resource-rich economies are committed to providing support and help with environmental agreements to the most vulnerable and resourceless economies. The international help given to resource-poor economies to fight climate change will be addressed in the third part of this thesis, Chapter 7.

More than a threat to the future, climate change is a reality that needs to be dealt with today. Improving environmental quality and accomplishing the SGDs are imperative and cannot be delayed. The eminent consequences of global warming place policymakers as central players in the current global discussion of climate change challenges. Consequently, it is crucial to provide valuable insights to help policymakers develop and implement effective and appropriate environmental protection policies and measures, which has motivated Chapter 5 of this thesis. This chapter is focused on the second main objective of this thesis, which can be divided into two bullet points. On the one hand, develop a relevant tool and source for environmental researchers. On the other hand, provide improvements in the environmental performance assessment.

The EKC is widely used to assess environmental performance in the environment-energy-economics literature, and it has attracted much attention from policymakers, theorists, and empirical researchers. Several policy recommendations have already been proposed based on the EKC analysis. However, policymakers must be aware of the high volatility and sensitivity of the EKC outcomes. Although the EKC hypothesis has been amply applied in the literature (e.g., Sarkodie & Strezov, 2019), it has not entirely incorporated the increasing complexity of environmental issues. In light of this, the second part of this thesis, Chapter 5, aims to fill this gap in the literature by pointing out critical issues and gaps in the EKC analysis and improving the environmental performance assessment. With this in mind, Chapter 5 aims to answer the following research questions:

(i) Is the EKC assessment keeping up with the increasing complexity of environmental issues?
(ii) Is the EKC vulnerable to each component of its functional specification?
(iii) How might the EKC assessment be improved to meet the increasing complexity of the economic growth and environmental degradation relationship?

To answer these questions, firstly, Chapter 5 provides a complete description of the background of the EKC, fully describing the origins, conceptual framework, and its shape. After that, this chapter provides an extensive survey of the EKC literature, addressing 200 articles from 1998 to 2022, with the objective of (i) describing the evolution of the EKC assessment and providing an integrated overview of the current state of EKC knowledge; (ii) identifying the factors that influence the EKC validation; and (iii) describing research insights, existing gaps, and providing improvement needs.

The knowledge and assessment of the EKC have developed noticeably since its inception. However, despite being broadly assessed within the vast literature, the EKC hypothesis has some gaps and econometric issues, and improvement needs are verified. The main conclusions of Chapter 5 focus on the absence of consensus about the existence and shape of the EKC, the need to integrate insights from other disciplines and research areas and the environmental mitigation tools that EKC hypothesis analysis has been overlooking. Firstly, the absence of consensus about the existence and shape of the EKC has given rise to doubts about econometric issues in EKC modelling. In this chapter, evidence has been provided about the sensitivity of the EKC estimation resulting from the data set used, the indicators, the type of analysis (time series or cross-sectional), the methodology applied, and additional variables included. Therefore, the econometric issues are mainly associated with the functional specifications and econometric techniques. The use of econometric methods dealing with the variable's features, non- or semi-parametric methods assessing short- and long-run elasticities, or non-econometric methods could be helpful to avoid EKC sensitivity to the approach used.

The complexity of environmental degradation issues is increasing, and any analysis of the EKC hypothesis will benefit from integrating insights from other disciplines and research areas. Scenarios such as relocated pollution, delocalized production, energy and production goods countries' dependence, lax environmental regulation, and comparative advantages, among others, can influence countries' environmental performance. Analysing environmental degradation indicators or other indicators over economic growth is not enough at this point; it is crucial to look further into environmental pollution indicators and consider the inclusion of environmental protection tools, such as technological progress, energy efficiency, energy transition, potential clean energy sources (such as nuclear), environmental regulation, and green and climate finance. Any one of these factors can influence this path and provide a realistic route to a cleaner environment. The findings of this chapter are crucial so that policymakers may interpret and filter the information from the EKC hypothesis assessment.

Sustainable development is a focused issue for policymakers locally and globally (Gigliotti, Schmidt-Traub, & Bastianoni, 2019; Opoku, 2019). Sustainable development is considered a process within the globalisation context, constituted by three main components: economic, social, and environmental. Once the consequences of globalisation on the environment under distinct economies' features were fully explored, and improvements to the environmental performance assessment were proposed, the third part of this thesis, Chapters 6 and 7, is focused on tools to achieve sustainable development and accomplish the SDGs. Chapters 6 and 7 focus on assessing globalisation as a driver of two of the main tools to achieve SDGs worldwide: energy efficiency and climate finance.

Sustainable development requires meeting the needs of the present without compromising the ability to meet the needs of future generations. In other words, sustainable development assumes improved economic growth without increasing environmental degradation. The difficulties lie in how to grow economies sustainably. Energy efficiency is one of the most relevant tools to achieve sustainable development. Considering globalisation as a tool to disseminate information and knowledge, transcend technological barriers and overcome national borders, Chapter 6 is focused on analysing the influence of globalisation on promoting energy efficiency and consequently inducing sustainable development. To the best of our knowledge, this essay innovates by analysing the interactions of each dimension and measure of globalisation on both the efficiency index and Index for Sustainable Economic Welfare (ISEW). The main objective of Chapter 6 is to answer the following central research question:

(i) Has globalisation been promoting energy efficiency and sustainable development?

To accomplish the objective of this chapter, the energy efficiency index and the ISEW were computed. The econometric procedure goes through the use of an ARDL model with a Driscoll-Kraay estimator. This analysis is performed for the top 20 energy consumers' economies per capita, divided into high-globalised countries and low-globalised countries according to the Overall Globalisation Ranking.

In Chapter 6, the main findings show that globalisation mostly contributes to energy efficiency and sustainable development in the high-globalised countries and drives sustainable development in the low-globalised ones. Nevertheless, economic globalisation *de facto* in the low-globalised countries and *de jure* in the high-globalised ones undermine sustainable development, which suggests that these measures are increasing environmental depletion. In contrast, social and political globalisation are drivers of the ISEW, encouraging sustainable development in both groups of countries. Furthermore, regarding renewable energy consumption, the outcomes evidenced the high implementation costs associated with renewable energy, though this finding was obtained through the analysis of historical data. Therefore, strategies for renewables penetration should be redesigned.

The achievement of the SDGs is a globally shared challenge and requires high investment. This situation awakens massive global challenges, mainly for developing economies due to their short supply of capital. Global economies do not contribute equally to climate change, as well as do not suffer the consequences of it in the same way. Resource-rich economies have a higher ecological footprint, while resource-poor economies suffer the severest consequences of climate change. In light of this, developed economies agreed to provide financial support to developing economies to face the challenge of climate change and improve their capability to respond to climate issues (Amighini, Giudici, & Ruet, 2022). According to the Global Commission on Adaptation (2019), from 2020 to 2030, $1.8 trillion might need to be invested in adaptation strategies to counteract climate change. These facts, and the findings of the first part of this thesis regarding developing economies, have motivated the last essay of this thesis, Chapter 7.

Climate finance has been one of the leading priorities in international climate negotiations. However, while traditional solutions to climate-related environmental quality have been discussed, the emerging area of climate finance has been overlooked (Lee, Li, Yu, & Zhao, 2022). In light of this, Chapter 7 is focused on three main analyses. Firstly, assessing climate finance as an effective tool for environmental degradation mitigation and its contribution to achieving SDGs. Second, analysing the contribution of climate finance to the improvement of the standard of living in developing economies. Lastly, evaluating some potential determinants of climate finance, among them human development, governance indicators, vulnerability, readiness, foreign capital inflow, and globalisation *de jure* and *de facto*. The last essay of this thesis has the following research questions:

(ii) Is climate finance effective in environmental degradation mitigation and contributing to improving the standard of living in developing economies?

(iii) Does Foreign Capital Inflow (FCI) conduct environmental sustainability in developing economies?

(iv) Are human development and globalisation drivers of climate finance?

This chapter focuses on several developing economies, and as such, panel data techniques were applied to annual data. Therefore, in order to fulfil the main objective of this work and consider the data characteristics, both the Panel Corrected Standard Error (PCSE) and the Feasible Generalized Least Squares (FGLS) estimators were used. The robustness of the results was guaranteed by using different structure models and applying the Seemingly Unrelated Regressions (SUR).

The main conclusions of Chapter 7 support that climate finance is an effective tool to mitigate environmental degradation and improve human development. Climate finance is more than just a financial resource to mitigate climate change; it also improves the living standard. However, the climate finance fund has not reached the projected amount for the expected needs and consequently cannot be expected to reach the proposed outcomes. In contrast, FCI reveals the opposite contribution. Beyond increasing environmental degradation, it also decreases human development. FCI is still connected with carbon-intensive activities and industries. Policymakers must play a key role in controlling investment and capital flows. Policies and directives should be implemented to assess capital inflow's carbon footprint. In addition, the regulatory scenario in upper-middle-income economies suggests they are not prioritising environmental quality. In order to promote environmental quality in developing economies, it is necessary to strengthen environmental laws and regulations to protect the environment.

1.1 Contribution to the literature

This thesis encompasses several contributions to the existing literature on the effects of each dimension and measure of globalisation in achieving sustainable development goals. Furthermore, this thesis provides improvements to the assessment of environmental performance. Chapters 2, 3, and 4 contribute to the literature by enhancing the understanding of the complexity of the relationship between globalisation and environmental performance. Apart from the individual contributions of each essay to the literature, these essays share one novel insight. Instead of using a proxy or aggregate index, the analyses performed in these essays use the economic, political, and social dimensions of globalisation and the two new *de jure* and *de facto* measures. The undifferentiated analysis of the phenomenon of globalisation, using a single variable, can produce biased results, as can an analysis using only the three dimensions of globalisation (Martens et al., 2015). To the best of our knowledge, empirical literature that considers the two new measures of globalisation is scarce.

Besides this transversal novelty across these three chapters of this thesis, each one provides innovative individual analysis. In Chapter 2, to the best of our knowledge, categorizing the countries by different levels of globalisation considering the new globalisation measures, *de jure* and *de facto*, is unprecedented in the literature. In fact, this chapter innovates by improving the understanding of the propensity of high and low-globalised *de facto* and *de jure* countries to achieve better environmental performance. The research performed in Chapter 3 contributes to the literature by providing new evidence to help understand the complex relationship between globalisation and environmental performance. This essay innovates by analysing the role of globalisation on environmental performance, considering distinct levels of development and environmental regulation. Furthermore, the essay also innovates by assessing the EKC hypothesis containing the phenomenon of globalisation, which represents a relevant novelty in the empirical literature. Chapter 4 aims to examine the role of globalisation in the environmental performance in economies with high levels of corruption, lax environmental regulations, low levels of globalisation, and high susceptibility to the effects of climate change. Chapter 4 represents an improvement in the literature by considering the phenomenon of globalisation in conjunction with corruption and energy poverty.

Chapter 5 enhances the environmental assessment literature field. It consists of a tool for EKC researchers. It innovates by providing a detailed description of the EKC background, the close relationship between the EKC and the macroeconomic Green Solow Model, an embracing description of the evolution of the EKC analysis, and a critical analysis of the EKC approach. Therefore, the contribution to the literature from Chapter 5 of this thesis is twofold. The first contribution is a detailed description of the evolution of the EKC analysis through an extensive literature survey that specifies each detail of the analysis of more than 200 articles from 1998 to 2022, namely country(ies) and time period; variables analysed on EKC validity; additional variables included in the EKC analysis; types of analysis and method(s) employed; relationships obtained, and the turning point. The second concerns the critical analysis of the EKC approach, identifying critical issues, proposing improvements, and future lines of research.

After examining the role of globalisation in environmental performance, Chapter 6 contributes to the literature by exploring the role of each measure and dimension of globalisation on energy efficiency and sustainable growth. This essay also innovates by considering economies with high levels of energy consumption and the economies' level of globalisation. This essay is able to stress effects such as the transfer of knowledge and good policy practices.

Lastly, the research performed in Chapter 7 represents an improvement in the literature. To the best of our knowledge and highlighted by other researchers in the climate finance field (e.g., Lee et al., 2022), there is a gap in the literature about the relationship between climate finance and low emissions, which is still ambiguous. Thus, this essay innovates by analysing both perspectives of climate finance, its effectiveness on environmental degradation mitigation and human development, and its drivers.

In short, this thesis provides diverse contributions to the literature as well as to policymakers. It provides an encompassing perception of the influence of each measure and dimension of globalisation on environmental performance, considering diverse and distinct economies' features. After that, it evidences challenges and provides improvements to the environmental performance assessment. Lastly, it focuses on two of the main tools to achieve sustainable development goals, energy efficiency and climate finance. Additionally, throughout the essays, diverse econometric methods were applied. This diversity of models was employed to ensure robust results and answer each chapter's research questions with confidence. To accomplish the proposed goals of this thesis, the econometric procedure was focused on ensuring the use of the most suitable econometric practices.

1.2 Structure and outcomes

This thesis consists of a compilation of six scientific works, including five articles and one chapter, following the directrices of the *Decreto Lei nº230/2009*. From Chapter 2 to Chapter 7, each chapter provides detailed background about the issue addressed on it. Chapter 2 is dedicated to analysing the role of the globalisation measures and energy efficiency on the environmental performance of a group of EU economies by segmenting the group of economies into high globalisation *de jure*, flow globalisation *de jure*, high globalisation *de facto*, and low globalisation *de facto*. Section 2.1 briefly contextualises of the globalisation index used, the motivation, and the objectives of the topic addressed. Section 2.2 presents the literature debate about the topic under study. The description of the data used in the empirical analysis and the econometric procedure are described in Section 2.3. The results are presented in Section 2.4, and their robustness is in Section 2.5. In Section 2.6, the discussion is presented, and Section 2.7 provides the conclusions and highlights the main findings of the essay. The main outcomes of Chapter 2 include a preliminary version of Chapter 2 which was presented at a conference:

- Leal, Patrícia H.; Marques, António C. (2019) "Are globalisation *de jure* and *de facto* undermining the environment? Evidence from high and low globalised EU countries", Workshop: Economic Development Thinking the Environment, Coimbra, Portugal, 9-10 May 2019

A journal article was published and the Portuguese Association of Energy Economics (APEEN – *Associação Portuguesa de Economia da Energia*) Young Researcher Award, as described below:

- Leal, P. H., & Marques, A. C. (2019). Are *de jure* and *de facto* globalization undermining the environment? Evidence from high and low globalised EU countries. Journal of Environmental Management, 250(April), 109460. http://dx.doi.org/10.1016/j.jenvman.2019.109460. Impact factor – 8.91, SJR – Q1

- Leal, Patrícia H.; Marques, António C. (2019) "Are *de jure* and *de facto* globalization undermining the environment? Evidence from high and low globalised EU countries", Journal of Environmental Management. APEEN Young Researcher

Award delivered at 5th Annual APEEN Conference - Energy Transition and Sustainability, Virtual Conference, 20- 21 January 2021

As recognised in the literature, globalisation might assume different roles in environmental performance considering the economies' features. Also, it might allow developed economies to benefit from comparative advantages over developing ones. Thus, distinct from Chapter 2, which analysed a group of developed economies with approximate globalisation levels and shared economic policies and environmental regulation, Chapter 3 is dedicated to analysing the behaviour of globalisation dimensions and measures on the environmental performance of economies with different levels of development and environmental regulation. It considers the framework of the EKC. Section 3.1 provides a short overview and the state-of-the-art relationship between globalisation and environmental performance, as well as the EKC. The data and methodology applied are described in Section 3.2. The results are presented in Section 3.3. In Section 3.4, the findings are discussed, and the conclusions are provided in Section 3.5. Chapter 3 resulted in a published journal article, as described below:

- Leal, P. H., Marques, A. C., & Shahbaz, M. (2020). The role of globalisation, *de jure* and *de facto*, on environmental performance: evidence from developing and developed countries. Environment, Development and Sustainability. https://doi.org/10.1007/s10668-020-00923-7. Impact factor – 4.08, SJR – Q2

The role of globalisation on the environmental performance of some of the lowest globalised countries, with high levels of corruption and a high percentage of the population without access to electricity, was examined in Chapter 4. It combines the role of globalisation with energy poverty and corruption. Section 4.1 outlines the topic, motivation, research questions and main objectives, and contribution to the literature. Section 4.2 revises the state-of-the-art of research topic. The data and method used are described in Section 4.3. Section 4.4 is devoted to the presentation of the results. The findings are discussed in Section 4.5, and the conclusions are provided in Section 4.6. This chapter resulted in one journal article published in Environmental Science and Policy:

- Leal, P. H., & Marques, A. C. (2021). The environmental impacts of globalisation and corruption: Evidence from a set of African countries. Environmental Science and Policy, 115, 116–124. https://doi.org/10.1016/j.envsci.2020.10. Impact factor – 6.424, SJR – Q1

Globalisation promotes and improves the interaction between different regions around the globe, and environmental degradation is a challenge shared by all countries around the globe. Thus, Chapter 5 is focused on one of the most prevalent methods to analyse environmental performance, the EKC. Distinct from the remaining chapters, which consist of empirical essays, Chapter 5 consists of a literature review. Section 5.1 provides a brief background of environmental landmarks and the EKC, the main objectives of the essay, research questions, and contribution to the literature. Section 5.2 describes the EKC's origins, conceptual framework, and shape. The close relationship between the EKC and the macroeconomic Green Solow Model is explained in Subsection 5.2.3. Section 5.3 provides a detailed description of the evolution of the EKC analysis in the literature, focusing on the EKC functional specification in Subsection 5.3.2. In Section 5.4, the gaps in the EKC assessment are identified. Finally, Section 5.5. concludes and provides policy recommendations. Chapter 5 resulted in a journal article publication, as described below:

- Leal, P. H., & Marques, A. C. (2022). The evolution of the environmental Kuznets curve hypothesis assessment: A literature review under a critical analysis perspective. Heliyon, 8(11). https://doi.org/10.1016/j.heliyon.2022.e11521. Impact factor – 3.776, SJR – Q1

After analysing the role of globalisation on environmental performance, the role of globalisation on sustainable development is the focus of Chapter 6. Section 6.1 presents a contextualisation of the topic, the motivation, the main objectives, and the research questions. Section 6.2 provides the literature review of the research topics, divided into globalisation in Subsection 6.2.1, energy efficiency in Subsection 6.2.2, and sustainable development in Subsection 6.2.3. The empirical procedure, the data used in the empirical analysis, the calculation of the ISEW and Efficiency Index, and the methodology are described in Section 6.3. The estimated models for both indicators are presented in Section 6.4 and discussed in Section 6.5. The conclusions are presented in Section 6.6. Chapter 6 resulted in two outputs, and a previous version of this chapter was presented:

- Leal, Patrícia H.; Marques, António C. (2021) " Is globalisation a driver for energy efficiency and sustainable development?", 5th Annual APEEN Conference: Energy Transition and Sustainability, Virtual Conference, 20- 21 January 2021

A chapter was published in the book entitled *Energy-Growth Nexus in an Era of Globalisation,* as described below:

- Leal, P. H., & Marques, A. C. (2022). Is globalisation a driver for energy efficiency and sustainable development? In M. Shahbaz, A. K. Tiwari, & A. Sinha (Eds.), *Energy-Growth Nexus in an Era of Globalisation* (pp. 257–285). Elsevier. https://doi.org/10.1016/B978-0-12-824440-1.00004-7.

Climate finance is an environmental landmark to develop economies by helping emergent ones improve environmental performance and promote sustainable development. Chapter 7 is dedicated to analysing the effectiveness of climate finance on environmental degradation mitigation, the determinants of climate finance, and the role of climate finance on human development in both upper- and lower-middle-income economies. Section 7.1 contextualises the investment needs and relevant landmarks on environmental degradation mitigation, motivation, main objectives and research questions, and the contribution to the literature. Section 7.2 presents a literature background focused on the role of finance on environmental performance. The data used in the empirical analysis and the methodology applied are presented and described in Section 7.3. The estimated models are presented in Section 7.4, and their robustness is provided in Subsection 7.4.1. The results are discussed in Section 7.5, and Section 7.6 provides conclusions and highlights the main findings. Two previous versions of this chapter were presented at the following conferences:

- Leal, Patrícia H.; Marques, António C.; Shahbaz, Muhammad (2022) " Are climate finance and foreign capital inflows driving decarbonization on the developing economies?", 6th APEEN annual Conference Sustainable Energy Challenges, Virtual Conference, ISBN: 978-972-789-749-0, Aveiro, Portugal, 3- 4 February 2022

- Leal, Patrícia H.; Marques, António C. (2022) "Is climate finance flow for developing economies promoting climate change mitigation?", Proceedings of 5th International Conference on Energy & Environment: Bringing together Economics and Engineering, School of Economics and Management of the University of Porto, Porto, Portugal, pp. 432-437, ISSN: 2183-3982, ISBN: 978-989-54471-2-1, Porto, Portugal, 2-3 June 2022

Each chapter, from Chapter 1 to Chapter 7, contains a section of bibliographic references. Lastly, the final chapter, Chapter 8, provides the main conclusions of this thesis, highlighting the significant findings and the contributions this thesis brings to the literature. Final remarks are provided in Section 8.1. To finalize, Section 8.2 presents future lines of research.

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Chapter 2

Are *de jure* and *de facto* globalisation undermining the environment? Evidence from high and low globalised EU countries

Globalisation as a mechanism to connect people at distance and share knowledge has been flourishing. Simultaneously, environmental degradation has been increasing, as reflected in global warming. Through three dimensions, the economic, the social and political, and two measures, *de jure* and *de facto*, this essay provides a disaggregated analysis of the effect of globalisation on the critical issue of global warming for 25 European Union countries from 1990 to 2016. To emphasize globalisation, the countries analysed were evaluated by two measures of globalisation, de jure and *de facto*, resulting in their classification as high or low globalised countries *de jure* and *de facto*. Furthermore, energy consumption, economic growth and efficiency were included in an Autoregressive Distributed Lag model performed with the Driscoll-Kraay estimator. Robustness was checked using a Feasible Generalized Least Squares estimator. The results revealed that, overall, globalisation increases environmental degradation, with the *de jure* measure having greater influence on high-globalised countries and the *de facto* measure having greater influence on low-globalised countries. Bearing in mind the increase in worldwide emissions driven by globalisation, practices such as the relocation of polluting industries from high globalised countries should be discouraged. Incentives to harmonize global environmental restrictions could contribute to decarbonization worldwide.

2.1 Introduction

Since the 1970s, humanity has lived in a state of ecological overreach and the Earth's biocapacity has been exceeded (WWF, 2014). Furthermore, for several decades it has generally been believed that environmental degradation is mainly caused by economic growth, while, at the same time, economic growth was considered the only tool for sustainable development. In the same period, increasing globalisation has been observed. Nowadays, in an era of globalisation, understanding the impact it has on environmental degradation is important to determine if it assists or handicaps the fight against global warming. With the objective of connecting players at distance, globalisation enables the formation of networks, the transcendence of national borders, and can surpass cultural, technological and governmental barriers (Gygli, Haelg, & Sturm, 2018). Therefore, citizens from different countries, communicating and sharing ideas, as well as governments working together, are also manifestations of globalisation. Thus, the questions that arise are: Is there a growing environmental awareness worldwide? What are the repercussions of globalisation on the environment?

Globalisation has to be interpreted and analysed as a multifaceted concept, considering how difficult it is to measure and quantify. Dreher (2006) proposed the KOF Globalisation Index, which is a composite indicator that allows the measurement of several aspects of globalisation. The KOF Globalisation Index is divided into three dimensions, namely the economic, the political and the social. Briefly, the economic dimension denotes flows and market exchanges; the political dimension signifies the diffusion and expansion of government policies; and the social dimension represents the propagation of people, information and ideas. The KOF Globalisation Index proposed by Dreher (2006), was revisited by Gygli et al. (2018). The revisited index, while including the same three dimensions as the first version, added two new measures, *de jure* and *de facto*. In short, the *de facto* measure of globalisation is intended to analyse flows and activities, while the *de jure* measure is intended to analyse the policies that allow the flows and activities.

The present work analyses the relationship between globalisation and environmental degradation as represented by carbon dioxide (CO2) emissions. Globalisation is analysed through the three dimensions of the KOF Globalisation Index (economic, social and political), and its two measures (*de jure* and *de facto*). Besides this, the level of globalisation is emphasized by dividing the 25 European Union (EU) countries studied into two groups according to the *de jure* and *de facto* measures of globalisation. The main aim of this division is to understand the effect of different levels of globalisation, and the different measures of globalisation, on the environment.

The analysis of the relationship between environmental degradation and globalisation was complemented with variables such as efficiency, economic growth, and renewable and non-renewable energy consumption. Many countries suffer from a trade-off between economic growth and environmental quality. The inclusion of economic growth in the estimation makes it possible to understand the effect of different income levels on CO2 emissions at different globalisation levels. In turn, efficiency denotes the reduction of energy use per unit of economic output. Efficiency, on the one hand, maximizes the use of energy and, on the other hand, reduces environmental degradation through the reduction of emissions.

In order to fulfil the main objective of this work, the Autoregressive Distributed Lag (ARDL) model with the Driscoll-Kraay was performed, while the use of a Feasible Generalized Least

Squares (FGLS) estimator allowed the robustness of the main results to be checked. This work contributes to the literature, firstly through its analysis of different levels of globalisation, and secondly, through the analysis of the two new measures of globalisation, *de jure* and *de facto*. This analysis makes it possible to understand the propensity of high and low globalised countries to achieve better environmental performance. This essay allows conclusions to be reached about whether globalisation, through its effect on global warming, actually represents a threat to humanity. This essay intends to provide results that will help identify climate change mitigation measures appropriate to a country's level of globalisation.

This essay is divided into six sections. Section 2.2 presents a literature review, and the data and method employed are described in Section 2.3. The results are presented in Section 2.4 and the robustness checks in Section 2.5. The final sections, 2.6 and 2.7, present a discussion of the results obtained, and the conclusions of the essay, respectively.

2.2 Debate

Global warming is a real threat to humankind, within a context where economies continue to grow, and environmental degradation continues to increase. Sun & Wang (1996) analysed the relationship between global warming (global surface temperature) and global CO2 emissions over 129 years from 1860 to 1988. Kraft & Kraft (1978) inaugurated the study of the relationship between economic growth and energy consumption. Over the years, this relationship has been exhaustively analysed and continues to merit attention nowadays (e.g. Gozgor, Lau, & Lu, 2018; Shahbaz, Zakaria, Shahzad, & Mahalik, 2018). In the meantime, environmental degradation has started to be increasingly considered (e.g. Acaravci & Ozturk, 2010; Alshehry & Belloumi, 2015; J. B. Ang, 2007; Leal, Marques, & Fuinhas, 2018; Moutinho, Varum, & Madaleno, 2017; Narayan, Saboori, & Soleymani, 2016; Soytas, Sari, & Ewing, 2007).

Since the 1970s, a rise in globalisation has been seen. However, the effect of globalisation has previously been neglected in the analysis of environmental degradation. Potrafke (2015) showed this through a survey of 120 empirical recent articles which employed the KOF index of globalisation in its 2007 version. Over the years, several indexes to measure globalisation have been proposed, namely: the GlobalIndex (Raab et al., 2008); the New Globalisation Index (Vujakovic, 2010); and the Maastricht Globalisation Index (Figge & Martens, 2014). Gygli et al. (2018) provide an overview of the most used globalisation indexes.

The KOF Globalisation Index proposed by Dreher (2006), measures globalisation using three dimensions, namely: economic, social and political. This index has become the one most commonly used in the literature. However, composite indicators are sometimes unrepresentative and can result in oversimplification, which could provoke a distorted interpretation of globalisation (Gygli et al., 2018). Thus, in order to provide a more complete and flexible index to measure globalisation, Gygli et al. (2018) followed Martens, Caselli, De Lombaerde, Figge, & Scholte (2015) and revisited the KOF Globalisation Index proposed by Dreher (2006). In addition to maintaining the three dimensions, economic, political and social, the revisited index innovated by proposing two new measures, namely *de jure* and *de facto*. Martens et al. (2015) argue that these new measures, *de facto* and *de jure*, overcome the propensity for distorted results which were previously caused by combining the two measures.

Globalisation can be analysed in an aggregated way, in the sense that a single dimension of globalisation is used (Lamla, 2009). Alternatively, it can be analysed through its three dimensions (Rudolph & Figge, 2017). In a disaggregated analysis, the economic dimension can provoke either an increase or a decrease in environmental degradation. One effect of this dimension that increases environmental degradation, results from incentivizing the relocation and growth of highly polluting industries to countries with less environmental regulation (Copeland & Taylor, 2004). Furthermore, more economically globalised countries may protect their economic objectives, while choosing to ignore their own growing carbon footprint (Dinda, 2004). Effects of economic globalisation that reduce environmental degradation can also be found (Rennen & Martens, 2003). This could be explained by foreign direct investments that can lead to the transfer and diffusion of clean technologies, thus allowing access to efficient production processes in developing countries (e.g. Gallagher, 2009; Tamazian & Bhaskara Rao, 2010; Tamazian, Pineiro, & Vadlamannati, 2009).

Regarding the effect of political globalisation on the environment, there are both positive and negative effect (Lemos & Agrawal, 2006). An example of a harmful effect of political globalisation on the environment is a reduction in the number of governance institutions that work on global issues like climate change (Stiglitz, 2007). The Kyoto protocol was unable to make a big impact on climate change, and it is still not clear if the Paris agreement will be a successful replacement (Elzen & Moor, 2002). Global governance has been negligent when it comes to the effects of economic development on the environment. In line with this, Bjørn et al. (2018) produced a study on Greenhouse Gas (GHG) emission targets based on the Paris Agreement. However, political globalisation can have beneficial effects on the environment (Lemos & Agrawal, 2006).

Lastly, social globalisation can have both a beneficial and a harmful effect on the environment. Greater knowledge about environmental problems does not necessarily provoke behavioural change or more environmental awareness. This can be explained by mental distance, a term meaning that citizens do not associate their individual behaviour with environmental problems (Steffen et al., 2005). Furthermore, the global media encourage people to value consumption over environmental protection (Rennen & Martens, 2003). On the other hand, social globalisation allows greater access to knowledge (Rennen & Martens, 2003). Given that access to education is increasing, populations now receive more information about the negative impact their behaviour has on the environment and become more environmentally aware. In addition, populations increase their consumption of cleaner products (Motoshita, Sakagami, Kudoh, & Tahara, 2015). Thus, social globalisation can initiate implicit regulation and create greater pressure for environmental protection (Dinda, 2004).

The release of emissions is mainly associated with energy consumption, which is indispensable for economies. Efficiency results from using less energy to produce the same quantity of economic output. Thus, efficiency maximizes the consumption of energy and could reduce environmental degradation. In the current literature, the subject of energy efficiency is widely discussed. Wang et al. (2018) provide a survey of the energy efficiency literature of the last decade, which includes various methods and their use in several areas.

Efficiency can also be analysed through the efficiency index, calculated using the Fisher Ideal Index proposed by Fisher (1921). This index makes it possible to analyse the evolution of efficiency over a period of years and to understand if a sector or country has improved its efficiency or become less efficient. The Fisher Ideal Index was developed based on index decomposition analysis (IDA). Decomposition models started to be employed in energy and environmental studies in the 1980s; a survey is provided by Ang & Zhang (2000). Some years later, decomposition models started to be used in environmental and economic analysis too (e.g. de Freitas & Kaneko, 2011; Ma, Ye, Shi, & Zou, 2016; Xingrong Zhao, Zhang, Li, Shao, & Geng, 2017; Xingrong Zhao, Zhang, & Shao, 2016).

The Fisher Ideal Index became the preferred decomposition method employed to differentiate the effects of a structural shift in economic activity from a reduction in energy use. The results of this index reflect the energy used per unit of economic output (Boyd & Roop, 2004; Xiaoli Zhao, Ma, & Hong, 2010). The present essay calculates the efficiency index and includes it in an econometric model in order to analyse the effect of efficiency on CO_2 emissions. This index makes it possible to understand the trajectory of efficiency over the period analysed. In line with this, Tajudeen, Wossink, & Banerjee (2018) calculated the efficiency index and, in addition, employed both bias-corrected least square dummy variable (LSDV) and structural time series modelling (STSM) in order to study the effect of efficiency on environmental degradation through emissions.

Overall, there is a gap in the literature concerning the analysis of the effect on environmental performance of the two measures, *de jure* and *de facto*, proposed in the revisited KOF Globalisation Index. Furthermore, the division of the countries employed here is unprecedented in the literature. Besides this, the inclusion of efficiency in the relationship between globalisation and environmental performance is also a novelty for the literature.

2.3 Data and Methodology

2.3.1 Data

This analysis employs annual data from 1990 to 2016 for, in total, 25 countries belonging to the EU. The time span used was selected in order to use the largest number of countries available, which are: Austria, Belgium, Bulgaria, Croatia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and United Kingdom.

The variables analysed were selected according to the literature. Energy consumption is commonly analysed on the field, and can be analysed aggregated or by sources. In this essay, fossil fuels consumption was included by sources, however, in view of the time span, renewable energy consumption had to be included aggregated, because there was no data available for the entire period for some renewable energy sources (RES). Furthermore, this analysis includes an efficiency variable, which was calculated through an efficiency index. Table 2.1 presents a description of the variables employed in this analysis, their units of measurement and sources.

Table 2.1 - Variables

Variable description	Description	Source
GDP	Gross Domestic Product (constant 2010 prices in US$)	United Nations Statistical Division (UNSD)
CO_2	CO_2 emissions (Mt)	BP Statistical Review of World Energy 2018
OIL	Oil consumption (Mt)	
COAL	Coal consumption (Mtoe)	
GAS	Gas consumption (Mtoe)	
RES	Renewable energy consumption (Mtoe)	

EFFI	Efficiency index (1990=1)	Own calculation
KOFEF	KOF Globalisation Index Economic Dimension *de Facto*	KOF Swiss Economic Institute
KOFEJ	KOF Globalisation Index Economic Dimension *de Jure*	
KOFSF	KOF Globalisation Index Social Dimension *de Facto*	
KOFSJ	KOF Globalisation Index Social Dimension *de Jure*	
KOFPF	KOF Globalisation Index Political Dimension *de Facto*	
KOFPJ	KOF Globalisation Index Political Dimension *de Jure*	

Notes: Mtoe denotes Millions of tonnes in oil equivalent; Mt denotes Million tonnes.

The efficiency variable was calculated using an efficiency index, the Fisher Ideal Index, which makes it possible to analyse the trajectory of national efficiency, specifically improvements or worsening in efficiency. In other words, this index reports the increase or decrease of energy used per unit of economic output. The Fisher Ideal Index was developed by Fisher (1921). Because of its ability to provides unbiased decomposition, this index is usually preferred and employed in the literature (Boyd & Roop, 2004). The Fisher Ideal Index allows us to decompose energy intensity into structural shift and energy efficiency (Metcalf, 2008). Firstly, energy intensity in an aggregate form (e_t) is calculated through the sum of energy intensity by sector (e_{it}) with the changes in the economy structure (s_{it}), which is represented in Equation 2.1.

$$e_t = \frac{E_t}{Y_t} = \sum_i \left(\frac{E_{it}}{Y_{it}}\right)\left(\frac{Y_{it}}{Y_t}\right) = \sum_i e_{it} s_{it}, \tag{2.1}$$

where E_t and Y_t denotes the total energy consumption and the total output (Gross Domestic Product (GDP)) in year t, respectively; and E_{it} and Y_{it} denote the energy consumption and measure of economic activity (Industry Gross Value Added (IGVA)) for sector i in year t respectively.

Subsequently, to calculate aggregate energy intensity (e_t), the energy intensity index (I_t) is calculated through the ratio of energy intensity in a year t (e_t) with the energy intensity in a year base 0 (e_0), Equation 2.2.

$$I_t = \frac{e_t}{e_0} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{i0} s_{i0}}. \tag{2.2}$$

Therefore, the efficiency index is calculated through the Laspeyres (L) and Paasche (P) indexes, Equation 2.3.

$$L_t^{EFF} = \frac{\sum_i e_{it} s_{i0}}{\sum_i e_{i0} s_{i0}}; P_t^{EFF} = \frac{\sum_i e_{it} s_{it}}{\sum_i e_{i0} s_{it}}. \tag{2.3}$$

Lastly, the Fisher Ideal Index of the efficiency index is calculated through the weighted average of the Laspeyres and Paasche indexes, Equation 2.4.

$$F_t^{EFF} = (L_t^{EFF} * P_t^{EFF})^{\frac{1}{2}}. \tag{2.4}$$

The efficiency index analyses the energy used per unit of economic output. The results of the calculated efficiency index should be interpreted as follows: a decrease in the index value denotes that improvements of efficiency occurred, which represents a reduction in the energy used per unit of economic output.

In order to reduce the correlation between variables, some of them were transformed in such a way that the variables CO_2 and *GDP* were transformed into *per capita*. The variables *COAL, GAS, OIL* and *RES* were transformed into percentages of primary energy consumption.

The initial group of 25 EU countries were divided into two groups according to the two measures of globalisation, *de jure* and *de facto*, which gave rise to four groups, as follows: high globalised counties *de jure* (HGCJ), low globalised counties *de jure* (LGCJ), high globalised counties *de facto* (HGCF), and low globalised counties *de facto* (LGCF). The groups were established by using the ranking of globalisation available in 2018. Then, the mean of the ranking of the initial group of countries was calculated for each measure of globalisation. The countries classified above the mean were then considered high globalised countries and the countries classified below the mean were deemed low globalised countries. For a better understanding, the procedure for dividing the countries is presented in Figure 2.1.

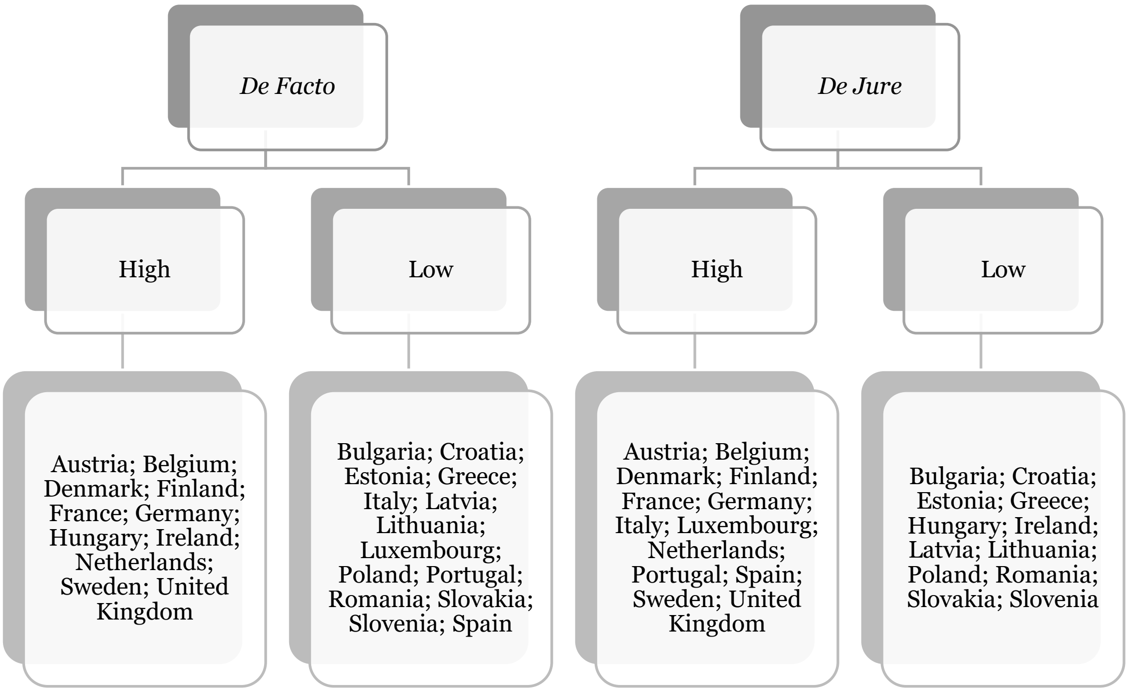

Figure 2.1 - Division of Countries

The descriptive statistics of the variables are presented in Table 2.2 for both *de jure* groups and in Table 2.3 for both *de facto* groups.

Table 2.2 - Descriptive Statistics - Globalised Countries *de Jure*

High Globalised Countries *de Jure*					
	Mean	Std. Dev.	Min.	Max.	Obs.
GDP_pc	41686.83	17905.21	16687.27	111968.4	351
CO_2_pc	9.98E-06	4.75E-06	4.11E-06	2.83E-05	351
OIL_p	46.18	11.05	27.33	76.64	351
COAL_p	13.28	8.10	1.24	41.34	351
GAS_p	19.89	10.95	0.00	44.61	351
RES_p	10.82	10.60	0.21	43.40	351
EFFI	0.86	0.17	0.41	1.19	351
KOFEF	68.19	14.08	30.55	92.26	351
KOFEJ	87.02	4.83	71.16	97.39	351
KOFSF	81.07	6.52	63.46	91.77	351
KOFSJ	81.77	7.12	55.44	93.34	351
KOFPF	89.83	11.33	43.02	98.35	351
KOFPJ	95.01	5.49	61.58	100.00	351

	Low Globalised Countries *de Jure*				
	Mean	Std. Dev.	Min.	Max.	Obs.
GDP_pc	15794.29	11559.71	3750.515	69892.33	264
CO_2_pc	6.99E-06	3.35E-06	2.93E-06	1.94E-05	264
OIL_p	36.53	13.08	16.29	66.40	264
COAL_p	24.48	19.18	1.06	73.81	264
GAS_p	23.16	11.26	0.17	48.35	264
RES_p	7.63	6.64	0.02	27.46	264
EFFI	0.65	0.27	0.27	1.41	264
KOFEF	66.04	15.21	26.97	92.01	264
KOFEJ	75.87	11.09	46.24	91.32	264
KOFSF	70.63	8.94	41.68	90.45	264
KOFSJ	78.28	8.38	55.38	92.17	264
KOFPF	77.04	12.76	41.91	92.44	264
KOFPJ	81.86	13.39	40.63	96.32	264

Notes: Max. – Maximum; Min. – Minimum; Std. Dev. – Standard deviation; Obs – Observations.

Table 2.3 - Descriptive Statistics - Globalised Countries *de Facto*

	High Globalised Countries *de Facto*				
	Mean	Std. Dev.	Min.	Max.	Obs.
GDP_pc	38300.93	12152.36	8544.51	69892.33	297
CO_2_pc	9.35e-06	2.83e-06	4.14E-06	0.000015	297
OIL_p	41.10	7.71	25.96	59.89	297
COAL_p	14.82	8.07	3.42	41.34	297
GAS_p	22.07	11.62	1.08	48.35	297
RES_p	10.12	11.33	0.16	43.4	297
EFFI	0.83	0.16	0.41	1.158	297
KOFEF	72.35	12.58	42.49	92.01	297
KOFEJ	86.66	5.92	55.49	94.87	297
KOFSF	82.53	4.54	67.07	90.45	297
KOFSJ	82.26	7.14	50.73	92.76	297
KOFPF	91.83	4.23	75.5	98.35	297
KOFPJ	92.46	10.41	48.81	100	297

	Low Globalised Countries *de Facto*				
	Mean	Std. Dev.	Min.	Max.	Obs.
GDP_pc	22393.4	22868.49	3750.52	111968.4	308
CO_2_pc	7.88E-06	4.98E-06	2.93E-06	2.75E-05	308
OIL_p	41.72	15.82	16.29	75.72	308
COAL_p	21.44	19.12	1.06	73.81	308
GAS_p	21.35	10.48	0.00	46.38	308
RES_p	8.75	6.83	0.02	28.77	308
EFFI	0.71	0.29	0.27	1.41	308
KOFEF	63.53	14.08	26.97	92.26	308
KOFEJ	77.62	11.28	46.24	97.39	308
KOFSF	71.16	8.98	41.68	91.77	308
KOFSJ	78.58	8.15	55.38	93.34	308
KOFPF	77.35	15.01	41.91	97.61	308
KOFPJ	85.98	12.78	40.63	99.70	308

Notes: Max. – Maximum; Min. – Minimum; Std. Dev. – Standard deviation; Obs – Observations.

In order to use the most appropriate estimator and guarantee robust results, the variables and countries were exhaustively analysed. The characteristics of variables and countries were assessed through Cross-section Dependence test (CD-test), panel unit root tests, correlation matrix values and the Variance Inflation Factors (VIFs). Firstly, the CD – test, under the null hypothesis of the absence of cross-sectional dependence on variables, was employed. The results of the CD-test are presented in Table 2.4 and Table 2.5.

Table 2.4 - Cross-Section Dependence Test (CD – Test) - Globalised Countries *de Jure*

	High Globalised Countries *de Jure*				Low Globalised Countries *de Jure*		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LGDP_pc	28.47***	0.635	0.903	*LGDP_pc*	33.15***	0.87	0.87
LCO_2_pc	29.04***	0.648	0.657	*LCO_2_pc*	7.99***	0.21	0.438
LOIL_p	7.04***	0.162	0.548	*LOIL_p*	1.63	0.043	0.362
LCOAL_p	19.55***	0.432	0.502	*LCOAL_p*	6.69***	0.176	0.484
LGAS_p	22.87***	0.505	0.658	*LGAS_p*	1.67*	0.044	0.499
LRES_p	33.53***	0.746	0.746	*LRES_p*	26.42***	0.693	0.693
LEFFI	35.98***	0.784	0.784	*LEFFI*	33.78***	0.886	0.886
LKOFEF	42.86***	0.934	0.934	*LKOFEF*	26.65***	0.699	0.809
LKOFEJ	36.80***	0.802	0.802	*LKOFEJ*	11.11***	0.291	0.544

LKOFSF	40.00***	0.872	0.872	*LKOFSF*	33.74***	0.885	0.885
LKOFSJ	43.04***	0.938	0.938	*LKOFSJ*	37.26***	0.978	0.978
LKOFPF	12.99***	0.283	0.336	*LKOFPF*	19.19***	0.504	0.545
LKOFPJ	44.74***	0.975	0.975	*LKOFPJ*	28.32***	0.743	0.866

Notes: *** denotes statistical significance at 1% level.

Table 2.5 - Cross-Section Dependence Test (CD – Test) - Globalised Countries *de Facto*

	High Globalised Countries *de Facto*				Low Globalised Countries *de Facto*		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LGDP_pc	23.79***	0.617	0.96	*LGDP_pc*	34.52***	0.776	0.776
LCO₂_pc	27.02***	0.701	0.704	*LCO₂_pc*	10.8***	0.243	0.454
LOIL_p	3.41***	0.088	0.41	*LOIL_p*	2.65***	0.06	0.42
LCOAL_p	22.74***	0.59	0.606	*LCOAL_p*	5.25***	0.118	0.452
LGAS_p	19.21***	0.499	0.642	*LGAS_p*	4.6***	0.104	0.52
LRES_p	28.95***	0.751	0.751	*LRES_p*	31.71***	0.713	0.713
LEFFI	35.79***	0.929	0.929	*LEFFI*	35.63***	0.796	0.796
LKOFEF	34.82***	0.904	0.904	*LKOFEF*	37.84***	0.846	0.846
LKOFEJ	25.75***	0.668	0.688	*LKOFEJ*	7.18***	0.161	0.58
LKOFSF	33.14***	0.86	0.86	*LKOFSF*	39.54***	0.884	0.884
LKOFSJ	36.17***	0.939	0.939	*LKOFSJ*	42.96***	0.96	0.96
LKOFPF	8.16***	0.212	0.305	*LKOFPF*	21.78***	0.487	0.523
LKOFPJ	36.3***	0.942	0.942	*LKOFPJ*	42.41***	0.948	0.948

Notes: *** denotes statistical significance at 1% level.

The results of the CD-test suggested the presence of cross-sectional dependence for most of the variables of the four groups of countries. Given that the presence of cross-sectional dependence could be a limitation on the validity of the first-generation unit root test and render it unreliable, the second-generation unit root tests (CIPS), proposed by Pesaran (2007), was employed for all variables. The Second-Generation Unit Root test (CIPS) is presented in Table 2.6 and Table 2.7. For the variable in which the absence of cross-sectional dependence was found (*LOIL_p* of LGCJ group), both unit root tests, first- and second-generation were performed. To do this, the first-generation unit root tests, proposed by Choi (2001); Levin, Lin, & Chu (2002); Maddala & Wu (1999) were employed and they confirmed the results of the second-generation test.

Table 2.6 - Second-Generation Unit Root Test (CIPS) - Globalised Countries *de Jure*

	High Globalised Countries *de Jure*			Low Globalised Countries *de Jure*	
	Without trend	With trend		Without trend	With trend
LGDP_pc	3.7	3.52	*LGDP_pc*	-1.2	0.59
DLGDP_pc	-7.37***	-4.96***	*DLGDP_pc*	-3.93***	-2.02**
LCO2_pc	-1.26	-0.68	*LCO2_pc*	1.57	-0.02
DLCO2_pc	-11.59***	-9.91***	*DLCO2_pc*	-8.68***	-8.65***
LOIL_p	-1.97**	-1.68**	*LOIL_p*	-1.1	-0.79
DLOIL_p	-13.07***	-12.14***	*DLOIL_p*	-10.95***	-10.35***
LCOAL_p	-2.64***	-0.65	*LCOAL_p*	-0.27	0.43
DLCOAL_p	-11.95***	-10.28***	*DLCOAL_p*	-10.2***	-9.56***
LGAS_p	-0.66	0.01	*LGAS_p*	0.83	-1.8**
DLGAS_p	-10.67***	-9.18***	*DLGAS_p*	-8.98***	-7.18***
LRES_p	-1.82**	-3.36***	*LRES_p*	-1.79**	-1.44*
DLRES_p	-13.97***	-12.82***	*DLRES_p*	-11.35***	-9.81***
LEFFI	-0.58	0.837	*LEFFI*	-1.62*	-0.11
DLEFFI	-11.33***	-10.46***	*DLEFFI*	-9.13***	-8.15***
LKOFEF	-2.08**	-1.1	*LKOFEF*	-5.64***	-3.7***
DLKOFEF	-9.1***	-7.52***	*DLKOFEF*	-8.88***	-7.36***
LKOFEJ	-2.76***	-2.04**	*LKOFEJ*	-1.88**	-0.22
DLKOFEJ	-13.04***	-11.96***	*DLKOFEJ*	-10***	-9***
LKOFSF	-3.21***	-2.13**	*LKOFSF*	-2.97***	-4.31***
DLKOFSF	-13.86***	-12.78***	*DLKOFSF*	-11.26***	-9.48***
LKOFSJ	-1.89**	-0.78	*LKOFSJ*	-3.63***	-3.23***
DLKOFDJ	-11.23***	-10.59***	*DLKOFDJ*	-10.16***	-8.16***
LKOFPF	-5.24***	-3.89***	*LKOFPF*	-2.07**	-1.79**
DLKOFPF	-11.79***	-10.61***	*DLKOFPF*	-9.36***	-8.1***
LKOFPJ	-5.49***	-4.84***	*LKOFPJ*	-4.07***	-4.15***
DLKOFPJ	-14.96***	-14.38***	*DLKOFPJ*	-10.29***	-8.71***

Notes: *, **, *** denotes statistical significance at 10%, 5% and 1%, respectively.

Table 2.7 - Second-Generation Unit Root Test (CIPS) - Globalised Countries *de Facto*

	High Globalised Countries *de Facto*			Low Globalised Countries *de Facto*	
	Without trend	With trend		Without trend	With trend
LGDP_pc	-0.68	0.09	*LGDP_pc*	-1.04	0.15
DLGDP_pc	-7.3***	-5.79***	*DLGDP_pc*	-3.57***	-1.73**
LCO2_pc	-2.49***	-2.46***	*LCO2_pc*	2.18	1.77
DLCO2_pc	-10.99***	-10.23***	*DLCO2_pc*	-8.49***	-8.63***
LOIL_p	-2.24**	-0.53	*LOIL_p*	-0.48	-1.36
DLOIL_p	-11.63***	-11.22***	*DLOIL_p*	-11.76***	-10.99***
LCOAL_p	-2.62***	-0.72	*LCOAL_p*	-0.35	0.81
DLCOAL_p	-10.59***	-9.17***	*DLCOAL_p*	-10.26***	-9.81***
LGAS_p	2.4	-0.14	*LGAS_p*	0.02	-1.56
DLGAS_p	-10.17***	-10.45***	*DLGAS_p*	-9.96***	-8.81***
LRES_p	-0.56	-1.56*	*LRES_p*	-4.12***	-3.97***
DLRES_p	-11.79***	-11.06***	*DLRES_p*	-13.71***	-11.82***
LEFFI	-0.93	-0.02	*LEFFI*	-0.42	1.76
DLEFFI	-11.39***	-10.24***	*DLEFFI*	-8.44***	-7.93***
LKOFEF	-1.63*	-0.33	*LKOFEF*	-3.9***	-2.63***
DLKOFEF	-7.96***	-6.88***	*DLKOFEF*	-8.6***	-7.11***
LKOFEJ	-1.39*	0.13	*LKOFEJ*	0.11	2.13
DLKOFEJ	-11.12***	-10.4***	*DLKOFEJ*	-9.1***	-8.34***
LKOFSF	-1.54*	-0.16	*LKOFSF*	-4.24***	-5.24***
DLKOFSF	-11.11***	-10.32***	*DLKOFSF*	-12.02***	-10.25***
LKOFSJ	-1.48*	-0.42	*LKOFSJ*	-2.92***	-1.97**
DLKOFDJ	-9.75***	-9.6***	*DLKOFDJ*	-9.67***	-7.47***
LKOFPF	-3.64***	-2.3**	*LKOFPF*	-2.44***	-2.34**
DLKOFPF	-11.66***	-10.64***	*DLKOFPF*	-10.37***	-9.69***
LKOFPJ	-8.66***	-11.95***	*LKOFPJ*	-2.98***	-3.63***
DLKOFPJ	-13.67***	-12.67***	*DLKOFPJ*	-12.13***	-10.89***

Notes: *, **, *** denotes statistical significance at 10%, 5% and 1%, respectively.

Globally, the results of the unit root tests, proved that the variables were stationary in level, or integrated of order one, i.e., I(0) and I(1), respectively. Therefore, the absence of variables integrated of order two, I(2), was confirmed, which allowed the employment of a dynamic structure following the ARDL procedure. The order of integration of the variables was also analysed using the Zivot & Andrews (1992) and Clemente, Montañés, & Reyes (1998) unit root tests with structural breaks. The outcomes of these tests were invaluable for identifying the breaks points, which were taken into account in the models by using dummies variables.

It is worthwhile noting that the results of these tests reinforced the results obtained with the second-generation unit root tests, they are not shown here, in order to preserve space, but are available upon request to the authors. The analysis of the correlation matrix values and the VIF test confirmed that neither collinearity nor multicollinearity were a concern for the estimations.

2.3.2 Method

In order to comply with the main objective of this essay, the ARDL-panel model was employed. The panel-ARDL model was proposed by Pesaran & Smith (1995) and Pesaran, Pesaran, Shin, & Smith (1999). This approach was chosen taking into account the characteristics of the data used. Among the many characteristics of the panel-ARDL model, some are more relevant for the present work, in particular, they: (i) allow the use of variables integrated of order one, and provide reliable and efficient parameter estimations; (ii) estimate both short- and long-run coefficients simultaneously; (iii) allow the inclusion of dummies to control potential events in the series; and (iv) provide the ability to cope with cointegration and endogeneity issues. Equation 2.5 denotes the ARDL model structure.

$$\begin{gathered} DLCO2_{it} = \mu_i + \vartheta_{i1} TREND + \beta_{i1} \sum_{i=1}^{n} DLGDP\_PC_{it} + \beta_{i2} \sum_{i=1}^{n} DLOIL\_P_{it} + \\ \beta_{i3} \sum_{i=1}^{n} DLCOAL\_P_{it} + \beta_{i4} \sum_{i=1}^{n} DLGAS\_P_{it} + \beta_{i5} \sum_{i=1}^{n} DLRES\_P_{it} + \beta_{i6} \sum_{i=1}^{n} DLEFFI_{it} + \\ \beta_{i7} \sum_{i=1}^{n} DLKOFECDF_{it} + \beta_{i8} \sum_{i=1}^{n} DLKOFECDJ_{it} + \beta_{i9} \sum_{i=1}^{n} DLKOFSODF_{it} + \\ \beta_{i10} \sum_{i=1}^{n} DLKOFSODJ_{it} + \beta_{i12} \sum_{i=1}^{n} DLKOFPODF_{it} + \beta_{i12} \sum_{i=1}^{n} DLKOFPODJ_{it} + \\ \propto_{i1} LCO2\_PC_{it-1} + \propto_{i2} LGDP\_PC_{it-1} + \propto_{i3} LOIL\_P_{it-1} + \propto_{i4} LCOAL\_P_{it-1} + \\ \propto_{i5} LGAS\_P_{it-1} + \propto_{i6} LRES\_P_{it-1} + \propto_{i7} LEFFI\_P_{it-1} + \propto_{i8} LKOFECDF_{it-1} + \\ \propto_{i9} LKOFECDJ_{it-1} + \propto_{i10} LKOFSODF_{it-1} + \propto_{i11} LKOFSODJ_{it-1} + \\ \propto_{i12} LKOFPODF_{it-1} + \propto_{i13} LKOFPODJ_{it-1} + \varepsilon_{it}, \end{gathered} \tag{2.5}$$

where μ_i denotes the intercept; ϑ_i denotes the coefficient of the trend; β_i denotes the estimated parameters in the short-run; $\propto_i$ denotes the estimated parameters in the long-run; and ε_{it} denotes the error term.

In order to select the most appropriated estimator, the Hausman Test, which provides support for the presence of fixed effects, was performed. This test is employed under the null hypothesis that the random effects are appropriate (Table 2.8). The Pesaran, Frees and Friedman tests for contemporaneous correlation, the Modified Wald test for heteroscedasticity and the Wooldridge test for autocorrelation were all performed (Table 2.8). According to the results of the Hausman test, the rejection of the null hypothesis suggested that the fixed effects were the most suitable effects for the estimations. The specification tests suggested the presence of contemporaneous correlation, heteroscedasticity and first order serial autocorrelation for all groups.

Table 2.8 - Hausman Test, F-Test and Specification Tests

	HGCJ	LGCJ	HGCF	LGCF
Hausman test	67.76***	24.4**	53.72***	35.23***
F - test	6.97***	2.37***	6.51***	2.97***

Specification Tests

	HGCJ	LGCJ	HGCF	LGCF
Pesaran test	1.97**	3.95***	3.51***	3.06***
Frees test	0.16*	0.17**	0.17**	0.18*
Friedman test	27.52***	31.92***	39.73***	26.54**
Modified Wald test	560.57***	93.34***	579.18***	204.66***
Wooldridge test	27.127***	43.12***	27.54***	46.07***

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively.

Considering all the features analysed, it was decided that the most appropriate and robust estimator would be the Driscoll-Kraay estimator, developed by Driscoll & Kraay (1998). In addition, the semi-elasticities and elasticities were calculated in order to analyse the short- and long-run effects.

2.4 Results

The Driscoll-Kraay estimator was employed for the four groups of countries, according to the ARDL structure represented in Equation 2.5. The HGCJ and HGCF models were estimated for the period from 1990 to 2016, while the LGCJ and LGCF models were estimated for the period from 1995 to 2016. The differing period is due to the availability of data, and the necessity to analyse the largest number of countries possible. Thus, the LGCF and LGCJ models only start in 1995. The ARDL estimations are summarized in Table 2.9.

Table 2.9 - Driscoll-Kraay panel ARDL model estimations

Variable	HGCJ	LGCJ	HGCF	LGCF
DLOIL_p				
DLGAS_p		- 0.0336**		
DLCOAL_p	0.143***		0.2153***	0.0493*
DLRES_p	- 0.0845***	- 0.0684***	- 0.0561***	- 0.0731***
DLGDP_pc	0.9892***	0.8141***	0.8688***	0.8319***

DLEFFI	0.6834***	0.5737***	0.5992***	0.655***
DLKOFEF		0.0728**		
DLKOFEJ				
DLKOFPF	- 0.0481*			
DLKOFPJ	- 0.2822**		- 0.1606*	
DLKOFSF	- 0.2431**	0.2132***		0.1675*
DLKOFSJ		0.2374**		0.133*
ECM	- 0.1214***	- 0.1674***	- 0.1122***	- 0.1509***
LOIL_p (-1)	0.0766*		0.1236***	
LGAS_p (-1)				
LCOAL_p (-1)				
LRES_p (-1)	- 0.0099*		- 0.0126***	
LGDP_pc (-1)		0.0837***		0.0754***
LEFFI (-1)	0.0892***	0.1761***	0.0631***	0.1350***
LKOFEF (-1)	0.0613***	- 0.038*		
LKOFEJ (-1)	0.1219**		0.1196***	
LKOFPF (-1)		- 0.0868*		- 0.0825***
LKOFPJ (-1)	- 0.2717**	0.1406***	- 0.1616**	0.1055***
LKOFSF (-1)			0.2525**	- 0.0627*
LKOFSJ (-1)	0.0821*			
C	- 1.6802**	- 3.0102***	- 2.7126***	- 2.4722***
Dum_1996			0.0245***	
Dum_1999				- 0.0092**
Dum_2000		- 0.0374***		- 0.027***
Dum_2010		0.0477***		
		Elasticities		
LOIL_p (-1)	0.6311**		1.101***	
LGAS_p (-1)				
LCOAL_p (-1)				
LRES_p (-1)	- 0.0819**		- 0.1119***	
LGDP_pc (-1)		0.4998***		0.4993***
LEFFI (-1)	0.7349***	1.0519***	0.562***	0.8941***
LKOFEF (-1)	0.5047***	- 0.2268**		
LKOFEJ (-1)	1.0037*		1.066***	
LKOFPF (-1)		- 0.5186*		- 0.5468***
LKOFPJ (-1)	- 2.2375**	0.8401***	- 1.4397**	0.6988***
LKOFSF (-1)			2.2496**	- 0.4153*
LKOFSJ (-1)	0.6762**			

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively; Dum – Dummies.

Dummies were applied to control events that occurred in the groups of countries. All of them revealed a notable adherence with actual events observed and, in general, they were substantiated by the unit root tests with structural breaks of Zivot & Andrews (1992) and Clemente et al. (1998). Furthermore, the Wald test for structural breaks with a known break date was also applied, and confirmed that the dummies applied were appropriate. For example, the dummy applied in HGCF for 1996, corresponds to an agreement reached within the automotive industry throughout the EU, under a strategy to reduce vehicle CO_2 emissions. In 1999, the year a dummy was applied for LGCF, the EU implemented a directive to inform consumers about the CO_2 emissions of passenger cars so that they could make an informed choice and contribute to mitigating GHG emissions. Haq & Weiss, (2016) provide an analysis of the directive's implementation. Furthermore, the dummy applied for LGCJ and LGCF in 2000, corresponds to the date when the European Climate Change Programme (ECCP) was released. Lastly, in 2010, a dummy included in the LGCJ estimation, probably represents a decrease in carbon prices.

With regard to economic growth, the results confirmed that GDP increases CO_2 emissions. Even so, the effect is not homogenous between the groups. Indeed, the effect is present in the short-run for all groups, while in the long-run GDP only increases CO_2 emissions in both low globalised countries. Regarding globalisation, the different effects of the *de jure* and *de facto* measures deserves to be highlighted within the political dimension. The *de facto* political dimension tends to reduce CO_2 emissions in the long-run for LGCJ and LGCF, while *de jure* measure increases them. Besides this, in both groups of high globalised countries, the predominant measure is *de jure*, while in the low globalised countries groups, it is the *de facto* measure. Overall, these findings deserve further consideration, and are discussed in the next section. Regarding the error correction mechanism (ECM), the four models reveal highly significant ECM, with a moderate speed of adjustment to long-run equilibrium.

2.5 Robustness checks

This section concerns checking robustness. In other words, further evidence that the main findings obtained with the Driscoll-Kraay panel ARDL model are robust. To do this, an alternative estimator was used. The results of the specification tests performed, suggested the presence of contemporaneous correlation, heteroscedasticity, and first order serial autocorrelation. It was concluded from this that the Driscoll-Kray estimator was the most appropriate, and that the Panel Corrected Standard Errors (PCSE) and the FGLS estimators would be the most appropriate alternatives (Neves, Cardoso Marques, & Alberto Fuinhas, 2018). The choice between the PCSE and the FGLS alternative estimators depends on the relationship between the cross-sectional dimension (N) and the time-series dimension (T). The PCSE is mostly employed when N is higher than T, (T<N) (Neves, Cardoso Marques, et al., 2018; Neves, Marques, & Fuinhas, 2018). In turn, the FGLS is robust when T>N (Reed & Ye, 2011). The latter is the case in the present work: 26 years and 11 or 14 crosses. Consequently, the FGLS estimator was used to check the robustness of the main models. Table 2.10 presents the results of the FGLS estimations for all the groups of countries.

Table 2.10 - FGLS panel ARDL model estimations

Variable	HGCJ	LGCJ	HGCF	LGCF
DLOIL_p			0.1074**	
DLGAS_p		- 0.0406***		
DLCOAL_p	0.1486***		0.2026***	0.0449***
DLRES_p	- 0.0726***	- 0.0773***	- 0.0462***	- 0.072***
DLGDP_pc	1.0107***	0.7922***	0.8871***	0.8824***
DLEFFI	0.7096***	0.581***	0.6478***	0.653***
DLKOFEF	0.0485*			0.0516**
DLKOFEJ				
DLKOFPF	- 0.0701***			
DLKOFPJ	- 0.2613***			
DLKOFSF	- 0.3081***	0.2117***		0.2474***
DLKOFSJ		0.2087***		
ECM	- 0.0962***	- 0.1657***	- 0.1411***	- 0.1489***
LOIL_p (-1)			0.1922***	
LGAS_p (-1)			0.0227*	
LCOAL_p (-1)				
LRES_p (-1)			- 0.014***	
LGDP_pc (-1)		0.0624***		0.0868***
LEFFI (-1)	0.078***	0.207***	0.0948***	0.1331***
LKOFEF (-1)	0.0401***	- 0.0635***		
LKOFEJ (-1)	0.1045***	0.0615***	0.0676***	
LKOFPF (-1)	- 0.0478**	- 0.0935***		- 0.075***
LKOFPJ (-1)	- 0.2177***	0.1564***	- 0.1164***	0.1205***
LKOFSF (-1)		0.0693*	0.3803***	
LKOFSJ (-1)				- 0.0822***
C	- 0.6417**	- 3.2048***	- 3.9551***	- 2.396***
Dum_1996			0.0191***	
Dum_2000		- 0.0349***		-0.0236***
Dum_2010		0.0488***		

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively; C denotes constant; Dum denotes

Overall, the results obtained corroborate the main findings of the main models. Thus, the use of FGLS provided additional confirmation, and indicated the robustness of the main finding of this work, such as GDP having no effect on CO_2 emissions in high globalised countries, or *RES* having no effect in low globalised countries. Furthermore, with respect to globalisation, they show that both the economic and political dimensions of *de jure* have a positive impact on high and low globalised countries, respectively, and political *de jure* and political *de facto* have a negative effect on the CO_2 emissions of the high and low globalised countries, respectively. In the following section all the results are discussed.

2.6 Discussion

Considering a set of 25 EU countries, this essay analyses the influence of globalisation levels, and the effect of *de jure* and *de facto* measures on environmental performance. The analysis of these two new measures of globalisation allowed a more complete analysis and avoided the distorted results caused by combining both measures and only analysing the dimensions of globalisation. The present work suggests that the same dimension of globalisation could have a different nature and magnitude on CO_2 emissions, for instance, the political dimension of globalisation for LGCF and LGCJ. Furthermore, in the high globalised countries the *de jure* measure of globalisation prevails, while in the low globalised countries it is the *de facto* measure. Moreover, the effect of globalisation on CO_2 emissions is most accentuated in the long-run, which could be explained by changes resulting from the financial crisis that EU countries suffered.

The relationship between energy consumption and environmental degradation has been frequently analysed in the literature and the results obtained are generally consensual, i.e. the consumption of oil and coal provoke an increase in CO_2 emissions. However, a notable finding of this essay is that renewable energy consumption decreases CO_2 emissions in all groups in the short-run, but in the long-run it only influences the CO_2 emissions of the high globalised countries and has no effect on the low globalised countries. This could be explained by the fact of the high globalised countries have more access to advanced technology and a greater capacity to invest in renewable energy in order to expand their installed capacity, producing more energy through renewable energy sources. These countries have advanced technology, while the low globalised countries are stuck with internal combustion engines and fossil powered technology. The efficiency index influences environmental degradation in all groups in both the short- and long-run. Efficiency tends to reduce energy consumption and consequently mitigates CO_2 emissions. Accordingly, the efficiency index has a positive impact on CO_2 emissions which means that a reduction in the index value denotes an increase in the efficiency rate and a reduction in CO_2 emissions.

As expected, economic growth, influences CO_2 emissions in all groups in the short-run. However, in the long-run it only influences the low globalised countries. This lack of impact of GDP in high globalised countries could suggest the exportation of environmental pressure to poorer and less regulated countries. This means that production becomes separated from consumption. The HGCJ and HGCF are highly environmentally regulated. Through the relocation of energy intensive and highly polluting industries to low wage countries, in addition to the comparative advantage of cheaper labour, these countries also benefit by relocating their emissions. Therefore, the GDP of the high globalised countries does not influence their CO_2 emissions. According to X. Li & Zhou (2017), companies in the USA frequently relocate their production to poorer and less regulated countries, thereby reducing pollution levels in their own country. An analysis developed by X. Li & Zhou (2017) reveals a link between imports and environmental performance for USA firms.

With respect to globalisation, this essay shows that *de facto* and *de jure* measures have different impacts on environmental performance. Considering all dimensions of globalisation, the predominant measure of globalisation in the high globalised countries is *de jure*, while in the low globalised countries the predominant measure is *de facto*. This finding could indicate that high globalised countries invest more in research and the development of technologies, policies, and treaties. On the other hand, the low globalised countries are more likely to be technology takers, meaning that they overwhelmingly use already developed technology rather than developing their own.

With regard to political globalisation, in the high globalised countries, the *de jure* measure tends to reduce CO_2 emissions while in the low globalised countries it is the *de facto* measure. This could indicate that the high globalised countries are more successful in designing policies and making treaties, while the low globalised countries are more successful in executing these policies. Correspondingly, *de jure* political globalisation increases the CO_2 emissions of low globalised countries in the long-run. This can be explained by the fact that high globalised countries are more often policy makers, whereas the low globalised countries are more frequently policy takers. Furthermore, this result also suggest that, essentially, it is the high globalised countries that most benefit from international treaties.

De jure social globalisation is shown to have a positive impact on CO_2 emissions in the LGCJ, which could be explained by the media's dissemination of a materialistic lifestyle, which puts greater value on consumerism than environmental protection (Rennen & Martens, 2003). *De facto* social globalisation reveals a higher disparity of results in the short- and long-run, which could be explained by the financial crisis that EU countries suffered. In the short-run, *de facto* social globalisation provokes an increase in CO_2 emissions in the low globalised countries. This could indicate that low globalised countries have a greater propensity for international tourism, a situation which could be explained by the fact that low globalised countries have lower lifestyle costs. According to Rudolph & Figge (2017), societies more open to other cultures have a higher demand for international products; a condition which could increase CO_2 emissions. In turn, *de facto* social globalisation reduces CO_2 emissions in the HGCJ in the short-run. These countries, which are more regulated and have more demanding policies, invest in research and development in advanced and efficient technology. Furthermore, after the financial crisis, there may have occurred a greater demand for migration among the HGCF, and this caused an increase in emissions in the long-run.

Lastly, *de jure* economic globalisation increases the CO_2 emissions of high globalised countries. More economically globalised countries have a larger ecological footprint (Rudolph & Figge, 2017). After financial crisis, *de facto* economic globalisation increases foreign direct investment in LGCJ, which encourages them to invest in efficient technology and consequently reduce CO_2 emissions. Furthermore, according to the results obtained by You & Lv (2018), there is a positive effect on the environmental quality of a country that is surrounded by highly economically globalised countries. In the HGCJ, after financial crisis, the trade in goods and services increases and exceeds the efficiency level, which causes an increase in CO_2 emissions. Furthermore, according to Rudolph & Figge (2017) countries that are more economically globalised are more likely to prefer economic objectives over carbon footprint mitigation.

In addition to air pollution and CO_2 emissions causing global warming, another impact on the environment of economic development and growing globalisation, could be water pollution. Water pollution is commonly measured by the discharge of ammonia nitrogen (NH3-N), combined with chemical oxygen demand (COD) (Fujii & Managi, 2017; J. Li, See, & Chi, 2019; Zhang et al., 2017), and biochemical oxygen demand (BOD) (Kapelewska et al., 2019). Evans, Mateo-Sagasta, Qadir, Boelee, & Ippolito (2019) developed a study that reflects the importance of analysing water pollution in agriculture and identifies the current gaps in the literature on water pollution. Water pollution has been increasing and has worsened in several regions all over the world. Europe is identified as a region with a high risk of pollution (Sadoff et al., 2015). With water deterioration increasing, it is expected that the threat to human health, the environment and sustainable development will also increase (Water, 2018).

Agriculture is one of the mainly causes of water pollution worldwide, through the discharge of large quantities of diverse chemicals. In some high-income countries, such as those of the EU, contamination from agriculture has overtaken that from settlements and industries, with groundwater polluted by nitrates and salts. In EU countries, 38% of bodies of water are under substantial pressure from agricultural water pollution (Mateo-Sagasta, Zadeh, Turral, & Burke, 2017). According to Mateo-Sagasta et al. (2017) and Evans et al. (2019) the primary drivers of water pollution are population growth, changes in consumption and climate change. Considering the driver of climate change and taking into account the results obtained, it could be suggested that the dimensions and measures of globalisation that increase environmental degradation also contribute to increase water pollution. Thus, the *de jure* economic globalisation in high globalised countries and *de jure* political globalisation in low globalised countries that increase CO_2 emissions, may also contribute to the increase of water pollution.

2.7 Conclusion

This essay analyses the relationship between globalisation and environmental quality for 25 EU countries, including renewable and non-renewable energy consumption, and efficiency. To the best of our knowledge, this is the first work analysing the two measures of globalisation, *de jure* and *de facto*, on environmental degradation. This work is looking for answers to the questions: Is the level of globalisation compromising the environment?; What are the dimensions of globalisation that are most beneficial and harmful to the environment?; and Do the *de jure* and *de facto* measures of globalisation influence the environment differently? To answer these questions, was performed using an ARDL model with a Driscoll-Kraay estimator, on a period from 1990 to 2016. To check the robustness of its results, an alternative estimator, the FGLS, was used with the aim of verifying the results obtained in the main models. The 25 countries were divided into four groups, two groups of *de jure* and two groups of *de facto* globalisation.

The main findings of this analysis reveal that globalisation, in general, has an expansive effect on CO_2 emissions for the four groups of countries. The political dimension of globalisation is more beneficial for the environment, while the social dimension is more harmful. The results obtained also provide evidence that the *de facto* and *de jure* measures have different effects, both in nature and magnitude. Furthermore, the results suggest that economic growth in the high globalised countries has no influence on CO_2 emissions; and this could be explained by the relocation of their most polluting industries, and high levels of regulation. In addition, in low globalised countries, the consumption of renewable energy is ineffective in mitigating CO_2 emissions in the long-run. In contrast, the efficiency index reveals the effectiveness of greater efficiency in reducing CO_2 emissions for all four groups in both the short- and long-run.

Taking into account the main findings, countries should consider the following recommendations for achieving better environmental quality in each of them and the planet as a whole. The low globalised countries need to focus on the implementation of measures directed to economic growth, renewable energy consumption and political globalisation. With regard to economic growth, the low globalised countries suffer from a trade-off between economic growth and environmental quality. In other words, economic growth increases CO_2 emissions. This effect could be reduced by increasing renewable energy consumption. In order to promote sustainable development, the low globalised countries should invest in RES and in diversifying their energy mix. Through energy efficiency and renewable energy consumption, the low globalised countries could attenuate the adverse effect of economic growth on the environment.

Furthermore, these countries are considered policy-takers, and as such, *de jure* political globalisation has had a harmful effect on the environment. Consequently, international treaties and commitments should be reformulated to be more beneficial to low globalised countries. According to the European Court of Auditors (2017), companies should invest in low-carbon technologies because the investment should be cheaper than buying EU Emissions Trading System (ETS) allowances on the market. For this to occur, according to the models employed by commission in 2011, the price per tonne of CO_2e should be 40 euro in 2020, and 100 euro in 2030. However, since 2009, the price has been decreasing. Considering the economic context, the reduction in the price of carbon may have discouraged investment in low-carbon technology to mitigate environmental degradation, thus failing to address the trade-off between economic growth and environmental quality experienced by low globalised countries.

With respect to high globalised countries, policies should mainly focus on economic globalisation. The high globalised countries should reformulate their regulations on international capital flows and non-tariff trade barriers. Furthermore, the HGCF in particular, should accommodate efficiency measures related to migration and international tourism. Migration and international tourism affect the environment, and HGCF need to increase their efficiency to be prepared for the likely occurrence of these phenomena.

During the development of this essay, and prompted by suggestions from the reviewers, several interesting new points arose, and these will be considered for future research with appropriate samples. Considering the scarcity of literature about the effect of globalisation on the environment, particularly analyses of globalisation disaggregated by measures, a comparative work conducted for developed and developing countries could greatly increase our understanding of the influence of each measure and dimension of globalisation on countries with a wider range of economies. A work of this kind could shed light on whether globalisation is a driver for the relocation of industries from developed to developing countries. It could also help in the formulation and adaptation of policies for both developed and developing countries to encourage better environmental quality worldwide. Similarly, different dimensions of pollution could also be analysed. Nowadays, besides concerns about air quality, water and soil quality are becoming an increasing source of uneasiness. In terms of econometric analysis, this has been developing over the years, and new approaches have emerged. Cross-sectionally (CS) ARDL is a recent estimator, which takes potential dynamic heterogeneity and cross-section dependency into account. However, it has specific requirements, and must be performed with appropriate data.

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Chapter 3

The Role of Globalisation, *de jure* and *de facto*, on Environmental Performance: Evidence from Developing and Developed Countries

In the context of globalisation, is a country's level of development an obstacle to its environmental performance? The main objective of this essay is to identify the role played in the environmental performance of countries with different levels of development, globalisation, and environmental regulation, by the three dimensions and two new measures of globalisation, *de jure* and *de facto*. This analysis was accomplished by assessing the environmental curve which relates economic growth to environmental degradation, known as the Environmental Kuznets Curve, for a sample of 32 developed and 26 developing economies from 1995 to 2017. It was found that developed countries produced an inverted U-shaped curve and that globalisation had a mostly beneficial effect on the environment. In contrast, developing economies produced a U-shaped curve and globalisation was generally harmful. Globalisation caused reductions of 0.88% and 0.85% in the environmental degradation of developed countries, and increases of 0.20% and 0.52% in developing ones. Political globalisation produced different effects for each measure in developed countries, and had no effect in developing countries. Economic globalisation suggests the relocation of polluting industries from developed to developing countries. As there is currently very little literature on the new measures of globalisation, this essay provides fresh insights for policy makers devising appropriate measures to achieve sustainability in both developed and developing countries.

3.1 Introduction

Global warming is considered the most critical environmental problem that humanity has faced so far. In the absence of appropriate control, this phenomenon is going to have devastating consequences on human life, on economies, and on the environment. These consequences will be far-reaching and long-lasting. Climate change is the result of anthropogenic behaviour and action, and global warming is mainly driven by carbon dioxide (CO_2) emissions (Sari & Soytas, 2009). Carbon sequestration is one potential mitigation strategy, and various researchers have begun to study it (e.g. Mardoyan & Braun, 2015; Maroušek, Strunecký, & Stehel, 2019). One of the main reasons behind the recent rapid rise in CO_2 emissions worldwide has been the substantial increase in these emissions from developing countries. In turn, climate change also has severe consequences for developing countries, such as reducing food production (Maroušek, Rowland, Valášková, & Král, 2020).

Acknowledging the need to act against global warming, world leaders reached a consensus in the Paris Agreement of 2015, and agreed to work together to mitigate this phenomenon. This collaboration by people from different countries sharing ideas and knowledge, and governments working together cooperatively, is a positive example of globalisation. Globalisation represents the integration of different countries from an economic, social, and political point of view. With globalisation increasing, it became necessary to quantify and measure it. The KOF globalisation index, first presented by Dreher (2006) and enhanced by Dreher, Gaston, & Martens (2008), become the preferred metric in academic literature. Gygli, Haelg, Potrafke, & Sturm (2019) provide a summary of the most commonly used globalisation indexes. The KOF globalisation index is widely applied throughout the literature and is still the most-used globalisation index in recent literature (e.g. Bilgili, Ulucak, Koçak, & İlkay, 2020; Gozgor, Mahalik, Demir, & Padhan, 2020; Guan, Kirikkaleli, Bibi, & Zhang, 2020; Patrícia Hipólito Leal & Marques, 2020; Liu, Ren, Cheng, & Wang, 2020; Sethi, Chakrabarti, & Bhattacharjee, 2020; Suki, Sharif, Afshan, & Suki, 2020; Ulucak, Koçak, Erdoğan, & Kassouri, 2020; L. Wang, Vo, Shahbaz, & Ak, 2020; Woo & Jun, 2020).

Recently, improvements in the analysis of globalisation were made by Gygli et al. (2019) through revisiting the first version of the KOF Globalisation Index. The revised KOF globalisation index consists of three dimensions, dividing the analysis of globalisation into economic, political, and social areas. In addition, they introduced the *de jure* and *de facto* measures of globalisation. These two new measures of globalisation represented an advance by providing a more comprehensive analysis of the phenomenon of globalisation, and greatly reducing bias in the results (Martens, Caselli, De Lombaerde, Figge, & Scholte, 2015). Thus the three dimensions can be summarized as follows: (i) The economic dimension represents variables of flows of goods, capital and services, and market exchanges; (ii) The social dimension consists of variables representing the circulation of ideas, information, and people; and lastly (iii) the political dimension comprises of variables representing the dissemination of government policies and measures. The two new measures of globalisation can be defined as follows: globalisation *de jure* is a measure of policies that permit and control flows and activities; globalisation *de facto* is a measure that represents the actual flows and activities.

Characterized by low barriers to goods, cross-border technologies, individuals, and capital, globalisation is considered, by many, key to defining the economic development and future of the planet (Intriligator, 2004). Therefore, the analysis of the influence of globalisation on the environment is extremely important (Zhu & Jiang, 2019). However, the relationship between globalisation and environmental degradation is controversial, as noted by Rafindadi & Usman (2019). Globalisation is very likely to have adverse environmental effects on developing countries, whereas, countries with high levels of income, strict environmental regulations, and strong environmental awareness, tend to experience environmental benefits from globalisation (Ulucak et al., 2020).

On the one hand, globalisation could help mitigate environmental degradation by facilitating the importation of clean technology or improving global ecological awareness. Moreover, by removing trade barriers and disseminating technological progress, globalisation may reduce the use of resources and produce less pollution, thereby enabling countries to achieve improvements in their environment, in the same way it has been observed to improve their welfare (Shahbaz et al. 2018).

On the other hand, globalisation could worse environmental quality by inducing trade openness (Bilgili et al., 2020). Through induced trade openness and market exchange, the exchange rate becomes an indicator of the state of the economy in the long-run (Vochozka, Horák, & Šuleř, 2019). Furthermore, globalisation increases environmental degradation through promoting the relocation of polluting industries from developed to developing countries, as found by Bilgili et al. (2020). Compared with developing economies, developed economies benefit from high levels of income, access to substantial amounts of energy, and strict environmental regulations, giving them a significant advantage. This advantage induces polluting industries to relocate to developing countries, which become pollution havens for developed economies, thereby increasing environmental degradation in the new host countries (Bilgili et al., 2020). For developing economies, businesses companies are one of the main driving forces (Machová & Vochozka, 2019). Globalisation also influences the environmental awareness of countries through social media and the internet (Rennen & Martens, 2003). They promote products and services (Kovacova, Kliestik, Pera, Grecu, & Grecu, 2019) which encourage consumerism, and disseminate materialistic lifestyles (Rennen & Martens, 2003).

An analysis of globalisation that only uses a single variable or a proxy could result in a deficient assessment. Therefore, more comprehensive analyses have been conducted using three dimensions of globalisation (the economic, social, and political) (e.g. Khan, Teng, Khan, & Khan, 2019; Rudolph & Figge, 2017). This analysis shows that the influence of each of these dimensions on the environment can have both worsening or mitigating effects on environmental degradation (see Patricia Hipolito Leal & Marques, 2019). In addition to these three dimensions, P. Leal & Marques (2019) also analysed globalisation through two further measures: *de jure* and *de facto*. They showed that these two measures could have differing effects, in nature and/or magnitude, as found by Martens et al. (2015).

Despite the significant effect of globalisation on environmental issues, globalisation is a neglected variable in environmental research and in assessments of the Environmental Kuznets Curve (EKC) hypothesis (e.g. P. Leal & Marques, 2019; Liu et al., 2020; Rahman, 2020; Shahbaz, Kumar, Jawad, & Shahzad, 2019; Zaidi, Zafar, Shahbaz, & Hou, 2019). The EKC hypothesis developed by Grossman & Krueger (1991) results from the "inverted-U hypothesis" proposed by Kuznets (1955). Kuznets demonstrated that the relationship between income per capita and income inequality follows an inverted U-shaped curve. Subsequently, the EKC hypothesis emerged as a potential explanation of the trajectory of pollution as a consequence of economic development (Grossman & Krueger, 1991; Panayotou, 1993; Shafik & Bandyopadhyay, 1992). Robust theoretical foundations for the EKC hypothesis are provided by Dinda, (2004); Kaika & Zervas (2013); Stern (2004).

The EKC hypothesis is employed in several contexts, for the most diverse countries, with various environmental indicators, and including numerous determining factors. A bibliometric and meta-analysis review of it is provided by Sarkodie & Strezov (2019). However, in the literature on the EKC, the relationship between Gross Domestic Product (GDP) and CO2 emissions is notable for receiving the most attention (e.g. Apergis & Payne, 2009; Lantz & Feng, 2006; Marques, Fuinhas, & Leal, 2018; Moutinho, Varum, & Madaleno, 2017; Rahman, 2020; Sarkodie & Ozturk, 2020; Soytas, Sari, & Ewing, 2007; Y. Wang & He, 2019; Zaidi et al., 2019). Furthermore a variety of determinant factors have been included in EKC estimation, such as energy consumption (Dhrifi, Jaziri, & Alnahdi, 2020; Sarkodie & Strezov, 2018). Among the diverse methodologies used, the Autoregressive Distributed Lag (ARDL) model stands out (Marques et al., 2018; Sarkodie & Ozturk, 2020). The ARDL model provides both short-run adjustments and long-run equilibrium, which allows the EKC hypothesis to be assessed (Ahmad & Du, 2017).

This work contributes to the literature, by addressing unresolved issues and providing new evidence to help understand the complex relationship between globalisation and environmental performance. This essay intends to answer the following two research questions: (i) Is globalisation improving environmental quality in developed countries?; and (ii) Is globalisation driving environmental degradation in developing countries? The novelty of this essay is its analysis of globalisation, which, instead of using a proxy or aggregate index, uses the economic, political, and social dimensions of globalisation, and the two new *de jure* and *de facto* measures. The undifferentiated analysis of the phenomenon of globalisation, using a single variable, can produce biased results, as can an analysis using only the three dimensions of globalisation (Martens et al., 2015). Literature that also considers the two new measures of globalisation is scarce. Therefore, this essay brings new insights into the specific effects of each dimension and measure of globalisation on environmental performance. Furthermore, this essay assesses the EKC hypothesis for developed and developing countries experiencing the phenomenon of globalisation.

The consequences of global warming are already being felt, so it is urgent to act to counter it, reducing emissions and pushing for worldwide decarbonization. However, globalisation enables the relocation of polluting industries from developed to developing countries (Bilgili et al., 2020), which consequently induces environmental degradation in developing countries, which have less resources to overcome the impact of climate change. Therefore, it is extremely important to make globalisation a driver of environmental quality worldwide to meet sustainable development goals and promote sustainability. For this, appropriate and effective policies must be devised, and a differentiated analysis of the phenomenon of globalisation by each dimension and measure, can provide invaluable insights to help policymakers. The countries analysed in this work have different levels of development, and also have different levels of globalisation and environmental regulation, and therefore, can shed light on how globalisation affects the environmental performance of countries with such distinct features. The main analysis in this essay is accomplished through the use of an ARDL model with a Driscoll-Kraay estimator. When the phenomenon is being studied in the long-run, it becomes important to understand the most immediate and persistent adjustment dynamics over time. Therefore, this work employs modelling capable of accommodating different adjustment dynamics over time.

This essay consists of five sections. Sections 3.2 and 3.3 present the data and methods employed, and the results of the estimations, respectively. Section 3.4 contains a discussion of the main findings, and section 3.5, the work's conclusions.

3.2 Data and Methodology

In order to meet the objectives of this work, a selection of 58 countries was analysed using annual data from 1995 to 2017. The time span corresponds to the data available to analyse the largest number of economies. The initial group of 58 countries was divided according to the categorization of the United Nations (2019a), resulting in a group of 32 developed economies, namely: Australia, Austria, Belgium, Bulgaria, Canada, Croatia, The Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, the Netherlands, New Zealand, Norway, Poland, Romania, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, The United Kingdom, and The United States; and a group of 26 developing and in transition economies, namely: Algeria, Argentina, Bangladesh, Belarus, Brazil, Chile, China, Colombia, The Arab Republic of Egypt, India, Indonesia, The Islamic Republic of Iran, Israel, Kazakhstan, Malaysia, Mexico, Morocco, Pakistan, Peru, The Philippines, The Russian Federation, South Africa, Thailand, Turkey, Ukraine and Uzbekistan.

The variables were selected in order to determine the effect of economic growth, energy consumption, and globalisation, on environmental damage. The variables used correspond to those used in the academic literature in this field. These variables are related to the various sustainable development goals of the United Nations (2019b), such as 7 "Affordable and Clean Energy", 13 "Climate action" and 17 "Partnerships for the goals". The variables that were considered in this essay are displayed in Table 3.1.

Table 3.1 - Variables

Variable description	Description	Source
GDP	Gross Domestic Product (constant 2015 prices in US$)	United Nations Statistical Division (UNSD)
CO_2	CO_2 emissions (Mt)	BP Statistical Review of World Energy 2019
OIL	Oil consumption (Mt)	
COAL	Coal consumption (Mtoe)	
GAS	Gas consumption (Mtoe)	
RES	Renewable energy consumption (Mtoe)	
KOFEF	KOF Globalisation Index Economic Dimension *de Facto*	KOF Swiss Economic Institute
KOFEJ	KOF Globalisation Index Economic Dimension *de Jure*	
KOFSF	KOF Globalisation Index Social Dimension *de Facto*	
KOFSJ	KOF Globalisation Index Social Dimension *de Jure*	
KOFPF	KOF Globalisation Index Political Dimension *de Facto*	
KOFPJ	KOF Globalisation Index Political Dimension *de Jure*	

Notes: Mtoe denotes Millions of tonnes in oil equivalent; Mt denotes Million tonnes.

Therefore, in order to analyse the features of the variables and descriptive statistics, Cross-sectional Dependence (CD) and unit root tests were realized. Descriptive statistics consisting of the mean, standard deviation, minimum and maximum, and the number of observations of each variable, for both groups of countries, are displayed in Table 3.2.

Table 3.2 - Descriptive Statistics

	Developed Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
CO_2_pc	9.40E-06	4.64E-06	2.93E-06	2.75E-05	736
GDP_pc	32990.37	21289.98	3484.149	105454.7	736
GDP2_pc	1.54E+09	1.90E+09	1.21E+07	1.11E+10	736
OIL_p	39.37749	12.00599	16.28537	77.01516	736
COAL_p	18.09192	15.83854	0.31058	73.80969	736
GAS_p	21.18075	10.25301	0.160152	48.58476	736
RES_p	12.57175	14.22387	0.021188	70.00538	736
KOFEF	67.11132	14.47544	27.13257	92.3781	736
KOFEJ	81.43444	9.363391	46.21674	97.38842	736
KOFSF	77.20307	10.1812	39.14899	95.15435	736
KOFSJ	81.92287	7.261441	54.84042	93.21019	736
KOFPF	84.65068	12.38591	41.90584	98.0887	736
KOFPJ	88.95044	11.2401	39.62223	100	736
	Developing Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
CO_2_pc	4.05E-06	3.02E-06	1.57E-07	1.25E-05	598
GDP_pc	5940.38	6055.932	551.3908	37057.81	598
GDP2_pc	7.19E+07	1.92E+08	304031.8	1.37E+09	598
OIL_p	39.66731	16.53883	5.499481	80.297	598
COAL_p	19.71761	21.30287	0.092383	75.01715	598
GAS_p	31.07856	23.23924	0.01816	88.72052	598
RES_p	8.339989	9.672246	0.016299	39.34713	598
KOFEF	46.32002	15.88939	16.24526	84.23129	598
KOFEJ	53.94171	13.61624	16.27871	88.10148	598
KOFSF	48.01743	16.84949	7.066115	89.54156	598
KOFSJ	57.62325	13.50492	19.86697	84.10851	598
KOFPF	75.84615	15.41984	25.75301	93.30902	598
KOFPJ	79.13463	12.0326	36.34521	96.57904	598

Notes: Max. denotes Maximum; Min. denotes Minimum; Std. Dev. denotes Standard deviation; Obs denotes Observations; pc denotes per capita; p denotes the share of primary energy consumption.

From Table 3.2, it can be seen that developed countries are more highly globalised than developing ones, with higher minimum and maximum values for all the dimensions and measures of globalisation. The variables of economic growth (*GDP*), energy consumption (*COAL*, *OIL*, *GAS* and *RES*) and environmental degradation (CO_2) suffer transformations with the objective to correlation does not represent a concern in the analysis.

Beyond correlation, the presence of CD is considered a challenge for a panel data series. In the context of a macro panel, the literature recommends looking in more detail at both the nature of the variables, and the idiosyncrasies of the countries under analysis (Daniel Hoechle, 2007). In turn, the presence of this phenomenon influences the analysis of the unit root of the variables. This occurs because the first-generation unit root tests assume the absence of CD, which means that the presence of CD is a limitation to performing the first-generation unit root tests, while second-generation unit root test (CIPS) is robust in its presence. Therefore, the CD test proposed by Pesaran (2004) was performed, and the results are displayed in Table 3.3.

Table 3.3 - Cross-Section Dependence Test (CD – Test)

	Developed countries				Developing countries		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LCO_2_pc	46.86***	0.439	0.591	*LCO_2_pc*	37.28***	0.431	0.697
LGDP_pc	93.36***	0.874	0.874	*LGDP_pc*	80.13***	0.927	0.927
LGDP2_pc	93.24***	0.873	0.873	*LGDP2_pc*	80.09***	0.926	0.926
LOIL_p	5.51***	0.052	0.420	*LOIL_p*	32.74***	0.379	0.535
LCOAL_p	27.98***	0.262	0.523	*LCOAL_p*	-1.49	-0.017	0.430
LGAS_p	10.23***	0.096	0.454	*LGAS_p*	28.45***	0.329	0.622
LRES_p	74.32***	0.696	0.696	*LRES_p*	0.89	0.010	0.296
LKOFEF	76.97***	0.721	0.768	*LKOFEF*	28.39***	0.328	0.487
LKOFEJ	27.94***	0.262	0.554	*LKOFEJ*	15.91***	0.184	0.450
LKOFSF	101.39***	0.949	0.949	*LKOFSF*	82.58***	0.955	0.955
LKOFSJ	96.46***	0.903	0.903	*LKOFSJ*	81.92***	0.948	0.948
LKOFPF	28.08***	0.263	0.403	*LKOFPF*	54.69***	0.633	0.641
LKOFPJ	87.72***	0.821	0.859	*LKOFPJ*	78.27***	0.905	0.905

Notes: *** denotes statistical significance at 1% level.

This test was performed according to the null hypothesis (H0) that there is no CD. As observed in Table 3.3, H0 was rejected, suggesting the presence of CD for all variables of the group of developed countries, while for the group of developing countries the presence of CD is revealed for all variables except *COAL* and *RES*. Hence, due to the presence of CD for most of the variables, the second-generation unit root test was performed for all variables, while the first-generation unit root tests were performed for *COAL_p* and *RES_p* for developing countries. The tests used were: the first-generation ADF-Fisher (Maddala & Wu, 1999), ADF-Choi (Choi, 2001) and LLC (Levin, Lin, & Chu, 2002) and the second-generation CIPS (Pesaran, 2007). As the results of both unit roots tests closely corresponded, only the second-generation test is displayed in Table 3.4.

Table 3.4 - Second-Generation Unit Root Test (CIPS)

	Developed countries			Developing countries	
	Without trend	With trend		Without trend	With trend
LCO2_pc	- 1.139	- 1.431*	*LCO2_pc*	- 1.908**	0.503
DLCO2_pc	- 15.544***	- 14.255***	*DLCO2_pc*	- 13.647***	- 12.602***
LGDP_pc	- 0.143	2.523	*LGDP_pc*	1.998	5.498
DLGDP_pc	- 7.566***	- 5.596***	*DLGDP_pc*	- 6.477***	- 6.851***
LGDP2_pc	0.128	2.697	*LGDP2_pc*	2.212	5.237
DLGDP2_pc	- 7.465***	- 5.519***	*DLGDP2_pc*	- 6.223***	- 6.562***
LOIL_p	- 1.721**	- 2.147**	*LOIL_p*	- 4.030***	- 2.903***
DLOIL_p	- 18.185***	- 16.735***	*DLOIL_p*	- 14.493***	- 12.122***
LCOAL_p	- 1.319*	0.062	*LCOAL_p*	0.743	0.122
DLCOAL_p	- 17.257***	- 16.078***	*DLCOAL_p*	- 14.499***	- 13.759***
LGAS_p	0.654	- 0.720	*LGAS_p*	- 0.725	- 0.350
DLGAS_p	- 14.294***	- 12.712***	*DLGAS_p*	- 11.872***	- 11.568***
LRES_p	- 0.720***	- 4.327***	*LRES_p*	- 14.472***	- 12.328***
DLRES_p	- 19.676***	- 17.750***	*DLRES_p*	- 14.472***	- 12.328***
LKOFEF	- 3.656***	- 3.249***	*LKOFEF*	- 0.196	- 0.449
DLKOFEF	- 15.128***	- 12.607***	*DLKOFEF*	- 12.878***	- 9.988***
LKOFEJ	- 0.337	2.373	*LKOFEJ*	- 2.317**	- 1.362*
DLKOFEJ	- 16.860***	- 15.497***	*DLKOFEJ*	- 13.567***	- 10.815***
LKOFSF	- 5.065***	- 3.226***	*LKOFSF*	- 6.861***	- 4.879***
DLKOFSF	- 17.565***	- 15.091***	*DLKOFSF*	- 17.926***	- 16.515***
LKOFSJ	- 3.431***	- 2.018**	*LKOFSJ*	- 4.096***	- 1.836*
DLKOFDJ	- 14.337***	- 11.434***	*DLKOFDJ*	- 15.281***	- 12.446***
LKOFPF	- 7.701***	- 6.482***	*LKOFPF*	- 5.153***	- 2.841***
DLKOFPF	- 18.377***	- 16.718***	*DLKOFPF*	- 15.682***	- 14.054***
LKOFPJ	- 5.732***	- 5.996***	*LKOFPJ*	- 6.472***	- 4.954***
DLKOFPJ	- 18.233***	- 15.727***	*DLKOFPJ*	- 17.107***	- 15.159***

Notes: *, **, *** denotes statistical significance at 10%, 5% and 1%, respectively.

The second-generation unit root test was performed under the H0, where the variables have a unit root. According to the results, the rejection of the H0 suggest that the variables are stationary, which means that there are variables stationary in level, I(0), and variables integrated of order one, I(1). Furthermore, the absence was confirmed of variables integrated of order two, i.e., I(2).

The analysis of the unit root of the variables was taken further with the analysis of the structural break points in the series. This analysis was performed using the Clemente, Montañés, & Reyes, (1998) and Zivot & Andrews (1992) unit roots tests with structural breaks. The results of these tests are useful to corroborate the unit root tests performed above, and to identify the structural break points that could be included as dummy variables in the estimations to control for events that could occur in the series. To reduce space, the results of the unit root tests with structural breaks are not presented, but are available on request to the authors. To conclude the assessment of the variables' features, correlation matrix values and variance inflation factor statistics were evaluated. The low values reveal that collinearity and multicollinearity are not a concern.

In view of the exhaustive assessment of the variables' features, the panel-ARDL model was used. Developed by Pesaran & Smith (1995) and Pesaran et al. (1999), this model gathers crucial characteristics to deal with the variables' features. Bearing in mind the variables' features, namely variables I(0) and I(1), and break points in the series, the ARDL model is robust to estimation with I(0), I(1), or borderline variables, and it enables the inclusion of dummy variables. Moreover, the panel-ARDL model provides both short-run adjustments and long-run equilibrium, which allows the EKC hypothesis to be assessed (Ahmad & Du, 2017). Additionally, this model has the capacity to deal with cointegration and endogeneity, computing unbiased coefficients. Therefore, in accordance with the literature, the ARDL model applied in panel data produces consistent parameter estimations (Papageorgiou, Michaelides, & Tsionas, 2016).

The general structure of the ARDL model is stated in Equation 3.1.

$$\Delta\varphi_t = \alpha_i + \beta_{i1}\Delta\vartheta_t + \sum_{p=1}^{n}\alpha_{1i}\varphi_{t-p} + \sum_{p=1}^{n}\alpha_{2i}\vartheta_{t-p} + \varepsilon_{i,t}\ , \tag{3.1}$$

where φ_t represents the vector of dependent variables; α_i corresponds to the intercept; β_{i1} corresponds to the semi-elasticities; ϑ_t represents the vector of independent variables; α_{1i} denotes the error correction mechanism (ECM); α_{2i} corresponds to the elasticities; and $\varepsilon_{i,t}$ corresponds to the error term.

In order to analyse the relationship between economic growth and environmental damage, the assessment of the EKC hypothesis was performed using a panel-ARDL model, with CO_2 emissions as a dependent variable and GDP and GDP squared integrated in the explanatory variables vector. The EKC hypothesis is validated by obtaining the following condition: $\delta_1 > 0$ and $\delta_2 < 0$. This condition represents the coefficient of GDP (δ_1) positive and the coefficient of GDP squared (δ_2) negative. However, if this condition is not validated, one of the following three relationships can be verified, namely: a U-shaped relationship ($\delta_1 < 0$ and $\delta_2 > 0$), a linear relationship ($\delta_1 > 0$ and $\delta_2 = 0$), or a declining relationship ($\delta_1 < 0$ and $\delta_2 = 0$). Lastly, the absence of a relationship can be revealed ($\delta_1 = \delta_2 = 0$).

3.3 Results

In order to analyse the features of the model, before estimation, a battery of model specification tests was undertaken, as displayed in Table 3.5. The use of these tests is crucial for selecting the most appropriate panel estimator. The appropriate estimator will handle the features of the panel database and provide robust estimations. First, the Hausman test was performed under the H0 that a random effects estimator is appropriate, assessing fixed effects vs random effects. The non-acceptance of the H0, as observed in Table 3.5, suggested that a fixed effects estimator is suitable.

Regarding the battery of model specification tests, contemporaneous correlation was evaluated using the Friedman (1937), Frees (1995), and Pesaran (2004) tests; group-wise heteroskedasticity using the modified Wald test; and serial correlation using the Wooldridge test. The contemporaneous tests are performed under the H0 of no contemporaneous correlation, the group-wise heteroskedasticity test is performed under the H0 of no heteroskedasticity, and the serial correlation test is performed under H0 of no serial correlation.

Table 3.5 - Hausman Test, F-Test and Specification Tests

	Developed countries	Developing countries
Hausman test	73.03***	55.02***
F - test	2.69***	2.34***
	Specification Tests	
	Developed countries	Developing countries
Pesaran test	17.860***	0.993
Frees test	1.209***	- 0.087
Friedman test	122.518***	23.927
Modified Wald test	1186.90***	452.91***
Wooldridge test	106.696***	52.113***

Notes: ***, * denotes significance level at 1% and 10%, respectively.

The results of these tests revealed the presence of contemporaneous correlation, heteroskedasticity and first order serial autocorrelation for developed countries, while for developing countries they revealed the presence of heteroskedasticity and first order serial autocorrelation.

Therefore, the Driscoll-Kraay estimator developed by Driscoll & Kraay (1998) was considered appropriate for handling these data features, as it is robust in the presence of heteroskedasticity, autocorrelation, and cross-sectional dependence (Daniel Hoechle, 2007). Furthermore, this estimator allows the use of fixed effects on estimations (D Hoechle, 2010).

Therefore, following the parsimonious principle, Table 3.6 displays the estimations.

Table 3.6 - ARDL Estimations

Variable	Developed countries	Developing countries
DLGDP_pc	0.4313***	
DLGDP2_pc		0.042***
DLOIL_p		
DLGAS_p		- 0.012*
DLCOAL_p	0.1041***	0.0457***
DLRES_p	- 0.0892***	- 0.0428***
DLKOFEF	0.1124**	0.0522**
DLKOFEJ		

DLKOFSF		0.0824***
DLKOFSJ		
DLKOFPF		
DLKOFPJ		
ECM	- 0.1173***	- 0.1022***
LGDP_pc (-1)	0.7687***	- 0.2222***
LGDP2_pc (-1)	- 0.0384***	0.0153***
LOIL_p (-1)	0.0425*	0.0662***
LGAS_p (-1)	0.0085*	
LCOAL_p (-1)		
LRES_p (-1)	- 0.0073**	- 0.0097***
LKOFEF (-1)	- 0.0381**	0.0112*
LKOFEJ (-1)		0.0201*
LKOFSF (-1)	- 0.1036***	0.0534***
LKOFSJ (-1)		
LKOFPF (-1)	- 0.1002**	
LKOFPJ (-1)	0.1106**	
C	- 4.8071***	- 1.08***
dum_1997	- 0.023***	
dum_2000	- 0.04***	- 0.0234***
Elasticities		
LGDP_pc (-1)	6.555****	- 2.1736***
LGDP2_pc (-1)	- 0.3277***	0.1497***
LOIL_p (-1)	0.3626*	0.6478***
LGAS_p (-1)	0.0727*	
LCOAL_p (-1)		
LRES_p (-1)	- 0.0626*	- 0.0948***
LKOFEF (-1)	- 0.3253**	0.1091*
LKOFEJ (-1)		0.1962**
LKOFSF (-1)	- 0.8839***	0.522***
LKOFSJ (-1)		
LKOFPF (-1)	- 0.8543**	
LKOFPJ (-1)	0.9434***	

Notes: *, **, *** denotes statistical significance at 10%, 5% and 1%, respectively; ECM denotes Error Correction Model; C denotes constant; Dum denotes dummies.

Considering the ability of the panel-ARDL model to include dummy variables to control events that may have occurred in the series, and bearing in mind the break points identified through the unit root tests with structural breaks, dummy variables were included in the estimations for 1997 and 2000 in the model for developed, and for 2000 for developing economies. The dummy variable for 1997 may represent the Kyoto Protocol international treaty adopted that year. The dummy variables for 2000, included in both estimations, may represent the Millennium Summit and the setting of environmental targets in the millennium development goals (United Nations, 2000).

The short-run semi-elasticities and long-run elasticities were computed and analysed. The short-run semi-elasticities revealed a decrease of 0.09 percentual points (pp) in CO_2 emissions for developed and 0.04 pp for developing economies, as a consequence of an increase of 1 pp in renewable energy consumption. In turn, the long-run elasticities revealed a decrease of 0.06 percent (%) in CO_2 emissions for developed and 0.09% for developing economies, as a consequence of an increase of 1% in renewable energy consumption.

Regarding the coefficients estimated, the EKC hypothesis was validated for developed countries, while in developing countries, a U-shaped curve was found. Besides this, the results suggest that CO_2 emissions of both groups of countries are mitigated by renewable energy consumption. In relation to globalisation, it generally has a greater influence in developed countries then in developing countries, and it helps mitigate CO_2 emissions in developed countries, while increasing them in developing countries. The ECM of both models are highly statistically significant and reveal a moderately fast adjustability to long-run equilibrium.

3.4 Discussion

Based on a dataset of 26 developing and 32 developed countries, from 1995 to 2017, this essay aims to assess the EKC hypothesis and identify the effects of globalisation, by each dimension and measure, on environmental performance in both developing and developed countries. The flowchart below briefly sets out the research process of this essay and its main findings:

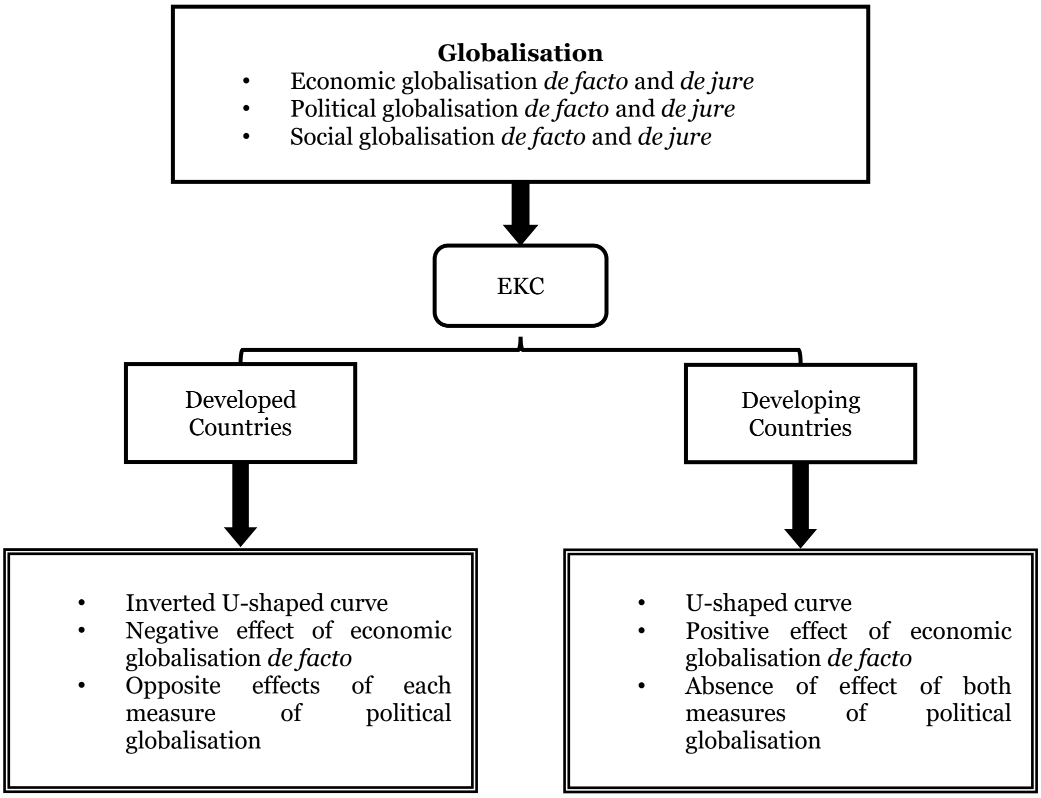

Figure 3.1 - Flowchart of research process and main findings
Source: Own elaboration

This essay suggests that the EKC hypothesis is validated for the developed countries, but not for the developing countries. Therefore, the relationship between economic growth and environmental degradation is presented by an inverted U-shaped curve for the developed countries, and a U-shaped curve for the developing ones. Both relationships are in concordance with the literature, with developed countries producing an EKC (Qiao, Zheng, Jiang, & Dong, 2019) and the developing countries producing a U-shaped curve (Dhrifi et al., 2020). The validation of the EKC for developed countries represents the three stages of the relationship between environmental damage and economic development as indicated by Grossman & Krueger (1991), specifically, the scale effect in the first stages of economic development, and the composition and technique effects in the later stages. The scale effect consists of increasing environmental degradation resulting from increased economic activity and economic development. This harmful effect of economic development on the environment is a consequence of the first stage of economic development which requires a higher use of energy to reach the production output needed to fulfil demand. The composition effect consists of changes in the economy structure, as there is a move from pollution-intensive industries to service-oriented industries. Lastly, the technique effect consists of decreasing environmental degradation with increased economic development, which is explained by investment in research & development and the substitution of polluting and old technologies with more efficient technologies.

The three stages of the relationship between environmental damage and economic development that developed countries experience could be related to the U-shaped curve that developing countries produce. This contrasting environmental performance may result from the relocation of polluting industries from developed to developing countries. When the industry of developed countries moves from pollution-intensive industries to service-based industries, the developing economies are still moving from agrarian economies to energy- and carbon-intensive industry economies. The relocation of polluting industries is induced by the lax environmental regulation of developing countries. In concordance with our results, Dean, Lovely, & Wang (2009) analysed whether weak environmental regulations attract foreign investors, and Chung (2014) analysed the includes Foreign Direct Investment (FDI) pattern shaped by environmental regulations, concluding that dirty industries tend to invest more in countries with weak environmental regulations.

The effect of economic globalisation *de facto*, that includes FDI, in both the short- and long-run, also suggests the relocation of polluting industries from developed to developing countries. In the short-run, economic globalisation *de facto* provokes an increase of environmental degradation in both groups of countries. In developed countries, this effect could be explained by trade openness, which induces economic growth. The growth and development of an economy involves significant energy use, and this consequently deteriorates environmental quality. According to Shahbaz et al. (2019) this is defined as the scale effect, and corresponds to the first phase of EKC, i.e., an increase in both environmental degradation and economic growth. This is in line with the validity of the EKC hypothesis for the developed countries. In developing countries, the harmful effect of economic globalisation *de facto* already suggests the relocation of polluting industries. In the long-run, the beneficial effect on the environment of developed countries, and the harmful effect on that of developing countries, reveals that by relocating polluting industries, developed countries reduce environmental damage, while environmental degradation increases in developing countries. According to Copeland & Taylor (2004) economic globalisation can induce pollution intensive industries in countries with lax environmental regulations, such as developing countries.

Political globalisation does not seem to affect the environmental performance of developing countries. This could be explained by the lax environmental regulation of developing countries. This is also consistent with the relocation of polluting industries from developed to developing countries suggested by economic globalisation *de facto* and the EKC hypothesis. Lax environmental regulations attract developed countries to relocate their polluting industries to developing countries. In developed countries, political globalisation was found to have differing effects on CO_2 emissions in the long-run. Political globalisation *de facto* decreases environmental degradation, while *de jure* increases it. The mitigation effect of the *de facto* measure on CO_2 emissions could be explained by the dissemination and sharing of environmental policies between countries. Whereas the expansive effect on CO_2 emissions could be explained by the lack of success of environmental treaties and insufficient environmental global management. Both harmful and beneficial effect of political globalisation on the environment are predicted in the literature (Lemos & Agrawal, 2006), respectively.

Social globalisation *de facto* has opposite effects on the emissions of the two groups of countries under analysis in the long-run. In developing countries it increases environmental degradation, in contrast to its mitigating effect in developed countries. This means that social globalisation *de facto* is harmful for the environment of developing countries and beneficial for developed countries. The effect in developing countries could be explained by the increasing affluence of international tourism and trade in cultural goods. Societies more receptive to other cultures have a higher demand for international products. Therefore, environmental awareness should be encouraged, as awareness of corrective measures and environmental issues are useful to consumers for safeguarding the environment (Udell, Stehel, Kliestik, Kliestikova, & Durana, 2019). The creation of environmental associations, as defined by Stehel, Rowland, & Mareček (2019), could help to re-educate society in environmentally-friendly behaviour and encourage environmental awareness. Overall, globalisation has a harmful effect on the environment of developing countries, as noted by Khan et al. (2019).

Regarding energy consumption, the results of burning fossil fuels reveal a transition in developed countries represented by the influence, in the long-run, of gas consumption on CO_2 emissions, while the effect is not verified in the short-run. Moreover, there is also evidence of an energy transition in the substitution of coal for oil consumption, with effects on CO_2 emissions in the short-run to the long-run in both groups of countries. Renewable energy consumption is a tool for mitigating environmental degradation, as noted by Yao, Zhang, & Zhang (2019), in the short-run and long-run in both groups of countries. Both developed and developing countries should continue to invest in this environmentally-friendly energy source to help mitigate environmental degradation. For instance, many developed countries have been increasing their targets of electricity production from renewables, and biofuels, such as biogas, play an increasing important role in meeting these targets (Maroušek, Bartoš, et al., 2020), as do solid biofuels, such as biomass (Hasková, 2017). The economic and environmentally appropriate use of any biowaste is made through a widely recognized process of anaerobic fermentation (Maroušek et al., 2019). However, this process could face technical challenges, particularly under a thermophilic process (Vochozka, Rowland, & ŠULEŘ, 2019). Countries should consider the most suitable energy sources according to their topographic and geographic features, such as mountain rivers useful for water energy production, vegetation for biomass energy, or sunlight for solar panels.

Some limitations were encountered in this work. The results obtained were limited to a time span of 1995-2017 due to the available data on the KOF globalisation index, the most recent of which dates from 2017. Additionally, the analysis of certain countries was limited by a lack of renewable energy and gas consumption data.

3.5 Conclusion

This essay provides a fresh analysis of the EKC hypothesis for developed and developing countries for the phenomenon of globalisation by each dimension and measure. The analysis of the economic, social, and political dimensions and *de jure* and *de facto* measures of globalisation provide insights for policymakers devising appropriate and effective measures and policies to achieve sustainability for both developed and developing countries. The results of this essay reveal which dimension and measure of globalisation policies should be focused on, and the specific policies that should be developed. Through these, this essay aims to help mitigate environmental degradation worldwide and foster sustainable economic development with globalisation as an ally of environmental quality.

With respect to the research questions, the results confirm both hypotheses. Globalisation does improve environmental quality in developed countries, and globalisation drives environmental degradation in developing ones. Therefore, globalisation generally has a beneficial effect on the environment of developed countries, and a harmful effect on the environment of developing ones. Through a variation of 1% in the respective dimension and measure of globalisation, it causes decreases of 0.88% and 0.85% in the environmental degradation of developed countries and increases of 0.20% and 0.52% in developing ones. In addition, the results confirm the differing effects of the *de facto* and *de jure* measures of the same dimensions of globalisation, which justifies the separate analysis of the measures to avoid the distortions in the results that arise when they are combined. Regarding the assessment of the EKC hypothesis, developed countries produce an inverted U-shaped curve, while developing reveal a U-shaped relationship.

The results indicate there is a flow of polluting industries relocating from developed to developing countries. The inverted U-shaped curve produced by developed countries and the U-shaped curve produced by the developing ones, suggest that developed economies become service-oriented while developing ones become carbon-intensive. Besides this, the beneficial effect of economic globalisation *de facto* on the environment in developed countries and the harmful effect in developing countries in the long-run, also indicate that developed countries relocate polluting industries to developing countries through FDI. The relocation of polluting industries occurs mainly due to the lax environmental regulations of developing countries. The absence of any effect of political globalisation in developing countries may also suggest they have lax environmental regulations. Therefore, these countries should strengthen their environmental regulations in order to avoid the relocation of emissions and promote worldwide decarbonization. Renewable energy consumption contributes to decarbonization, and was shown to be a tool for mitigating environmental degradation in both groups of countries. Therefore, countries should continue to invest in renewable energy sources to increase installed capacity and electricity production from environmentally friendly sources. Energy transition is observed in both groups of countries, through the substitution of consumption of coal by oil from the short-run to the long-run.

Several areas of future research are suggested by this work. An analysis of globalisation could be made using the subdimensions of each dimension of globalisation, namely: economic globalisation, consisting of both *de jure* and *de facto* trade globalisation and financial globalisation; and social globalisation consisting of the *de jure* and *de facto* interpersonal, informational, and cultural dimensions. Secondly, different groups of countries could be studied, such as a more detailed analysis of developing countries, which were shown to suffer more from environmental degradation with increased globalisation. Lastly, in the context of other major challenges faced by developing countries, an analysis could be made combining corruption and energy poverty with globalisation.

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Chapter 4

The environmental impacts of globalisation and corruption: evidence from a set of African countries

Achieving sustainable development while avoiding further environmental degradation is a crucial challenge faced by society today. The African countries in this work have shown considerable growth, but still face various barriers to comply with international environmental agreements. This essay analyses the effect of globalisation and corruption on the environmental performance of 23 African countries from 1999 to 2017. The Autoregressive Distributed Lag model with Driscoll-Kraay estimator was chosen as most suitable to achieve the aim of this analysis. The main findings provide confirmation of the advantage of analysing globalisation through three dimensions, namely, the economic, social, and political, and through two measures, the *de jure* and *de facto*. Economic globalisation *de facto* increases environmental degradation, suggesting the relocation of polluting industries to African countries. Economic and political globalisation *de jure* improves the environment. Stricter regulation could reduce the level of corruption and restrict the relocation of polluting industries. Foreign investment attracted to these countries should be directed to achieving sustainable development goals.

4.1 Introduction

The consequences of globalisation and climate change are urgent items on the world's agenda, and global climate change and sustainability are frequently discussed internationally. Sustainable development strategies are focused on reaching a clean environment without undermining economic growth (Rehman, Ma, Ozturk, et al., 2020). The wealthy mainly focus on economic costs and benefits, whereas the often terrible environmental costs of development are mostly incurred by the poor (Hao, Chen, & Zhang, 2016). African countries are considered highly susceptible to the impact of climate change and, as a consequence, problems of air quality, poverty, and infectious diseases are increasing in these countries (Zaidi & Saidi, 2018).

There is a temporal relationship between the phenomenon of globalisation and the surpassing of the Earth's biocapacity. Since the 1970s, humanity has been living in a state of ecological overshoot, which exceeds the Earth's biocapacity (WWF, 2014). This same period has been marked by rising globalisation. This confluence gives rise to the following question: Does the globalisation of the world economy augment the effects of climate change? To answer this, the analysis of the influence of globalisation on environmental performance and global emissions becomes particularly important (Zhu & Jiang, 2019). As noted by Potrafke (2014), globalisation is one of the most overlooked variables in environmental studies.

When faced with the need (and difficulty) of measuring and quantifying globalisation, Dreher (2006) proposed the KOF Globalisation Index. According to Gygli, Haelg, Potrafke, & Sturm (2019), who provide a summary of the most popular globalisation indexes, the KOF Globalisation Index became the most commonly used in the literature. This index consists of several variables, allowing the various aspects of globalisation to be measured. The KOF Globalisation Index is divided into three dimensions: (i) Economic globalisation, which contains variables representative of flows of goods, capital and services, and of market exchanges; (ii) Political globalisation, which consists of variables representing the dissemination of government policies; and (iii) Social globalisation, which includes variables that represent the diffusion of ideas, information, and people.

To take into account an increasingly complex reality, and to avoid the risk of oversimplification, Gygli et al. (2019), following Martens, Caselli, De Lombaerde, Figge, & Scholte (2015) proposed a revised KOF Globalisation Index. This index, while maintaining the dimensions proposed by the first version, added two new measures of globalisation, namely *de jure* and *de facto*. Briefly, globalisation *de jure* consists of variables for the policies that allow the flows and activities. Globalisation *de facto* consists of variables for the actual flows and activities. The advantage of analysing globalisation using these two new measures is that it avoids the biased results that can arise when these two aspects are undifferentiated (Martens et al., 2015).

Also within the field of environmental degradation, corruption, like globalisation, is a complex and much-debated issue. Academic research shows that corruption reduces the strict implementation and efficacy of environmental regulations (Fredriksson, Vollebergh, & Dijkgraaf, 2004; López & Mitra, 2000). Furthermore, it suggests that environmental degradation tends to rise with the level of corruption. Developing countries, including a large number of African countries, are widely used as pollution havens for developed countries (Cai, Che, Zhu, Zhao, & Xie, 2018). The main features of pollution havens are their lax environmental regulations, excellent market access to developed countries, and opportunities for corruption (Candau & Dienesch, 2017).

Globalisation transcends national and cultural borders, as well as technological and governmental barriers (Gygli et al., 2019). However, access to energy, and energy consumption are a concern in these countries. Energy consumption causes carbon dioxide (CO_2) emissions and consequent environmental degradation. Therefore, renewable and non-renewable energy consumption, and access to electricity are included in this analysis. Having access to, and being able to use reliable, affordable, clean, and advanced energy sources is crucial to achieving the various sustainable development goals put forward by the United Nations (Rosenthal, Quinn, Grieshop, Pillarisetti, & Glass, 2018). According to Dong & Hao (2018), promoting the use of electricity and, particularly, increasing its generation through renewable energy sources are important measures for reducing environmental degradation.

Overall, this essay contributes to the literature by filling a gap in the analysis of the effect on environmental degradation of globalisation, using its three dimensions (economic, social, and political) and the two measures (*de jure* and *de facto*), for a set of 23 African countries, namely: Benin, Burundi, Burkina Faso, Cameroon, Egypt, Ghana, Guinea, Kenya, Madagascar, Malawi, Mali, Morocco, Mozambique, Niger, Nigeria, Senegal, South Africa, Sudan, Togo, Tunisia, Uganda, Zambia, and Zimbabwe. The analysis of globalisation using only aggregated dimensions and measures may produce misleading conclusions, and result in less appropriate and efficient measures and policies. Hence, an analysis of globalisation that takes into account all its dimensions and measures is more useful for policymakers, allowing them to decide on the most appropriate specific measures and policies. Furthermore, this analysis also factors in the phenomenon of corruption. Therefore, this essay was undertaken to answer the research question: What is the environmental impact of globalisation on African countries where corruption is perceived to be prevalent? This research question is analysed using an Autoregressive Distributed Lag (ARDL) model with the Driscoll-Kraay estimator. The results reveal that the effect on the environment of each *de jure* and *de facto* dimension, differs in nature and/or magnitude.

The rest of this essay is divided into six sections. Section 4.2 consists of the literature review. After that, the data and methods employed are presented and explained in Section 4.3, and the results of the estimations are shown in Section 4.4. The final sections, 4.5 and 4.6, present a discussion of the main findings, and the conclusions of the essay, respectively.

4.2 Literature Review

The relationship between environmental degradation and globalisation is contentious (Rafindadi & Usman, 2019). This relationship can be analysed through three effects: scale, composition, and technique. The scale effect consists of globalisation encouraging economic growth and energy consumption, which consequently increases environmental degradation (Dedeoğlu & Kaya, 2013). The composition effect represents decreasing energy consumption, increasing economic activity and beneficial, less carbon-intensive production processes (Stern, 2007). Lastly, the technique effect consists of globalisation decreasing energy consumption, which consequently reduces environmental degradation, a situation brought about by the transfer of modern technologies and technical knowledge (Jena & Grote, 2008).

The influence of globalisation on environmental degradation has been widely analysed in recent environmental literature (e.g. Akadiri, Alola, & Akadiri, 2019; Bilgili, Ulucak, Koçak, & İlkay, 2020; Khan, Teng, Khan, & Khan, 2019; P. H. Leal & Marques, 2020; P. H. Leal, Marques, & Shahbaz, 2020; P. Leal & Marques, 2019; Liu, Ren, Cheng, & Wang, 2020; Rahman, 2020; Suki, Sharif, Afshan, & Suki, 2020; Sun, Chen, & Zhang, 2020; L. Wang, Vo, Shahbaz, & Ak, 2020), and for African countries (e.g. Acheampong, Adams, & Boateng, 2019; Rafindadi & Usman, 2019; Salahuddin et al., 2019). In the literature, globalisation is analysed from different perspectives. A specific and aggregate analysis is performed through: (i) Individual variables such as Foreign Direct Investment (FDI) and Trade Openness (Acheampong et al., 2019), or FDI, Foreign Liabilities, and Foreign Debt (Egbetunde & Akinlo, 2015), (ii) A single dimension, such as the economic dimension (Lv & Xu, 2018); and (iii) The KOF overall globalisation index (e.g. Akadiri et al., 2019; Bilgili et al., 2020; Gozgor, Mahalik, Demir, & Padhan, 2020; Guan, Kirikkaleli, Bibi, & Zhang, 2020; P. H. Leal & Marques, 2020; Liu et al., 2020; Rafindadi & Usman, 2019; Rahman, 2020; Salahuddin et al., 2019; Sethi, Chakrabarti, & Bhattacharjee, 2020; Shahbaz, Kumar, Jawad, & Shahzad, 2019; Suki et al., 2020; Ulucak, Koçak, Erdoğan, & Kassouri, 2020; L. Wang et al., 2020; Woo & Jun, 2020).

Therefore, a comprehensive and all-embracing analysis of globalisation is performed using the globalisation index of the three dimensions of globalisation: the economic, political, and social globalisation indexes (Hammudeh, Sohag, Husain, & Husain, 2020; Khan et al., 2019; Rudolph & Figge, 2017). Each dimension of globalisation may have both harmful and beneficial effects on the environment. P. Leal & Marques, (2019) provide a summary of the effects of each dimension. The introduction of two new *de jure* and *de facto* measures of globalisation, (Gygli et al., 2019), which avoid the biased results arising from aggregating the effect of the two measures (Martens et al., 2015), improved the analysis of the relationship between environmental degradation and globalisation. Further evidence, for European countries, of the varying qualitative and quantitative effects on environmental degradation of each dimension and measure of globalisation, has been presented by P. Leal & Marques (2019).

Despite increasing globalisation, corruption remains a challenge in African countries. Corruption is widely incorporated in the analysis of various environmental and energy issues, such as ecological efficiency (S. Wang, Zhao, & Chen, 2020), the oil sector (Moisé, 2020), environmental regulatory policy (Dincer & Fredriksson, 2018), deforestation (Fischer, Giessen, & Günter, 2020) and CO2 emissions (Akhbari & Nejati, 2019; Z. Wang, Danish, Zhang, & Wang, 2018). S. Wang et al. (2020) provide a literature review of the relationship between corruption and economic growth, resource allocation, and ecological efficiency. Furthermore, Arminen & Menegaki (2019) present a literature review of corruption and the energy-environment-growth nexus, including corruption, economic growth, energy consumption, and pollution. A summary of the literature on corruption and environmental pollution is provided by Chen, Hao, Li, & Song (2018). Corruption is widely analysed in developing counties, such as Brazil, Russia, India, China, and South Africa (BRICS) and the Next 11 countries (Sinha, Gupta, Shahbaz, & Sengupta, 2019); Africa (Sulemana & Kpienbaareh, 2018); and China (S. Wang et al., 2020). Akhbari & Nejati (2019) provide an analysis of both developed and developing countries, allowing these two groups of countries to be compared.

This essay contributes to the literature by providing an analysis of the three dimensions of globalisation (economic, social, and political), and the two measures, *de jure* and *de facto* for a group of 23 African countries. Furthermore, the analysis includes corruption, a phenomenon that must be mitigated to achieve sustainable economic development in African countries. This analysis is made on a group of African countries chosen for their high levels of corruption, lax environmental regulations, and low levels of globalisation, and because they are highly susceptible to the effects of climate change (Gygli et al., 2019; Kwabena, Danso-mensah, & Bokpin, 2017; United Nations Environmental Programme, African Union, 2015; World Bank, 2019b; Zaidi & Saidi, 2018). Therefore, this analysis of a group of African countries, is extremely important for understanding whether globalisation has made a positive contribution to mitigating environmental degradation and achieving sustainable development goals.

4.3 Data and Methodology

4.3.1 Data

This essay uses annual data from 1999 to 2017 for 23 African countries, described above. Considering the available data, the African countries under analysis were selected according to their level of corruption. All the 23 countries have a negative corruption index which means that they have high corruption levels (World Bank, 2019b). In turn, the time span under analysis was selected considering the available data, in order to analyse the greatest number of years and countries. As stated in the literature review, this analysis seeks to capture the effects of economic growth, energy consumption, energy access, globalisation, corruption, and environmental degradation. Table 4.1 displays the variables under analysis, their definitions and sources.

Table 4.1 - Variables

Variable	Definition	Source
GDP	Gross Domestic Product (constant LCU)	World Bank Development Indicators
ENPOV	Energy Poverty (Percentage of population with access to electricity)	
CORR	Corruption (Control of Corruption Index)	
CO_2	Carbon Dioxide Emissions (MMtons)	U.S. Energy Information Administration
NRES	Non-Renewable energy consumption (quad Btu)	
RES	Renewable energy consumption (quad Btu)	
KOFEF	KOF Globalisation Index Economic Dimension *de Facto*	KOF Swiss Economic Institute[1]
KOFEJ	KOF Globalisation Index Economic Dimension *de Jure*	
KOFSF	KOF Globalisation Index Social Dimension *de Facto*	
KOFSJ	KOF Globalisation Index Social Dimension *de Jure*	
KOFPF	KOF Globalisation Index Political Dimension *de Facto*	
KOFPJ	KOF Globalisation Index Political Dimension *de Jure*	

Notes: LCU denotes local currency units; MMtons denotes Million Metric tonnes; quad Btu denotes quadrillion British thermal unit. 1 - (http://globalisation.kof.ethz.ch/)

Corruption is analysed according to the World Bank's definition "Control of Corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests." (Kaufmann, Kraay, & Mastruzzi, 2011).

In order to ensure there was no correlation between the variables, *NRES* and *RES* were converted into shares of primary energy consumption and CO_2 and *GDP* were converted into *per capita* (pc) values. Table 4.2 displays descriptive statistics of the variables.

Table 4.2 - Descriptive Statistics

	Mean	Std. Dev.	Min.	Max.	Obs.
GDP_pc	390701.3	814817.4	503.7505	4976149	437
CO_2_pc	8.59E-07	1.83E-06	2.05E-08	9.45E-06	437
NRES_p	77.8551	20.9572	17.6294	99.7896	437
RES_p	22.1450	20.9572	0.2104	82.3706	437
KOFEF	46.3738	11.2247	21.7709	78.3331	437
KOFEJ	40.8355	11.7853	14.1842	69.5586	437
KOFSF	32.6099	13.0356	8.5067	66.9936	437
KOFSJ	43.4672	11.7673	15.8775	73.3469	437
KOFPF	65.4363	15.5163	22.0087	93.3090	437
KOFPJ	72.2746	10.5613	44.2886	94.1716	437
ENPOV	39.2503	28.9193	2.7599	100	437
CORR	-0.6595	0.4377	-1.5320	0.6744	437

Notes: Max. – Maximum; Min. – Minimum; Std. Dev. – Standard deviation; Obs – Observations; pc denotes per capita; p denotes the share of primary energy consumption.

Cross-sectional dependence is a common occurrence and one of the challenges in panel data settings that can lead to inconsistent estimates. In order to ensure robust results, the Pesaran (2004) Cross-section Dependence test (CD-test) was performed, as shown in Table 4.3.

Table 4.3 - Cross-Section Dependence Test (CD – Test)

	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LGDP_pc	45.73***	0.660	0.708	*DLGDP_pc*	4.43***	0.066	0.238
LCO_2_pc	10.72***	0.155	0.510	*$DLCO_2$_pc*	5.52***	0.082	0.260
LNRES_p	-0.55	-0.008	0.357	*DLNRES_p*	0.79	0.012	0.198
LRES_p	-0.87	-0.013	0.359	*DLRES_p*	0.03	0.001	0.198
LKOFEF	5.61***	0.081	0.440	*DLKOFEF*	4.95***	0.073	0.201
LKOFEJ	4.65***	0.067	0.308	*DLKOFEJ*	11.10***	0.165	0.270
LKOFSF	64.89***	0.936	0.936	*DLKOFSF*	12.22***	0.181	0.266
LKOFSJ	66.73***	0.962	0.962	*DLKOFSJ*	14.36***	0.213	0.276
LKOFPF	28.92***	0.417	0.557	*DLKOFPF*	2.96***	0.044	0.243
LKOFPJ	63.27***	0.913	0.913	*DLKOFPJ*	22.47***	0.333	0.357
LENPOV	56.30***	0.812	0.812	*DLENPOV*	0.53	0.008	0.207
CORR	2.41**	0.035	0.365	*DCORR*	0.68	0.010	0.244

Notes: ***, ** denotes significance level at 1% and 5%, respectively; prefix L denotes logarithm; prefix D denotes differences.

The presence of cross-sectional dependence was verified for all variables excluding *LNRES_p* and *LRES_p* in both level and differences, and *DLENPOV* and *DCORR*. As a consequence of the presence of cross-sectional dependence, both first- and second-generation unit root tests were performed. First-generation unit root tests are not appropriate in the presence of cross-sectional dependence, while second-generation unit root tests are robust. The second-generation unit root test (CIPS) proposed by Pesaran (2007) and the first-generation unit root tests ADF-Fisher (Maddala & Wu, 1999), ADF-Choi (Choi, 2001) and LLC (Levin, Lin, & Chu, 2002) were performed. Table 4.4 displays the results of the second-generation unit root test (CIPS).

Table 4.4 - Second-Generation Unit Root Test (CIPS)

	Without trend	With trend		Without trend	With trend
LGDP_pc	2.788	4.270	*DLGDP_pc*	- 6.361***	- 6.692***
LCO2_pc	- 0.271	- 1.075	*DLCO2_pc*	- 12.852***	- 10.693***
LNRES_p	- 3.601***	- 2.923***	*DLNRES_p*	- 12.588***	- 10.220***
LRES_p	0.285	0.553	*DLRES_p*	- 12.016***	- 10.933***
LKOFEF	- 2.428***	- 0.496	*DLKOFEF*	- 12.386***	- 10.126***
LKOFEJ	- 1.534*	- 2.607***	*DLKOFEJ*	- 12.534***	- 9.946***
LKOFSF	- 3.993***	- 2.558***	*DLKOFSF*	- 12.973***	- 10.811***
LKOFSJ	- 5.171***	- 3.506***	*DLKOFSJ*	- 11.992***	- 9.181***
LKOFPF	- 5.504***	- 6.258***	*DLKOFPF*	- 13.679***	- 12.465***
LKOFPJ	- 5.609***	- 4.031***	*DLKOFPJ*	- 12.146***	- 10.057***
LENPOV	- 7.644***	- 6.614***	*DLENPOV*	- 18.043***	- 16.595***
CORR	- 2.463***	0.088	*DCORR*	- 11.900***	- 9.897***

Notes: *, *** denotes significance level at 10% and 1%, respectively.

In order to preserve space, only the results of the second-generation unit root test (CIPS) are presented, and these indicated that the variables under analysis are stationary in level and integrated of order one. The first-generation unit root tests corroborated the results of the second-generation unit root test (CIPS), confirming that no variable is integrated of order two.

The unit root analysis was taken further, analysing structural breaks in the series through Zivot & Andrews (1992) unit root tests with structural breaks, commonly applied in energy economics studies (P. H. Leal, Marques, & Fuinhas, 2018; Zafar et al., 2019). The unit root test with structural breaks bears out the results of first- and second-generation unit root tests. The results of the unit root test with structural breaks are displayed in Table 4.5.

Table 4.5 - Unit root test with structural breaks (Zivot & Andrews, 1992)

		Intercept	break	Trend	break	Both	break
Benin	LCO_2_pc	-4.576	2012	-3.026	2010	-4.127	2012
	$DLCO_2$_pc	-5.811***	2011	-3.962	2005	-6.202***	2011
Burkina Faso	LCO_2_pc	-2.904	2012	-2.092	2006	-2.182	2005
	$DLCO_2$_pc	-1.837	2014	-4.945***	2014	-4.763	2013
Burundi	LCO_2_pc	-5.247**	2007	-4.921**	2012	-5.528**	2009
	$DLCO_2$_pc	-6.590***	2012	-5.693***	2008	-6.617***	2012
Cameroon	LCO_2_pc	-5.384***	2008	-3.777	2012	-5.231**	2008

	$DLCO_2$_pc	-7.363***	2007	-6.112***	2009	-7.027***	2007
Egypt	LCO_2_pc	-2.436	2014	-3.755	2013	-3.743	2011
	$DLCO_2$_pc	-6.601***	2013	-5.989***	2012	-7.052***	2011
Ghana	LCO_2_pc	-5.141**	2010	-3.124	2008	-5.412**	2010
	$DLCO_2$_pc	-6.228***	2010	-5.685***	2012	-7.280***	2010
Guinea	LCO_2_pc	-10.797***	2011	-3.102	2008	-9.843***	2011
	$DLCO_2$_pc	-5.114**	2013	-4.732**	2012	-5.75***	2011
Kenya	LCO_2_pc	-4.728*	2012	-4.087	2014	-7.086***	2012
	$DLCO_2$_pc	-3.735	2008	-3.600	2013	-3.933	2007
Madagascar	LCO_2_pc	-3.951	2009	-3.346	2011	-5.326**	2009
	$DLCO_2$_pc	-7.298***	2011	-3.405	2006	-6.546***	2011
Malawi	LCO_2_pc	-5.343***	2009	-5.072***	2006	-6.164***	2007
	$DLCO_2$_pc	-8.646***	2011	-7.574***	2010	-8.301***	2011
Mali	LCO_2_pc	-18.811***	2011	-2.648	2008	-22.087***	2011
	$DLCO_2$_pc	-5.192**	2011	-4.819**	2012	-8.306***	2011
Morocco	LCO_2_pc	-4.714*	2010	-1.968	2014	-3.992	2010
	$DLCO_2$_pc	-5.081**	2008	-3.853	2011	-4.838*	2008
Mozambique	LCO_2_pc	-4.967**	2011	-3.912	2010	-3.744	2008
	$DLCO_2$_pc	-6.060***	2011	-2.704	2014	-7.961***	2011
Niger	LCO_2_pc	-5.741***	2011	-3.093	2010	-2.951	2009
	$DLCO_2$_pc	-3.996	2014	-3.463	2013	-5.736***	2001
Nigeria	LCO_2_pc	-3.352	2009	-2.394	2010	-3.338	2009
	$DLCO_2$_pc	-6.144***	2011	-4.411*	2014	-6.542***	2011
Senegal	LCO_2_pc	-3.537	2009	-3.421	2014	-3.803	2012
	$DLCO_2$_pc	-5.175**	2014	-4.604**	2010	-5.826***	2014
South Africa	LCO_2_pc	-2.990	2003	-4.634**	2008	-4.436	2008
	$DLCO_2$_pc	-5.331**	2008	-5.226***	2013	-5.442**	2011
Sudan	LCO_2_pc	-4.704*	2012	-3.563	2010	-4.177	2012
	$DLCO_2$_pc	-4.848**	2014	-4.904**	2013	-4.966*	2011
Togo	Lnco2_pc	-6.437***	2003	-4.891**	2005	-6.269***	2003
	$DLCO_2$_pc	-6.169***	2006	-6.008***	2010	-6.143***	2009
Tunisia	LCO_2_pc	-3.105	2014	-3.790	2012	-3.955	2009
	$DLCO_2$_pc	-6.560***	2012	-5.888***	2008	-6.326***	2012

Uganda	LCO_2_pc	-8.861***	2009	-2.339	2014	-7.850***	2009
	$DLCO_2$_pc	-5.735***	2009	-5.070***	2010	-6.586***	2009
Zambia	LCO_2_pc	-1.829	2006	-4.291*	2012	-4.753	2010
	$DLCO_2$_pc	-7.102***	2012	-5.299***	2008	-6.676***	2012
Zimbabwe	LCO_2_pc	-3.805	2011	-2.065	2005	-2.332	2011
	$DLCO_2$_pc	-4.285	2010	-3.823	2013	-5.660***	2010

Both correlation coefficients and variance inflation factors (VIF) statistics are assessed. Small correlation values and VIF statistics strongly indicate that collinearity and multicollinearity are not a concern.

4.3.2 Method

To pursue the main objective of this work, bearing in mind the data characteristics, the panel-ARDL model proposed by Pesaran & Smith (1995) and Pesaran, Pesaran, Shin, & Smith (1999) was used. The ARDL model structure followed is specified as:

$$\begin{aligned} DLCO2_{it} &= \rho_i + \vartheta_{i1} TREND + \varphi_{i1} \textstyle\sum_{i=1}^{n} DLGDP_{PC_{it}} + \varphi_{i2} \sum_{i=1}^{n} DLNRES_{P_{it}} + \\ &\varphi_{i3} \textstyle\sum_{i=1}^{n} DLRES_{P_{it}} + \varphi_{i4} \sum_{i=1}^{n} DLKOFECDF_{it} + \varphi_{i5} \sum_{i=1}^{n} DLKOFECDJ_{it} + \\ &\varphi_{i6} \textstyle\sum_{i=1}^{n} DLKOFSODF_{it} + \varphi_{i7} \sum_{i=1}^{n} DLKOFSODJ_{it} + \varphi_{i8} \sum_{i=1}^{n} DLKOFPODF_{it} + \\ &\varphi_{i9} \textstyle\sum_{i=1}^{n} DLKOFPODJ_{it} + \varphi_{i10} \sum_{i=1}^{n} DLENPOV_{it} + \varphi_{i11} \sum_{i=1}^{n} DCORR_{it} + \\ &\propto_{i1} LCO2\_PC_{it-1} + \propto_{i2} LGDP\_PC_{it-1} + \propto_{i3} LNRES\_P_{it-1} + \propto_{i4} LRES\_P_{it-1} + \\ &\propto_{i5} LKOFECDF_{it-1} + \propto_{i6} LKOFECDJ_{it-1} + \propto_{i7} LKOFSODF_{it-1} + \\ &\propto_{i8} LKOFSODJ_{it-1} + \propto_{i9} LKOFPODF_{it-1} + \propto_{i10} LKOFPODJ_{it-1} + \\ &\propto_{i11} LENPOV_{it-1} + \propto_{i12} CORR_{it-1} + \varepsilon_{it}, \end{aligned} \tag{4.1}$$

where ρ_i represents the intercept; ϑ_i symbolizes the coefficient of the trend; φ_i denotes the estimated parameters in the short-run; $\propto_i$ represents the estimated parameters in the long-run; and ε_{it} denotes the error term.

The panel-ARDL model is robust in the presence of variables with different orders of integration, and allows the use of dummies to control events in the series. Considering the length of the time period studied, it is possible that events would occur that justify testing in the models. Furthermore, this model enables separate short- and long-run adjustment, and can handle cointegration and endogeneity among variables. According to the literature, the ARDL model generates consistent and efficient parameter estimates (Papageorgiou, Michaelides, & Tsionas, 2016).

A battery of model specification tests was performed. Table 4.6 displays the following tests, namely: (i) the Hausman test to assess whether fixed effects (FE) or random effects (RE) are more appropriate for the estimation, analysing the presence of individual effects versus random effects; (ii) the Pesaran (2004), Frees (1995) and Friedman (1937) tests to assess contemporaneous correlation; (iii) the Modified Wald test to assess heteroskedasticity; and (iv) the Wooldridge test to assess autocorrelation.

Table 4.6 - Hausman test, F - test and Specification tests

Hausman test	55.51***
F - test	2.78***
Specification Tests	
Pesaran test	2.952***
Frees test	0.340***
Friedman test	32.910*
Modified Wald test	3977.28***
Wooldridge test	36.440***

Notes: ***, * denotes significance level at 1% and 10%, respectively.

The specification tests performed suggest that fixed effects are suitable, together with the presence of contemporaneous correlation, heteroskedasticity and first-order serial autocorrelation. The Driscoll-Kraay estimator, proposed by Driscoll & Kraay (1998), takes into account cross-sectional dependence and assumes that the error structure is heteroskedastic, autocorrelated and correlated between the groups in the panel. Therefore, this estimator gives robust results in the presence of cross-section dependence, contemporaneous correlation, first-order serial correlation and heteroskedasticity.

4.4 Results

Following the process described above, this section presents the results of the ARDL model estimation, displayed in Table 4.7.

Table 4.7 - Estimations from the ARDL model

Short-run		Long-run	
DLGDP_pc	0.4146***	*ECM*	- 0.2716***
DLNRES_p	0.7950***	*LGDP_pc (-1)*	0.1246**
DLRES_p		*LNRES_p (-1)*	0.2239**
DLKOFEF	0.1678*	*LRES_p (-1)*	
DLKOFEJ		*LKOFEF (-1)*	
DLKOFPF		*LKOFEJ (-1)*	- 0.0805**
DLKOFPJ	- 1.2746***	*LKOFPF (-1)*	
DLKOFSF	- 0.1573***	*LKOFPJ (-1)*	- 0.5708***
DLKOFSJ		*LKOFSF (-1)*	
DLENPOV		*LKOFSJ (-1)*	
DCORR		*LENPOV(-1)*	0.1473***
		CORR(-1)	
		C	- 4.1619**

Elasticities	
LGDP_pc (-1)	0.4588***
LNRES_p (-1)	0.8242***
LRES_p (-1)	
LKOFEF (-1)	
LKOFEJ (-1)	- 0.2963*
LKOFPF (-1)	
LKOFPJ (-1)	- 2.1012***
LKOFSF (-1)	
LKOFSJ (-1)	
LENPOV(-1)	0.5423***
CORR(-1)	

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively; ECM denotes Error correction model; C denotes constant.

The results demonstrate the value of carrying out this analysis of globalisation using *de jure* and *de facto* measures. Indeed, in both the short- and long-run, the effects on CO_2 emissions of globalisation *de jure*, in all dimensions, vary in nature and magnitude from those of globalisation *de facto* in the countries under analysis. Among the dimensions and measures of globalisation, in both the short- and long-run, globalisation generally has a mitigating effect on environmental degradation in the African countries in this analysis. A reduction in environmental degradation occurs through political and economic globalisation *de jure* in the long-run. However, economic globalisation *de facto* increases environmental degradation in the African countries.

Corruption, as defined by the World Bank, is measured on a scale ranging from -2.5 to 2.5. The negative value denotes lax governance, and maximum corruption, while the positive value denotes strict governance, and minimum corruption. Therefore, a negative effect of *CORR* on environmental degradation means that an increase in *CORR*, i.e. stricter governance and lower corruption, mitigates environmental degradation, and conversely, that corruption increases environmental degradation. However, in our work, corruption does not seem to affect the environmental performance of the African countries under analysis.

Concerning the effect of energy on environmental performance, measured by CO_2 emissions, the results are as expected and in line with the literature. Non-renewable energy consumption, mainly in the short-run, has the largest influence on CO_2 emissions, increasing environmental degradation. In turn, renewable energy consumption does not have an impact on environmental degradation in either the short- or long-run in the African countries. With regard to energy poverty, it tends to increase environmental degradation in the long-run.

Semi-elasticities and elasticities were calculated. With semi-elasticities, the estimated short-run coefficient, an increase of 1 percentual point (pp) of *LKOFEF* and *LNRES* causes an increase of 0.17 pp and of 0.80 pp in CO_2 emissions, respectively. In turn, an increase of 1 pp of *LKOFPJ* and *LKOFSF* causes a decrease of 1.27 pp and 0.16 pp in CO_2 emissions, respectively. Regarding the elasticities, calculated through the long-run coefficients, an increase of 1 percent (%) of *LENPOV* and *LNRES* causes an increase of 0.54% and 0.82% in CO_2 emissions, respectively. Lastly, an increase of 1% in *LKOFPJ* and *LKOFEJ* causes a decrease of 2.1% and 0.3% in CO_2 emissions, respectively.

4.5 Discussion

This essay was undertaken with the objective of assessing the role of corruption and of each dimension and measure of globalisation, on the environmental performance of a set of African countries. To the best of our knowledge, analysis of the *de jure* and *de facto* measures of globalisation, is extremely scarce. Therefore, this essay aims to provide further evidence of the advantages of analysing them. Besides this, our work here combines an analysis of both globalisation and corruption, for a set of countries with a high level of corruption. With regard to globalisation, according to the overall globalisation index ranking for 2017 (https://kof.ethz.ch/en/forecasts-and-indicators/indicators/kof-globalisation-index.html), Morocco is the most, and Burundi the least globalised of the countries under analysis.

The essay's results provide evidence that the measures of globalisation can have different effects on environmental degradation, in both nature and/or magnitude. Economic globalisation *de facto* increases environmental degradation, while economic globalisation *de jure* reduces it. Furthermore, political globalisation *de jure* mitigates environmental degradation, while political globalisation *de facto* does not have a statistically significant effect. Social globalisation *de facto* mitigates environmental degradation, while social globalisation *de jure* does not have a statistically significant effect. Economic globalisation *de facto* provokes environmental degradation. This latter dimension and measure of globalisation consists mainly of trade in goods and services, FDI, and international income payments. Trade in goods and services induces economic growth and requires more energy consumption, which adversely affects the environment. This is consistent with the scale effect in the relationship between globalisation and environmental degradation, in which both environmental degradation and economic growth increase (P. H. Leal et al., 2020; Shahbaz et al., 2019).

FDI is a source of external capital for developing countries (Shahbaz, Nasreen, Abbas, & Anis, 2015). It is advantageous for developed countries, because it provides access to foreign markets, reduces production costs, and leads to the relocation of polluting industries. FDI may cause an increase in environmental degradation in the host countries, because, urgently required economic development and lax environmental regulation, attract foreign investments (Copeland & Taylor, 2004). International income payments consist of capital and labour income from outside the country. Both FDI and international income payments suggest the relocation of polluting industries from abroad to the African countries in this essay.

Economic globalisation *de jure* improves environmental quality. This dimension and measure of globalisation consists mainly of trade taxes and the openness of capital accounts. Trade taxes represent the income from taxes on international trade, and the openness of capital accounts includes foreign aid and remittances. Foreign aid is intended to improve the quality of life in developing countries and promote economic development. Furthermore, remittances are also intended to improve the quality of residents´ life. Quality of life is linked to environmental quality, as noted by Zaidi & Saidi (2018), who conclude that poverty, climate change, and poor air quality reduce the quality of life in developing countries.

Regarding political globalisation *de jure*, it mainly quantified by the number of international organisations to which a country is member, and the number of partners in bilateral investment treaties. These treaties include obligations for investors with regard to environmental and social impacts (United Nations, 2016). Therefore, political globalisation has a beneficial effect on the environment, as noted by Lemos & Agrawal (2006). With regard to social globalisation *de facto*, this includes international tourism. According to Rehman, Ma, Irfan, Ahmad, & Traore (2020) the rising growth of the tourism industry in the twenty-first century is a consequence of globalisation, with the added advantage of introducing modern technologies.

As explained above, globalisation *de facto* aim to analyse actual flows and activities, while globalisation *de jure* aims to analyse the policies that permit these flows and activities. Beyond the direct effects that globalisation may have on environmental degradation, as suggested in Table 4.7, the measures of globalisation may be related to environmental regulation. There are environmental regulation measures established by law, but some of these measures might not be properly enforced. In other words, some countries have robust regulations, but they are not implemented because of corruption. In this case, the *de jure* measure denotes the environmental regulations established by law, while the *de facto* measure represents the environmental regulations actually implemented.

Corruption may affect environmental degradation both directly and indirectly. Corruption can have a direct effect by impacting economic structures and environmental regulations (Cole, 2007). Corrupt practices can also manipulate the subsidies obtained by companies or the level of trade protection (Arminen & Menegaki, 2019). Besides that, corruption can lead to regulatory measures becoming ineffective, as both high- and low-level corruption have a significant impact on the effectiveness of environmental policy (Wilson & Damania, 2005). In terms of indirect effects, corruption can influence pollution via its effect on income (e.g. Cole, 2007; Welsch, 2004). It can influence income levels by increasing the stock of FDI, or helping enterprises obtain competitive advantages through rent-seeking, or leading to declines in per capita income and private investment. Furthermore, corruption can influence the structure of resource allocation (S. Wang et al., 2020). All the African countries under analysis experience corruption, however we were unable to prove it has a direct effect on environmental degradation. This does not imply that corruption has no effect on environmental degradation in these countries, as it may have an indirect effect by reducing income. Thus, the analysis of the effect of corruption on African countries deserves further research.

Access to energy and energy consumption in African countries is also a subject that deserves further research. According to Zaidi & Saidi (2018), these countries also have limited resources to implement measures to mitigate climate change. As suggested by the increasing effect of NRES on the emissions observed in this essay, energy consumption increases environmental degradation when it comes from fossil fuels. With regard to energy consumption from renewable energy sources, they do not seem to influence environmental degradation in the countries under analysis, which could be a consequence of the energy poverty currently prevailing in African countries. Energy poverty is a current reality in the African countries analysed. According to the World Bank (2019b), in 2017, in 13 out of 24 countries, less than 50% of the population had access to electricity, namely: Togo, Mali, Benin, Zimbabwe and Zambia with between 48% and 40%; Guinea, Mozambique, Burkina, Madagascar, Uganda, and Niger, with between 36% and 20%; Malawi with 12.7%, and lastly, Burundi, where only 9.3% of the population had access to electricity, (World Bank, 2019a).

Energy poverty was found to have a harmful effect on the environment, increasing environmental degradation, in line with the literature, such as Obrumah, Asuman, & Pokuaa (2019), while access to modern energy technology is crucial for achieving sustainable development goals, as noted by Adusah-Poku & Takeuchi (2019). The increasing effect of energy poverty on environmental degradation is consistent with the harmful effect of non-renewable energy consumption and the absence of renewable energy consumption. To reduce energy poverty the countries under analysis must increase the percentage of their populations with access to electricity. As renewable technology is expensive, it is likely that electricity is currently mainly produced from fossil fuels. Thus, there is a challenge to expand coverage without damaging the environment.

Strategies to reduce energy poverty by improving access to modern and affordable energy, should be incorporated into strategies of income poverty reduction. Increased energy consumption from renewable energy sources is crucial to promoting sustainable development with environmental quality. Recent reductions in the cost on the international market of renewable technologies, such as photovoltaic solar panels, make it easier for these countries to access low-cost electricity and decentralized production, thereby increasing access to electricity and reducing energy poverty. In addition, FDI that increases pressure on local fossil-based electricity-generating systems in the host countries must be carefully considered, as it may lead to an internal substitution effect, leaving even more people without access to electricity. Therefore, FDI should incorporated in development plans for renewable sources.

4.6 Conclusion

This essay contributes to the literature by analysing the effect on the environment of globalisation through the *de jure* and *de facto* measures of its economic, social and political, dimensions, and by a combined analysis of globalisation and corruption. To the best of our knowledge, no previous work has analysed the effect on environmental performance of each dimension and measure of globalisation together with corruption. The main findings of this essay reveal that the dimensions and measures of globalisation have different qualitative and quantitative effects on the environmental degradation of the African countries under analysis. The impact of economic globalisation *de facto* suggests that polluting industries are being relocated to these African countries. In contrast, economic globalisation *de jure* improves the quality of life and the environment. With regard to corruption, all the countries under analysis have high levels of corruption, but we found no indications that it directly affected environmental degradation. However, further research should be undertaken to analyse the specific nature and origin of the corruption, and consider appropriate measures to mitigate it, such as greater political stability.

With respect to energy access and consumption, in 13 out of 23 countries under analysis less than 50% of the population had access to electricity. This energy poverty increases environmental degradation, and the African countries under analysis are stuck with fossil-powered technology. This is a consequence of the absence of adequate, high-quality, and environmentally benign energy services. Fossil fuel consumption is the most significant driver of environmental degradation in these countries, so, to promote sustainable development and environmental quality, it is crucial to replace this with consumption of energy from renewable energy sources.

FDI should be directed to renewable energy technologies, as foreign investors can play a fundamental role in achieving sustainable development goals. Measures should be implemented to dissuade activities that aggravate global warming. For example, policies need to be put in place to eliminate the distortions so often seen when a company based in a country with strict environmental regulations relocates its production to a country with lax environmental regulations. These measures should be allied with complementary measures that persuade emerging economies to accept the possibility of a slowdown in economic growth and compensate them for this.

This essay suggests that a future lines of research could be a deeper analysis of the effect of corruption and globalisation on environmental degradation in African countries. Corruption may have direct and indirect effects on environmental degradation, through economic structures and income levels, respectively. Understanding the specific effect of corruption on the environment could be a useful tool for policy makers seeking to devise appropriate measures to mitigate corruption and its environmental impact. In addition to its environmental impact, corruption can render environmental regulation ineffective, when *de jure* measures developed by law, are not effectively implemented *de facto*. Thus, the analysis of the relationship between, *de jure* and *de facto* globalisation measures, corruption, and environmental regulation, could be an invaluable tool to reduce the harmful effects of corruption, and promote sustainable development.

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Chapter 5

The evolution of the Environmental Kuznets Curve hypothesis assessment: a literature review under a critical analysis perspective

Environmental changes based on factors like urbanization, population, economic growth, increase in energy consumption, and agricultural intensification are never far from the top of any agenda. The topics of environmental degradation and climate change cannot be confined to a single country or region but need to be addressed on a global scale. If the focus is on the relationship between environmental degradation and economic growth, then one hypothesis that is comprehensively used as an empirically model is the widely known Environmental Kuznets Curve. A substantial amount of research has been published about the Environmental Kuznets Curve, and this present essay provides a detailed and extensive literature review of more than 200 articles from 1998 to 2022 to explain and assess its evolution. This literature review provides in detail the Environmental Kuznets Curve relationship under analysis, the additional variables included, the type of analysis and methods performed, the relationships obtained, and if the turning point is calculated. Furthermore, this comprehensive literature points out critical issues and gaps in the Environmental Kuznets Curve analysis. It is important to note that there are components that are not considered in the Environmental Kuznets Curve analysis. The Environmental Kuznets Curve only focuses on production and overlooks the impact of the consumption of imported goods on the environment. Consequently, environmental improvements from technological progress will be offset, and economic growth will result in more environmental degradation. This goes against the change in consumer behaviour which occurs with a rise in income, which is one basic assumption of the Environmental Kuznets Curve. The relocation of pollutant industries and consequent relocation of emissions could distort the emissions trajectory over the economic growth path and is also not considered in the Environmental Kuznets Curve analysis. On the other hand, the growth path traced by the inverted U-shaped is not efficient, and the environmental damage provoked in the first phases of the EKC might not be repairable. Therefore, technological progress, climate finance, and energy transition could improve the Environmental Kuznets Curve assessment.

5.1 Introduction

In the pre-industrial period, the earth's carbon circle was considered balanced. However, once the industrial revolution was underway, the burning of fossil fuels provoked a substantial increase in greenhouse gas (GHG) emissions. Society's extreme dependence on fossil fuels came from the necessity to meet rising energy demand. In light of this, the creation of wealth and energy consumption, that is, the income *per capita* of a country and the amount of energy used became indissociable. Since economic growth relies on increasing energy consumption, it goes hand in hand with rising GHG emissions. Therefore, over decades, economic growth has been achieved to the detriment of the environment, leading to global climate change. The current pandemic situation provides further evidence of this relationship. With economic activity severely affected, global emissions in 2020 were lower than the previous year (IAE, 2021).

Global warming and climate change are primarily a consequence of anthropogenic behaviours. The production of goods, generation of energy, agricultural activity, transport, and the heating and cooling of buildings are responsible for the release of, on average, 51 billion tons of GHG emissions into the atmosphere each year. The planet's biocapacity has been exceeded, and society is living in a state of ecological transcendence (WWF, 2014). The rising risk of undesirable effects for human life, the economy and the environment come from increasing global warming. GHG emissions are the primary driver of and are responsible for rising global average temperature. GHG emissions have increased because of the growth of production, consumption, and population. Obsolete technology plays its part as well. The energy sector is strongly linked to the economy, policy, geopolitical demographics, financial market, and the environment (Mahmood, 2022a). Carbon dioxide emissions (CO_2), the primary greenhouse gas, are closely related to economic growth, human well-being, financial development, industrialization and urbanization (Sarkodie & Ozturk, 2020).

Throughout the years, there have been many discussions about the climate change path and the future of the environment. The Brundtland Commission (also known as the World Commission on Environment and Development (WCED)), in the Brundtland report of 1987, raised concerns about the capacity of the environment to satisfy the present and future needs of humanity (World Commission on Environment and Development, 1987). In such a way, a conflict between traditional economic development and environmental well-being arose (Holdren, J. & Ehrlich, P., 1974; Meadows, D., Meadows, D., Randers, & Behrens, W., 1972). Sustainable development includes appropriate care of the environment. Since the 1990s, mitigation strategies have been the focus of discussion in both developed and developing countries. To discuss these strategies, summits and agreements were established, such as the Earth Summit conference in 1992 and the Kyoto Summit in 1997. After these, the Conference of Parts (COP), particularly COP21 (Paris in 2015), became one of the most relevant conferences, where a limit on the increase of the global temperature of less than 1.5°C above pre-industrial levels was established, giving rise to the Paris Agreement. This agreement, which is an international treaty on climate change and is considered a valuable landmark in the climate change mitigation process, defined the necessity to meet every five years to re-evaluate the current state of climate change. The 26th United Nations Climate Change Conference of the Parties (COP26), five years apart from the Paris agreement, was the time for countries to strengthen climate action and define ambitious goals.

The Environmental Kuznets Curve (EKC) is one of the most prevalent methods to analyse environmental performance. The EKC is based on an inverted U-shaped curve created by Kuznets in 1955 (Kuznets, 1955). It was initially designed to study the relationship between income per capita and income inequality. The EKC became more popular when the inverted U-shape started to be adopted in environmental studies. Since then, it has been widely and intensely used as a theoretical framework to study the relationship between yield and environmental degradation (Grossman & Krueger, 1991). The emergence of the EKC provoked a change in environmental discussion focus. Before the EKC, concerns were focused on the limited capacity of the planet to absorb urban and industrial waste. With the EKC, the environmental concerns changed from environmental resource scarcity to the inevitable necessity of income growth to deal with pollution (Rashid Gill, Viswanathan, & Hassan, 2018).

The EKC defines the trajectory of pollution over time and the income resulting from the economic development of an economy (Shafik & Bandyopadhyay, 1992). Therefore, the EKC is commonly divided into three phases: the early stages of economic development, the turning point, and the later stages of economic development. Briefly (a detailed definition is provided in the following section), considering economic growth over time, the first phase is characterized by an intensive use of resources and a rapid increase in environmental degradation. The second phase, the turning point, is reached when a certain level of income is achieved, and a change in the pollution trajectory occurs, which leads to the third phase, characterized by environmental degradation mitigation. Bringing into mind the indissociable relationship described at the beginning of this section, the early stages of economic development represent that. However, when the turning point is reached, income starts to be dissociable from emissions and environmental degradation, leading to the later stages of economic development, where there is the dissemination of clean technology and innovation.

The EKC has been widely applied in the environment-energy-economics literature, and innumerable researchers have attempted to validate the inverted U-shaped between environmental degradation and income. Therefore, the EKC has been assessed for the most diverse contexts (country/ies, time span, variables, and methods) yet there is still no consensus on the results. With this in mind, this essay aims to answer the following research questions: (i) Is the EKC keeping up with the increasing complexity of environmental issues?; (ii) What has been influencing the inverted U-shaped curve?; and (iii) How can the fit of the EKC be improved to meet the complexity of the economic growth and environmental degradation relationship? To answer these questions, an extensive survey of the EKC literature is provided with the objective to (i) describe the evolution of the EKC assessment and provide an integrated overview of the current state of EKC knowledge; (ii) identify the factors that influence the EKC validation; and (iii) describe research insights, existing gaps, and provide improvement needs.

Overall, this essay intends to be a valuable tool for EKC researchers and is differentiated from the existing review articles by providing a detailed description of the EKC background, which includes the origins and conceptual framework, an explanation of the EKC shape, and the distinct phases of development, issues, and challenges of the EKC analysis, and the factors that most affect the EKC shape. Besides that, this essay also describes the close relationship between the EKC and the macroeconomic Green Solow Model. Furthermore, this literature review provides an embracing description of the evolution of the EKC analysis through an extensive literature survey and specifies each detail of the analysis of more than 200 articles from 1998 to 2022. The analysis of the EKC literature for this extended period allows us to understand what is currently analysed, in addition to the evolution of the EKC assessment over the years. This literature survey is being conducted so as to be an intuitive tool for researchers to efficiently find specific information about the procedures used in the literature focused on the EKC study, namely: (i) country(ies) and time period; (ii) variables analysed on EKC validity; (iii) additional variables included in the EKC analysis; (iv) types of analysis and method(s) employed; (v) relationships obtained, and (vi) turning point. This literature survey conducts a critical analysis of the EKC approach, identifying critical issues, proposing improvements, and future lines of research.

The sections of this chapter will be organized as follows. Section 5.2 presents the origins, conceptual framework and shape of the EKC. Section 5.3 follows, where the details of the evolution of the EKC analysis can be found. Section 5.4 describes the gaps in the EKC assessment, and lastly, in Section 5.5, the conclusions of the research are given.

5.2 Origins, conceptual framework, and shape of the EKC

The EKC was preceded by the Research of Kuznets (1955), on which the EKC is based. Simon Kuznets won a Nobel prize for his framework based on the economic and social structure of national development procedures (Roy Chowdhury & Moran, 2012). The results of the research of Kuznets (1955) disclosed an inverted U-shaped relationship between income per capita and income inequality. According to Kuznets (1955), the inverted U-shaped relationship revealed an unequal income distribution in the early stages of income growth that moves towards equal income distribution with increasing economic productivity in the later stages of economic growth. Therefore, Kuznets (1955) specified that the transition from a pre-industrial to an industrial development firstly led to income inequality. This is followed by a rising income per capita together with superior income equality. The EKC attracted a lot of attention from policymakers, theorists and empirical researchers and started to be widely used in environmental studies (Holtz-Eakin & Selden, 1995; Theodore Panayotou, 1993) through the seminal research of Grossman & Krueger (1991), carried out in 1991. They revealed that the relationship between income per capita and environmental degradation, like the income per capita and income inequality of Kuznets (1955), also follows an inverted U-shaped curve.

In the early 1990s, the main idea in economics was "*too poor to be green*" (Beckerman, 1992). According to Beckerman (1992) point of view regarding the effect of economic growth on environmental degradation, the author argues that there is: «*clear evidence that, although economic growth usually leads to environmental deterioration in the early stages of the process, in the end, the best and probably the only way to attain a decent environment in most countries is to become rich*». This view reflects the basic philosophy of the EKC theory. The World Development Report in 1992 argues that some environmental problems are aggravated by the growth of economic activity, and it suggests that accelerated equitable income growth will make it possible to achieve higher world output and improved environmental conditions (Ekins, 1993; World Bank, 1992). This proposal lays the foundation of the EKC literature. A robust foundation for the EKC is provided by Dinda (2004), D. I. Stern (2004b), and Kaika & Zervas (2013), and it is presented throughout this essay. Kwabena Twerefou, Danso-Mensah, & Bokpin (2017) and Olale, Ochuodho, Lantz, & El Armali (2018) provide a survey of theoretical research related to the EKC.

5.2.1 Conceptual framework of the EKC

The EKC is commonly interpreted in two ways. One is through the division into two phases, namely the early and later stages of economic development. The early stages are defined, on the one hand, by a decreasing capacity of ecosystem regeneration as a consequence of intensive use of resources that lead to a rising ecological footprint and pollution (Theodore Panayotou, 1993; Sarkodie & Strezov, 2018). On the other hand, the early stages are linked with lax environmental regulations associated with a low capacity to pay for environmental conservation (Dasgupta, Laplante, Wang, & Wheeler, 2002). The later stages are characterized by mitigation of environmental degradation resulting from the dissemination of clean technology and innovation, society environmental awareness, and effectiveness and institutional quality associated with an increase in the level of income (Theodore Panayotou, 1993; Sarkodie & Strezov, 2018). In addition, these stages are also characterized by two effects, i.e., policy effect and income effect. The policy effect consists of greater public concern about the environment, which leads to rigorous regulatory requirements. At the same time, the income effect consists of the increase in income that leads to an increase in the willingness to pay for environmentally-friendly features (Dasgupta et al., 2002). The other way that the inverted U-shaped curve is commonly interpreted is when economic development is divided into three phases of (Kaika & Zervas, 2013; Theodore Panayotou, 1993; Sarkodie & Strezov, 2019a), namely: (i) the pre-industrial economy, mainly characterised by primary sector and low levels of income; (ii) the industrial economy, constituted by the secondary sector and associated with middle-income levels; and (iii) the post-industrial economy, formed by the tertiary sector and services, and associated with higher levels of income. In the pre-industrial economy, economic activity is limited and results in a natural resource abundance and reduced formation of waste (Kaika & Zervas, 2013; D. I. Stern, 2004a). In this phase, the use of pollutant technology, the lack of environmental awareness, and the prioritisation of economic growth result in rising environmental degradation (Yandle, Vijayaraghavan, & Bhattarai, 2002). The industrial economy is characterised by natural resources that are starting to run out and increasing waste accumulation because of industrialisation. In this phase, a positive relationship between economic growth and environmental deterioration is verified, and it occurs before the turning point is achieved. The third phase of economic development is characterised by a structural change in the economy, changing to information- and technology-intensive industries and a services-directed economy. This change is linked with the reinforcement of environmental regulations, the use of cleaner and efficient technology, and a strengthening of environmental awareness, resulting in a mitigation of environmental degradation (Kaika & Zervas, 2013; D. I. Stern, 2004a). In this phase, a negative relationship between economic growth and environmental deterioration is verified, and it occurs after the turning point has been reached.

5.2.2 Shape of the EKC

The EKC consists of an inverted U-shaped curve between income and environmental degradation; that is, the EKC defines the pollution trajectory over time and income resulting from economic development (Shafik & Bandyopadhyay, 1992). The EKC is a long-run concept (S. P. A. Brown & McDonough, 2016). In light of this, the EKC reflects a dynamic environment–economy relationship concentrating on long-run processes of change (Bimonte & Stabile, 2017). The EKC is assessed through the nature of the effect of the income and its square (to ensure the concavity of the curve) on environmental degradation. The inverted U-shaped curve is validated through the significant and positive coefficient and elasticity of income simultaneously with the significant and negative coefficient and elasticity of income squared. Therefore, considering β_1 as the coefficient of income and β_2 as the coefficient of income squared, both in the longrun, the EKC is verified according to the condition $\beta_1 > 0 \wedge \beta_2 < 0$ (in which this essay is focused).

The assessment of the EKC could lead to the validity of the following conditions (see Figure 5.1):

1. $\beta_1 = \beta_2 = 0$. No relationship between x and y.

2. $\beta_1 > 0 \wedge \beta_2 = 0$. Linear relationship between x and y.

3. $\beta_1 < 0 \wedge \beta_2 = 0$. Decreasing relationship between x and y.

4. $\beta_1 < 0 \wedge \beta_2 > 0$. U-shaped relationship.

5. $\beta_1 > 0 \wedge \beta_2 < 0$. Inverted U-shaped relationship – EKC.

where, y is the environmental indicator and x is the income.

Besides these ones, two more conditions might be obtained in the EKC assessment. These two imply the inclusion of the third polynomial, income cubed (β_3).

6. $\beta_1 < 0,\ \beta_2 > 0 \wedge \beta_3 < 0$. Opposed to the N-shaped curve.

7. $\beta_1 > 0,\ \beta_2 < 0 \wedge \beta_3 > 0$. Cubic polynomial or N-shaped curve.

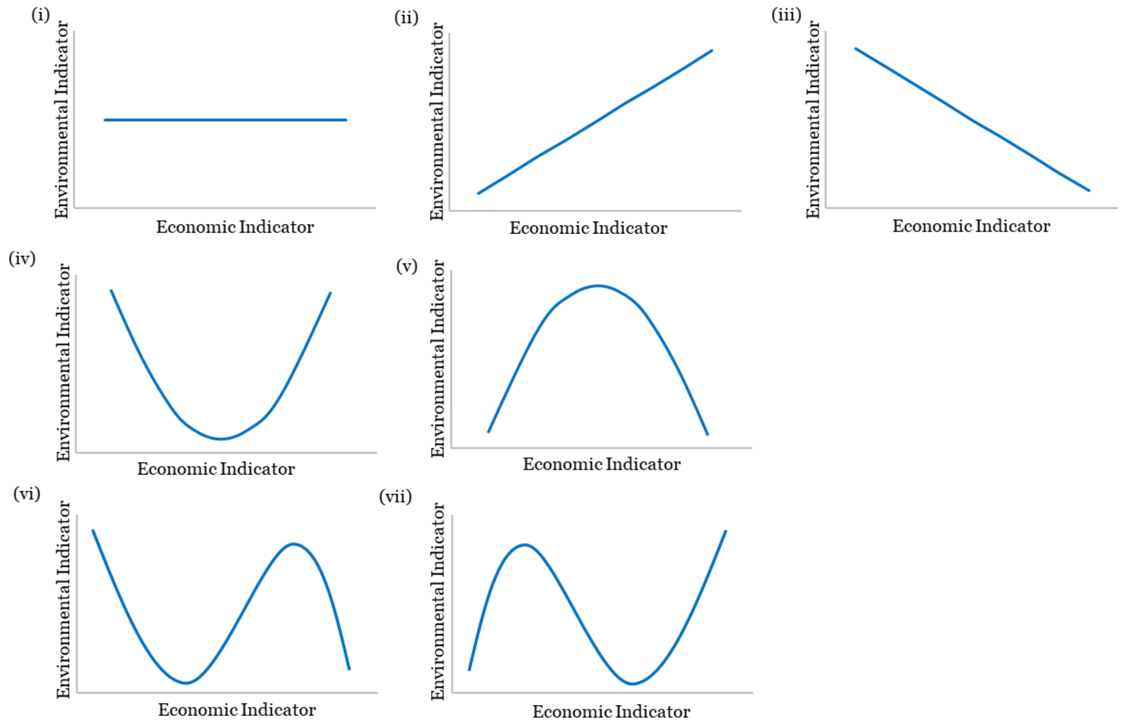

Figure 5.1 - Graphical representation of the relationship between an Environmental Indicator and an Economic Indicator.

Legenda: (i) No relationship between x and y; (ii) Positive relationship between x and y; (iii) Decreasing relationship between x and y; (iv) U-shaped relationship between x and y; (v) Inverted U-shaped relationship between x and y; (vi) Inverted N-shaped relationship between x and y; and (vii) N-shaped relationship between x and y.

Throughout the years, several authors have highlighted factors that affect the shape of the inverted U-shaped curve. Theodore Panayotou (1993), one of the first authors assessing the EKC hypothesis, disclosed that policy distortions, such as market breakdowns, under-pricing of natural resources, and subsidies on economic structures intensive in carbon and energy affect the slope of the inverted U-shaped curve. In turn, Kaika & Zervas (2013) identified the following factors: institutional framework and governance, consumers' preferences, and equity of income distribution. The willingness of governance to implement environmental regulation is considered crucial to mitigate environmental degradation (T. Panayotou, 1997). When governance institutions are weak, less effective or corrupted, this could affect the shape of a possible EKC and change the turning point to higher income levels (López & Mitra, 2000).

Many researchers have assessed whether the equity of income distribution affects the EKC pattern (Bimonte, 2002; Magnani, 2000; Torras & Boyce, 1998). To assess this, the crucial question is whether economic growth leads to equitable income distribution or increases income inequality. The automatic thought could be that economic growth leads to a more equitable income distribution that consequently leads to an improvement in public awareness of environmental degradation and the imposition of suitable environmental regulations. Income distribution is the distribution of power, and pollution decreases or increases depending on the gap of power between the citizens who suffer due to pollution and the ones that benefit from pollution (Torras & Boyce, 1998). Therefore, if income inequality worsens, this will lead to continuing environmental deterioration due to the fact that the ones who suffer from environmental degradation will not have the economic conditions to impose environmental regulations on the ones that would benefit from it (Bimonte, 2002).

In the recent literature, the factors most considered to affect the shape of the EKC are the scale, composition, and technique effect; income elasticity of environmental quality; and international trade (Sarkodie & Strezov, 2019a). The scale, composition, and technique effect are the three stages used to characterise the relationship between environmental degradation and economic development (Grossman & Krueger, 1991). The scale effect denotes environmental degradation as a consequence of economic development, that is, a negative impact of economic growth on the environment. The negative impact is a consequence of intensive use of natural resources to supply an increasing demand and consequent increasing production output. This intensive energy consumption comes mainly from fossil fuels that are a cheap, abundant, and easy-to-transport energy source. The composition effect is characterised by structural changes in the economy, which could provoke both negative and positive impacts of economic development on the environment. A change from an economy directed to the primary sector to energy- and carbon-intensive industries results in a negative impact. In contrast, a shift from pollution-intensive industries to an economy directed to the services sector results in a positive impact (Sarkodie & Strezov, 2018). The technique effect denotes a mitigation effect of economic development on environmental degradation. This is explained by a higher level of income that leads to investing in research and development, replacement of dirty and outdated technologies, and strengthened environmental regulations.

The income elasticity of environmental quality demand consists of the ratio between the variation in the environmental quality demand and the variation in income level. The role of this factor on environmental degradation mitigation is highlighted (Acaravci & Ozturk, 2010; Dinda, 2004; Sarkodie & Strezov, 2018). The income elasticity denotes that with rising economic development, society intuitively lives in a higher standard and yearns for quality instead of quantity. Therefore, there is greater environmental awareness and availability of money to pay for a cleaner environment (Baldwin, 1995), which leads to an adjustment in consumer behaviour, for instance, opting for energy-efficient and environmentally friendly products and services (Girod, van Vuuren, & Hertwich, 2014; Selden & Song, 1994) and donating to environmental protection organizations (Dinda, 2004).

International trade is considered one of the most crucial factors explaining and affecting the shape of the EKC, and the EKC pattern may appear as a result of it (Cole, 2004; Kearsley & Riddel, 2010; Suri & Chapman, 1998). In light of this, trade policies are crucial to explain the EKC. Trade openness leads to economic expansion through the request to increase the production of goods to satisfy its exports. Broadly speaking, countries tend to become specialized in sectors in which they have a competitive advantage as a consequence of trade liberalization. However, on the one hand, if these sectors derive from weak environmental regulation, trade liberalization induces environmental damage, which consequently results in an industrial process with high pollution abatement costs (Grossman & Krueger, 1991). On the other hand, when income and environmental degradation significantly increase, stringent environmental regulations are imposed and implemented, which consequently lead to the shift of pollution-intensive goods production to other countries. These countries are usually low-income countries with weak and lax environmental legislation (Dinda, 2004; Kaika & Zervas, 2013). This is defined as the Pollution Haven Hypothesis (PHH). The lax environmental regulation in the developing countries provides a comparative advantage for the developed economies, which leads to the reduction of environmental degradation in the developed economies while increasing it in the developing ones (Sarkodie & Strezov, 2019b). An inverted U-shaped curve is obtained through two phases. Firstly, the export of goods in a developed country causes the upwards slope of the curve (early stages of economic development). After that, the import of goods from developing countries causes the downward slope of the curve (later stages of economic development). The downward slope of the curve is reported as the PHH (Dinda, 2004).

5.2.3 The EKC and the Green Solow model

The assessment of the EKC occurs through the analysis of environmental degradation over an increasing income. Economic growth is a macroeconomic indicator, and the Solow Model is considered the main model of modern macroeconomics. Brock & Taylor (2010) developed a theoretical framework to explain the EKC. By incorporating environmental pollution into the Solow Model (Solow, 1956), the authors created the Green Solow Model. According to Brock & Taylor (2010) pollution data and their empirical work on the EKC, three dilemmas were revealed, and the Green Solow Model provides an explanation for each one. The dilemmas are namely: (i) the ongoing huge decline in emissions intensity simultaneously with almost stagnant pollution abatement costs; (ii) what feature gives the humped-shape profile to the pollution levels when it is graphically represented against income per capita or time; and (iii) the fragile empirical results of cross-country analysis indicate that the EKC is not validated, or the problem is applying empirical approaches that are subject to extensive variance.

To assess the first dilemma, the authors (Brock & Taylor, 2010) analysed two concrete cases, the United States (US) and Europe. In both cases, while a huge variation in emissions occurred, an insignificant variation in the pollution abatement expenditures/costs was observed. However, in both cases, the EKC pattern is graphically visible when emissions are graphed against time and an income increase over the same period is considered (Brock & Taylor, 2010). In the US, a huge variation in emissions has taken place over the last 20 years while simultaneously, pollution abatement costs have remained at less than one-half of 1% of Gross Domestic Product (GDP) for the same time period (Vogan, 1996). In Europe, an emissions reduction of 4 - 5% per year has been observed alongside a pollution control cost with an average of only 1 - 2% of GDP. To provide answers to this dilemma, the authors considered exogenous technological progress in abatement and a fixed intensity of abatement.

Theories based on strict environmental policies expect growing costs to mitigate environmental degradation. In a scenario of a world that does not have technological progress for this, a huge investment in pollution control is needed (Stokey, 1998). Technological progress in goods production and abatement leads to continual growth alongside increasing environmental quality. Through the formulation and development of the model, the authors conclude that technological progress in goods production is required to produce income growth. Besides that, technological progress in abatement must go above growth in aggregate output for pollution to decrease and, consequently environmental quality to increase. These two conditions make sustainable growth guaranteed. In light of this, technological progress in abatement increases the effectiveness of the share of output applied to reducing environmental damage. Output growth results in an increase in emissions; however, then emissions decrease as technology is applied to offset environmental damage.

The second dilemma refers to the feature that gives the humped-shaped profile to emissions when graphed against time or income. This dilemma consists of the analysis of the existence of the turning point, which allows the humped-shaped through inverting the emissions' trajectory. Through the Green Solow Model, and as mentioned in the first dilemma, sustainable growth is guaranteed when technological progress exists in production (it is essential to produce income growth), and when technological progress in abatement goes further than the growth of aggregate output (this mitigates pollution). In addition, by recurring to the Cobb-Douglas function, Brock & Taylor (2010) conclude that if an economy has small initial capital stock, then emissions firstly increase and then start to decrease as development continues. Therefore, the emissions humped-shaped EKC profile is obtained if growth is sustainable, and simultaneously the stock of capital at the turning point is higher than the initial stock of capital. This leads to an initial positive growth rate of aggregate emissions that become negative in finite time. The answer to the first dilemma also helps in understanding the second dilemma. Through technological progress in abatement, a time profile of increasing and then decreasing emissions, with income per capita growing along a path of sustainable growth, is generated.

The third dilemma is related to the variation that samples and the estimation procedure provoke on the EKC empirical regressions. The answer for this dilemma starts in the second dilemma by recurring to the Cobb-Douglas function to assess the initial conditions, which are the initial technological progress in goods production, labour and units of pollution. Different profiles of income per capita and emission over time are obtained as a consequence of economies with different initial conditions. Considering this, heterogeneity could explain the sensitivity of the EKC results to the sample. Therefore, this explains the absence of a consensus on the EKC results in country-level data and the possible difference between the EKC empirical results in cross-country analysis and the country-level analysis of the same countries. The cross-country analysis that includes developed and developing countries is a plausible example to demonstrate the effect of heterogeneity. Clearly, these countries differ in more than the initial condition. The heterogeneity in this analysis may further confound the estimation. According to the EKC literature, the time period, the countries sampled, and even the environmental indicator chosen could provoke a change in the shape of the estimated EKC. Even for similar countries, the EKC profiles are not unique due to the differences in the initial conditions.

5.3 Getting inside the evolution of EKC analysis

The first literature on the theory of the EKC was focused on developing models that replicated the inverted U-shaped curve relationship. Considering the increasing complexity of reality (such as technological development, the introduction of renewable energy sources in the energy sector, increasing industrialization and globalisation) the EKC analysis has had to be continuously improved. Throughout the EKC literature, diverse literature surveys were developed. However, on the one hand, most of the articles that provide a comprehensive contextualization of the EKC literature are not focused on the EKC theoretical background or critical analysis, instead, they are focused on an empirical analysis (Kacprzyk & Kuchta, 2020; Mosconi et al., 2020; Moutinho, Varum, & Madaleno, 2017; Mrabet & Alsamara, 2017). On the other hand, articles focused on the evolution of the EKC literature use specific approaches to assess the EKC literature, such as meta- and bibliometric analysis (Anwar et al., 2022; Saqib & Benhmad, 2021; Sarkodie & Strezov, 2019a), which provide the research areas on the subject, the author's contribution and most cited authors, journals that are publishing on the subject, and keywords used. Differentiated from these, the present essay is focused on providing an extensive and comprehensive contextualization of the EKC framework, the evolution of the literature, current analysis, and critical analysis that addresses gaps, issues, and improvement needs. Besides that, and as a prominent contribution to the literature, this essay provides a useful and intuitive tool for EKC researchers where they can find detailed information about the EKC analysis in more than 200 articles since the country(ies) and time period under analysis, and the variables for each EKC relationship is analysed, until each additional variables included, the types of analysis and method(s) employed, the relationship obtained for each sample analysed, and if the turning point is calculated.

The procedure for an analysis of the EKC focuses on two key areas: the selection of the EKC relationship variables and the selection of the EKC functional specification. The latter includes the method, additional variables, temporal period, and cross-country or individual analysis. This section demonstrates how the selection of each element has progressed in the EKC literature. Some examples are displayed in tables (just a few examples from the substantial number of articles presented in the tables in the Appendix 5), providing an organised and intuitive literature review of the EKC literature. The tables are organized into the EKC relationship analysed, approaches used, additional variables included, countries analysed (individual or cross-country), and the relationship obtained. This schematisation allows not only an observation of the evolution of the EKC analysis but also an identification of gaps in the analysis. The third dilemma identified by Brock & Taylor (2010) regarding the variation that the sample and the estimation procedure provoke on the EKC empirical regressions is also explored.

5.3.1 The EKC relationship: From environmental to other types of indicators

The variables selected to assess the EKC, that is, the variables for which a relationship that follows the EKC is assessed, are originally an environmental indicator and an economic indicator. However, over the years, in place of the environmental indicator, several other types of indicators have been used to assess the EKC. Considering the EKC literature collected in this essay, the relationship between CO_2 emissions and GDP is the most frequently analysed (Akalpler & Hove, 2019; Aslam et al., 2021; Kim, Suen, & Lin, 2019;

Ma, Ahmad, & Oei, 2021; Rahman, 2020; Sarkodie & Ozturk, 2020) (see Appendix 5), which makes CO_2 emissions the environmental indicator most often used (about 100 articles out of 200 collected in this essay). Notwithstanding, throughout the years, innumerable environmental indicators have been used to assess the EKC, such as air pollution, ecological footprint, waste, afforestation, water consumption, and others. However, not only are environmental indicators assessed. Besides these indicators, also energy consumption, pollution abatement costs, environmental crimes, and health indicators have been analysed. In Table 5.1, the diversity of EKC relationships analysed are displayed.

Table 5.1 - Variables of EKC relationship

Environmental indicators	
(Adzawla, Sawaneh, & Yusuf, 2019)	(i) CO_2 emissions – GDP (ii) Ammonium – GDP (iii) Nitrous Oxide – GDP
(Aydin, Esen, & Aydin, 2019)	6 Footprint components (Built, Carbon, Cropland, Fishing, Forest, Grazing) – GDP
(Gui, Zhao, & Zhang, 2019)	Municipal Solid Waste – GDP
(Hao, Xu, et al., 2019)	(i) Timber output – GDP and FDI (ii) Afforestation Area – GDP and FDI
(Mahmood, 2022b)	(i) Territory-based CO_2 emissions – GDP (ii) Consumption-based CO_2 emissions – GDP
(J. Zhao, Zhao, & Zhang, 2019)	(i) Sulphur Dioxide emissions- GRP (ii) Industrial Solid Waste - GRP (iii) Industrial Wastewater Discharge – GRP
(S. Chen, Zhang, Zhang, & Liu, 2019)	Haze Pollution - GDP
(Hao, Hu, & Chen, 2019)	(i) Water Consumption – GDP (ii) Industrial Water Consumption – GDP (iii) Non-Industrial Water Consumption – GDP

Other types of indicators	
(Suri & Chapman, 1998)	Consumption of Primary Commercial Energy - GDP
(Andreoni & Levinson, 2001)	Pollution Abatement Costs - Gross State Product
(Alam & Paramati, 2016)	Income Inequality - Tourism Revenue
(Pata & Balsalobre-Lorente, 2022)	Load Capacity Factor – GDP
(Mahmood, Alkhateeb, Tanveer, & Mahmoud, 2021)	(i) Primary Energy Consumption - GDP (ii) Oil Consumption - GDP (iii) Natural Gas Consumption - GDP (iv) Coal Consumption - GDP (v) Hydroelectricity Consumption - GDP
(Pablo-Romero & De Jesús, 2016)	Energy Consumption - GVA
(Kurniawan & Managi, 2018)	Coal Consumption - GDP
(Nguyen & Kakinaka, 2019)	(i) Renewable Energy Consumption - GDP (ii) Non-Renewable Energy Consumption - GDP

(Ding, Zhang, Chen, Wang, & Nie, 2019)	$PM_{2.5}$ emissions - GRP
(Haug & Ucal, 2019)	(i) CO_2 emissions – GDP (ii) CO_2 Intensity – GDP (iii) CO_2 emissions by sector – GDP
(Miao, Gu, Zhang, Zhen, & Wang, 2019)	Residential CO_2 emissions - GDP
(L. Zhang, Pang, Chen, & Lu, 2019)	Agricultural CO_2 emissions – Agricultural Economic Growth
(Liang & Yang, 2019)	(i) Wastewater Discharge – GDP (ii) Wastewater Discharge – Urbanization
(Q. Chen & Taylor, 2020)	Chromium – GDP
(Ike, Usman, & Sarkodie, 2020)	(i) CO_2 emissions of solid – GDP (ii) CO_2 emissions of liquid – GDP (iii) CO_2 emissions of gaseous – GDP (iv) CO_2 emissions aggregate – GDP
(L. Brown, McFarlane, Campbell, & Das, 2020)	CO_2 emissions – Remittances
(Tenaw & Beyene, 2021)	(i) Environmental Degradation Index – HDI (ii) Ecological footprint – HDI
(Li, Qiao, Li, & Wang, 2022)	(i) CO_2 emissions – GDP (ii) Sulphur Dioxide – GDP (iii) Volatile Organic Compounds – GDP (iv) Nitrogen Oxides – GDP (v) Carbon Monoxide – GDP

(Pothen & Welsch, 2019)	(i) Domestic Material Consumption – GDP (ii) Material Footprint - GDP
(Hien, 2019)	Electricity Intensity - GDP
(Dyrstad, Skonhoft, Christensen, & Ødegaard, 2019)	Fossil Fuel Electricity Production - GDP
(Deichmann, Reuter, Vollmer, & Zhang, 2019)	Energy Intensity - GDP
(Borozan, 2019)	Final energy Consumption in Households - GDP
(Kibria, Akhundjanov, & Oladi, 2019)	Fossil fuel share in energy mix - GDP
(Germani, Ker, & Castaldo, 2020)	(i) Environmental Crimes - GDP and Education (ii) Environmental Crimes - Household income and Education
(Xu, Yiwen, Cheng, Li, & Zhang, 2020)	Noise Pollution – GDP
(Boubellouta & Kusch-Brandt, 2020)	(i) E-waste – GDP
(S. A. R. Khan, Zaman, & Zhang, 2016)	Energy-Resource Depletion: (i) Energy Depletion – GDP (ii) Net Forest Depletion – GDP (iii) Natural Resource Depletion – GDP Climate Change: (iv) Perfluorocarbon emissions – GDP (v) $PM_{2.5}$ emissions – GDP (vi) Sulphur Hexafluoride emissions – GDP (vii) GHG emissions – GDP

(Sheikhzeinoddin, Tarazkar, Behjat, Al-mulali, & Ozturk, 2022)	Composite Index of Environmental Performance – GDP		Health Resources: (viii) Tuberculosis – GDP (ix) Infant Deaths – GDP (x) Health Expenditures - GDP

Notes: FDI denotes Foreign Direct Investment; GHG denotes Greenhouse Gases GRP denotes Gross Regional Product; GVA denotes Gross Value Added; HDI denotes Human Development Index; $PM_{2.5}$ denotes Particulate Matter (2.5 micrometres).

In respect of the environmental indicators, choosing among diverse indicators of environmental degradation is challenging considering the complexity and multiple dimensions of environmental problems. Therefore, the selection of an indicator takes place between numerous types; however, atmospheric indicators have been the most abundant. This type of indicator includes emissions of CO_2, GHG, Nitrous Oxide (N_2O or NO_2), and others. The pollutant under analysis could be local or global. Some studies use local pollutants, such as Sulphur Dioxide (SO_2), water pollution and deforestation, while others use global pollutants, such as CO_2 emissions. Environmental degradation indicators are the most often chosen to assess the EKC. However, the indicator does not have to be of degradation; it could be of environment recovery, concern, or protection. Besides the atmospheric indicators, (i) land and forests; (ii) oceans, seas, coasts, and biodiversity; and (iii) freshwater indicators have also been analysed (Sarkodie & Strezov, 2019a).

The various indicators used in assessing the EKC relationship throughout the literature have given rise to different forms of this model. Consequently, the EKC concept is often converted depending on the type of indicator used in the relationship. Energy indicators (e.g. renewable energy consumption, non-renewable energy consumption, energy consumption, energy intensity, and others) are frequently used to assess the EKC relationship, from which emerge adaptations of the EKC depending on the energy indicator used, such as the Renewable Kuznets Curve. Therefore, it is common in the literature to see adaptations from the EKC linked to the specific indicator used instead of the usual environmental indicators. Throughout this essay, several EKC forms are addressed (see Table 5.1 and Appendix 5).

The selection of the EKC relationship to analyse is one of the first steps in EKC studies, and this choice influences the validation of the EKC. The empirical results of the EKC are not unique, and they are sensitive to the variables under analysis, as is the type of pollutant. One example of that is the study developed by Shafik & Bandyopadhyay (1992), which analysed ten indicators of environmental pressure, and from these ten, only two followed the EKC. In light of this, it is notable to mention the degree of sensitivity of the EKC regarding the environmental degradation indicator under analysis. Another example is the study developed by Altıntaş & Kassouri (2020), which analysed the EKC relationship between CO_2 emissions and GDP, and ecological footprint and GDP, for the same samples of countries and time period, and with the same approaches. They obtained different results for each environmental indicator. Ecological footprint validated the EKC, while CO_2 emissions revealed a U-shaped curve. The selection of the environmental indicator or other indicator used in the EKC analysis gives rise to a gap in the literature, which confirms that the inverted U-shaped curve (EKC) is only demonstrated for some environmental indicators. This is, according to Liu (2012), due to the lack of consistent data, assessing the EKC for industrial pollution and human health had not been possible.

Besides the immense variety of environmental or other types of indicators applied in the hypothesis, variables chosen for the economic indicator also have been diverse, although not to the same extent. GDP is the most frequent economic indicator used in the EKC relationship. However, over the years, other indicators have been used, such as Gross Regional Product (GRP), Foreign Direct Investment (FDI), Gross Value Added (GVA), Gross State Product, income inequality, economic complexity index (Pata, 2021), air transport passenger (Balsalobre-Lorente, Driha, Leitão, & Murshed, 2021), manufacturing sub-sector output (Abokyi, Appiah-Konadu, Tangato, & Abokyi, 2021), Oil Rents (Mahmood & Furqan, 2021), and others. In the selection of the economic indicator, not only does the indicator used in the EKC relationship influence its validation, but also the data analysed. Kacprzyk & Kuchta (2020) developed an analysis using different GDP data for analysing the EKC between GDP and CO2 emissions. The use of three different measures of GDP revealed mixed results.

5.3.2 EKC functional specification: approach, additional variables, time period and countries sample

After selecting the variables to assess the EKC relationship, follows the adoption of the functional specifications, which consists of choosing the method/approach and the structure of the model. The structure of the model includes the additional variables beyond the variables of the EKC relationship, the time period, and the sample of countries to analyse.

5.3.2.1 Additional variables

The additional variables are those included in the estimation beyond the variables for which the EKC relationship is assessed. With the increasing complexity of reality, the additional variables included in the estimations are innumerable and of several types. According to Kaufmann, Davidsdottir, Garnham, & Pauly (1998) and Itkonen (2012), the inclusion of additional controls influences the EKC assessment and the results of the EKC estimation. Table 5.2 displays a summary of the additional variables.

Table 5.2 - Additional variables

Energy	Renewable energy consumption; Non-renewable energy consumption; Energy consumption; Energy consumption by sector; Oil consumption; Coal consumption; Biomass energy consumption; Hydroelectricity consumption; Agricultural energy consumption; Electricity consumption; Nuclear electricity output; Electricity production from non-renewable sources; Renewable electricity production; Energy Intensity; Energy price; Energy efficiency; Electrification; Energy taxes; Energy innovation.
Economic	Trade openness; Imports; Exports; Unemployment; FDI; Industry added value; Agriculture added value; Gross capital formation; Financial development; Share of manufacturing in GDP; Industrialization; Fiscal policy index; Income inequality; Corruption; Risk of poverty; Governance; Gross saving; Government expenditure on educations; Economic complexity index; Oil price; Merchandise trade; Labour productivity; Regulation; Tourism; Index of economic freedom of Heritage Foundation; Sanitation investment; Industrial structures; Education; Human Development Index; Political stability; Government effectiveness; Total factor productivity; Economic stability; Health expenditures; Research and development.
Environment	Environmental cleaning capacity; Atmospheric environmental regulations; Greening level; Cooling degree days; Temperature over three summer months; Temperature over three winter months; Climate conditions; Water resources; Green patent counts; Environmental regulation; Quality of the institutional environment; Biocapacity; Stringency of environmental regulation; Enforcement of environmental regulations.
Technology	Technological innovation; Information and communication technologies; Technology level.
Sociodemographic	Population density; Population; Urbanization; Ratio of Females; Age ranges; Geographical location; Globalisation; Area; Density.

Energy consumption quickly became the most common variable added to the EKC estimations (Apergis & Payne, 2009; Arouri, Ben Youssef, M'henni, & Rault, 2012; López-Menéndez, Pérez, & Moreno, 2014; Pao & Tsai, 2010; Wang, Zhou, Zhou, & Wang, 2011). Considered as one of the main drivers of environmental degradation and climate change, energy consumption has been analysed with most of the environmental indicators. The analysis of energy consumption has improved over the years. It started with the analysis of energy consumption in its aggregate form, as a whole, and evolved by analysing energy consumption by types of technology, renewable and non-renewable, and after that by energy sources, such as coal, oil, gas, nuclear, solar, wind, and others. The inclusion of energy consumption in the EKC assessment keeps up with any improvement in energy consumption analysis (Antonakakis, Chatziantoniou, & Filis, 2017; Danish, Zhang, Wang,

& Wang, 2017; Dong, Sun, & Dong, 2018; Mahmood, 2022; Marques, Fuinhas, & Leal, 2018; Sarkodie & Adams, 2018). However, the inclusion of energy consumption as one of the CO2 emissions determinates could cause an underestimation of both the sensitivity of CO2 emissions to income growth and the turning point of the EKC (Itkonen, 2012; Jaforullah & King, 2017). This occurs because the two data series are related by construction. Consequently, any other variable included in the model can only explain the carbon intensity of energy consumption and not the CO2 emissions level (Itkonen, 2012).

5.3.2.2 Approach or method

At the beginning of the EKC literature, countless studies focused on the proximate aspects of the theory, which consequently took to reduced-form models. These models connect income and pollution directly through estimations and tests of correlations between indices of environmental condition and development (Grossman & Krueger, 1994). The reduced-form models are simpler and are of limited utility (Roy Chowdhury & Moran, 2012). Therefore, the need arose to improve the EKC analysis, and the studies started to employ structural equation models and included intervenient variables, which in turn, connected development processes with environmental outcomes. In light of this, and until the present day, the EKC has been assessed through innumerable approaches/methods and econometric procedures. Table 5.3 displays some examples of the methodologies applied (more examples are given in the Appendix 5).

Table 5.3 - Approaches performed

Time series data		Panel data	
(Pao & Tsai, 2010)	(i) VECM (ii) GARCH	(Farhani, Mrizak, Chaibi, & Rault, 2014) (Ma et al., 2021)	(i) FMOLS (ii) DOLS (iii) VECM
(Pata & Aydin, 2020)	(i) Toda–Yamamoto (ii) Fourier Toda–Yamamoto	(Işik et al., 2020)	AMG
(Ozturk & Acaravci, 2010) (Acaravci & Ozturk, 2010) (Shahbaz, Lean, & Shabbir, 2012)	(i) ARDL (ii) Granger causality	(Pao & Tsai, 2010)	(i) VECM (ii) GARCH
(Soytas, Sari, & Ewing, 2007)	(i) Toda–Yamamoto (ii) Generalized Forecast Error Variance Decomposition (iii) Generalized Impulse Response	(Martínez-Zarzoso & Bengochea-Morancho, 2004)	(i) PMG (ii) MG (iii) DFE (iv) SFE
(Pao & Tsai, 2011)	OLS	(Apergis & Payne, 2009) (Apergis & Payne, 2010)	FMOLS
(Robalino-López, Mena-Nieto, García-Ramos, & Golpe, 2015)	DOLS	(Andreoni & Levinson, 2001)	OLS

(Bölük & Mert, 2015) (Sugiawan & Managi, 2016) (Shahbaz, Mallick, Mahalik, & Loganathan, 2015) (Simionescu, Strielkowski, & Gavurova, 2022)	ARDL
(Danish et al., 2017)	(i) ARDL (ii) DOLS (iii) FMOLS (iv) CCR (v) VECM
(Ertugrul, Cetin, Seker, & Dogan, 2016) (Farhani, Chaibi, & Rault, 2014) (Aslam et al., 2021)	(i) ARDL (ii) VECM
(Dong, Sun, Jiang, & Zeng, 2018)	(i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR (v) VECM (vi) Sasabuchi–Lind–Mehlum U test
(Abokyi et al., 2021)	(i) ARDL (ii) DOLS (iii) FMOLS (iv) Lind and Mehlum test
(Shahbaz, Kumar, Jawad, & Shahzad, 2019)	Coefficient of Cross–Correlation
(Sun, Yesilada, Andlib, & Ajaz, 2021)	Quantile ARDL
(Tajudeen, Wossink, & Banerjee, 2018)	STSM
(Haug & Ucal, 2019)	(i) NARDL (ii) ARDL
(Pata & Balsalobre-Lorente, 2022)	Dynamic ARDL
(Suri & Chapman, 1998) (Luzzati & Orsini, 2009)	FGLS
(Rehermann & Pablo-Romero, 2018)	(i) FGLS (ii) GMM
(S. Khan, Peng, & Li, 2019)	(i) SUR (ii) GMM (iii) 2SGMM (iv) SYS–GMM (v) Sys2Step
(Yang, Huo, Saqib, & Mahmood, 2022)	(i) FE-OLS (ii) FMOLS (iii) DOLS (iv) MMQR
(Li et al., 2022)	(i) PCSE (ii) GLS
(W. Zhao, Liu, & Huang, 2022)	(i) CS-ARDL (ii) AMG (iii) CCEMG
(Dhrifi, Jaziri, & Alnahdi, 2020)	Simultaneous–equations
(Dyrstad et al., 2019)	Partial adjustment model
(J. Zhao et al., 2019)	(i) Pooled OLS (ii) SDM
(S. Chen et al., 2019)	SGVAR
(Gui et al., 2019)	(i) SLM (ii) SEM (iii) LSDV (iv) Convergence
(Adzawla et al., 2019)	(i) VAR (ii) OLS

Notes: ARDL denotes Autoregressive Distributed Lag; CCEMG denotes Common Correlated Effects Mean Group; CCR denotes Canonical Cointegrating Regression; CS denotes Cross-Sectional; DFE denotes Dynamic Fixed Effect; DOLS denotes Dynamic Ordinary Least Square; FGLS denotes Feasible General Least Squares; FMOLS denotes Fully Modified Ordinary Least Square; GARCH denotes Generalized Autoregressive Conditional Heteroskedasticity; GLS denotes Generalized Least Squares; GMM denotes Generalized Method of Moments; LSDV denotes Least Square Dummy Variable; MG denotes Mean Group; MMQR denotes Method of Moments of Quantile Regression; OLS denotes Ordinary Least Square; NARDL denotes Nonlinear Autoregressive Distributed Lag; PCSE denotes Panel Corrected Standard Errors; PMG denotes Pooled Mean Group; SDM denotes Spatial Durbin Model; SEM denotes Spatial Error Model; SFE denotes Static Fixed Effect; SGVAR denotes Semi-Parametric Global Vector Autoregressive Model; SLM denotes Spatial Lag Model; STSM denotes Structural Time Series Model; SUR denotes Seemingly Unrelated Regression; SYS-GMM denotes System Generalized Method of Moments; Sys2Step denotes Two-Step Dynamic System Generalized Method of Moments; VAR denotes Vector Autoregressive Model; VECM denotes Vector Error Correction Model; 2SGMM denotes Two-step Dynamic Generalized Method of Moments.

The econometric issues are one of the main topics criticised in the EKC estimation. Therefore, the methods employed in the EKC analysis give rise to significant criticism. The EKC is commonly estimated through reduced-from regressions, which is frequently disparaged by several researchers (Ben Youssef, Hammoudeh, & Omri, 2016; Copeland & Taylor, 2004; D. I. Stern, Common, & Barbier, 1996). Furthermore, empirical EKC research commonly uses standard cointegration techniques that are often considered unsuitable (D. I. Stern, 2004b; Wagner, 2008, 2015). Kacprzyk & Kuchta (2020) provide further explanations for this inadequacy. According to Rashid Gill et al. (2018), the EKC literature is not econometrically demanding, and the empirical results of the EKC analysis are very sensitive regarding the functional form of the model. Considering this, it is fair to say that the EKC assessment is sensitive and influenced by the model or econometric procedure used (please see Table 5.6 displays several examples of this).

Underlined in Table 5.6 are examples of studies that use more than one methodology and obtain different results for the same country, depending on the methodology applied. In the study developed by Bilgili, Koçak, & Bulut (2016) two methodologies are used, Dynamic Ordinary Least Square (DOLS) and Fully Modified Ordinary Least Square (FMOLS) and 17 Organisation for Economic Co-operation and Development (OECD) countries are analysed. In the individual countries analysis, different results are obtained for Turkey, France and Netherlands. With the FMOLS, a U-shaped relationship was obtained for Turkey, while an inverted U-shaped curve (EKC) was obtained for France and Netherlands. However, with the DOLS, an inverted U-shaped curve (EKC) was obtained for Turkey. In contrast, a U-shaped relationship was obtained for France and the Netherlands.

Another example is the study developed by Destek & Sinha (2020). Two methodologies were used to assess the EKC in the individual countries´ analysis, namely FMOLS and Common Correlated Effects (CCE). Through both approaches, FMOLS and CCE, a U-shaped curve relationship was obtained for Austria, Canada, Greece, Italy, Japan, S. Korea, Spain and the US, while an inverted U-shaped curve relationship was revealed for Germany and Turkey. However, for Belgium, Switzerland, Denmark, and the Netherlands, only one of the two methodologies obtained a U-shaped curve relationship. The same for Chile, France, Mexico, New Zealand, Portugal, and the United Kingdom, where only one of the two methodologies obtained an inverted U-shaped curve relationship.

5.3.2.3 Countries sample

The EKC has been assessed for several individual countries (see Table 5.4) or groups of countries (see Table 5.5).

Table 5.4 - Individual analysis

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
(Işik et al., 2020)	Canada, France, Germany, Italy, Japan, the UK, and the US (1995–2015)	CO_2 emissions – GDP	(i) Renewable EC (ii) International Tourism	(Time series) AMG		√ France		
(L. Brown et al., 2020)	Jamaica (1976–2014)	CO_2 emissions – Remittances	–	(Time series) (i) ARDL (ii) NARDL		√		
(Aslam et al., 2021)	Malaysia (1971–2016)	CO_2 emissions – GDP	(i) Globalisation (ii) Industrialization (iii) TO	(Time series) (i) ARDL (ii) VECM		√		
(Pata, 2021)	USA (1980–2016)	(i) EF – Economic Complexity Index (ii) CO_2 emissions – Economic Complexity Index	(i) Non–Renewable EC (ii) Renewable EC (iii) Globalisation	(Time series) (i) FMOLS (ii) DOLS (iii) CCR		√		
(Pata & Caglar, 2020)	China (1980–2016)	(i) CO_2 emissions –GDP (ii) EF – GDP	(i) Human Capital (ii) Globalisation (iii) Renewable EC (iv) TO	(Time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR	√			
(Ardakani & Mohsen, 2019)	Algeria, Bahrain, Iran, Kuwait, Oman, Qatar, and Saudi Arabia (1995–2014)	CO_2 emissions – GDP	Electric Power Consumption	(Time series) Multivariate Regression	√ Algeria and Bahrain	√ Oman, Qatar, and Saudi Arabia		

(Y. Zhang, Chen, Wu, Shuai, & Shen, 2019)	Manufacturing and Construction Industries of 121 Countries (1960–2014)	(i) CO_2 intensity – GDP (ii) CO_2 emission per capita – GDP (iii) total CO_2 emission – GDP	–	(Time series) OLS		√ 95 of 121 Countries – CO_2 Intensity and CO_2 emission per capita √ 92 of 121 Countries – total CO_2 emissions		
(Shokoohi, Dehbidi, & Tarazkar, 2022)	Iran, Iraq, and Turkey (1971-2015)	(i) CO_2 emissions – GDP (ii) EF – GDP	(i) Energy Intensity (ii) TO	(Time series) ARDL	√ Iran and Iraq - CO_2	√ Iran, Iraq, and Turkey - EF √ Turkey - CO_2		
(Laverde-Rojas, Guevara-Fletcher, & Camacho-Murillo, 2021)	Colombia (1971-2014)	CO_2 emissions – GDP	(i) Economic Complexity Index (ii) EC (iii) TO (iv) FDI	(Time series) (i) VECM (ii) DOLS (iii) FMOLS (iv) CCR	√ CCR, DOLS	√ FMOLS		

Notes: AMG denotes Augmented Mean Group; ARDL denotes Autoregressive Distributed Lag; CCR denotes Canonical Cointegrating Regression; DOLS denotes Dynamic Ordinary Least Square; EC denotes Energy Consumption; EF denotes Ecological Footprint; FMOLS denotes Fully Modified Ordinary Least Square; NARDL denotes Nonlinear Autoregressive Distributed Lag; OLS denotes Ordinary Least Square; TO denotes Trade Openness; UK denotes United Kingdom; US denotes United States; VECM denotes Vector Error Correction Model.

Table 5.5 - Cross-country analysis

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
(Danish, Baloch, & Wang, 2019)	BRICS Countries (1996–2017)	CO_2 emissions – GDP	(i) Governance	(panel) (i) OLS (ii) DOLS (iii) PMG		√		

(Du, Li, & Yan, 2019)	71 Countries (1996–2012)	CO_2 emissions – GDP	(i) Urbanization (ii) Industrial Structure (iii) TO (iv) EC Structure (v) Green Patent Counts (vi) Output Gap Ratio	(panel) OLS–FE		√		
(S. Khan et al., 2019)	193 Countries (1990–2017)	CO_2 emissions – GDP	(i) EC (ii) FD by Private Sector Credit (iii) TO (iv) Bank FD (v) Population (vi) Merchandise Trade (vii) Infrastructures (viii) Merchandise Trade (ix) Gross Saving (x) Government Expenditure on Educations	(panel) (i) SUR (ii) GMM (iii) 2SGMM (iv) SYS–GMM (v) Sys2Step		√		
(Qiao, Zheng, Jiang, & Dong, 2019)	19 of G20 Countries*[13] (1990–2014)	CO_2 emissions – GDP	(i) Agricultural Value Added (ii) Renewable EC	(panel) FMOLS		√ Full sample √ Developed panel		
(Ma et al., 2021)	France and Germany (1995–2015)	CO_2 emissions –GDP	(i) International Tourism Arrivals (ii) Labour Force (iii) Renewable EC (iv) Non–Renewable EC	(panel) (i) FMOLS (ii) DOLS (iii) VECM-PMG		√		

(Tenaw & Beyene, 2021)	20 sub-Saharan African (SSA) countries (1990–2015)	(i) Environmental Degradation Index (EDI) – HDI (ii) EF – HDI	(i) EC (ii) FD (iii) FDI (iv) TO (v) Urbanization (vi) Livestock production	(panel) (i) ARDL (ii) CCE-PMG		√ Global panel – EDI and EF √ Resource-Intensive SSA countries panel - EDI		
(Singhania & Saini, 2021)	21 developed and developing countries (1990–2016)	CO_2 emissions –GDP	(i) EC (ii) TO (iii) FDI (iv) FD (v) Institutional Framework	(panel) (i) GMM (ii) Sys-GMM		√ Global panel √ Developed Countries panel √ Developing Countries panel		
(Li, Qiao, Li, & Wang, 2022)	89 Belt and Road Initiative Countries (1995-2017)	(i) CO_2 emissions – GDP (ii) Sulphur Dioxide (SO_2) – GDP (iii) Volatile Organic Compounds (VOC) – GDP (iv) Nitrogen Oxides (NO_X) – GDP (v) Carbon Monoxide (CO) – GDP	(i) FDI (ii) Energy Structure (iii) Urbanization (iv) Industrial Structure	(panel) (i) PCSE (ii) GLS	√ Sub-region LA – GLS – CO √ Sub-region LA – PCSE – CO_2, VOC, CO √ Sub-region SSA – PCSE – SO_2, VOC, NO_X √ Sub-region MENA – PCSE – CO_2, SO_2, NO_X √ Sub-region MENA – GLS – SO_2	√ Full panel – PCSE – all environmental indicators √ Full panel – GLS – CO_2, SO_2, NO_X, CO √ Sub-region EU – PCSE and GLS – all environmental indicators √ Sub-region LA – GLS – SO_2 √ Sub-region AP – PCSE – CO_2, SO_2, NO_X, CO √ Sub-region AP – GLS – SO_2, NO_X		

Notes: ARDL denotes Autoregressive Distributed Lag; BRICS denotes Brazil, Russia, India, China and South Africa; CCE denotes Common Correlated Effects; DOLS denotes Dynamic Ordinary Least Square; EC denotes Energy Consumption; EF denotes Ecological Footprint; FD denotes Financial Development; FE denotes Fixed Effects; FMOLS denotes Fully Modified Ordinary Least Square; GLS denotes Generalized Least Squares; GMM denotes Generalized Method of Moments; HDI denotes Human Development Index; OLS denotes Ordinary Least Square; PMG denotes Pooled Mean Group; SUR denotes Seemingly Unrelated Regression; TO denotes Trade Openness; VECM denotes Vector Error Correction Model.

However, there is no consensus in the results. The selection of the country(ies), and consequently the cross-sectional or individual analysis performed, directly influences the relationship obtained. According to the literature (see some examples in Table 5.6), and as identified by Brock & Taylor (2010) as the third dilemma of the EKC, heterogeneity makes the EKC results sensitive to the sample. With this in mind, heterogeneity could be one of the main reasons for the difference between the EKC empirical results in cross-country analysis and country-level analysis. Therefore, studies that perform both cross-sectional and individual analyses obtain mixed results. This means when validating the EKC for a group of countries and when analysing each country individually, some countries follow the EKC trajectory, other countries follow a U-shaped relationship, and other countries follow neither a U-shaped nor inverted U-shaped relationship. Table 5.6 displays various examples of EKC studies that performed both cross-sectional and individual analysis, obtaining different results. Cross-sectional analysis results are in bold in Table 5.6.

Table 5.6 - Individual vs cross-country analysis

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained			
					U-shaped	EKC (inverted U-shaped)	N-shaped	inverted N-shaped
(Shahbaz, Solarin, Sbia, & Bibi, 2015)	Sub Saharan African Countries (1980-2012)	CO_2 emissions - GDP	Energy Intensity	(Time series and panel) (i) VECM (ii) Johansen Maximum Likelihood	√ Senegal, Nigeria and Cameroon	√ South Africa, Congo Republic, Ethiopia and Togo (ii) panel		
(Bilgili, Koçak, & Bulut, 2016)	17 OECD Countries (1977–2010)	CO_2 emissions - GDP	Renewable Energy Consumption	(Time series and panel) (i) FMOLS (ii) DOLS	√ FMOLS: Austria, Canada, Turkey √ DOLS: France, Luxemburg, Netherlands, Norway	√ panel √ FMOLS: Denmark, France, Greece, Netherlands, Sweden (iii) DOLS: Australia, Belgium, Greece, New Zealand, Portugal, Turkey		

(Lazăr, Minea, & Purcel, 2019)	11 Central and Eastern European Countries (1996-2015)	(i) CO_2 emissions – GDP (ii) Biocapacity – GDP (iii) EF – GDP (iv) SO_2 emissions-GDP	(i) Gross Inland Energy Consumption (ii) Index of Economic Freedom of Heritage Foundation (iii) Globalisation (iv) FDI (v) Labour Productivity (vi) Economic Complexity Index (vii) HDI (viii) Sectoral Structure of Agriculture, industry, and Services	(Panel and time series) (i) MG (ii) MG-FMOLS (iii) AMG	√ CO_2 emissions – Bulgaria and Latvia	√ CO_2 emissions – Czech R. and Hungary	√ CO_2 emissions, Biocapacity and SO_2 emissions - panel √ CO_2 emissions – Croatia and Estonia	√ CO_2 emissions – Poland and Slovakia
(Destek & Sarkodie, 2019)	11 newly industrialized Countries (1977-2013)	EF - GDP	(i) Energy Consumption (ii) Financial Development	(Time series and panel) AMG	√ China, India, South Korea, Thailand, and Turkey	√ Mexico, Philippines, Singapore, and South Africa √ panel		
(Rahman, 2020)	10 electricity consuming Countries (1971-2013)	CO_2 emissions - GDP	(i) Electricity Consumption (ii) KOF Globalisation Index	(Panel) (i) FMOLS (ii) DOLS (Time series) FMOLS	√ China, USA and UK	√ Panel √ Japan, Germany and S. Korea		

(Destek & Sinha, 2020)	24 OECD countries (1980-2014)	Ecological Footprint - GDP	(i) Renewable Energy Consumption (ii) Non-Renewable Energy Consumption (ii) Trade Openness	(Panel) (i) MG (ii) FMOLS-MG (iii) DOLS-MG (iv) CCE-MG (Time series) (i) FMOLS (ii) CCE	√ MG, FMOLS-MG and DOLS-MG: panel √ CCE: Austria; <u>Belgium</u>; Canada; Greece; Italy; Japan; S. Korea; Spain; <u>Switzerland</u>; US √ FMOLS: Austria; Canada; <u>Denmark</u>; Greece; Italy; Japan; S. Korea; <u>Netherlands</u>; Spain; US	√ CCE: Germany; Turkey √ FMOLS: <u>Chile</u>; <u>France</u>; Germany; <u>Mexico</u>; <u>New Zealand</u>; <u>Portugal</u>; Turkey; <u>UK</u>		
(Jun et al., 2021)	South Asian Economies*3 (1985-2018)	CO_2 emissions – GDP	(i) Globalisation (ii) Non-Renewable Energy Consumption	(Time series and panel) FMOLS		√ Full panel √ Bangladesh, India, Sri Lanka, and Nepal		

Notes: AMG denotes Augmented Mean Group; CCE denotes Common Correlated Effects; DOLS denotes Dynamic Ordinary Least Square; EF denotes Ecological Footprint; FMOLS denotes Fully Modified Ordinary Least Square; HDI denotes Human Development Index; MG denotes Mean Group; OECD denotes Organisation for Economic Co-operation and Development; SO_2 denotes Sulphur dioxide; UK denotes United Kingdom; US denotes United States; USA denotes United States of America; VECM denotes Vector Error Correction Model.

The individual country data analysis assesses the EKC for the environmental condition of a nation, a single economy, throughout time, with increasing income as it develops. Instead of that, cross-country analysis assesses the EKC for the environmental and economic conditions of a group of countries, with distinct stages of development, at a certain moment in time or within a limited time period. Therefore, considering fundamental disparities in national backgrounds and differences in the development paths, a cross-country analysis that reveals an inverted U-shaped pattern does not reveal that each country individually follows the EKC trajectory (Mather, Needle, & Fairbairn, 1999). In line with this, through the development of the Green Solow Model, it was concluded that different profiles of income and emissions over time are obtained as a consequence of economies with different initial conditions. EKC profiles are not unique due to the differences in the initial conditions (Brock & Taylor, 2010). The EKC estimation is vulnerable to the selection of scale, sample, and range, as well as the spatial and temporal sample range. Therefore, changes could occur in the estimated coefficients, significance levels and variables specification as a consequence of the country or countries under analysis (Shafik & Bandyopadhyay, 1992).

5.4 Which are the gaps in the EKC assessment?

With an extensive range of literature, the EKC is a method massively employed to analyse economies' environmental performance. Through the fast growth and development of economies and technology and the increasing complexity of environmental degradation issues, the EKC has started to be employed to analyse not only environmental indicators and not only through simple models. However, an absence of consensus is noted, as well as the degree of sensitivity of the EKC estimation to all the elements that are incorporated into the analysis process. The selection of the indicators, country or countries, time period, methodology and additional variables produce a unique result, and when the EKC is validated, the estimated curve is unlike any other. In light of this, a change of a single component of the functional structure produces changes in the results, validating or not the EKC or changing its shape.

The sensitivity of the EKC function and the consequent change in the results is criticised in some cases. A critical issue raised about the relationship obtained in a panel analysis is that it does not imply that individual countries follow the same pattern (as shown in Table 5.6). The cross-sectional analysis in EKC studies, mainly performed due to the lack of reliable long-term data (Roy Chowdhury & Moran, 2012), analyses a set of economies with different conditions and backgrounds. Taking this into account, the results obtained during a panel analysis should not be directly compared with individual analysis results.

Studies that perform a cross-sectional analysis provide results and measures for the specific group of countries under analysis, which may not be the most appropriate for each country in particular. Therefore, to create and apply measures adequate for the characteristics of each economy, the analysis of each country individually or by sector could provide and reveal more specific and beneficial results to the policymakers.

Besides that, EKC estimations are found to be sensitive to the method performed to assess the hypothesis (see Subsection 5.3.2.2 and Table 5.6). In other words, the shape obtained is linked to the econometric method chosen and functional specification. Several econometric issues in the EKC modelling have been identified throughout the EKC literature. EKC function and the use of income and squared income variables raised some criticism due to the production of econometric issues. Model emissions as a function of income augmented by income squared and income-cubed raise econometric issues, such as collinearity or multicollinearity (Narayan & Narayan, 2010). In order to avoid multicollinearity in the estimation, the use of non-parametric or semi-parametric methods should be explored. Besides that, the validity of the EKC hypothesis could be based on the assessment of short- and long-run income elasticities, as stated by Narayan and Narayan (Narayan & Narayan, 2010). Income elasticities should be interpreted as if the long-run elasticity is less than the short-run elasticity suggesting that the country has reduced its emissions with income growth and consequently further proving the existence of the EKC (Narayan & Narayan, 2010; Shahbaz et al., 2012).

Besides multicollinearity, there are more econometric issues associated with the modelling of the EKC. Hasanov, Hunt, Mikayilov, & Hunt (2021) extensively identify the major econometric issues in the EKC literature and provide a full mathematically and empirically explanation for each one. The authors mainly focused on the following issues: functional specifications used, and the econometric techniques employed; the use of a trend in the specification and level versus logarithmic variables; and the monotonic, quadratic, cubic, and quartic potential relationship between income and environmental degradation. In light of this, the authors developed a modelling strategy that should ensure a consistent approach when assessing the EKC. The Green Solow Model might be useful to overcome the sensitivity of the EKC to the econometric models employed.

Besides the critical issues identified in the EKC assessment and strategies to overcome them, from the extensive EKC literature arises the challenge: what are the EKC assessment gaps? Throughout the EKC literature, it has been noted that essential components for environmental degradation may not have been taken into consideration, such as consumption instead of production and technological progress. A criticism made of the EKC arises because it does not take into account the evolution of consumption coinciding with economic growth. That is, the EKC only explains how the process of production is converted into something environmentally friendly as a consequence of economic growth (Rashid Gill et al., 2018). Besides, according to Kaika and Zervas (Kaika & Zervas, 2011), the EKC only focuses on domestic production and overlooks the impact of the consumption of imported goods on the environment. In turn, the income elasticity of demand for dirty goods has been disregarded by the EKC (Cole, 2004). If, with high income levels, the demand for dirty goods persists, then this situation will lead to developed countries importing these goods from developing economies to satisfy demand. Consequently, any environmental improvement resulting from technological progress will be offset, and economic growth will result in more environmental degradation. This is a critical issue that goes against one of the basic assumptions of the EKC, that is, that there is a change in consumer behaviour with a rise in income.

Technological progress is a crucial tool to help with climate change and global warming mitigation. EKC supporters believe that environmental mitigation depends on technological progress and improvement. Therefore, they believe that only if technology and investment in the environment persist stagnantly, then the enlargement of economic activities harms the environment. However, the fact that technology enhances environmental quality is an ambition in dynamic economies, making economic growth a tool to accomplish environmental quality instead of being a threat (Rashid Gill et al., 2018). The EKC hypothesis assumes that rising income induces technological improvements and environmental awareness, and consequently, it should safeguard the improvement of environmental performance in the later stages of economic growth. At this point surfaces the doubt if technological advancements can outrun the worrying pace of environmental damage. Rashid Gill et al. (2018) present a summary of examples of recent technological improvements in diverse sectors. Therefore it is crucial to include technological progress in the EKC assessment. Currently, technological progress is focused on environmental research, and technological progress indexes have been developed (Ahmad & Wu, 2022; Huang, Xiang, Wu, & Chen, 2022). Also, the Green Solow Model could be a valuable tool to analyse technological improvements as it incorporates technological progress and resorts to enunciating the two conditions needed to guarantee sustainable growth.

Technological improvement encourages the replacement of obsolete technology and drives intensive pollutant economies to efficient ones. These changes mean that economies that reduce their energy consumption per unit of economic output consequently reduce emissions. The level of technology is vastly different in developing economies compared with developed, and therefore the developing economies are more carbon-intensive. According to Beckerman (1992), only prosperous economies have the means to access environmentally friendly technologies in order to mitigate environmental degradation, while the poor economies, according to the author, are “too poor to be green”. However, when a developed or prosperous economy appears to be able to achieve economic growth without significant environmental impact, then it is necessary to look deeper into the location of that economy’s pollutant industries. Developing economies’ lax environmental regulations attract the relocation of pollutant industries from developed economies where there is pressure to accomplish environmental targets.

The relocation of pollutant industries separates production from consumption, which allows an increase in GDP with a reduction in emissions as the emissions are being emitted in another country. Therefore, the relocation of emissions-intensive industries could create an illusion that economies are becoming efficient and that they perform the EKC trajectory, and it deserves to be taken into consideration in the analysis of environmental performance. The analysis of technological progress (or energy efficiency index) could be useful in order to observe if any emissions reduction actually comes from the replacement with efficient technology or if their emissions are reducing through the relocation of their pollutant industries. A sectoral analysis or a joint analysis of the home with the host country (the country that receives the industry) could overcome the illusion of emissions reduction when they are just being relocated. A sectoral analysis could reveal from which sector the industries were relocated. In turn, an analysis of the home and host country could reveal the reduction of emissions in the home country that consequently represents an increase in the emissions of the host country.

Nevertheless, in order to achieve a significant reduction in environmental problems and produce more economic growth with less environmental damage, the technology improvements have to be huge. Considering that energy consumption is the main source of emissions, energy efficiency through efficient technology may not be enough to achieve meaningful emissions reduction. In light of this, the studies should focus on how economic growth can promote energy transition from fossil energy use to renewable energy use. Energy transition is currently a hot topic due to the global environmental agenda, and throughout the literature, energy transition indicators have been rising in importance (Cui, Mu, Shen, & Wang, 2022; Ritchie & Roser, 2020). It is critical to be concerned about the shortcoming of the storage of renewable energy sources. Scenarios with nuclear may be analysed as an intermediate process, but they must take into account the risks associated with this energy source. Producing more economic growth with less environmental damage is crucial to accomplishing the Sustainable Development Goals, also known as Agenda 2030. Global economic growth patterns are considered responsible for the issue of rising climatic disasters across the globe (United Nations, 2019), and reducing global emissions and moving toward decarbonization is urgent. However, sustainable development goals accomplishment requires large investment needs. The COP26 was focused on tools to reduce climate change issues, such as green and climate finance. Green and climate finance could be powerful tools to bring about adaptation and mitigation of climate change issues mainly in countries with capital in short supply and could have a meaningful influence on the assessment of the EKC path. Green finance and climate finance have recently started to be addressed in the literature about the environment (Lee, Li, Yu, & Zhao, 2022; OECD-DAC, 2018).

As the doubt if technological progress can slow down and reverse the pace of environmental damage grows, there is also the increasing uncertainty of what will happen to the environmental degradation already in place. Is it repairable? According to the EKC relationship, after achieving a certain level of income, the turning point, environmental degradation starts to decrease with growing income. However, can the later stages of economic development really repair the environmental damage of the first stages? The EKC hypothesis assumes that in the later stages of economic growth, the environmental damage as a consequence of economic growth can be reversed. However, this assumption is an object of criticism by various researchers. The ability to reverse environmental damage might be effective for specific air and water pollutants but might not work with things like carcinogenic chemicals, as they are considered irreparable (Dasgupta et al., 2002). Furthermore, environmental damage because of industrialization is also extraordinarily complex to overturn.

Global warming is considered the most critical environmental problem humanity has ever faced. Therefore, it is crucial to understand if the environmental damage provoked by economic growth can be repaired through more economic growth. At the moment, it is not enough to only analyse if the country or a group of countries perform the EKC trajectory. It is now necessary to start exploring how the environmental damage provoked in the first phase of the EKC can be repaired. In line with this, also arises the doubt if the growth path traced by the inverted U-shaped is efficient, a Pareto efficient. The Pareto efficient, or optimal, defines the optimum resource allocation at which it is not possible to reallocate in order to benefit or improve a specific resource allocation without harming the allocation of others. The EKC hypothesis transmits the message of 'grow now and clean later' (Rashid Gill et al., 2018). This growth strategy is highly intensive in resources, which makes it incompatible with being Pareto efficient.

Considering that the EKC is not Pareto efficient and that the growth path is highly resource-intensive, it is highly likely that the environmental damage provoked in the first phases of the EKC might not be repairable. A growth path that takes care of both economic development and the environment simultaneously could avoid substantial losses, avoid the huge environmental impact of economic development, and the percentage of economic growth that in the future will be necessary to repair the environmental damage provoked before. On the one hand, a growth path that takes care of the environment in the early stages of economic growth could represent a global GDP loss of 1%. On the other hand, a loss in order of 5-20% of global GDP is a consequence of the absence of environmental care (N. H. Stern, 2007). Therefore, environmental protection throughout all the stages of economic development could diminish environmental and GDP losses.

5.5 Conclusion

Motivated by the will to develop a useful EKC's research tool/guide that allows EKC researchers to learn from the origins and framework of the EKC until the evolution of the literature, gaps, econometric issues, and improvements needs, this present essay fulfils a gap in the EKC literature by providing a detailed and comprehensive description of the EKC framework, an extensive contextualization of the EKC evolution and literature, and a critical analysis. With various novelty aspects, this essay strives to enlarge the knowledge of the EKC field. The main contribution of this essay consists of providing an extremely detailed description of the literature and evolution of the EKC analysis. Through the analysis of more than 200 articles from 1998 to 2022, a considerable number of EKC relationships analysed in the literature are provided, along with additional variables included in EKC estimations and methodologies used. Furthermore, each detail of the EKC assessment for each one of the more than 200 articles supplied allows researchers to find specific information to support their analysis.

The knowledge and assessment of the EKC has developed noticeably since its inception. However, despite being broadly assessed within the vast literature, the EKC hypothesis possesses some gaps and econometric issues, and improvement needs are verified. The absence of consensus throughout the EKC literature on the existence and shape of the curve has given rise to doubts about econometric issues in EKC modelling. The same geographic region, country or countries can generate opposing arguments regarding the existence and shape of the EKC. Throughout the literature review, evidence has been provided regarding the sensitivity of the EKC estimation resulting from the data set used, the indicators, the type of analysis (time series or cross-sectional), the methodology applied, and additional variables included. In light of this, the econometric issues are mainly associated with the functional specifications and econometric techniques used and the use of income quadratic, cubic and quartic variables. The use of econometric methods which deal with collinearity and multicollinearity is crucial. Non- or semi-parametric methods assessing short- and long-run elasticities could avoid these phenomena. Also, non-econometric methods instead of econometric could be helpful to avoid EKC sensitivity to the approach used.

Besides improvements needed for the econometric procedure, further improvements should be made to fill gaps in the EKC analysis. Knowledge of the EKC needs to be improved by integrating insights from other disciplines and research areas. These could include the inclusion of certain socio-political indicators that can influence efforts to improve environmental quality, such as research and development of alternative energy sources; economic complexity; economic uncertainty; economic, cultural, and political shocks; corruption; and political cooperation. All of these would be beneficial for economic analysis and policy recommendations. The complexity of environmental degradation issues is increasing, and scenarios such as relocated pollution, delocalized production, energy and production goods countries' dependence, lax environmental regulation, and comparative advantages, among others, can influence the environmental performance of countries. The relocation of pollutant industries could produce a result that does not fit with reality. The relocation that comes from lax environmental regulation from the host country, comparative advantages from home countries over the host ones that result in relocated pollution, delocalized production, and a countries' dependence increases environmental degradation in the host countries while the goods produced are consumed in the home country. At this point, it is crucial to consider these scenarios during the EKC assessment in order to allow policymakers to develop and implement fair and effective policies conducive to the achievement of the sustainable development goals. Furthermore, policies should be developed in order to dissolve the strong disparity in environmental regulation between developed and developing countries, allowing an EKC analysis to be more reliable.

COP 26, five years apart from the Paris agreement, was the time for countries to strengthen their environmental commitment and goals. Achieving decarbonisation is urgent and requires the collaboration of all countries all over the world. In light of this, as widely implemented to assess environmental performance, the EKC assessment should be demanding. Analysing environmental degradation indicators or other indicators over the economic growth is not enough at this point; it is crucial to look further into environmental pollution indicators. The standard approach to global warming, which mainly consists of alleviating the restrictions on economic growth while supporting continuous technological development thought suitable to compensate for environmental damage, may be critical. A set of strategies and tools have been developed, and they should be included in the assessment of the path of environmental pollution over economic development. Technological progress, energy efficiency, energy transition, potential clean energy sources (such as nuclear), environmental regulation, and green and climate finance can influence this path and provide a realistic route to a cleaner environment. In light of this, the inclusion of these tools and drivers of environmental quality in the EKC analysis may allow policymakers to develop particular policies and measures in order to encourage their progress and improvement towards sustainability. A major concern of environmental mitigation is the economic growth path; however, achieving sustainable and low-carbon development may, under reasonable conditions, operate as an explicit contributing component to growth.

The eminent consequences of global warming place policymakers as central players in the current global discussion of climate change challenges. The EKC is extensively used to evaluate the environmental performance of economies, and several policy recommendations have already been proposed based on its analysis. However, policymakers must be aware of the high volatility and sensitivity of the EKC outcomes. Panel data analysis could produce strong limitations for the development of policies. Specific policies should not be designed for a particular country based on a panel data analysis where the country is inserted when it is not mandatory that the country follows the trajectory that the group follows as a whole. Therefore, the outcomes of the panel data analysis should only be considered as a reference for how those countries behave together under the same conditions and in a specific scenario. Considering the sensitivity of the EKC outcomes, the EKC might be considered as an environmental performance indicator on policy design and implementation, but as a reference and not as a decisive indicator by itself.

The present essay provides a comprehensive and detailed picture of the EKC field. The development of this work faced some limitations, which are necessary to be highlighted to improve future research. Each EKC shape obtained is unique, considering things such as the functional specification, econometric methods used, and sample. Consequently, with a very extensive literature on the field, a huge limitation was faced in identifying all the issues related to the EKC assessment, mainly econometric issues. Moreover, developing a review work, mainly a particularly detailed one, is unending work, considering the tremendous amount of research on the field and that it is constantly growing. At this point, the length of the work could be a limitation. For the future direction of research, it could be relevant to explore methods beyond econometric methods that could fulfil the EKC assessment and overcome the identified econometric issues. Also, it could be useful to further investigate the influence of the additional variables on the EKC assessment. Additionally, providing individual reports about each strand of the Kuznets curve, beyond the Environmental, could be a relevant contribution to the literature.

Appendix 5

Acronyms List

Countries		Variables	
APEC	Asia Pacific Economic Cooperation	CO	Carbon Monoxide
		CO_2	Dioxide Carbon
		BOD	Biochemical Oxygen Demand
ASEAN	Association of Southeast Asian Nations	EC	Energy Consumption
		EDI	Environmental Degradation Index
BIC	Brazil, India and China	EF	Ecological Footprint
BRIC	Brazil, Russia, India and China	FD	Financial Development
BRICS	Brazil, Russia, India, China and South Africa	FDI	Foreign direct investment
EU	European Union	ICT	Information and Communications Technology
MENA	Middle East and North African	GDP	Gross Domestic Product
NEA	Northeast Asian countries	GFCF	Gross Fixed Capital Formation
NSEA	Northeast and Southeast Asian	GHG	Greenhouse Gases
OECD	Organisation for Economic Co-operation and Development	GRP	Gross Regional Product
		GSP	Gross State Product
OPEC	Organization of Petroleum Exporting Countries	GVA	Gross Value Added
SEA	Southeast Asian countries	HDI	Human Development Index
UAE	United Arab Emirates	N_2O/NOx	Nitrous oxide
UK	United Kingdom	NH_4	Ammonium
USA	United States of America	$PM_{2.5}$/ PM_{10}	Particulate Matter (2.5/ 10 micrometres)
		R&D	Research and Development
		SF6	Sulphur Hexafluoride
		SO_2	Sulphur Dioxide
		TFP	Total Factor Productivity
		TO	Trade Openness
		VA	Value Added
		VOC	Volatile Organic Compounds

Methods			
AMG	Augmented Mean Group	OLG	Overlapping Generations
ARDL	Autoregressive Distributed Lag	OLS	Ordinary Least Square

CCE	Common Correlated Effects
CCEMG	Common Correlated Effects Mean Group
CCR	Canonical Cointegrating Regression
CRR	Cox, Ross and Rubinstein
CS	Cross-Sectional
CUP-BC	Continuously Updated Bias-Corrected
CUP-FM	Continuously Updated Fully Modified
DFE	Dynamic Fixed Effect
DOLS	Dynamic Ordinary Least Square
EKC	Environmental Kuznets Curve
FE	Fixed Effect
FGLS	Feasible General Least Squares
FMOLS	Fully Modified Ordinary Least Square
FOC	First Order Conditions
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GLS	Generalized Least Squares
GMM	Generalized Method of Moments
IV	Instrumental Variable
IR	Impulse Response
LPOLSM	Local Polynomial Smoothing Model
LSCV	Least-Squares Cross-Validation
LSDV	Least Square Dummy Variable
LSDVC	Least Square Dummy Variable Corrected
MG	Mean Group
MMQR	Method of Moments of Quantile Regression
NARDL	Nonlinear Autoregressive Distributed Lag
PCSE	Panel Corrected Standard Errors
PDOLS	Panel Dynamic Ordinary Least Square
PLS	Panel Least Squares
PMG	Pooled Mean Group
PVAR	Panel Vector Autoregressive Model
PSTR	Panel Smooth transition Regression
RE	Random Effect
SAR	Spatial Autoregressive Model
SARAR	Spatial Autoregressive Model with Spatial Autoregressive Disturbances
SDM	Spatial Durbin Model
SEM	Spatial Error Model
SFE	Static Fixed Effect
SGMM/ SYS-GMM	System Generalized Method of Moments
SGVAR	Semi-Parametric Global Vector Autoregressive Model
SLM	Spatial Lag Model
SOC	Second Order Conditions
STSM	Structural Time Series Model
SUR	Seemingly Unrelated Regression
Sys2Step	Two-Step Dynamic System Generalized Method of Moments
TSLS/2SLS	Two-stage Least Squares
TY	Toda–Yamamoto
VAR	Vector Autoregressive Model
VECM	Vector Error Correction Model
WWCC	Wavelet Window Cross Correlation
2SGMM	Two-step Dynamic Generalized Method of Moments

Table A5.1 - Literature survey from 1998 to 2014

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turning Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Suri & Chapman, 1998)	33 Countries (1971–1991)	Primary Commercial EC – GDP	(i) Ratio of Imports of all Manufactured Goods to Domestic Production of all Manufacturers (ii) Ratio of Exports of Manufactured Goods to Domestic Manufacturing Production (iii) Manufacturing VA	(panel) FGLS		√			√
(Andreoni & Levinson, 2001)	US (1977–1994)	Pollution Abatement Costs – GSP	Abatement Cost	(panel) OLS		√			-
(Martínez-Zarzoso & Bengochea-Morancho, 2004)	22 OECD Countries (1975–1998)	CO_2 emissions – GDP	–	(panel) (i) PMG (ii) MG (iii) DFE (iv) SFE			√ MG and PMG		√

(Lantz & Feng, 2006)	5 Canadian Regions[*1] (1970–2000)	(i) CO_2 emissions – GDP (ii) CO_2 emissions – GDP, Population and Technology	–	(panel) (i) GLS–Pooled (ii) GLS–FE	√ GSL–FE: CO_2 emissions – GDP √ GLS–FE: CO_2 emissions – Technology	√ GLS–Pooled: CO_2 emissions – Population √ GLS–FE: CO_2 emissions – Population			√
(Soytas et al., 2007)	US (1960–2004)	CO_2 emissions – GDP	(i) EC (ii) Labour Force (iii) GFCF	(time series) (i) TY (ii) Generalized Forecast Error Variance Decomposition (iii) Generalized IR	Non–validity				-
(Akbostanci, Türüt-Aşik, & Tunç, 2009)	Turkey (1968–2003) 58 Turkish Provinces (1992–2001)	Turkey: CO_2 emissions – GDP Turkish provinces: (i) (i) PM_{10} emissions – GDP (ii) SO_2 emissions – GDP	Population Density	(time series) VAR (panel) Pooled GLS (FGLS with cross-section weights)			√		√
(Apergis & Payne, 2009)	Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama (1971–2004)	CO_2 emissions – GDP	EC	(panel) FMOLS		√			-

(Lamla, 2009)	47 Countries (1980–2000)	(i) CO_2 emissions – GDP (ii) SO_2 emissions – GDP (iii) BOD – GDP	32 variables	(panel) Bayesian Averaging of Classical Estimates		√			√
(Tamazian, Pineiro, & Vadlamannati, 2009)	BRIC Economies + US and Japan (1992–2004)	CO_2 emissions – GDP	(i) Industry Share (ii) Gross Domestic Expenditure in R&D (iii) Stock Market VA (iv) FDI (v) Deposit Money Bank Assets (vi) Capital Account Convertibility (vii) Financial Liberalization (viii) Financial Openness (ix) Energy Imports (x) Oil Consumption (xi) EC	(panel) Standard Reduced–Form Modelling Approach		√ US, Japan and BRIC panel model with Energy Imports, Oil Consumption and EC √ BRIC panel model and US, Japan and BRIC panel model without Energy Imports, Oil Consumption and EC			-
(Luzzati & Orsini, 2009)	113 Countries (1971–2004)	EC – GDP	–	(panel) FGLS	Non–validity				-
(Ozturk & Acaravci, 2010)	Turkey (1968–2005)	CO_2 emissions – GDP	(i) EC (ii) Labour Force	(time series) (i) ARDL (ii) Granger causality	Non–validity				-

(Acaravci & Ozturk, 2010)	19 European Countries (1960–2005)	CO_2 emissions – GDP	EC	(time series) (i) ARDL (ii) Granger causality		√ Denmark and Italy			-
(Apergis & Payne, 2010)	11 Countries of Commonwealth of Independent States[*2] (1992–2004)	CO_2 emissions – GDP	EC	(panel) FMOLS		√			-
(Pao & Tsai, 2010)	BRIC Countries (1971–2005)	CO_2 emissions – GDP	EC	(panel and time series) (i) VECM (ii) GARCH	√ Russia	√ India, China, panel BRIC and panel BIC			√
(Tamazian & Bhaskara Rao, 2010)	24 Transition Economies (1993–2004)	CO_2 emissions – GDP	(i) Inflation (ii) FDI (iii) Price Liberalization (iv) Forex and Trade Liberalization (v) TO (vi) Financial Liberalization (vii) Institutional Quality (viii) EC (ix) Energy Imports	(panel) (i) OLS–RE (ii) GMM (iii) GLS		√ RE and GMM all models excluding the RE model with Financial Liberalization* Institutional Quality			-
(Pao & Tsai, 2011)	Brazil (1980–2007) (2008–2013)	(i) CO_2 emissions – GDP (ii) EC – GDP	–	(time series) OLS		√			√
(S. S. Wang et al., 2011)	28 Chinese Provinces (1995–2007)	CO_2 emissions – GDP	EC	(panel) Granger causality	√				√

(Arouri et al., 2012)	12 MENA Countries*3 (1981–2005)	CO_2 emissions – GDP	EC	(panel and time series) (i) CCE (ii) CCE–MG		√ Algeria, Egypt, Jordan, Lebanon, Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and panel (Only Jordan and the panel have the turning point value between the GDP maximum and minimum of the sample)			√
(Rehman, Nasir, & Kanwal, 2012)	Pakistan, India, Bangladesh, and Sri Lanka (1984–2008)	CO_2 emissions – GDP	(i) EC (ii) TO (iii) Corruption	(panel) OLS–FE		√			√
(Shahbaz et al., 2012)	Pakistan (1971–2009)	CO_2 emissions – GDP	(i) EC (ii) TO	(time series) (i) ARDL (ii) Granger causality		√			-
(Chandran & Tang, 2013)	Indonesia, Malaysia, the Philippines, Singapore and Thailand (1971–2008)	CO_2 emissions – GDP	(i) EC of Road Transportation Sector (ii) FDI	(time series) VECM	Non–validity				-
(Farhani, Mrizak, et al., 2014)	10 MENA Countries (1990–2010)	(i) CO_2 emissions – GDP (ii) Genuine Saving index – HDI	(i) EC (ii) Manufacture VA (iii) TO (iv) Rule of Law	(panel) (i) FMOLS (ii) DOLS (iii) VECM		√			-
(Farhani, Chaibi, et al., 2014)	Tunisia (1971–2008)	CO_2 emissions – GDP	(i) EC (ii) TO	(time series) (i) ARDL (ii) VECM		√			-
Onafowora & Owoye, 2014)	Brazil, China, Egypt, Japan, Mexico, Nigeria,	CO_2 emissions – GDP	(i) EC (ii) TO (iii) Population Density	(time series) ARDL			√ Brazil, China, Egypt, Mexico,	√ S. Korea	√

	South Korea, and South Africa (1970–2010)						Nigeria and S. Africa		
(López-Menéndez et al., 2014)	27 EU Countries (1996–2010)	CO_2 emissions – GDP	Renewable EC	(panel and time series) (i) OLS–FE (ii) OLS–RE	√ Denmark, Ireland and Luxembourg √ panel model without Renewable EC (Models related to variables in logarithms)	√ Cyprus, Greece, Slovenia and Spain	√ RE: panel model with Renewable EC √ RE and Fixed and time effects: panel model without Renewable EC (Models with variables in levels)		√
(Shahbaz, Khraief, Uddin, & Ozturk, 2014)	Tunisia (1971–2010)	CO_2 emissions – GDP	(i) EC (ii) TO	(time series) (i) ARDL (ii) VECM (iii) Innovative Accounting Approach (iv) Variance Decomposition		√			-

[*1] – Atlantic Canada, Quebec, Ontario, the Prairies, and British Columbia.
[*2] – Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Ukraine, and Uzbekistan.
[*3] – Algeria, Bahrain, Egypt, Jordan, Kuwait, Lebanon, Morocco, Oman, Qatar, Saudi Arabia, Tunisia, and UAE.

Table A5.2 - Literature survey from 2015 to 2018

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turnin g Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Aşici & Acar, 2015)	116 Countries (2004–2008)	(i) EF of Production – GDP (ii) EF of Imports – GDP	(i) Biocapacity (ii) Population (iii) EC (iv) TO (v) Industry VA (vi) Stringency of Environmental Regulation (vii) Enforcement of Environmental Regulations	(panel) OLS–FE		√			√
(Shahbaz, Farhani, & Ozturk, 2015)	China and India (1971–2011)	Industrial CO_2 emissions – Industrial Production	Industrial Coal Consumption	(time series) OLS	√ China	√ India			-
(Shahbaz, Mallick, et al., 2015)	India (1970–2012)	CO_2 emissions – GDP	(i) EC (ii) FD (iii) Globalisation	(time series) ARDL		√			-
(Yin, Zheng, & Chen, 2015)	29 Provinces, Cities, and Autonomous Regions of China (1999–2011)	CO_2 emissions – GDP, GDP* Environmental Regulation and GDP*Technical Progress	(i) Environmental Regulation (ii) Technical Progress (iii) Population (iv) Energy Efficiency (v) Energy structure	(panel) GLS		√ GDP – all models excluding the model without GDP* Environmental Regulation √ GDP* Environmental Regulation			-

			(vi) Industrial Structure (vii) International Trade (viii) FDI						
(Bölük & Mert, 2015)	Turkey (1961–2010)	CO_2 emissions – GDP	Renewables Electricity Generation	(time series) ARDL		√			√
(Robalino-López et al., 2015)	Venezuela (1980–2025)	CO_2 emissions – GDP	–	(time series) DOLS	Non–validity				-
(Al-Mulali, Saboori, & Ozturk, 2015)	Vietnam (1981–2011)	CO_2 emissions – GDP	(i) Fossil Fuels Electricity Consumption (ii) Renewable Electricity Consumption (iii) Capital (iv) Labor Force (v) Export (vi) Imports	(time series) ARDL	Non–validity				-
(Jammazi & Aloui, 2015)	Saudi Arabia, Oman, Bahrain, Kuwait, UAE and Qatar (1980–2013)	(i) CO_2 emissions – GDP (ii) EC – GDP	–	(time series) WWCC		√			-
(Ben Jebli & Ben Youssef, 2015)	Tunisia (1980–2009)	CO_2 emissions – GDP	(i) Renewable Electricity Consumption (ii) Non–Renewable EC (iii) International Trade	(time series) (i) ARDL (ii) Granger causality	√				-

(Ozturk & Al-Mulali, 2015)	Cambodia (1996–2012)	CO_2 emissions – GDP	(i) TO (ii) EC (iii) Urbanization (iv) Corruption (v) Government Effectiveness	(time series) (i) TSLS (ii) GMM	√				-
(Al-Mulali, Weng-Wai, Sheau-Ting, & Mohammed, 2015)	Ninety–three Countries (1980–2008)	EF – GDP	(i) EC (ii) FD (iii) TO (iv) Urbanization	(panel) (i) OLS–FE (ii) GMM		√ upper middle– and high–income Countries			-
(Shahbaz, Solarin, et al., 2015)	Sub Saharan African Countries *1 (1980–2012)	CO_2 emissions – GDP	Energy Intensity	(time series and panel) (i) VECM (ii) Johansen Maximum Likelihood	√ Senegal, Nigeria and Cameroon	√ S. Africa, Congo Republic, Ethiopia and Togo √ panel			-
(Apergis & Ozturk, 2015)	14 Asian Countries (1990–2011)	(i) Panel A: CO_2 emissions – GDP, Population Density (ii) Panel B: CO_2 emissions – GDP, Population Density, Industry Share and Land	(i) Corruption (ii) Regulation (iii) Government Effectiveness (iv) Political Stability (v) Government Expenditures	(panel) (i) GMM (ii) FMOLS (iii) DOLS (iv) PMG (v) MG	√ GMM: Population Density of panel B √ FMOLS, DOLS, PMG and MG: Population Density of panel B	√ GMM: GDP of panel B √ GMM: Industry Share of panel B √ FMOLS, DOLS, PMG and MG: GDP of panel B √ FMOLS, DOLS, PMG and MG: Industry Share of panel B	√ GMM: GDP of panel A √ GMM: Land of panel B √ FMOLS, DOLS, PMG and MG: GDP of panel A (iv) FMOLS, DOLS, PMG and MG: land of panel B	√ GMM: Population Density of panel A √ FMOLS, DOLS, PMG and MG: Population Density of panel A	√

(S. X. Wang, Fu, & Zhang, 2015)	30 Chinese Provinces (2001–2010)	(i) Industrial Waste Gas – GDP (ii) Industrial Solid Waste – GDP	Population Growth	(panel) OLG		√			√
(Tutulmaz, 2015)	Turkey (1968–2007)	CO_2 emissions – GDP	–	(time series) Cointegration Equation		√			√
(Kang, Zhao, & Yang, 2016)	30 Provinces of China (1997–2012)	CO_2 emissions – GDP	(i) TO (ii) Energy Structure (iii) Urbanization (iv) Population Density	(panel) (i) SDM (ii) Pooled OLS				√	√
(Apergis, 2016)	15 Countries[*2] (1960–2013)	CO_2 emissions – GDP	–	(time series) (i) FMOLS (ii) CCE (iii) Quantiles (panel) (i) MG (ii) MG–FMOLS (ii) MG–DOLS (iii) CCE–MG (iv) CUP–BC (v) CUP–FM	√ Portugal, Sweden, Switzerland – CCE √ Portugal – 80 and 90 Quantiles	√ CCE and Quantiles excluding 10, 80, 90: Austria √ Belgium, Canada, Denmark, Finland, UK, US √ FMOLS and Quantiles: France, Italy, Netherlands, Spain, Sweden √ CCE and Quantiles: Norway √ FMOLS: Portugal √ FMOLS and Quantiles excluding 10: Switzerland √ panel			-
(Ben Youssef et al., 2016)	56 Countries (1990–2012)	CO_2 emissions – GDP	(i) TO (ii) FD (iii) EC	(panel) GMM		√			-

(Ertugrul et al., 2016)	Top ten CO_2 emitters among the developing Countries[*3] (1971–2011)	CO_2 emissions – GDP	(i) TO (ii) EC	(time series) (i) ARDL (ii) VECM		√ Turkey, India, China and Korea			-
(T. Li, Wang, & Zhao, 2016)	28 Provinces of China (1996–2012)	(i) CO_2 emissions – GDP (ii) Industrial Wastewater – GDP (iii) Industrial Waste Solid – GDP	(i) EC (ii) Urbanization (iii) TO	(panel) (i) GMM (ii) ARDL (PMG, MG, DFE)		√ GMM: CO_2 emissions, Industrial Wastewater and Industrial Waste Solid √ PMG and DFE: CO_2 emissions, Industrial Wastewater and Industrial Waste Solid			√
(Pablo-Romero & De Jesús, 2016)	22 Latin American and Caribbean Countries[*4] (1990–2011)	EC – GVA	–	(panel) GLS	Non–validity				-
(Bouznit & Pablo-Romero, 2016)	Algeria (1970–2010)	CO_2 emissions – GDP	(i) EC (ii) Electricity Consumption (iii) Exports (iv) Imports	(time series) ARDL		√			√
(Sugiawan & Managi, 2016)	Indonesia (1971–2010)	CO_2 emissions – GDP	(i) Electricity Production from Renewable Sources (ii) TFP (iii) EC	(time series) ARDL		√ model with TFP			√

(Lin, Omoju, Nwakeze, Okonkwo, & Megbowon, 2016)	Nigeria, Kenya, Congo, Egypt and South Africa (1980–2011)	CO_2 emissions – GDP, Industrial VA and Agricultural VA	(i) Population (ii) Energy Intensity (iii) Energy Structure (iv) Urbanisation	(panel) (i) FMOLS (ii) FE	Non–validity				-
(Azam & Khan, 2016)	Tanzania, Guatemala, China and the USA (1975–2014)	CO_2 emissions – GDP	(i) EC (ii) Urbanization (iii) TO	(time series) OLS		√ Tanzania and Guatemala			-
(Narayan, Saboori, & Soleymani, 2016)	181 Countries (1960–2008)	CO_2 emissions – GDP	–	(time series) Cross–Correlation Coefficient		√ 21 out of 181 Countries			-
(Bilgili et al., 2016)	17 OECD Countries (1977–2010)	CO_2 emissions – GDP	Renewable EC	(time series and panel) (i) FMOLS (ii) DOLS	√ FMOLS: Austria, Canada, Turkey √ DOLS: France, Luxemburg, Netherlands, Norway	√ panel √ FMOLS: Denmark, France, Greece, Netherlands, Sweden √ DOLS: Australia, Belgium, Greece, New Zealand, Portugal, Turkey			-
(Rodríguez, Pena-Boquete, & Pardo-Fernández, 2016)	15 OECD Countries[*5] (1979–2004)	CO_2 emissions – GDP	(i) Oil Prices (ii) Coal Prices (iii) Gas Prices (iv) Oil Energy Independence (v) Coal Energy Independence (vi) Gas Energy Independence (vii) Carbon Free Energy Independence	(panel) (i) FE (ii) Linear model (iii) Partially linear model		√ FE: model with coal and gas prices √ Linear and the partially linear model (with no country–specific and year–specific effects)			√

(Shahbaz, Solarin, & Ozturk, 2016)	19 African Countries (1971–2012)	CO_2 emissions – GDP	(i) Globalisation (ii) Energy Intensity	(time series) ARDL	√ Kenya, Sudan and Tanzania	√ Africa, Algeria, Cameroon, Congo Republic, Morocco, Tunisia and Zambia			-
(Kais & Sami, 2016)	58 Countries (1990–2012)	CO_2 emissions – GDP	(i) EC (ii) Urbanization (iii) TO	(panel) GMM	√ Latin American and Caribbean Region	√ European and North Asian Region and Middle Eastern, North African, and sub–Saharan Region			-
(Sinha & Bhattacharya, 2016)	139 Indian cities (2001–2013)	NO_2 emissions – GDP	(i) Population (ii) Electricity Consumption (iii) Petroleum Consumption	(panel) (i) FOC (ii) SOC		√ Industrial panel and Residential panel – model with Electricity Consumption and model with Petroleum Consumption √ High Industrial panel – model with Electricity Consumption √ High Residential panel – model with Electricity Consumption and model with Petroleum Consumption		√ Medium Residential panel – model with Electricity Consumptio n and model with Petroleum Consumptio n √ Low Residential panel – model with Petroleum Consumptio n	-
(S. A. R. Khan et al., 2016)	Austria, Czech Republic, Estonia, Germany, Ireland, Lithuania, Poland, Slovenia, and Slovak Republic	Energy– Resource Depletion: (i) Energy Depletion – GDP (ii) Net Forest Depletion – GDP (iii) Natural Resource	(i) EC (ii) Fossil fuel EC (iii) CO_2 emissions	(panel) GMM	√ Climate Change – Perfluorocarbo n emissions and $PM_{2.5}$ emissions √ Health Resources – tuberculosis	√ Energy–Resource Depletion – all models √ Health Resources – Infants Death and Health Expenditures			-

	(2000–2013)	Depletion – GDP Climate Change: (i) Perfluorocarbon emissions – GDP (ii) $PM_{2.5}$ emissions – GDP (iii) SF6 emissions – GDP (iv) GHG emissions – GDP Health Resources: (i) Tuberculosis – GDP (ii) Infant Deaths – GDP (iii) Health Expenditures – GDP							
(Alam & Paramati, 2016)	49 developing economies (1991–2012)	Income Inequality – Tourism Revenue	(i) TO (ii) GDP (iii) FDI	(panel) FMOLS		√			-
(Liobikienė & Butkus, 2017)	180 Countries (1990–2011)	GHG emissions – GDP		(panel) (i) OLS–FE (ii) OLS–RE (iii) SGMM	√ SGMM: model with natural logarithm of GHG	√ FE and RE √ SGMM: model with natural logarithm of per capita GHG			√

(Riti, Song, Shu, & Kamah, 2017)	China (1970–2015)	CO_2 emissions – GDP	(i) EC	(time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) VECM (v) Variance Decomposition		√ FMOLS and DOLS			√
(Ali, Abdullah, & Azam, 2017)	Malaysia (1971–2012)	CO_2 emissions – GDP	(i) FD (ii) TO (iii) FDI (iv) EC	(time series) (i) ARDL (ii) DOLS (iii) Granger causality		√			-
(Ahmad et al., 2017)	Croatia (1992Q1–2011Q1)	CO_2 emissions – GDP	–	(time series) (i) ARDL (ii) DOLS (iii) FMOLS (iv) Variance Decomposition (v) Granger causality		√			-
(Danish et al., 2017)	Pakistan (1970–2012)	CO_2 emissions – GDP	(i) Renewable EC (ii) Non–Renewable EC	(time series) (i) ARDL (ii) DOLS (iii) FMOLS (iv) CCR (v) VECM		√			-
(Hanif & Gago-de-santos, 2017)	86 developing Countries (1972–2011)	CO_2 emissions – GDP	(i) Population (ii) Economic Stability	(panel) (i) OLS (ii) OLS–robust (iii) OLS–FE (iv) OLS–IV		√ all models excluding OLS model			√

(Kwabena Twerefou et al., 2017)	36 Sub–Saharan African Countries (1990–2013)	(i) CO_2 emissions – GDP (ii) Adjusted Net Savings – GDP	(i) Population (ii) FDI (iii) TO	(panel) (i) SGMM (ii) GLS–FE		√			-
(Moutinho et al., 2017)	13 Portuguese and 13 Spanish sectors (1975–2012)	CO_2 emissions – GVA	EC	(panel) (i) PCSE (ii) FGLS			√ 13 Portuguese sectors	√ 13 Spanish sectors √ 26 Iberian sectors	√
(Ozokcu & Ozdemir, 2017)	26 OECD Countries and 52 emerging Countries (1980–2010)	CO_2 emissions – GDP	EC	(panel) (i) Driscoll-Kraay Standard Errors (ii) OLS–FE (iii) OLS–RE			√ 52 Emerging Countries	√ 26 OECD Countries	-
(Antonakakis et al., 2017)	106 Countries (1971–2011)	CO_2 emissions – GDP	(i) Renewable EC (ii) Electricity Consumption (iii) Oil Consumption (iv) Natural gas Consumption (v) Coal Consumption	(panel) (i) PVAR (ii) IR	Non–validity				-

(Apergis, Christou, & Gupta, 2017)	48 US States (1960–2010)	CO_2 emissions – GDP	–	(panel) (i) CCE–MG (ii) MG (iii) MG–FMOLS (iv) MG–DOLS (time series) (i) CCE (ii) FMOLS	√ CCE: Alabama, Georgia, Maine, Maryland, Massachusetts, Missouri, New Hampshire, New York, Pennsylvania √ FMOLS: Rhode Island	√ MG, MG–FMOLS and MG–DOLS: panel √ CCE: Idaho, Kansas, Michigan, Mississippi, North Dakota, Ohio, Utah, Virginia, Washington, West Virginia, Wyoming √ FMOLS: Arizona, California, Colorado, Delaware, Florida, Georgia, Kansas, Kentucky, Louisiana, Mississippi, Nevada, New Mexico, North Carolina, Ohio, Oklahoma, S. Dakota, Tennessee, Texas, Utah, Washington, West Virginia, Wyoming			-
(Mrabet & Alsamara, 2017)	Qatar (1980–2011)	(i) CO_2 emissions – GDP (ii) EF – GDP	(i) EC (ii) FD (iii) TO	(time series) ARDL	√ CO_2 emissions	√ EF			-

(Zaman & Moemen, 2017)	90 Countries (1975–2015)	CO_2 emissions – GDP	(i) EC (ii) FDI (iii) TO (iv) Population Growth (v) Agricultural VA (vi) Industry VA (vii) Services VA (viii) Health Expenditures (ix) Government Expenditures on Education	(panel) (i) GMM (ii) FE		√ Low income, lower Middle and Upper Middle–Income Countries √ Global panel			√
(Zoundi, 2017)	25 African Countries (1980–2012)	CO_2 emissions – GDP	(i) Primary EC (ii) Renewable EC (iii) Population	(panel) (i) DOLS (ii) SGMM (iii) DFE (iv) MG (v) PMG	√ SGMM				-
(You & Lv, 2018)	83 Countries (1985–2013)	CO_2 emissions – GDP	(i) Population (ii) Urbanization (iii) Industrialization (iv) Economic Globalisation	(panel) (i) SDM (ii) Pooled OLS (iii) FE		√			-
(Marques et al., 2018)	Australia (1965–2016)	CO_2 emissions – GDP	(i) Coal Consumption (ii) Oil Consumption (iii) Renewable EC	(time series) (i) ARDL (ii) VECM		√			√

(Pata, 2018a)	Turkey (1974–2014)	CO_2 emissions – GDP	(i) Urbanization (ii) FD (iii) Renewable EC (iv) Hydroelectricity Consumption (v) Alternative EC	(time series) (i) ARDL (ii) FMOLS (iii) CCR		√			√
(Balsalobre-Lorente, Shahbaz, Roubaud, & Farhani, 2018)	Germany, France, Italy, Spain, and the UK (1985–2016)	CO_2 emissions – GDP	(i) Renewable Electricity Consumption (ii) TO (iii) Natural Resource Abundance (iv) Energy Innovation	(panel) PLS			√		√
(Churchill, Inekwe, Ivanovski, & Smyth, 2018)	20 OECD Countries (1870–2014)	CO_2 emissions – GDP	(i) Population (ii) FD (iii) TO	(panel) (i) MG (ii) CCEMG (iii) AMG (iv) PMG (time series) AMG	√ New Zealand and Portugal √ Norway – model without FD	√ MG, AMG, PMG: panel √ Australia, Canada, Denmark, Finland, France, Japan, Spain, UK, USA	√ Australia, Canada, Japan	√ Denmark	√
(Olale et al., 2018)	10 Canadian provinces and Territories (1990–2014)	GHG emissions – GDP	TO	(panel) (i) Pooled OLS (ii) FE		√ panel √ Pooled OLS: Alberta, Saskatchewan, British Columbia, Nova Scotia, Prince Edward Island √ FE: all Provinces and Territories			√

(Rehermann & Pablo-Romero, 2018)	22 Latin American and Caribbean Countries*[6] (1990–2014)	Transport sector EC – GDP	(i) TO (ii) Population Density (iii) Urbanization (iv) Economy Structure	(panel) (i) FGLS (ii) GMM		√	√		-
(Santos, Gilio, Halmenschlager, Diniz, & Almeida, 2018)	26 Brazilian states and the Federal District (1998–2013)	GHG emissions – GDP and Number of Passenger Cars Times	(i) Number of Passenger Cars (ii) Number of Other Vehicles (iii) Number of Bovine Animals (iv) Area Under Sugar Cane Cultivation	(panel) (i) Pooled OLS (ii) OLS–FE (iii) OLS–RE (iv) LSCV		√ OLS–FE and OLS–RE – GDP √ Number of Passenger Cars Times model only with Number of Passenger Cars			-
(Sarkodie & Adams, 2018)	South Africa (1971–2017)	CO_2 emissions – GDP	(i) Urban Population (ii) EC (iii) Political Institutional Quality (iv) Renewable Energy (v) Fossil Fuel Energy (vi) Nuclear Electricity Net Generation	(time series) ARDL		√			√

(Sarkodie & Strezov, 2018)	Australia, China, Ghana and the USA (1971–2013)	(i) CO_2 emissions – GDP (ii) Biocapacity – GDP (iii) Biocapacity – EC (iv) CO_2 emissions – Biocapacity	(i) Energy intensity (ii) Energy imports (iii) Household final Consumption expenditure (iv) Electric power Consumption (v) Urban population	(time series) PMG–ARDL	√ Australia: Biocapacity – GDP	√ Australia and China: CO_2 emissions – GDP √ China: Biocapacity – GDP	√ USA: Biocapacity – EC √ USA – CO_2 emissions – Biocapacity	√ USA: CO_2 emissions – GDP √ Ghana and USA: Biocapacity – GDP √ China and Ghana: Biocapacity – EC √ China and Ghana: CO_2 emissions – Biocapacity	√
(Shahbaz, Nasir, & Roubaud, 2018)	France (1955–2016)	CO_2 emissions – GDP, FDI and domestic credit to private sector	(i) EC (ii) R&D Expenditures for Energy Innovations	(time series) ARDL	√ FDI	√ GDP and Domestic Credit to Private Sector			-
(Sinha & Shahbaz, 2018)	India (1971–2015)	CO_2 emissions – GDP	(i) Renewable Energy Generation (ii) EC (iii) Volume of Foreign Trade (iv) TFP	(time series) ARDL		√ model without TFP			-
(Tajudeen et al., 2018)	30 OECD Countries (1971–2015)	CO_2 emissions – Energy Efficiency	(i) TO (ii) GDP (iii) Structural Shift Index (iv) Cleaner Energy Substitution	(time series) STSM (panel) (i) OLS–FE (ii) LSDVC		√ Denmark, Japan, Luxembourg, Turkey and USA √ panel			-

(D. Yang et al., 2018)	197 Countries (1998–2015)	$PM_{2.5}$ emissions – industrial added values	(i) Urbanization (ii) Growth rate of GDP	(panel) (i) FE (ii) RE		√			-
(Y. Zhang & Zhang, 2018)	China (1982–2016)	CO_2 emissions – GDP	(i) Trade Structure (ii) Exchange Rate (iii) FDI	(time series) (i) ARDL (ii) Granger causality		√ Granger causality			-
(Acheampong, 2018)	116 Countries (1990–2014)	CO_2 emissions – GDP	(i) EC (ii) TO	(panel) (i) SGMM (ii) PVAR (iii) IR		√ Global panel √ Sub–Saharan Africa Countries			-
(Alvarado, Ponce, Criollo, Córdova, & Khan, 2018)	151 Countries (1980–2016)	CO_2 emissions – GDP	(i) Urbanization (ii) EC (iii) Manufacturing	(panel) (i) OLS–FE (ii) OLS–RE	√ Middle–high–income Countries model with no additional variables	√ Global panel √ High income Countries √ Middle–low–income Countries model with additional variables			-
(Balaguer & Cantavella, 2018)	Australia (1950–2014)	CO_2 emissions – GDP and Education	(i) Oil Price (ii) Income Inequality (iii) TO	(time series) ARDL		√			√
(Dong, Sun, & Dong, 2018)	China (1965–2016)	CO_2 emissions – GDP	(i) Natural Gas Consumption (ii) Renewable EC	(time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR		√			-

(Dong, Sun, Jiang, et al., 2018)	China (1993–2016)	CO_2 emissions – GDP	(i) Fossil Fuels Consumption (ii) Nuclear EC (iii) Renewable EC	(time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR (v) VECM (vi) Sasabuchi–Lind–Mehlum U test		√ all excluding VECM			√
(Dong, Sun, Li, & Liao, 2018)	14 Asia–Pacific Countries[*7] (1970–2016)	CO_2 emissions – GDP	Natural Gas Consumption	(panel) (i) VECM (ii) AMG (iii) FMOLS		√ AMG: 13 of the 14 Countries (excluding Philippines) √ FMOLS: 12 of 14 Countries (excluding Philippines and Bangladesh) √ AMG and FMOLS: panel			√
(Ercolano, Lucio Gaeta, Ghinoi, & Silvestri, 2018)	Municipalitie s from Lombardy region of Northern Italy (2005–2011)	Waste Generation – Average Tax Return per Inhabitant	(i) Density of Inhabitants (ii) People more than 65 years old (iii) Sleeping Accommodation (iv) Foreigners over Population	(panel) (i) GMM (ii) OLS		√			√
(Kurniawan & Managi, 2018)	Indonesia (1970–2015)	Coal Consumption – GDP	(i) Industry VA (ii) TO (iii) Urban Population	(time series) ARDL		√			-

(Huang & Zhao, 2018)	30 provinces in China (2000–2014)	CO_2 emissions embodied in Exports – GDP CO_2 emissions embodied in net Exports – GDP	(i) Financial Scale Development (ii) Financial Efficiency (iii) Opening–up (iv) Industrial Structure (v) Imitation Innovation (vi) FDI (vii) R&D (viii) Financialization	(panel) GMM	√ CO_2 emissions embodied in net Exports all model with Financial Scale Development √ CO_2 emissions embodied in net Exports all model with Financial efficiency √ CO_2 emissions embodied in net Exports all model with Financialization	√ CO_2 emissions embodied in Exports model with Financial Scale Development* Imitation Innovation and model with Financial Scale Development* R&D √ CO_2 emissions embodied in Exports model with Financialization and model with Financialization*FDI			-
(Hanif, 2018)	12 developing East Asian and Pacific Countries*8 (1990–2014)	CO_2 emissions – GDP	(i) Fossil Fuels EC (ii) Urbanization (iii) Energy Management Policies	(panel) SGMM		√			√

(Halkos & Polemis, 2018)	Power Generation Sector of 50 USA States (2000–2012)	(i) CO_2 + SO_2 + NOx emissions – GDP (ii) SO_2 + NOx emissions – GDP (iii) CO_2 emissions – GDP	–	(panel) (i) OLS (ii) SYS–GMM (iii)GMM (iv) LPOLSM			√ CO_2 + SO_2 + NOx emissions √ OLS and DIF–GMM: SO_2 + NOx emissions √ SYS–GMM and DIF–GMM: CO_2 emissions √ LPOLSM	√ SYS–GMM: SO_2 + NOx emissions	√
(Pata, 2018b)	Turkey (1971–2014)	CO_2 emissions – GDP	(i) FD (ii) TO (iii) Industrialization (iv) Urbanization (v) Coal Consumption (vi) Noncarbohydrate EC	(Time series) ARDL		√			√

*1 – Benin, Botswana, Cameroon, Congo Republic, Ethiopia, Gabon, Ghana, Kenya, Nigeria, Senegal, South Africa and Zambia.
*2 – Austria, Belgium, Canada, Denmark, Finland, France, Italy, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, UK and US.
*3 – China, India, South Korea, Brazil, Mexico, Indonesia, South Africa, Turkey, Thailand and Malaysia.
*4 – Argentina, Barbados, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Dominican Republic, Trinidad and Tobago, Uruguay and Venezuela.
*5 – Austria, Belgium, the Czech Republic, Denmark, Finland, France, Hungary, Italy, Japan, Poland, the Slovak Republic, Switzerland, Turkey, the UK and the US.
*6 – Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, the Dominican Republic, Trinidad and Tobago, Uruguay and Venezuela.
*7 – Australia, Bangladesh, China, India, Indonesia, Japan, Malaysia, New Zealand, Pakistan, the Philippines, Singapore, South Korea, Thailand, and Vietnam.
*8 – Cambodia, China, Indonesia, the Korean Republic, Lao PDR, Malaysia, Mongolia, Myanmar, Philippines, Thailand, Timor–Leste, and Vietnam.

Table A5.3 - Literature survey of 2019

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turning Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Shahbaz, Haouas, Hong, & Hoang, 2019)	Vietnam (1974–2016)	CO_2 emissions – GDP	(i) EC (ii) Industry VA (iii) Agriculture VA (iv) FDI inflow (v) Urban population	(Time series) (i) ARDL (ii)VECM		√	√		√
(Z. U. Rahman & Ahmad, 2019)	Pakistan (1980–2016)	CO_2 emissions – GDP	(i) Gross Capital Formation (ii) Oil Consumption (iii) Coal Consumption	(Time series) NARDL		√			-
(Destek & Sarkodie, 2019)	11 newly industrialized Countries*[1] (1977–2013)	EF – GDP	(i) EC (ii) FD	(Time series and panel) AMG	√ China, India, S. Korea, Thailand, and Turkey	√ Mexico, Philippines, Singapore, and S. Africa √ panel			-
(Shahbaz, Balsalobre-Lorente, & Sinha, 2019)	MENA region (1990–2015)	CO_2 emissions – GDP and FDI	(i) Biomass EC	(panel) GMM		√	√		-

(Acheampong, Adams, & Boateng, 2019)	46 sub–Saharan African Countries (1980–2015)	CO_2 emissions – GDP and FDI	(i) Renewable Energy (ii) Regulation (iii) FDI (iv) TO (v) Population (vi) FD	(panel) (i) IV–GMM (ii) OLS–FE (iii) OLS–RE (iv) OLS–DFE	√ IV–GMM: Central–Eastern Africa – GDP	√ FE, RE, DFE and IV–GMM: panel – GDP √ IV–GMM: Southern Africa – GDP			-
(Lau, Choong, Ng, Liew, & Ching, 2019)	18 OECD Countries (1995–2015)	CO_2 emissions – GDP	(i) Nuclear Electricity Output (ii) Non–Renewable Electricity Production (iii) TO	(panel) (i) GMM (ii) FMOLS		√			-
(Sharif, Raza, Ozturk, & Afshan, 2019)	74 most carbon emission economies (1990–2015)	CO_2 emissions – GDP	(i) Non–Renewable EC (ii) Renewable EC (iii) FD	(panel) (i) DOLS (ii) FMOLS		√			-
(Zaidi, Zafar, Shahbaz, & Hou, 2019)	APEC Countries (1990–2016)	CO_2 emissions – GDP	(i) Energy Intensity (ii) FD (iii) Globalisation	(panel) (i) CUP–BC (ii) CUP–FM		√			-
(Uzar & Eyuboglu, 2019)	Turkey (1984–2014)	CO_2 emissions – GDP	(i) Income Inequality (ii) EC (iii) Industrialization (iv) Urbanization (v) FD (vi) TO	(Time series) ARDL		√			-
(Waqih, Bhutto, Ghumro,	South Asian region (1986–2014)	CO_2 emissions – GDP	(i) EC (ii) FDI	(panel) (i) ARDL (ii) FMOLS		√			-

Kumar, & Salam, 2019)									
(Cosmas, Chitedze, & Mourad, 2019)	Nigeria (1981–2016)	CO_2 emissions – GDP	(i) EC (ii) TO (iii) Population (iv) FD (v) Share of Manufacturing in GDP	(Time series) (i) ARDL (ii) NARDL			√		√
(Rafindadi & Usman, 2019)	South Africa (1971–2014)	CO_2 emissions – GDP	(i) EC (ii) Globalisation	(Time series) (i) FMOLS (ii) CRR (iii) ARDL (iv) TY		√			√
(L. Zhang et al., 2019)	China's main grain – Producing Areas (1996–2015)	Agricultural CO_2 emissions – Agricultural Economic Growth	Agricultural EC	(panel) ARDL		√			-
(Liang & Yang, 2019)	30 provinces and cities in China (2006–2015)	(i) Wastewater Discharge – GDP (ii) Wastewater Discharge – Urbanization	(i) Level of Infrastructure (ii) Greening Level (iii) Industrial Structures (iv) Environmental Cleaning Capacity	(panel) Simultaneous–Equation		√			√

(Kibria et al., 2019)	151 Countries (1971–2013)	Fossil Fuel Share in Energy Mix – GDP	Population Density	(panel) (i) Pooled OLS (ii) OLS–FE (iii) OLS–RE (iv) Nadaraya–Watson Kernel Regression (v) Local Linear Regression		√			-
(Miao et al., 2019)	China's 28 provinces (2000–2016)	Residential CO_2 emissions – GDP	(i) Population (ii) Urbanization (iii) Energy Price (iv) Cooling Degree Days (v) Energy Intensity	(panel) (i) FGLS (ii) PCSE		√ Eastern	√ national (graphically)		-
(Y. Chen, Zhao, Lai, Wang, & Xia, 2019)	China (1995–2012)	CO_2 emissions – GDP	(i) Renewable EC (ii) Non–Renewable EC	(panel) (i) DOLS (ii) FMOLS	√ Western Region	√ Eastern Region			-
(Y. Chen, Wang, & Zhong, 2019)	China (1980–2014)	CO_2 emissions – GDP	(i) Renewable Electricity Production (ii) Non–Renewable Energy Production (iii) TO	(time series) (i) ARDL (ii) VECM	√ without Renewable Energy	√ with Renewable Energy			√
(Danish, Baloch, Mahmood, & Zhang, 2019)	BRICS Countries (1990–2015)	CO_2 emissions – GDP	Renewable Energy Natural Resources	(panel and time series) AMG		√ Brazil, China, Russia, S. Africa √ panel			√

(Dehghan Shabani & Shahnazi, 2019)	28 Iranian Provinces Economic Sectors (2002–2013)	CO_2 emissions by Sector – GDP by Sector	(i) ICT Capital Stock (ii) EC by Sector	(panel) DOLS		√			√
(Arminen & Menegaki, 2019)	67 Countries (1985–2011)	CO_2 emissions – GDP	(i) EC (ii) Corruption (iii) Temperature over Three Summer Months (iv) Temperature over Three Winter Months (v) Urbanization	(panel) Simultaneous–equations – GMM	Non–validity				-
(Gui, Zhao, & Zhang, 2019)	285 Chinese Cities (2006–2015)	Municipal Solid Waste – GDP	(i) Sanitation Investment (ii) Education (iii) Tertiary Industry Proportion (iv) Urbanization (v) Length of road	(panel) (i) SLM (ii) SEM (iii) LSDV (iv) Convergence	Non–validity				-
(Cheng, Ren, & Wang, 2019)	35 OECD Countries (1996–2015)	CO_2 emissions – GDP	(i) Investment (ii) Renewable Energy (iii) Export Trade (iv) Development of Patent	(panel) Quantile	Non–validity				-
(Gorus & Aslan, 2019)	MENA Countries (1980–2013)	CO_2 emissions – GDP	(i) FDI (ii) EC	(panel and time series) PDOLS	√ Iran and Jordan	√ Algeria, Egypt, Sudan and Turkey			√

(Haug & Ucal, 2019)	Turkey sectors*2 (1974–2014)	(i) CO_2 emissions – GDP (ii) CO_2 intensity – GDP (iii) CO_2 emissions by sector – GDP	(i) Urbanization (ii) FD (iii) Exports (iv) Imports (v) FDI	(time series) (i) NARDL (ii) ARDL	√ Electricity and Heat Production Sector	√ CO_2 emissions, CO_2 intensity √ Manufacturing Industries and Construction Sector, Residential Buildings and Commercial and Public Services Sector			√
(S. Zhang & Liu, 2019)	NSEA–10*3 Countries (1995–2014)	CO_2 emissions – GDP	(i) Non–Renewable EC (ii) Renewable EC (iii) Tourism	(panel) (i) FMOLS (ii) AMG (time series) FMOLS	√ China, S. Korea, Russia, Philippines, Singapore √ NEA–4*4, SEA–6*5, NSEA–10	√ Indonesia			-
(Hanif, Faraz Raza, Gago-de-Santos, & Abbas, 2019)	15 developing Asian Countries*6 (1990–2013)	CO_2 emissions – GDP	(i) Fossil fuels Consumption (ii) FDI (iii) Population	(panel) ARDL		√			-
(Xie, Xu, & Liu, 2019)	249 Chinese cities (2015)	$PM_{2.5}$ emissions – GDP	(i) Population Density (ii) Industrialization (iii) Technological Innovation (iv) Green Coverage (v) Geographical Location (vi) Urbanization (vii) Traffic Development	(panel) (i) SLM (ii) SARAR (iii) 2SLS (iv) Quantile		√			√

(Y. Wang & He, 2019)	30 Chinese Provinces (1995–2013)	CO_2 intensity – GDP	(i) Population (ii) FDI (iii) TO (iv) EC Structure (v) Industrial Structure (vi) Urbanization	(panel) SAR			√ (according to the authors)	√ (model)	-
(Shahbaz, Kumar, Jawad, & Shahzad, 2019)	87 Countries*[7] (1970–2012)	CO_2 emissions – Globalisation	–	(time series) Coefficient of Cross–Correlation	√ 7 of 87 Countries (3 high–, 2 middle– and 2 low–income Countries)	√ 16 of 87 Countries (6 high– and 10 middle–income Countries)			-
(Ding et al., 2019)	13 cities in Beijing–Tianjin–Hebei (1998–2016)	$PM_{2.5}$ emissions– GRP	(i) Population Density (ii) Secondary Industry	(panel) (i) Pooled OLS (ii) OLS – FE (iii) SDM		√			√
(Y. Zhang et al., 2019)	Manufacturing and Construction Industries of 121 Countries (1960–2014)	(i) CO_2 intensity – GDP (ii) CO_2 emission per capita – GDP (iii) total CO_2 emission – GDP	–	(time series) OLS		√ 95 of 121 Countries – CO_2 Intensity and CO_2 emission per capita √ 92 of 121 Countries – total CO_2 emissions			√

(S. C. Xu et al., 2019)	China's Provincial (2005–2015)	(i) $PM_{2.5}$ emissions – GDP (ii) SO_2 emissions – GDP, Population Urbanization and Land Urbanization (iii) NOx – GDP, Population Urbanization and Land Urbanization (iv) $PM_{2.5}$ emissions – GDP, Population Urbanization and Land Urbanization	(i) Population (ii) Energy Efficiency (iii) Industrialization	(panel) (i) OLS–RE (ii) OLS–FE	√ SO_2 emissions – Population Urbanization: Eastern region √ $PM_{2.5}$ emissions – Population Urbanization: Eastern region √ NOx – Population Urbanization: Eastern region	√ SO_2 emissions – Population Urbanization: Western region √ $PM_{2.5}$ emissions – GDP: Eastern region √ $PM_{2.5}$ emissions – Population Urbanization: Western region √ NOx – GDP: Eastern, Central and Western region √ SO_2 emissions – Land Urbanization: Eastern, Central and Western region √ $PM_{2.5}$ emissions – Land Urbanization: Eastern, Central and Western region √ NOx – Land Urbanization: Eastern and Central region		√ NOx – Population Urbanization – Western region √ $PM_{2.5}$ emissions – GDP – Western region	√
(Junxian, Jingya, & Kai, 2019)	29 Chinese provinces (1996–2015)	CO_2 emissions – GDP and FDI	(i) Trade Liberalization (ii) Industrial Upgrading (iii) Technical Diffusion (iv) EC	(panel) OLS–FE		√ GDP		√ FDI	√

(Yao, Zhang, & Zhang, 2019)	(i) 17 Developing and Developed Countries*8 (ii) 6 geo–Economic Regions*9 (1990–2014)	(i) CO_2 emissions – GDP (ii) Renewable EC – GDP	–	(time series and panel) (i) FMOLS (ii) DOLS	17 Countries: √ FMOLS: Renewable EC – S. Africa, Turkey, France, USA, Canada, Japan, S. Korea and Australia √ DOLS: Renewable EC – Turkey, France, USA, Canada, S. Korea and Australia √ FMOLS and DOLS: Renewable EC rate – panel 6 regions: √ FMOLS: Renewable EC – North America, Europe, Central Asia and Latin America √ DOLS: Renewable EC – North and Latin America, and Central Asia √ FMOLS and DOLS: Renewable EC rate – panel	17 Countries: √ FMOLS: CO_2 emissions – Brazil, India, S. Africa, Germany, France, UK, Spain, Canada, Japan, S. Korea and Australia √ DOLS: CO_2 emissions – Brazil, India, S. Africa, Germany, France, UK, Canada, S. Korea and Australia √ FMOLS and DOLS: CO_2 emissions – panel (iv) FMOLS: Renewable EC rate – Russia and India √ DOLS: Renewable EC rate – Russia and India 6 regions: √ FMOLS: CO_2 emissions – North America, Europe, Central Asia, Latin America, S. Asia, and Africa √ DOLS: CO_2 emissions – Central Asia, Latin America,			√

						S. Asia, and Africa √ FMOLS and DOLS: CO_2 emissions – panel			
(Tiberiu, Kumar, Yoon, & Hoon, 2019)	14 Latin America Countries*[10] (1980–2010)	CO_2 emissions – GDP	(i) GFCF (ii) Educational Attainment (iii) Population (iv) EC (v) Unemployment (vi) FDI	(panel) (i) Quantile of Powell et al. (Powell, Corporation, & Powell, 2016) (ii) Quantile of Canay (Canay, 2011) (iii) RE	√ Quantile (Powell et al., 2016): full sample (0.95) √ Quantile (Powell et al., 2016): low–income Countries (0.75–0.95) √ Quantile (Canay, 2011): low–income Countries (0.65–0.95) √ RE (Level estimation): Countries with Income<$3550	√ Quantile (Powell et al., 2016): full sample (0.05–0.5, 0.65–0.75) √ Quantile (Powell et al., 2016): (0.05) √ Quantile (Powell et al., 2016): high–income Countries (0.05, 0.65–0.95) √ Quantile (Canay, 2011): full sample (0.05–0.15, 0.45–0.5) √ Quantile (Canay, 2011): high–income Countries (0.05)			-
(Amri, Zaied, & Lahouel, 2019)	Tunisia (1975–2014)	CO_2 emissions – TFP	ICT	(time series) ARDL	Non–validity				-

(Nasir, Duc Huynh, & Xuan Tram, 2019)	ASEAN–5*[11] (1982–2014)	CO_2 emissions – GDP	(i) FDI (ii) Bank Credit to Bank Deposit (iii) The Number of Listed Companies (iv) International Debt issued over total GDP	(panel) (i) FMOLS (ii) DOLS	Non–validity				-
(Ardakani & Mohsen, 2019)	Algeria, Bahrain, Iran, Kuwait, Oman, Qatar, and Saudi Arabia (1995–2014)	CO_2 emissions – GDP	Electric Power Consumption	(time series) Multivariate Regression	√ Algeria and Bahrain	√ Oman, Qatar, and Saudi Arabia			√
(Borozan, 2019)	EU Countries (2005–2016)	Final EC in Households – GDP	(i) Energy Taxes (ii) Energy Prices (iii) Tertiary Education (iv) Risk of Poverty (v) Climate Conditions	(panel) Quantile		√ lower quantiles			-

(Hao, Hu, et al., 2019)	29 Provinces and cities in China (1999–2014)	(i) Water Consumption – GDP (ii) Industrial Water Consumption – GDP (iii) Non–Industrial Water Consumption – GDP	(i) Water Resources (ii) Secondary Industry VA (iii) TO (iv) Population Density	(panel) (i) Simultaneous–equation (ii) OLS–FE	√ FE: Water Consumption and Non–Industrial Water Consumption		√ FE: Industrial water Consumption √ Simultaneous equation: Water Consumption, Industrial Water Consumption and Non–Industrial Water Consumption		√
(S. Chen et al., 2019)	30 Chinese Provinces (2001–2010)	Haze Pollution – GDP	(i) Technology Level (ii) Industrial Structure (iii) Energy Structure	(panel) SGVAR		√ all except Beijing and Shanghai			-
(Akram, Chen, Khalid, Ye, & Majeed, 2019)	66 Developing Countries (1990–2014)	CO_2 emissions – GDP	(i) Energy Efficiency (ii) Renewable EC (iii) Nuclear EC (iv) Urbanization	(panel) (i) OLS (ii) Quantile		√			-
(Danish, Baloch, & Wang, 2019)	BRICS Countries (1996–2017)	CO_2 emissions – GDP	(i) Governance	(panel) (i) OLS (ii) DOLS (iii) PMG		√			√

(Danish & Wang, 2019)	BRICS Countries (1992–2013)	CO_2 emissions – GDP	(i) TO (ii) Biomass EC (iii) FDI (iv) Urbanization (v) Kyoto Protocol	(panel) (i) GMM (ii) OLS–FE (iii) PMG			√ GMM: all excluding the model with FDI √ FE: all excluding the model without TO and FDI √ PMG		-
(Du et al., 2019)	71 Countries (1996–2012)	CO_2 emissions – GDP	(i) Urbanization (ii) Industrial Structure (iii) TO (iv) EC Structure (v) Green Patent Counts (vi) Output Gap Ratio	(panel) OLS–FE		√			√
(S. Khan et al., 2019)	193 Countries (1990–2017)	CO_2 emissions – GDP	(i) EC (ii) FD by Private Sector Credit (iii) TO (iv) Bank FD (v) Population (vi) Merchandise Trade (vii) Infrastructures (viii) Merchandise Trade (ix) Gross Saving (x) Government Expenditure on Educations	(panel) (i) SUR (ii) GMM (iii) 2SGMM (iv) SYS–GMM (v) Sys2Step		√			-

(Lazăr et al., 2019)	11 Central and Eastern European Countries*[12] (1996–2015)	(i) CO_2 emissions – GDP (ii) Biocapacity – GDP (iii) EF – GDP (iv) SO_2 – GDP	(i) Gross inland EC (ii) Index of economic freedom of Heritage Foundation (iii) Globalisation (iv) FDI (v) Labor productivity (vi) Economic Complexity (vii) HDI (viii) Sectoral Structure of Agriculture, Industry, and Services	(panel and time series) (i) MG (ii) MG–FMOLS (iii) AMG	√ CO_2 emissions – Bulgaria and Latvia	√ CO_2 emissions – Czech R. and Hungary	√ CO_2 emissions, Biocapacity and SO_2 – panel √ CO_2 emissions – Croatia and Estonia	√ CO_2 emissions – Poland and Slovakia	√
(J. Zhao et al., 2019)	30 Chinese provinces (1999–2017)	(i) SO_2 – GRP (ii) Industrial Solid Waste – GRP (iii) Industrial Wastewater Discharge – GRP	(i) FD (ii) EC (iii) Industrial Structure (iv) FDI (v) Technical Progress (vi) Environmental Regulation	(panel) (i) Pooled OLS (ii) SDM				√	√

(X. Zhao, Zhou, Han, & Locke, 2019)	185 Chinese Cities (2015–2016)	(i) $PM_{2.5}$ emissions – Total Population (ii) $PM_{2.5}$ – Size of Built–up Area (iii) $PM_{2.5}$ – GDP (iv) $PM_{2.5}$ emissions – Private Vehicles (v) $PM_{2.5}$ – Population Density (vi) $PM_{2.5}$ emissions – Secondary Industry Share (vii) $PM_{2.5}$ emissions – Disposable Income	–	(panel) (i) Scatterplots (ii) OLS		√ $PM_{2.5}$ emissions (2015 and ($\triangle PM_{2.5}$ < 0)) – Total population, size of built–up area, GDP and private vehicles.			-
(Qiao et al., 2019)	19 of G20 Countries*[13] (1990–2014)	CO_2 emissions – GDP	(i) Agricultural VA (ii) Renewable EC	(panel) FMOLS		√ Full sample √ Developed panel			-
(Sarkodie & Strezov, 2019	China, India, Iran, Indonesia and South Africa (1982–2016)	(i) CO_2 emissions – GDP and FDI (ii) GHG emissions – GDP and FDI	(i) EC	(panel) (i) Pooled OLS (ii) Quantile (time series) (i) U–test	√ CO_2 emissions – GDP: India and S. Africa √ GHG emissions – GDP: Indonesia √ GHG emissions – FDI: Iran	√ CO_2 emissions – GDP: China and Indonesia √ CO_2 emissions – FDI: China, India, Iran and S. Africa √ GHG emissions – GDP: India √ GHG emissions – FDI: China, India and S. Africa	√ panel		√

(Hao, Xu, et al., 2019)	30 Provinces in China (2002–2015)	(i) Timber output – GDP and FDI (ii) Afforestation Area – GDP and FDI	(i) Urbanization (ii) TO (iii) Second Industry	(panel) (i) GMM (ii) OLS–FE	(i) FE: Afforestation Area – Whole sample and Western	√ FE: Timber output – Whole sample, Central and Western √ GMM: Timber output – Eastern, Central and Western	√ GMM: Timber output – Whole sample	√ FE: Timber output – Eastern (ii) FE: Afforestation area – Eastern and Central √ GMM: Afforestation area – Whole sample, Eastern, Central and Western	√
(Aydin et al., 2019)	26 EU Countries (1990–2013)	6 Footprint components (Built, Carbon, Cropland, Fishing, Forest, Grazing) – GDP	–	(panel) PSTR		√ Carbon and Cropland			-
(Adzawla et al., 2019)	Sub–Saharan Africa Countries (1970–2012)	(i) CO_2 emissions – GDP (ii) NH_4 – GDP (iii) NO_2 – GDP	–	(panel) (i) VAR (ii) OLS	√ NO_2			√ NH_4 and NO_2	√
(Akalpler & Hove, 2019)	India (1971–2014)	CO_2 emissions – GDP	(i) EC (ii) Imports (iii) Exports (iv) Gross Fixed Capital Formation	(time series) Granger causality	Non–validity				-
(Akhbari & Nejati, 2019)	61 Countries (2003–2016)	(i) CO_2 emissions – GDP (ii) CO_2 emissions – Corruption*HDI	(i) EC (ii) Corruption (iii) HDI (iv) TO (v) Population	(panel) (i) FE (ii) Threshold model		√ Corruption*HDI	√ GDP		√

(J. Yang, Tan, & Xue, 2019)	21 cities in Guangdong Province (1990–2015)	Environmental Quality – Globalisation	–	(panel) (i) Granger causality (ii) IR	√				√
(Deichmann et al., 2019)	137 Countries (1990–2014)	Energy Intensity – GDP	Share of EC of Industry, Transport, Residential, Services, Agriculture and Non–EC	(panel) (i) Pooled OLS (ii) Differences–in–Differences Regressions	√ Pooled OLS				-
(Dyrstad et al., 2019)	27 OECD–Countries (1980–2014)	Fossil Fuel Electricity Production – GDP	(i) Non–Fossil Fuel Electricity Production (ii) Kyoto protocol	(panel) Partial adjustment model			√		√
(Liobikienė & Butkus, 2019)	147 Countries (1990–2012)	(i) GHG emissions – GDP (ii) GHG emissions – Urbanization (iii) GHG emissions – FDI (iv) GHG emissions – TO	(i) Industrialization (ii) Renewable EC (iii) Energy Efficiency	(panel) SGMM		√ GDP: Scale effect (+ GHG) and Technique effects (– GHG)			-

(Hien, 2019)	22 Asia–Pacific Countries (1975/1995–2014)	Electricity Intensity – GDP	(i) Service VA (ii) Labor Productivity (iii) Average Residential Electricity Tariff (iv) Quality of the Institutional Environment (v) Electrification (vi) EC (vii) Efficiency of the power (viii) Efficiency of EC	(panel and time series) Factor model		√			√
(Kim et al., 2019)	131 developing and Advanced Countries (1960–2013)	CO_2 emissions – GDP	(i) Imports (ii) Exports (iii) Trade (iv) Urbanization (v) Population (vi) Schooling (vii) Initial CO_2 emissions	(panel) (i) GMM (ii) Quantiles		√ Quantiles: model with Trade (all quantiles excluding 0.10) – Whole Countries √ GMM: model with Trade – Whole Countries √ Quantiles and GMM: Model with export – Whole Countries √ Quantiles and GMM: Model with import – Whole Countries √ Quantiles and GMM: model with Trade – advanced (North) Countries			-

						√ Quantiles: model with Export – all quantiles excluding 0.10 and 0.75 – advanced (North) Countries √ Quantile and GMM: model with Import – advanced (North) Countries √ Quantiles: model with Trade – all quantiles excluding 0.10 – developing (South) Countries √ GMM: model with Trade – Developing (South) Countries √ Quantiles and GMM: model with export and model with import – developing (South) Countries			

(Pothen & Welsch, 2019)	144 Countries (1990–2008)	(i) Domestic Material Consumption – GDP (ii) Material Footprint – GDP	–	(panel) 2SLS	√ Domestic Material Consumption – non–OECD (ii) Material Footprint – Full	√ Domestic Material Consumption – OECD		√ Domestic Material Consumption and Material Footprint – OECD and Non–OECD	√
(Nguyen & Kakinaka, 2019)	107 Countries (1990–2013)	(i) Renewable EC – GDP (ii) Non–Renewable EC – GDP	(i) CO_2 emissions (ii) Oil Price	(panel) (i) FMOLS (ii) DOLS		√			-

*1 – Brazil, China, India, Malaysia, Mexico, Philippines, Singapore, South Africa, South Korea, Thailand, and Turkey.
*2 – Electricity and heat production; manufacturing industries and construction; residential buildings, and commercial and public services; and transport.
*3 – China, Japan, South Korea, Russia, Indonesia, Malaysia, the Philippines, Singapore, Thailand and Vietnam.
*4 – China, Japan, South Korea and Russia.
*5 – Indonesia, Malaysia, the Philippines, Singapore, Thailand and Vietnam.
*6 – Bangladesh, China, India, Indonesia, Iran, Jordan, Malaysia, Mongolia, Nepal, Pakistan, Philippine, Sri Lanka, Thailand, Turkey and Vietnam.
*7 – 30 high–, 48 middle– and 9 low–income Countries.
*8 – Brazil, Russia, India, China, South Africa, Turkey, Indonesia, Germany, France, UK, Italy, Spain, Australia, Canada, USA, Japan and South Korea.
*9 – North America, Europe, Central Asia, Latin America, South Asia, and Africa.
*10 – Argentina, Brazil, Bolivia, Chile, Colombia, Costa Rica, Honduras, Mexico, Nicaragua, Panama, Paraguay, Peru, Uruguay and Venezuela.
*11 – Singapore, Thailand, Malaysia, Philippines and Indonesia.
*14 – Bulgaria, Croatia, the Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, and Slovenia.
*13 – Developed: Australia, Canada, France, Germany, Italy, Japan, Korea, UK, and US. Developing: Argentina, Brazil, China, India, Indonesia, Mexico, Russia, Saudi Arabia, South Africa, and Turkey.

Table A5.4 - Literature survey of 2020

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turning Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Germani et al., 2020)	110 Italian provinces (2010–2015)	(i) Environmental Crimes – GDP and Education (ii) Environmental Crimes – Household Income and Education	(i) Area (ii) Density (iii) Ratio of Females (iv) Unemployment (v) Entrepreneurship (vi) Trial Length (vii) Age ranges*1	(panel) FE		√			√
(Yilanci & Pata, 2020)	China (1965–2016)	EF – GDP	(i) EC (ii) Economic Complexity Index	(time series) Fourier ARDL	Non–validity				-
(Destek & Sinha, 2020)	24 OECD Countries (1980–2014)	EF – GDP	(i) Renewable EC (ii) Non–Renewable EC (ii) TO	(panel) (i) MG (ii) FMOLS–MG (iii) DOLS–MG (iv) CCE–MG (time series) (i) FMOLS (ii) CCE	√ MG, FMOLS–MG and DOLS–MG: panel √ CCE: Austria, Belgium, Canada, Greece, Italy, Japan, S. Korea, Spain, Switzerland and US √ FMOLS: Austria, Canada, Denmark, Greece, Italy, Japan, S. Korea, Netherlands, Spain and US	√ CCE – Germany; Turkey √ FMOLS: Chile, France, Germany, Mexico, New Zealand, Portugal, Turkey and UK			-

(Ike et al., 2020)	Thailand (1972–2014)	(i) CO_2 emissions of Solid – GDP (ii) CO_2 emissions of Liquid – GDP (iii) CO_2 emissions of Gaseous – GDP (iv) CO_2 emissions aggregate – GDP	Fiscal Policy	(time series) (i) DOLS (ii) TY		√			-
(M. M. Rahman, 2020)	10 electricity consuming Countries*[2] (1971–2013)	CO_2 emissions – GDP	(i) Electricity Consumption (ii) Globalisation	(panel) (i) FMOLS (ii) DOLS (time series) FMOLS	√ China, USA and UK	√ FMOLS and DOLS – panel √ Japan, Germany and S. Korea			-
(Sarkodie & Ozturk, 2020)	Kenya (1971–2013)	CO_2 emissions – GDP	(i) EC (ii) Urban Population	(time series) (i) ARDL (ii) U–test		√			√
(Dhrifi et al., 2020)	98 developing Countries (1995–2017)	CO_2 emissions – FDI and GDP	(i) Poverty (ii) EC	(panel) Simultaneous–equations	√ Africa panel – GDP √ Asia panel – GDP √ Lain America panel – GDP	√ Global panel – both FDI and GDP √ Asia panel – FDI			-
(Q. Chen & Taylor, 2020)	Singapore (1950–2017)	Chromium – GDP	(i) FDI (ii) TO (iii) Atmospheric Environmental Regulations	(time series) VECM		√			√
(Altıntaş & Kassouri, 2020)	14 European Countries*[3] (1990–2014)	(i) CO_2 emissions – GDP (ii) EF – GDP	(i) Renewable EC (ii) Fossil fuels Consumption	(panel) (i) Interactive FE (ii) Dynamic-CCE	√ CO_2 emissions	√ EF			-

(Moutinho, Madaleno, & Elheddad, 2020)	12 OPEC countries[*4] and seven economic activity sectors[*5] (1992–2015)	CO_2 emissions – GVA	(i) EC (ii) Oil Prices (iii) TO	(panel) PCSE	√ Panel countries √ Sector 1, 4 and 7	√ Sector 3 and 6			-
(Suki, Sharif, Afshan, & Suki, 2020)	Malaysia (1970–2018)	EF – GDP	(i) Overall Globalisation (ii) Economic Globalisation (iii) Social Globalisation (iv) Political Globalisation	(time series) Quantile ARDL		√			-
(Boubellouta & Kusch-Brandt, 2020)	30 European countries (2000–2016)	E-waste – GDP	(i) Information and communication technology goods exports (ii) Population	(panel) (i) GMM (ii) 2SLS (iii) OLS		√			√
(Le, Nguyen, Su, & Tran-Nam, 2020)	90 countries (2002–2014)	Income Inequality – GDP and Export diversification	(i) Human Capital (ii) Industrialization (iii) FDI Inflows (iv) TO	(panel) (i) PCSE (ii) FGLS	√ High-income economies panel – GDP	√ Global panel, – both GDP and Export Diversification √ Low and lower-middle income economies, Upper-middle income economies panel – both GDP and Export Diversification √ High-income economies panel – Export Diversification			-

(Pata & Aydin, 2020)	Top six hydropower energy-consuming countries*6 (1965–2016)	EF – GDP	Hydropower EC	(time series) (i) TY (ii) Fourier TY	Non–validity				-
(C. Xu et al., 2020)	111 China' cities (1991–2017)	Noise Pollution – GDP	(i) Population Density (ii) Industrial Structure (iii) Investment in Real Estate Development	(panel) (i) two-way fixed effects model (ii) GMM		√ Global panel √ Eastern Region and Central Region panel		√ Global panel √ Eastern Region panel	√
(Işik et al., 2020)	Canada, France, Germany, Italy, Japan, the UK, and the US (1995–2015)	CO_2 emissions – GDP	(i) Renewable EC (ii) International Tourism	(time series) AMG		√ France			-
(L. Brown et al., 2020)	Jamaica (1976–2014)	CO_2 emissions – Remittances	–	(time series) (i) ARDL (ii) NARDL		√			√

*1 – Age 15 to 19, Age 20 to 39, Age 40 to 59, Age 60 to 64, Age 65 and over.
*2 – China, the USA, India, Japan, Germany, Canada, Brazil, South Korea, France and the UK.
*3 – Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, and the UK.
*4 – Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates and Venezuela.
*5 – Sector 1 - Agriculture, Forestry and Fisheries industries; Sector 2 - Extractive and manufacturing industries; Electricity, gas and water industries; Sector 3 - All manufacturing industries; Sector 4 - Construction sector; Sector 5 - Wholesale, Lodging, Restoration and similar activities; Sector 6 - Transport activities, storage and communication; Sector 7 - Remaining economic activities.
*6 – China, Canada, Brazil, the US, Norway, and India.

Table A5.5 - Literature survey of 2021

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turning Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Ma et al., 2021)	France and Germany (1995–2015)	CO_2 emissions – GDP	(i) International Tourism Arrivals (ii) Labor Force (iii) Renewable EC (iv) Non–Renewable EC	(panel) (i) FMOLS (ii) DOLS (iii) VECM-PMG		√			√
(Aslam et al., 2021)	Malaysia (1971–2016)	CO_2 emissions – GDP	(i) Globalisation (ii) Industrialization (iii) TO	(time series) (i) ARDL (ii) VECM		√			-
(Tenaw & Beyene, 2021)	20 sub-Saharan African (SSA) countries (1990–2015)	(i) Environmental Degradation Index (EDI) – HDI (ii) EF – HDI	(i) EC (ii) FD (iii) FDI (iv) TO (v) Urbanization (vi) Livestock production	(panel) (i) ARDL (ii) CCE-PMG		√ Global panel – EDI and EF √ Resource-Intensive SSA countries panel - EDI			√
(Pata, Aydin, & Haouas, 2021)	Top ten countries with the largest ecological footprint*[1] (1992–2016)	EF – HDI	(i) Renewable EC (ii) Globalisation (iii) Total natural resources rents	(panel) AMG	Non–validity				-

(Singhania & Saini, 2021)	21 developed and developing countries (1990–2016)	CO_2 emissions – GDP	(i) EC (ii) TO (iii) FDI (iv) FD (v) Institutional Framework	(panel) (i) GMM (ii) Sys-GMM		√ Global panel √ Developed Countries panel √ Developing Countries panel			-
(Boubellouta & Kusch-Brandt, 2021)	174 countries (2016)	(i) E-waste per capita – GDP per capita (ii) Total e-waste generation – GDP	(i) Population (ii) Urbanization (iii) Industrialization (iv) Access to electricity	(panel) OLS	√ Oceania continent panel (with GDP per capita) – total e-waste	√ Global panel – both e-waste and total e-waste √ Europe, American, Africa (only with GDP per capita) and Oceania continent panel – e-waste per capita √ Europe, American (only with GDP), Africa and Oceania (only with GDP) continent panel – total e-waste			√
(Pata, 2021)	USA (1980–2016)	(i) EF – Economic Complexity Index (ii) CO_2 emissions – Economic Complexity Index	(i) Non–Renewable EC (ii) Renewable EC (iii) Globalisation	(time series) (i) FMOLS (ii) DOLS (iii) CCR		√			-
(Pata & Caglar, 2021)	China (1980–2016)	(i) CO_2 emissions – GDP (ii) EF – GDP	(i) Human Capital (ii) Globalisation (iii) Renewable EC (iv) TO	(time series) (i) ARDL (ii) FMOLS (iii) DOLS (iv) CCR	√				√
(Pata & Isik, 2021)	China (1981-2017)	Load Capacity Factor – GDP	(i) EC (ii) Tourist Arrivals	(time series) Dynamic ARDL		√			-

(Abokyi et al., 2021)	Ghana (1971-2014)	CO_2 emissions – Manufacturing Sub-sector Output	(i) Electricity Consumption (ii) TO	(time series) (i) ARDL (ii) DOLS (iii) FMOLS (iv) Lind and Mehlum test	√				√
(Balsalobre-Lorente et al., 2021)	EU-5 Countries (1990-2015)	CO_2 emissions – GDP and Air Transport Passenger	(i) FDI (ii) Renewable Energy Production (iii) Public Budget in Energy Innovation	(panel) FMOLS		√			-
(Caglar, Mert, & Boluk, 2021)	10 Countries with the worst Environmental Degradation*[2] (1982-2014)	EF – GDP	(i) Information and Communication Technologies (ii) Renewable EC (iii) Non-Renewable EC (iv) FD	(panel) ARDL - PMG	√				-
(Chien et al., 2021)	Pakistan (1980-2018)	CO_2 emissions – GDP	(i) Globalisation (ii) Technology Innovation (iii) Renewable Energy	(time series) Quantile ARDL		√ (quantiles between 0.7 – 0.95)			-
(Hussain & Dogan, 2021)	BRICS (1992-2016)	EF – GDP	(i) Investment in Environment-related Technologies (ii) EC (iii) Institutional Quality	(panel) (i) CS-ARDL (ii) AMG (iii) CCEMG	Non-validity				-
(Jun et al., 2021)	South Asian Economies*[3] (1985-2018)	CO_2 emissions – GDP	(i) Globalisation (ii) Non-Renewable EC	(time series and panel) FMOLS		√ Full panel √ Bangladesh, India, Sri Lanka, and Nepal			-
(Sun et al., 2021)	USA (1980-2018)	CO_2 emissions – GDP	(i) Globalisation (ii) Eco-innovation	(time series) Quantile ARDL		√ (quantiles between 0.6 – 0.95)			-

(Laverde-Rojas et al., 2021)	Colombia (1971-2014)	CO_2 emissions – GDP	(i) Economic Complexity Index (ii) EC (iii) TO (iv) FDI	(time series) (i) VECM (ii) DOLS (iii) FMOLS (iv) CCR	√ CCR, DOLS	√ FMOLS			-

*[1] – China, the United States, India, Russia, Brazil, Japan, Indonesia, Germany, Mexico, and the UK.
*[2] – China, Brazil, Germany, Indonesia, India, Japan, Mexico, Russian Federation, United States and UK.
*[3] – Bangladesh, India, Sri Lanka, Pakistan, and Nepal.

Table A5.6 - Literature survey of 2022

Authors	Country(ies) and period	Variables analysed on EKC validity	Additional variables included on EKC analysis	Type of analysis and Method(s) employed	Relationship obtained				Turning Point
					U–shaped	EKC (inverted U–shaped)	N–shaped	inverted N–shaped	
(Pata & Balsalobre-Lorente, 2022)	Turkey (1965-2017)	Load Capacity Factor – GDP	(i) Human Capital (ii) Natural Resource Rent (iii) Energy Intensity	(time series) Dynamic ARDL		√			-
(Shehzad, Zeraibi, & Zaman, 2022)	Algeria (1970-2017)	EF – GDP	(i) Economic Globalisation (ii) Natural Resources Rent	(time series) ARDL			√		-
(Tahir, Burki, & Azid, 2022)	MENA*[1] (2002-2019)	CO_2 emissions – GDP	(i) Terrorism (ii) EC (iii) TO (iv) Urbanization	(panel) (i) RE (ii) FE (iii) GLS (iv) 2SLS		√ FE, GLS, 2SLS			-
(Liu, Sadiq, Ali, & Kumail, 2022)	Pakistan (1980-2017)	EF – Trade and Tourism	(i) GDP (ii) EC (iii) FDI (iv) TO	(time series) ARDL		√			√
(Shokoohi et al., 2022)	Iran, Iraq, and Turkey (1971-2015)	(i) CO_2 emissions – GDP (ii) EF – GDP	(i) Energy Intensity (ii) TO	(time series) ARDL	√ Iran and Iraq - CO_2	√ Iran, Iraq, and Turkey - EF √ Turkey - CO_2			√
(Q. Yang et al., 2022)	Emerging Seven Countries*[2] (1995-2018)	CO_2 emissions – GDP	(i) Renewable Energy (ii) Public-Private Partnership	(panel) (i) FE-OLS (ii) FMOLS (iii) DOLS (iv) MMQR		√ FE-OLS, FMOLS, DOLS, MMQR (lower quantiles)			-
(Burki & Tahir, 2022)	ASEAN Region*[3] (2001-2020)	CO_2 emissions – GDP	(i) EC (ii) TO (iii) FD	(panel) (i) RE (ii) FE (iii) GLS (iv) 2SLS		√	√		-

(Xia et al., 2022)	67 Developed and Developing Countries (1971-2018)	CO_2 emissions – GDP	(i) EC (ii) Globalisation	(panel) (i) GMM (ii) FE-2SLS (iii) GLS (iv) 2SLS		√			-
(Sheikhzeinoddin et al., 2022)	MENA (2000-2015)	Composite Index of Environmental Performance – GDP	(i) Energy Intensity (ii) Population	(panel) ARDL - PMG			√		√
(W. Li et al., 2022)	89 Belt and Road Initiative Countries (1995-2017)	(i) CO_2 emissions – GDP (ii) SO_2 – GDP (iii) VOC – GDP (iv) NOx – GDP (v) CO – GDP	(i) FDI (ii) Energy Structure (iii) Urbanization (iv) Industrial Structure	(panel) (i) PCSE (ii) GLS	√ Sub-region LA – GLS – CO √ Sub-region LA – PCSE – CO_2, VOC, CO √ Sub-region SSA – PCSE – SO_2, VOC, NO_X √ Sub-region MENA – PCSE – CO_2, SO_2, NO_X √ Sub-region MENA – GLS – SO_2	√ Full panel – PCSE – all environmental indicators √ Full panel – GLS – CO_2, SO_2, NO_X, CO √ Sub-region EU – PCSE and GLS – all environmental indicators √ Sub-region LA – GLS – SO_2 √ Sub-region AP – PCSE – CO_2, SO_2, NO_X, CO √ Sub-region AP – GLS – SO_2, NO_X			√
(W. Zhao et al., 2022)	G7 (1995-2018)	CO_2 emissions – GDP	(i) Eco-innovations (ii) Solar Energy	(panel) (i) CS-ARDL (ii) AMG (iii) CCEMG		√			-

*[1] – Algeria, Bahrain, Egypt, Iran, Iraq, Israel, Jordon, Kuwait, Lebanon, Libya, Morocco, Qatar, Saudi Arabia, Tunisia, and UAE.
*[2] – China, Turkey, Russia, India, Indonesia, Brazil, and Mexico.
*[3] – Brunei Darussalam, Cambodia, Indonesia, Malaysia, Philippines, Singapore, Thailand, and Vietnam.

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Chapter 6

Is globalisation a driver for energy efficiency and sustainable development?

Within the context of globalisation, sustainable development is an issue which is frequently deliberated over by policymakers, both locally and globally. A challenge surfaces as to how to grow economies sustainably and efficiently. With this in mind, a question arises: Can globalisation promote sustainable development and energy efficiency? The main objective of this essay is to assess the role of the phenomenon of globalisation through its three dimensions, economic, social, and political, and the two new measures, *de jure* and *de facto*, in sustainable development (measured in this study by the Index of Sustainable Economic Welfare) and in energy efficiency (measured in this study by the Efficiency Index). To accomplish this purpose, this essay provides a debate of the literature on these issues: globalisation, sustainable development, and energy efficiency. Besides that, this essay goes further by providing empirical evidence of the role of globalisation in sustainable development and in energy efficiency through the Autoregressive Distributed Lag model and Driscoll-Kraay estimator. This analysis is performed for the top 20 energy consumers per capita countries from 1995 to 2017, divided into high globalised countries and low globalised countries according to the Overall Globalisation Ranking. Overall, the results show that globalisation is mostly a driver of energy efficiency in the high globalised countries, and a driver of sustainable development in both groups of countries. Nevertheless, economic globalisation *de facto* in the low globalised countries and *de jure* in the high globalised ones undermines sustainable development. Furthermore, renewable energy consumption also reduces sustainable development in both groups of countries. Therefore, policymakers should be focused on restructuring renewable energy penetration strategies, as well as developing measures specifically for economic globalisation *de facto* and *de jure* according to each group of countries.

6.1 Introduction

Global warming is one of the greatest challenges facing mankind. Economically, environmental degradation has become one of the biggest issues confronting the planet. Resources are scarce, and the environment is considered within this scarcity. Therefore, the Paris Agreement and the Climate and Energy Framework Agreement reinforce the necessity to combat climate changes. In line with this, sustainable development is the main issue focused on by policymakers locally and globally (Gigliotti, Schmidt-Traub, & Bastianoni, 2019; Opoku, 2019). Sustainable development is frequently considered a process within the globalisation context, constituted by three main components: economic, social, and environmental. Globalisation is considered sustainable if it has a positive impact on the three main sustainable development components. Therefore, if globalisation provokes negative effects, it may be considered unsustainable (Beumer, Figge, & Elliott, 2018). Since the 1990s, growing globalisation has been noted, and since then, this phenomenon has affected economies, the environment, and human life. As asserted by Intriligator (2004), globalisation is considered crucial to define economic development and the future of the planet. With increasing and enhanced globalisation, the world's output is continuously growing, such as noted by Rahman (2020). Economic growth depends on energy, and society's excessive dependence on energy arises from the necessity to ensure the supply of growing energy demand and to sustain economic development. Consequently, carbon dioxide (CO_2) emissions are directly related to economic growth due to the fact that output growth needs energy consumption (Rahman, 2017).

Characterised by the integration of national economies with the world economy in aspects of trade, capital, socio-economic, and politics, globalisation is viewed as a driving force of economic growth (Mishkin, 2009). Consequently, it could undermine the integrity of the environment and induce its degradation (Shahbaz, Shahzad, & Mahalik, 2018; You & Lv, 2018). On the one hand, the phenomenon of globalisation stimulates environmental degradation by inducing trade openness and enabling the relocation of pollutant industries. The relocation of industries occurs from strict environmentally regulated countries to permissive environmentally regulated ones, that is, mainly from developed to developing countries. Consequently, this phenomenon could provoke significant environmental damage. According to the message of the Kyoto Protocol in 1997 and the Paris Agreement in 2015, both developed and developing countries have to mitigate CO_2 emissions, and consequently could have to sacrifice high growth of income or the ambition of high-income growth in order to promote environmental quality (Rahman, 2017). Diverse environmentalists consider that globalisation promotes the rising global demand for goods and services, which provokes an increase in economic activities and production, and consequently leads to environmental damage (Rahman, 2020). On the other hand, globalisation can induce environmental quality by allowing clean and environmentally friendly technology import.

One of the foremost common goals of countries worldwide is to promote economic growth while ensuring a clean and suitable environment. The difficulties lie in how to grow economies in a sustainable way. In order to accomplish sustainable development, understanding how to promote energy efficiency and its key benefits, consequently promoting environmental enhancement without compromising economic growth, is crucial. The effect of globalisation on energy consumption and the environment is not consensual in the literature. Therefore, considering globalisation as a tool to disseminate information and knowledge, able to transcend technological barriers and overcome national borders, the question arises: Could globalisation be a driver of energy efficiency and sustainable development? Through the recent improvements in globalisation measurement by Gygli, Haelg, Potrafke, & Sturm (2019), globalisation can be analysed through three dimensions, namely economic, social and political, and each dimension divided into the variables that represent the policies that allow and control the flows and the activities, and into the variables that represent the flows and activities, the measure *de jure* and *de facto*, respectively. This measurement of globalisation makes it possible to obtain specific results for each dimension and measure, which in turn allows the development of appropriate and assertive instruments and policies to suitably combat environmental degradation and promote energy efficiency and sustainable development. Considering the necessity and urgency to act against climate change, it is crucial to implement measures and policies that stimulate the beneficial effects of globalisation on the environment.

This essay first aims to present the background of the main issues under analysis and discussion, namely globalisation, energy efficiency, and sustainable development. Therefore, a comprehensive debate of the literature of these research topics is provided, which becomes a useful tool for the researchers that intend to study these issues. Besides that, this essay innovates by employing empirical procedures to assess the effect of each dimension and measure of globalisation on energy efficiency and sustainable growth, aiming to give an answer to the research question: Is globalisation a driver of energy efficiency and sustainable development? Taking into account the gap in the literature of the analysis of the new measures of globalisation, *de jure* and *de facto*, this essay brings an innovative contribution to the current literature, filling the gap in the analysis of globalisation *de jure* and *de facto* on sustainable development and energy efficiency. Sustainable development is assessed through the Index for Sustainable Economic Welfare (ISEW), which is considered an aggregate welfare measure that encompasses economic values that integrate distribution inequality of income, social impacts, environmental damage and quality, and elements that are beneficial to welfare (O'Mahony, Escardó-Serra, & Dufour, 2018). Therefore, this research is able to stress effects, such as the transfer of know-how and good policy practices. Considering that the time span covers more than two economic cycles, the use of a methodology that permits the analysis of the distinction of effects between the short- and the long-run is required. Therefore, to answer the proposed research question, this research uses the Autoregressive Distributed Lag (ARDL) model.

Henceforth, this essay is structured as follows. In the next section, a comprehensive debate about the relevant literature of globalisation, energy efficiency and sustainable development is presented. Subsequently, the data and empirical methods used in this research are explained in Section 3. Furthermore, Section 4 presents the obtained results. Lastly, Sections 5 and 6 consist of the discussion and conclusions of the main results, respectively.

6.2 Debate

To present a comprehensive literature review in an organised way, this section is divided into three subsections. The first subsection presents a summary of the globalisation literature. The second concentrates on a summary of the literature on energy efficiency. Lastly, the third one focuses on a summary of the sustainable development literature.

6.2.1 Globalisation

First introduced by Dreher (2006) and later improved by Dreher, Gaston, & Martens (2008), the KOF globalisation index has become the most used globalisation measurement in the literature (Gygli et al., 2019) among diverse globalisation indexes proposed over time, such as GlobalIndex (Raab et al., 2008); New Globalisation Index (Vujakovic, 2010); and Maastricht Globalisation Index (Figge & Martens, 2014). Therefore, the KOF globalisation index is widely used in the current literature (Bilgili, Ulucak, Koçak, & İlkay, 2020; Gozgor, Mahalik, Demir, & Padhan, 2020; Guan, Kirikkaleli, Bibi, & Zhang, 2020; P. H. Leal & Marques, 2020; M. Liu, Ren, Cheng, & Wang, 2020; Sethi, Chakrabarti, & Bhattacharjee, 2020; Suki, Sharif, Afshan, & Suki, 2020; Ulucak, Koçak, Erdoğan, & Kassouri, 2020; Wang, Vo, Shahbaz, & Ak, 2020; Woo & Jun, 2020). Recently, Gygli et al. (2019) updated the KOF globalisation index and proposed a revisited KOF globalisation index. The updated version includes new variables in the KOF globalisation index structure, capturing diverse interaction activities, and introduces two new measures, *de jure* and *de facto*.

The phenomenon of globalisation consists of economic, social, and political aspects, and it has a direct effect on production, consumption, environment, and human behaviours (Bilgili et al., 2020). Since the 1990s, the fast-increasing globalisation phenomenon has affected human life and economies through economic, political, and social aspects.

Consequently, globalisation represents diverse challenges in the widely varying areas of economics, energy, and environmental performance. Various authors have addressed the research questions of the role of globalisation in the environment (Ahmed, Cary, & Phong, 2021; Aluko, Opoku, & Ibrahim, 2021; Bilgili et al., 2020; P. H. Leal & Marques, 2020; P. Leal & Marques, 2019a; M. Liu et al., 2020; Suki et al., 2020; Sun, Chen, & Zhang, 2020; Wang et al., 2020; Yameogo, Omojolaibi, & Dauda, 2021). A summary of the literature that examines the relationship between globalisation and environmental performance is provided by Bilgili et al. (2020). Nevertheless, there is no consensus if globalisation is beneficial or harmful to the environment. Bilgili et al. (2020) reveal a negative causality that runs from financial globalisation, political globalisation, and trade globalisation to ecological footprint. In turn, Suki et al. (2020) reveal that economic and overall globalisation undermine the environment, while political and social globalisation are beneficial.

On the one hand, globalisation is harmful to the environment, reducing environmental quality, through stimulating trade openness and promoting the relocation of pollutant industries from developed countries to developing (Bilgili et al., 2020). Globalisation induces an increase in economic activities, such as trade and transportation, which consequently provokes more resource use and pollution (Copeland & Taylor, 2013). Furthermore, countries with an abundance of natural resources could overuse their resources in order to increase exports and consequently deteriorate environmental quality (Bilgili et al., 2020). On the other hand, globalisation could promote environmental quality through the importation of clean and green technology or by improving global ecological awareness. Furthermore, through the dissemination of technological progress, which is useful for decreasing the use of resources and consequently producing less pollution and overcoming trade barriers, it is expected that globalisation enhances countries' welfare (Shahbaz et al., 2018). The sustainable use of natural resources is a challenge with increasing globalisation. The phenomenon of globalisation provokes a split of production from consumption and consequently leads to the global redistribution of natural resources (Bolwig, Ponte, Toit, Riisgaard, & Halberg, 2010). According to Bilgili et al. (2020), globalisation has a crucial influence on the shape of efficient material use and consequently determines environmental sustainability. Ulucak et al. (2020) conclude that higher globalisation levels induce reduced material consumption and promote sustainable resource management.

By importing technology directed related to energy consumption and production activities, globalisation has the ability to decrease the energy demand of economies (Baek, Cho, & Koo, 2009). Therefore, economic globalisation improves the level of technology and consequently increases the productivity of energy sources and decreases the energy cost. Motivated by the findings provided by Shahbaz, Mallick, Mahalik, & Sadorsky (2016) regarding the effect of economic globalisation on the evolution of the energy demand in India, Gozgor et al. (2020) considered that this relationship should be addressed by developed countries. Therefore, Gozgor et al. (2020) focused on the effect of economic globalisation on renewable energy consumption in the Organisation for Economic Co-operation and Development (OECD) countries, concluding that a higher level of economic globalisation induces the use of renewable energy. These authors provide a summary of the energy-globalisation nexus literature.

6.2.2 Energy Efficiency

Introduced into the literature by Fisher (1921) with the objective of decomposing energy intensity into structural shift and energy efficiency (Metcalf, 2008), the Fisher Ideal Index is, according to the literature, commonly preferred and used (Boyd & Roop, 2004). This index perfectly decomposes the change in energy intensity into efficiency and activity changes, as well as the Log Mean Divisia index (LMDI). The Fisher Ideal Index and the LMDI derivate from the Index decomposition analysis (IDA). The IDA includes Laspeyres index methods and Divisia index methods. The Fisher Ideal Index is included in the Laspeyres index methods (Ang & Liu, 2001), while the LMDI in the Divisia index methods. According to Dargahi & Khameneh (2019), decomposition results via the LMDI method are similar to the results of the decomposition via the Fisher Ideal Index. These two indexes can be used in the same analysis to provide further evidence or to complement the results. P. A. Leal, Marques, & Fuinhas (2019) combine the LMDI method and the Fisher Ideal Index in order to perform a decomposition analysis by sectoral factors for the Australian sectors. The Fisher Ideal Index has most of the desirable properties on which the assessment of the IDA methods should be based, namely adaptability, strong theoretical foundation, easy use and interpretation, robustness to zero values, and consistency in aggregation (Ang, 2004). Furthermore, the Fisher Ideal Index computes decomposition without leaving any residual term. Therefore, the Fisher Ideal index, through its ability to compute an irreproachable decomposition of aggregate energy intensity into structural and efficiency components, is considered attractive to observe the relevance of industry composition and efficiency effects (Zhang, 2013).

Throughout the years, the Fisher Ideal Index has been applied in a wide diversity of contexts. The index was first used in industrial energy demand studies by F. L. Liu & Ang (2003). In turn, Boyd & Roop (2004) performed the Fisher Ideal Index in the United States manufacturing sector to assess the sources of energy intensity change.

Furthermore, this index was applied to assess the trends of economy-wide energy intensity (Metcalf, 2008). The Fisher Ideal Index can be applied to two strands. On the one hand, this index can be used to perform a decomposition analysis (P. A. Leal et al., 2019). On the other hand, beyond the decomposition, it can be included in regression techniques. Jimenez & Mercado (2014) applied the Fisher Ideal Index for 75 Latin American Countries to decompose the energy intensity into the relative contributions of energy efficiency and economic structure. Furthermore, the authors examined the main drivers of the energy indexes through panel data regression techniques. P. Leal & Marques, (2019a) and Özbuğday & Erbas (2015) computed the Fisher Ideal Index and introduced the energy efficiency index into the panel regression technique in order to analyse its effect on environmental degradation. Ullah, Neelum, & Jabeen (2019) applied the Fisher Ideal Index to decompose the change in electricity intensity into efficiency and activity changes in Pakistan. Then the authors proceeded to analyse the drivers of the activity index, efficiency index, and intensity index. In turn, Karimu, Brännlund, Lundgren, & Söderholm (2017), and Deichmann, Reuter, Vollmer, & Zhang (2019) examined the determinants of the energy intensity index.

6.2.3 Sustainable development

Sustainable development is commonly measured and analysed through Gross Domestic Product (GDP). Although GDP is the most popular indicator, its creators (Kuznets, 1934) recognised it as insufficient to assess sustainable development. This inadequacy comes from the fact that GDP is powerless to measure welfare and sustainability (Aşici, 2013; Gaspar, Marques, & Fuinhas, 2017a; Marques, Fuinhas, & Gaspar, 2016; Menegaki & Tugcu, 2018; Pais, Afonso, Marques, & Fuinhas, 2019), as well as being inefficient for quantifying social welfare (Costanza, Hart, Talberth, & Posner, 2009; Li & Fang, 2014; Stockhammer, Hochreiter, Obermayr, & Steiner, 1997). It is crucial to incorporate the three main dimensions of sustainability when measuring sustainable development, namely economic efficiency, social cohesion, and environmental responsibility (Aust, Morais, & Pinto, 2020; Dartey-Baah, 2014). This is one of the main limitations of the sustainable development measurements across the literature when measured through indicators such as The Human Development Indicator (Apinran, Taşpınar, & Gökmenoğlu, 2018; Sharma & Gani, 2004) and The Ecological Footprint (Balsalobre-Lorente, Gokmenoglu, Taspinar, & Cantos-Cantos, 2019; Doytch, 2020). Kwatra, Kumar, & Sharma (2020) provide a critical perspective on the evolution of sustainable development measurements.

Firstly computed by Daly & Cobb (1989) and later improved by Cobb & Cobb (1994), the ISEW arose as an alternative to measure sustainable development (Beça & Santos, 2010, 2014; Coscieme et al., 2020; Gaspar, Marques, & Fuinhas, 2017b; Marques, Fuinhas, & Pais, 2018; Menegaki, Marques, & Fuinhas, 2017; Menegaki & Tiwari, 2017; Menegaki & Tsagarakis, 2015). A study developed by Gaspar et al. (2017b), which compared the sustainable development approach, measured by the ISEW, with the economic growth approach, measured by GDP, reveals that a sensitivity exists when the ISEW is used in place of GDP. Welfare is considered an ambiguous and multi-faceted concept, and a composite indicator is essential to reflect it (Menegaki et al., 2017). The ISEW is an aggregate indicator for both current and future well-being, which includes environmental depletion through the costs of using available natural resources in its calculation. This makes it more trustworthy from an ecological point of view when compared with GDP. Therefore, according to Hák, Janoušková, & Moldan (2016), the ISEW is suitable for analysing the accomplishment of the Sustainable Development Goals of the United Nations. The most crucial obstacles and opportunities of the ISEW calculation are presented by Bleys & Whitby (2015). The ISEW combines three spheres of sustainability, namely: environment, society, and economy (Menegaki et al., 2017). A summarised explanation of measuring sustainable development is provided by Gaspar et al. (2017b), and Sánchez, Ochoa M, Toledo, & Ordóñez (2020) provide the theories of sustainable economic well-being.

The ISEW is widely used in energy economics literature, being analysed in diverse contexts, mainly in the energy-growth nexus (Gaspar et al., 2017b; Menegaki et al., 2017; Menegaki & Tiwari, 2017; Menegaki & Tugcu, 2016a, 2016b, 2018), but also in the context of food consumption (Marques et al., 2018) and in the accomplishment of the United Nations Sustainable Development Goals (Coscieme et al., 2020). Besides that, the ISEW has been applied to diverse groups of countries, namely Sub-Saharan emerging economies (Menegaki & Tugcu, 2016a), 15 emerging economies (Menegaki & Tugcu, 2016b), American countries (Menegaki & Tiwari, 2017), Europe (Gaspar et al., 2017b; Menegaki et al., 2017), Asian countries (Menegaki & Tugcu, 2018), Spain (O'Mahony et al., 2018), and Ecuador (Sánchez et al., 2020).

6.3 Empirical Procedure

The purpose of this section is to present the features of the data and sample under analysis. It will also describe and explain the methodology applied to fulfil the main objective of this research, which is to analyse the influence of globalisation, its dimensions and measures, on sustainable development and on energy efficiency.

6.3.1 Data

This research is performed for the top 20 energy consumers *per capita* countries of 2017. These countries were selected using the BP Statistical Review of World Energy 2019 and the data availability of the variables included in this analysis. This group of 20 countries was divided into two groups. The division was made to capture the effect of different levels of globalisation among the countries, giving rise to two groups, namely the high globalised countries (HGC) and the low globalised countries (LGC). Therefore, the countries were divided through the Overall Globalisation Ranking obtained from the KOF Swiss Economic Institute. After collecting the score of each country in the Overall Globalisation Ranking, the division was made through the calculation of the mean and median. Both mean and median calculation resulted in the same groups of countries, they are: (i) HGC consist of Austria, Belgium, The Czech Republic, Finland, France, Germany, The Netherlands, Norway, Sweden, and Switzerland (ii) LGC include Australia, Canada, Estonia, Ireland, Japan, Luxembourg, New Zealand, Slovakia, Slovenia, and The United States. In order to use the most available data, two time periods are under analysis. The computation of the ISEW is only available from 2000 to 2017, considering the availability of its components, so consequently, the model with the ISEW as the dependent variable was estimated for this time period. Nevertheless, considering available data from 1995 to 2017, for the remaining variables under analysis, the model with efficiency index as the dependent variable is estimated for this time period.

In order to capture economic, sustainable development, globalisation, energy, and environmental effects, according with the literature, the variables under analysis are namely: (i) Gross Domestic Product (*GDP*), as a proxy of economic growth, collected from World Data Bank and measured in constant 2010 prices in US$; (ii) the Index for Sustainable Economic Welfare (*ISEW*), as a proxy of sustainable development, from own elaboration; (iii) the KOF Globalisation Index Economic Dimension *de Facto* (*KOFEF*); the KOF Globalisation Index Economic Dimension *de Jure* (*KOFEJ*); the KOF Globalisation Index Social Dimension *de Facto* (*KOFSF*); the KOF Globalisation Index Social Dimension *de Jure* (*KOFSJ*); the KOF Globalisation Index Political Dimension *de Facto* (*KOFPF*); and the KOF Globalisation Index Political Dimension *de Jure* (*KOFPJ*) obtained from the KOF Swiss Economic Institute (http://globalisation.kof.ethz.ch/); (iv) oil consumption (*OIL*); coal consumption (*COAL*); gas consumption (*GAS*), and renewable energy consumption (*RES*), all collected from the BP Statistical Review of World Energy 2019. *OIL* is measured in Million tonnes (Mt), and *COAL*, *GAS* and *RES* are measured in Millions of tonnes in oil equivalent (Mtoe); (v) Carbon Dioxide (CO_2) emissions, collected from the BP Statistical Review of World Energy 2019, is measured in Mt; (vi) Efficiency index (EF) (1990=1) is computed through the Fisher Ideal Index developed by Fisher (1921).

6.3.1.1 Index for Sustainable Economic Welfare (ISEW)

The ISEW is an aggregate indicator for present and future well-being based on economic, environmental and social dimensions and is used as a proxy for sustainable development (Gaspar et al., 2017a; Marques et al., 2018). The ISEW calculation is initiated with the personal consumption expenditure weighted for income inequality. This takes into account the advantages that rich countries benefit from economic growth compared to poorer ones. To this, positive magnitudes of welfare, namely public health and education expenditures, are added, and from this negative magnitudes of welfare, namely environmental costs (defensive costs), are subtracted. The ISEW computation used in the present study was adopted from Marques et al. (2018), Menegaki et al, (2017) and Menegaki & Tsagarakis (2015), following the formal expression described in Equation 6.1:

$$ISEW = C_w + G_{eh} + K_n + S - N - C_s \tag{6.1}$$

where C_w denotes the weighted private consumption, G_{eh} denotes the non-defensive public expenditure, K_n represents the net capital growth, S consists of the unpaid work benefit, N measures the depletion of the natural environment and C_s describes the cost of social issues.

Due to lack of data, as in Marques et al. (2018) and Menegaki et al. (2017), social costs were not included in the ISEW calculation. The parameters and calculation process of the ISEW are described in Table 6.1.

Table 6.1 - ISEW components

Variables	Sign	Calculation method	Source
Adjusted personal consumption with durables (C_w)	+	PC*(1-GINI)	PC: https://data.worldbank.org/indicator/NE.CON.PRVT.CD GINI:https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/LM4OWF
Education expenditure (G_{eh})	+	Education expenditure*0,5	http://data.worldbank.org/indicator/NY.ADJ.AEDU.CD
Health expenditure (G_{eh})	+	Health expenditure*0,5	https://data.worldbank.org/indicator/SH.XPD.CHEX.PC.CD
Net capital growth (K_n)	±	FCA-CFC	FCA: http://data.worldbank.org/indicator/NE.GDI.TOTL.CD CFC: http://data.worldbank.org/indicator/NY.ADJ.DKAP.CD
Mineral depletion (N)	-		http://data.worldbank.org/indicator/NY.ADJ.DMIN.CD
Energy depletion (N)	-		http://data.worldbank.org/indicator/NY.ADJ.DNGY.CD
Forest depletion (N)	-		http://data.worldbank.org/indicator/NY.ADJ.DFOR.CD
Damage from CO_2 emissions (N)	-		http://data.worldbank.org/indicator/NY.ADJ.DCO2.CD

Note: PC denotes Final household consumption expenditure; FCA denotes fixed capital accumulation; CFC denotes consumption of fixed capital. The sources were last accessed in June 2020.

In the process of the calculation of the ISEW, extrapolation technique had to be used to calculate a few observations due to the lack of data. This technique was used to calculate the GINI coefficient for Japan for the years of 2016 and 2017.

6.3.1.2 Efficiency Index

To calculate the efficiency index, the following variables were collected: (a) Energy consumption by sector, collected from the International Energy Agency (IEA) measured in kilotons of oil equivalent (ktoe); (b) Gross Value Added (GVA) and Gross Domestic Product (GDP) both collected from the United Nations Statistical Division (UNSD) and measured in constant 2015 prices in US$. The Fisher Ideal Index is computed as follows (The present study only analyses the efficiency index. Therefore, the computation presented is for the efficiency index. A complete computation of the three indexes can be found in (P. Leal & Marques, 2019b).).

Energy intensity is mathematically specified as a function of energy efficiency and economic activity (Metcalf, 2008). Therefore, aggregate energy intensity (e_t) is obtained through the total energy consumption (E_t) and the total output (GDP) (Y_t) in year t, that corresponds to the sum of energy intensity by sector (e_{it}) with the changes in the economy structure (s_{it}). Written as Equation 6.2:

$$e_t = \frac{E_t}{Y_t} = \sum_i \left(\frac{E_{it}}{Y_{it}}\right)\left(\frac{Y_{it}}{Y_t}\right) = \sum_i e_{it}s_{it}, \tag{6.2}$$

where E_{it} and Y_{it} denotes energy consumption and the measure of economic activity for sector i in year t, respectively.

The computation of the Fisher Ideal index requires the construction of Laspeyres index (L) and Paasche index (P). Equation 6.3 represents the calculation of the Laspeyres and Paasche indexes of efficiency (EF).

$$L_t^{EF} = \frac{\sum_i e_{it}s_{i0}}{\sum_i e_{i0}s_{i0}} \; ; \; P_t^{EF} = \frac{\sum_i e_{it}s_{it}}{\sum_i e_{i0}s_{it}}, \tag{6.3}$$

Lastly, the efficiency index is obtained through the Fisher Ideal Index given by the Laspeyres and Paasche indexes, as written in Equation 6.4.

$$F_t^{EF} = (L_t^{EF} * P_t^{EF})^{\frac{1}{2}} \; . \tag{6.4}$$

The energy efficiency index is interpreted as follows. A positive variation of the index value denotes a decrease in the efficiency since it matches the increase of the energy used per unit of economic output. Therefore, a negative variation of the index value denotes an enhancement of the efficiency, since it matches the decrease in the energy used per unit of economic output. Thus, the efficiency index demonstrates the efficiency trajectory and the evolution through the years.

6.3.1.3 Preliminary tests

A preliminary analysis of the coefficients of the correlation matrix was performed to realise transformations on the variables to avoid correlation concerns. Therefore, the transformations performed, namely *GDP* and *CO_2*, were transformed into *per capita*, and *OIL*, *COAL*, *GAS* were summed and gave rise to the *FF* (fossil fuels consumption) variable, that is *RES* were transformed into a percentage of primary energy consumption.

Descriptive statistics of the variables under analysis for the high and low globalised countries and for both time periods are displayed in Table 6.2 and 6.3.

Table 6.2 - Descriptive statistics from 1995 to 2017 - Efficiency Index

	High Globalised Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
EF	0.8113	0.1405	0.5118	1.1545	230
GDP_pc	48079.06	17974.28	13462.99	91565.73	230
CO_2_pc	9.17E-06	2.98E-06	4.47E-06	1.46E-05	230
FF_p	66.3131	20.5673	29.9946	98.8285	230
RES_p	19.536	19.8065	0.2068	70.0054	230
KOFEF	73.9462	9.9082	43.7157	92.0529	230
KOFEJ	86.6182	4.4914	68.196	94.7231	230
KOFSF	82.9711	5.7338	66.4892	95.1544	230
KOFSJ	84.3414	5.3839	68.5726	92.6337	230
KOFPF	91.8538	3.7365	84.0649	98.0264	230
KOFPJ	95.5783	4.747	66.8212	100	230
	Low Globalised Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
EF	0.8111	0.2514	0.2765	2.1529	230
GDP_pc	41243.33	23966.81	7205.101	111968.4	230
CO_2_pc	0.0000132	5.40e-06	5.50e-06	0.0000275	230
FF_p	83.3317	13.3325	58.6107	99.9788	230
RES_p	10.4968	11.1732	0.02119	39.5422	230
KOFEF	65.0015	17.4401	27.8283	92.3781	230
KOFEJ	80.5243	8.9836	46.6112	97.3884	230
KOFSF	78.8434	8.5545	54.5939	92.1187	230
KOFSJ	83.679	5.575	64.9952	93.2102	230
KOFPF	9.593	12.9355	43.0076	94.8829	230
KOFPJ	81.8009	11.1257	39.6222	95.5342	230

Notes: Max. denotes Maximum; Min. denotes Minimum; Std. Dev. denotes Standard deviation; Obs denotes Observations.

Table 6.3 - Descriptive statistics from 2000 to 2017 - ISEW

	High Globalised Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
ISEW	4.31E+11	5.01E+11	2.97E+10	1.87E+12	180
CO_2_pc	9.01E-06	2.99E-06	4.47E-06	1.46E-05	180
FF_p	65.652	20.4767	29.9946	98.18945	180
RES_p	20.0835	19.8137	0.3688	70.0054	180
EF	0.76862	0.1223	0.5118	1.0906	180
KOFEF	76.7725	7.6865	60.991	92.0529	180
KOFEJ	86.2908	3.9418	74.4174	94.7231	180
KOFSF	84.4701	5.072	71.8423	95.1544	180
KOFSJ	86.0051	3.8582	73.1227	92.6337	180
KOFPF	92.0462	3.7351	84.3439	98.0264	180
KOFPJ	96.3892	3.3583	81.5323	100	180
	Low Globalised Countries				
	Mean	Std. Dev.	Min.	Max.	Obs.
ISEW	1.19E+12	2.50E+12	2.98E+09	1.10E+13	180
CO_2_pc	1.32E-05	5.51E-06	5.50E-06	2.75E-05	180
FF_p	83.0118	13.3154	58.6107	99.9155	180
RES_p	10.7502	11.0202	0.0845	38.6843	180
EF	0.7587	0.2040	0.2764	1.4859	180
KOFEF	66.9945	16.5009	29.8409	92.3781	180
KOFEJ	81.7494	6.9768	62.5938	97.3884	180
KOFSF	80.8765	7.5105	59.5395	92.1187	180
KOFSJ	85.5427	3.7712	73.9270	93.2102	180
KOFPF	80.7622	11.7220	43.2533	93.4251	180
KOFPJ	83.9222	9.4142	59.9408	95.5342	180

Notes: Max. denotes Maximum; Min. denotes Minimum; Std. Dev. denotes Standard deviation; Obs denotes Observations.

To detect the characteristics of the panel data, some preliminary tests were carried out, namely the Pesaran (2004) cross-section dependence test (CD-test) (Table 6.4 and 6.5). Cross-section dependence commonly occurs, and it is one of the challenges in panel data settings. Therefore, according with the literature, it is advised to give further attention to both the nature of the variables and the idiosyncrasies of the countries analysed, mainly in the macro panel (Eberhardt, 2011; Hoechle, 2007). The results from the CD-test strongly suggest the presence of cross-sectional dependence for all variables of both groups of countries, HGC and LGC, for the period of 1995-2017 (Table 6.4). For the period 2000-2017, the presence of cross-sectional dependence is suggested for all variables of the HGC, while in the LGC it is suggested for all variables except for *KOFEF* and *KOFPF* (Table 6.5).

Table 6.4 - Cross-section Dependence test from 1995 to 2017 - Efficiency Index

	High Globalised Countries				Low Globalised Countries		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LEF	30.06***	0.934	0.934	*LEF*	28.91***	0.899	0.899
LGDP_pc	30.84***	0.959	0.959	*LGDP_pc*	30.36***	0.944	0.944
LCO_2_pc	27.36***	0.850	0.850	LCO_2_pc	11.80***	0.367	0.569
LFF_p	21.61***	0.672	0.672	*LFF_p*	12.88***	0.400	0.691
LRES_p	23.20***	0.721	0.721	*LRES_p*	21.81***	0.678	0.678
LKOFEF	31.06***	0.966	0.966	*LKOFEF*	10.46***	0.325	0.490
LKOFEJ	19.44***	0.604	0.758	*LKOFEJ*	12.81***	0.398	0.453
LKOFSF	30.80***	0.957	0.957	*LKOFSF*	30.15***	0.937	0.937
LKOFSJ	27.96***	0.869	0.869	*LKOFSJ*	28.64***	0.890	0.890
LKOFPF	9.63***	0.299	0.370	*LKOFPF*	3.68***	0.114	0.456
LKOFPJ	26.86***	0.835	0.835	*LKOFPJ*	21.71***	0.675	0.805

Notes: ***, ** denotes significance level at 1% and 5%, respectively.

Table 6.5: Cross-section Dependence test (CD – test) from 2000 to 2017 - ISEW

	High Globalised Countries				Low Globalised Countries		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LISEW	27.45***	0.965	0.965	*LISEW*	22.70***	0.797	0.797
LCO_2_pc	25.69***	0.903	0.903	LCO_2_pc	12.38***	0.435	0.674
LFF_p	18.20***	0.64	0.64	*LFF_p*	13.91***	0.489	0.793
LRES_p	21.31***	0.749	0.749	*LRES_p*	22.18***	0.779	0.779
LEF	25.96***	0.912	0.912	*LEF*	24.81***	0.872	0.872
LKOFEF	24.41***	0.858	0.858	*LKOFEF*	1.34	0.047	0.546
LKOFEJ	17.82***	0.626	0.729	*LKOFEJ*	5.55***	0.195	0.339
LKOFSF	26.99***	0.948	0.948	*LKOFSF*	25.54***	0.897	0.897
LKOFSJ	16.30***	0.573	0.573	*LKOFSJ*	22.13***	0.778	0.778
LKOFPF	8.34***	0.293	0.413	*LKOFPF*	0.77	0.027	0.46
LKOFPJ	21.61***	0.759	0.759	*LKOFPJ*	18.78***	0.66	0.764

Notes: ***, ** denotes significance level at 1% and 5%, respectively.

Therefore, due to the presence of cross-sectional dependence, the second-generation unit root test (CIPS) (M. Hashem Pesaran, 2007) was carried out. Whereas the presence of cross-sectional dependence could be a limitation for the first-generation unit root tests, the second-generation unit root test has the advantage of being suitable in its presence. However, for the variable with an absence of cross-sectional dependence, the first-generation unit roots tests LLC (Levin, Lin, & Chu, 2002), ADF-Fisher (Maddala & Wu, 1999) and ADF-Choi (Choi, 2001) were performed. The CIPS test is performed under the null hypothesis of non-stationarity. This test revealed that the variables under analysis are integrated in level I(0) and integrated of order one I(1), ensuring the absence of variables integrated of order two I(2) (Table 6.6 and 6.7) and the first-generation unit root tests corroborate the results obtained.

Table 6.6 - 2nd Generation Unit Root test (CIPS) from 1995 to 2017 - Efficiency Index

	High Globalised Countries			Low Globalised Countries	
	Without trend	With trend		Without trend	With trend
LEF	- 0.924	- 0.161	*LEF*	1.014	2.405
DLEF	- 9.501***	- 8.528***	*DLEF*	- 8.579***	- 8.165***
LGDP_pc	- 0.246	1.165	*LGDP_pc*	0.272	2.710
DLGDP_pc	- 4.833***	- 3.035***	*DLGDP_pc*	- 4.576***	- 3.585***
LCO2_pc	- 2.658***	- 3.436***	*LCO2_pc*	0.284	- 0.307
DLCO2_pc	- 9.920***	- 8.343***	*DLCO2_pc*	- 7.288***	- 6.194***
LFF_p	- 1.806**	- 2.773***	*LFF_p*	- 1.598*	0.096
DLFF_p	- 11.185***	- 9.875***	*DLFF_p*	- 8.150***	- 7.810***
LRES_p	- 0.834	- 2.969***	*LRES_p*	- 1.242	- 0.854
DLRES_p	- 12.946***	- 11.723***	*DLRES_p*	- 10.287***	- 9.913***
LKOFEF	- 0.363	- 0.257	*LKOFEF*	- 1.332*	- 0.119
DLKOFEF	- 9.533***	- 8.357***	*DLKOFEF*	- 5.394***	- 4.550***
LKOFEJ	- 1.048	- 1.523*	*LKOFEJ*	- 1.105	0.800
DLKOFEJ	- 11.306***	- 9.866***	*DLKOFEJ*	- 9.616***	- 9.227***
LKOFSF	- 2.400***	- 1.721**	*LKOFSF*	- 3.479***	- 1.702**
DLKOFSF	- 9.770***	- 9.351***	*DLKOFSF*	- 9.455***	- 8.052***
LKOFSJ	- 1.538*	- 1.510*	*LKOFSJ*	- 3.063***	- 1.271
DLKOFDJ	- 8.728***	- 7.106***	*DLKOFDJ*	- 9.786***	- 8.845***
LKOFPF	- 3.209***	- 0.479	*LKOFPF*	- 4.036***	- 4.475***
DLKOFPF	- 9.811***	- 8.100***	*DLKOFPF*	- 9.734***	- 8.299***
LKOFPJ	- 2.765***	- 2.898***	*LKOFPJ*	- 2.325**	- 2.040**
DLKOFPJ	- 10.007***	- 9.388***	*DLKOFPJ*	- 8.518***	- 7.729***

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively.

Table 6.7 - 2nd Generation Unit Root test (CIPS) from 2000 to 2017 - ISEW

	High Globalised Countries			Low Globalised Countries	
	Without trend	With trend		Without trend	With trend
LISEW	- 1.454*	- 0.288	*LISEW*	0.555	1.309
DLISEW	- 6.346***	- 4.812***	*DLISEW*	- 3.715***	- 1.378*
LCO2_pc	- 3.076***	- 1.595*	*LCO2_pc*	- 0.868	- 0.255
DLCO2_pc	- 7.31***	- 5.551***	*DLCO2_pc*	- 6.243***	- 4.275***
LFF_p	- 1.636*	- 1.673**	*LFF_p*	- 0.766	0.414
DLFF_p	- 8.399***	- 6.547***	*DLFF_p*	- 6.273***	- 5.162***
LRES_p	- 1.097	- 1.462*	*LRES_p*	- 1.964**	- 0.281
DLRES_p	- 9.760***	- 8.941***	*DLRES_p*	- 7.342***	- 6.354***
LEF	- 0.971	- 0.664	*LEF*	- 0.245	1.577
DLEF	- 7.268***	- 6.074***	*DLEF*	- 6.222***	- 6.229***
LKOFEF	- 0.049	0.726	*LKOFEF*	- 0.628	- 1.296*
DLKOFEF	- 6.877***	- 5.775***	*DLKOFEF*	- 7.175***	- 6.629***
LKOFEJ	- 2.849***	- 2.282**	*LKOFEJ*	- 0.999	0.499
DLKOFEJ	- 8.958***	- 7.922***	*DLKOFEJ*	- 7.264***	- 7.477***
LKOFSF	- 1.84**	- 1.496*	*LKOFSF*	- 3.036***	- 1.723**
DLKOFSF	- 7.306***	- 5.922***	*DLKOFSF*	- 7.971***	- 6.019***
LKOFSJ	- 3.627***	- 1.963**	*LKOFSJ*	-3.472***	- 2.624***
DLKOFDJ	- 7.850***	- 7.669***	*DLKOFDJ*	- 8.245***	- 6.662***
LKOFPF	0.142	2.644	*LKOFPF*	- 0.975	- 0.813
DLKOFPF	- 4.745***	- 3.979***	*DLKOFPF*	- 7.206***	- 7.240***
LKOFPJ	- 3.675***	- 2.554***	*LKOFPJ*	- 1.496*	- 2.637***
DLKOFPJ	- 7.947***	- 6.243***	*DLKOFPJ*	- 6.882***	- 5.412***

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively.

The time span under analysis consists of more than two economic cycles, which give rise to doubt about the occurrence of events in the series. Considering this, the unit root test with structural breaks is useful to corroborate the traditional unit root test and to reveal the break points in the series. These break points could be included as dummy variables in the estimations. Therefore, the Zivot & Andrews (1992) unit root test with structural breaks was carried out. To perverse space, the test is not displayed but is available from the authors on request.

Lastly, collinearity and multicollinearity among variables are computed to perform a comprehensive analysis of the data features. Hence, coefficients of correlation and the variance inflation factor (VIF) statistics were assessed, revealing that neither collinearity nor multicollinearity are a concern. Considering the features of the data, it is concluded that the use of the ARDL model is suitable.

6.3.2 Methodology

Considering the time span of more than two economic cycles in which diverse events could have occurred, the ARDL model developed by M. Hashem Pesaran, Pesaran, Shin, & Smith (1999) and M. Hashem Pesaran & Smith (1995) has diverse characteristics that can be considered as a benefit. According with the literature, the ARDL model produces consistent and efficient parameter estimates (Marques, Fuinhas, & Pereira, 2019; Papageorgiou, Michaelides, & Tsionas, 2016). Through the ARDL model, two important aspects are observed (Marques, Fuinhas, & Pereira, 2019; M.H. Pesaran & Shin, 1999), namely the dynamics of the short-run of the dependent variable adjustment when variations or shocks in explanatory variables occur; and the long-run equilibrium. Beyond this, the ARDL model allows the analysis of the dynamics of variables, disaggregating the impacts in both the short- and long-run. It also allows the inclusion of dummy variables to control the events that occurred in the series. Besides that, the ARDL model has the advantage of being able to deal with variables with different integration orders, such as variables I(0), I(1) and borderline, which is a feature of the data under analysis. This feature consents variables with long memory patterns to be conducted properly. Therefore, the ARDL model was used.

The general ARDL model is provided in Equation 6.5.

$$\Delta\varphi_t = \beta_i + \vartheta_{i1}\Delta\theta_t + \sum_{p=1}^{k}\beta_{1i}\varphi_{t-p} + \sum_{p=1}^{k}\beta_{2i}\theta_{t-p} + \mu_{i,t}\ , \tag{6.5}$$

where φ_t denotes the vector of dependent variables, β_i represents the intercept, ϑ_{i1} denotes the semi-elasticities, θ_t denotes the vector of independent variables, β_{1i} consists of the error correction mechanism (ECM), β_{2i} denotes the elasticities, and $\mu_{i,t}$ denotes the error term.

Following the general ARDL model structure Equation 6.5, the following two equation represent the models estimated with the ISEW and Efficiency Index as dependent variables. Therefore, Equation 6.6 for ISEW and Equation 6.7 for Efficiency Index.

$$\begin{gathered} DLISEW_{it} = \alpha_0 + \textstyle\sum_{j=0}^{n}\eta_{i1}DLCO2\_PC_{it} + \sum_{j=0}^{n}\eta_{i2}DLFF\_P_{it} + \\ \textstyle\sum_{j=0}^{n}\eta_{i3}DLRES\_P_{it} + \sum_{j=0}^{n}\eta_{i4}DLEF_{it} + \sum_{j=0}^{n}\eta_{i5}DLKOFECDF_{it} + \end{gathered} \tag{6.6}$$

$$\sum_{j=0}^{n}\eta_{i6}DLKOFECDJ_{it} + \sum_{j=0}^{n}\eta_{i7}DLKOFSODF_{it} + \sum_{j=0}^{n}\eta_{i8}DLKOFSODJ_{it} + \sum_{j=0}^{n}\eta_{i9}DLKOFPODF_{it} + \sum_{j=0}^{n}\eta_{i10}DLKOFPODJ_{it} + \omega_{i1}LISEW_{it-1} + \omega_{i2}LCO2\_PC_{it-1} + \omega_{i3}LFF\_P_{it-1} + \omega_{i4}LRES\_P_{it-1} + \omega_{i5}LEF\_P_{it-1} + \omega_{i6}LKOFECDF_{it-1} + \omega_{i7}LKOFECDJ_{it-1} + \omega_{i8}LKOFSODF_{it-1} + \omega_{i9}LKOFSODJ_{it-1} + \omega_{i10}LKOFPODF_{it-1} + \omega_{i11}LKOFPODJ_{it-1} + \varepsilon_{it},$$

$$DLEF_{it} = \alpha_0 + \sum_{j=0}^{n}\eta_{i1}DLGDP\_PC_{it} + \sum_{j=0}^{n}\eta_{i2}DLCO2\_PC_{it} + \sum_{j=0}^{n}\eta_{i3}DLFF\_P_{it} + \sum_{j=0}^{n}\eta_{i4}DLRES\_P_{it} + \sum_{j=0}^{n}\eta_{i5}DLKOFECDF_{it} + \sum_{j=0}^{n}\eta_{i6}DLKOFECDJ_{it} + \sum_{j=0}^{n}\eta_{i7}DLKOFSODF_{it} + \sum_{j=0}^{n}\eta_{i8}DLKOFSODJ_{it} + \sum_{j=0}^{n}\eta_{i9}DLKOFPODF_{it} + \sum_{j=0}^{n}\eta_{i10}DLKOFPODJ_{it} + \omega_{i1}LEF_{it-1} + \omega_{i2}LGDP\_PC_{it-1} + \omega_{i3}LCO2\_PC_{it-1} + \omega_{i4}LFF\_P_{it-1} + \omega_{i5}LRES\_P_{it-1} + \omega_{i6}LKOFECDF_{it-1} + \omega_{i7}LKOFECDJ_{it-1} + \omega_{i8}LKOFSODF_{it-1} + \omega_{i9}LKOFSODJ_{it-1} + \omega_{i10}LKOFPODF_{it-1} + \omega_{i11}LKOFPODJ_{it-1} + \varepsilon_{it}, \quad (6.7)$$

In these equations, the prefix D indicates first differences; α_0 exemplifies the intercept; n is the lag order; η_i represents the estimated parameters in the short-run; ω_i denotes the estimated parameters in the long-run; and ε_{it} symbolizes the error term.

A set of panel data specification tests were carried out in order to provide a suitable estimation. Hausman tests assess random effects against fixed effects, aiming to detect the most appropriate estimator to deal with the specific characteristics of the panel data. This test is performed under the null hypothesis that random effects are appropriate. The results are displayed in Table 6.8.

Table 6.8 - Hausman test and F - test

	HGC – ISEW	HGC - EF
F - test	5.68***	4.98***
Hausman test	41.61***	37.95***
	LGC - ISEW	LGC - EF
F - test	1.88*	6.43***
Hausman test	16.06*	46.41***

Notes: ***, **, * denotes significance level at 1%, 5% and 10% respectively.

According with the results, the Hausman test supports the appropriateness of the fixed effect estimator for all models. Considering that, the phenomena of heteroscedasticity, autocorrelation and contemporaneous correlation were assessed through the Modified Wald test, Wooldridge test, and the Pesaran-test (M Hashem Pesaran, 2004), Frees-test (Frees, 1995), and Friedman-test (Friedman, 1937), respectively, among cross sections were evaluated to decide on the most robust estimator (Table 6.9).

Table 6.9 - Specification tests

	HGC - ISEW	HGC - EF
Pesaran test	11.638***	5.725***
Frees test	1.518***	0.398***
Fiedman test	74.996***	55.418***
Modified Wald test	35.28***	6.98
Wooldrige test	48.232***	81.317***
	LGC - ISEW	LGC - EF
Pesaran test	10.806***	1.061
Frees test	0.729***	0.130*
Fiedman test	60.361***	28.458***
Modified Wald test	79.17***	691.37***
Wooldrige test	29.005***	5.289**

Notes: ***, **, * denotes significance level at 1%, 5% and 10% respectively.

The presence of heteroscedasticity, autocorrelation and contemporaneous correlation is revealed for almost all the models. The presence of all the features mentioned is suggested for the models of both groups of countries with ISEW as the dependent variable and for the LGC with the efficiency index as the dependent variable. Whereas for HGC with the efficiency index as the dependent variable, the presence of autocorrelation and contemporaneous correlation is suggested, and there is an absence of heteroscedasticity.

Therefore, the model specification tests indicated that the Driscoll-Kraay estimator (Driscoll & Kraay, 1998) is suitable for handling these data features. The presence of cross-section dependence provokes inconsistent estimates. However, the Driscoll-Kraay estimator computes consistent and robust estimated standard errors in the presence of cross-section dependence. Furthermore, this estimator assumes that the error structure is heteroskedastic, autocorrelated and correlated (Driscoll & Kraay, 1998; Sarkodie & Strezov, 2019). This study employs a panel data regression with the Driscoll-Kraay estimator.

6.4 Results

The estimations and results of the relationship between globalisation and energy efficiency, and globalisation and sustainable development, through the ARDL model and Driscoll-Kraay estimator, are presented in Table 6.10 for both groups of countries, high and low globalised countries.

Table 6.10 - ARDL Estimations

	High Globalised Countries		Low Globalised Countries	
	ISEW	EF	ISEW	EF
DLGDP_pc		- 0.9543***		- 0.7635***
DLCO2_pc		0.4272***	0.7364**	0.3808***
DLFF_p		- 0.2145***	- 0.6969**	- 0.2103**
DLRES_p	- 0.1193**		- 0.1878**	- 0.0574**
DLEF	- 0.7930**			
DLKOFEF			- 0.9248***	
DLKOFEJ			0.4725***	
DLKOFSF	1.7996***	- 0.3183***		
DLKOFSJ			1.3013***	
DLKOFPF		- 0.2642**	0.1749*	0.0716*
DLKOFPJ				
LISEW (-1)	**- 0.3171*** **		**- 0.2419*** **	
LEF (-1)	- 0.4604**	**- 0.3673*** **		**- 0.4363*** **
LGDP_pc (-1)		- 0.2774***		- 0.1590***
LCO2_pc (-1)		0.1231**		0.1368***
LFF_p (-1)	0.5455***	- 0.1994**		
LRES_p (-1)	- 0.0671***		- 0.0226*	- 0.0281**
LKOFEF (-1)		- 0.0405*	- 0.2443***	
LKOFEJ (-1)	- 0.9486***	- 0.2265**	0.3687*	0.1265**
LKOFSF (-1)		- 0.3000**		- 0.1424***
LKOFSJ (-1)				
LKOFPF (-1)				
LKOFPJ (-1)	3.5561***	0.3127**		- 0.2852***
C	- 5.4001*	6.6127***	5.7408***	4.9282***
Dum_2001		0.0171***	- 0.2947***	
Dum_2002			- 0.1392***	
Dum_2014		- 0.0374***		
		Elasticities		
LGDP_pc (-1)		- 0.7554***		- 0.3644***
LEF (-1)	- 1.4518***			

LCO2_pc (-1)		0.3351***		0.3136***
LFF_p (-1)	1.72***	- 0.5428***		
LRES_p (-1)	- 0.2116***		- 0.0934*	- 0.0644***
LKOFEF (-1)		- 0.1102*	- 1.01***	
LKOFEJ (-1)	- 2.991***	- 0.6167**	1.524*	0.2900**
LKOFSF (-1)		- 0.8170**		- 0.3263***
LKOFSJ (-1)				
LKOFPF (-1)				
LKOFPJ (-1)	11.2128***	0.8513**		- 0.6536***

Notes: ***, **, * denotes significance level at 1%, 5% and 10% respectively; Dum denotes dummy; C denotes constant; Values in bold are the ECM.

Taking into account the results of the Zivot & Andrews (1992) unit root test with structural breaks, the break points obtained through the test and in both the preceding and following years were tested in the models. Therefore, the dummies included in the models are supported by the unit root test with structural breaks, and it demonstrated adherence to actual events. For instance, the dummy in 2001 may control the implementation of the Millennium Development Goals. Furthermore, simultaneously, in this year, the OECD countries created their own International Development Goals. The semi-elasticities and the elasticities were computed. With semi-elasticities, an increase of 1 percentual point (pp) of *LKOFSF*, ceteris paribus, follows a 1.8 pp increase of ISEW on HGC, and an increase of 1 pp of *LKOFSJ*, ceteris paribus, follows a 1.3 increase of ISEW on LGC. In turn, an increase of 1 pp of *LGDP*, ceteris paribus, follows a 0.95 pp and 0.76 pp decrease in the efficiency index of HGC and LGC, respectively. Regarding the elasticities, an increase of 1 percent (%) of *LKOFEJ* causes a decrease of 2.99% and an increase of 1.52% on ISEW of HGC and LGC, respectively. Furthermore, an increase of 1% of *LKOFPJ* follows a 0.85% increase and a decrease of 0.65% in the efficiency index of HGC and LGC, respectively.

Referring back to Table 6.10, keep in mind that the results of the efficiency index should be interpreted as: an increase in the index represents a decrease in energy efficiency, while a decrease in the index is characterised by an improvement in energy efficiency. Therefore, the negative effect of *LGDP* on *LEF* means that GDP improves efficiency, reducing the index value. The same effect is provoked by fossil fuels and renewable energy consumption, while CO2 emissions increase the value of the index, worsening efficiency. With regard to globalisation, in the HGC, globalisation mostly has a negative effect on the efficiency index, which represents an improvement of efficiency. In the LGC, *LKOFPF* and *LKOFEJ* decrease efficiency, while *LKOFSF* and *LKOFPJ* increase it.

Concerning the ISEW, renewable energy consumption reduces the ISEW in both HGC and LGC. Simultaneously, globalisation mostly has a positive effect on the ISEW of both groups of countries. Overall, the results suggest diverse drivers of sustainable development. The Error Correction Model (ECM) of all models is highly significant with moderate speed of adjustment to long-run equilibrium.

6.5 Discussion

Motivated by the will to understand the interaction between globalisation, energy efficiency, and sustainable development, this essay analyses two samples of countries according to their level of globalisation. Therefore, this study introduces the novelty of analysing globalisation through its three dimensions and two new measures of energy efficiency and sustainable development. This analysis is performed for a set of 20 countries - the top 20 energy consumers per capita countries, divided into high and low globalised countries. To the best of our knowledge, this is the first work analysing the interactions of each dimension and measure of globalisation on both the efficiency index and ISEW. Overall, the estimations reveal the advantage of analysing globalisation using the new measures by obtaining different effects in nature or magnitude of the same dimension of globalisation, as stated by Martens, Caselli, De Lombaerde, Figge, & Scholte (2015).

6.5.1 Efficiency Index (EF)

The results of the estimations with the efficiency index as the dependent variable, shown in Table 6.10, reveal that GDP and fossil fuel consumption increase energy efficiency while emissions decrease it, as noted by (Marques, Fuinhas, & Tomás, 2019) in both groups of countries, HGC and LGC. Economic growth has a positive effect on energy efficiency in both groups of countries. Considering the United Nations Sustainable Development Goals, mainly Goal 12 - Responsible Consumption and Production, and Goal 13 – Climate Action, and the Millennium Development Goals focused on the promotion of environmental sustainability, they push the economies towards energy efficiency, and the economies still search for techniques to produce more output with less cost and less energy. Therefore, with a growing GDP, the investment in efficient technology and Research and Development (R&D) is higher and consequently improves energy efficiency. In turn, CO_2 emissions decrease energy efficiency as energy efficiency improves environmental quality and induces decarbonization.

Regarding globalisation, it primarily improves energy efficiency by reducing the index value in the HGC. Only political globalisation *de jure* decreases energy efficiency, while economic globalisation both *de jure* and *de facto*, and social and political globalisation *de facto* improve energy efficiency. In turn, in the LGC, social globalisation *de facto* and political globalisation *de jure* improve energy efficiency reducing the efficiency index, while political globalisation *de facto* and economic globalisation *de jure* decrease energy efficiency, increasing the efficiency index. With a negative effect on the efficiency index in both groups of countries, HGC and LGC, in the long-run, the improving influence of social globalisation *de facto* on energy efficiency could be explained by both patent applications and high technology exports. High technology exports represent products with high R&D intensity, which means that the countries invest in R&D of efficient technology. Furthermore, the patent applications also represent innovative ideas that could be related to efficient and green technology. In the HGC, social globalisation *de facto* improves efficiency in both the short- and long-run, while in the LGC, it is only in the long-run, meaning that the LGC started to invest in products with high R&D intensity more recently than the HGC.

Concerning economic globalisation, both measures *de jure* and *de facto* induce energy efficiency in the HGC in the long-run. On the one hand, economic globalisation *de facto* improves energy efficiency through Foreign Direct Investment (FDI), while on the other hand, economic globalisation *de jure* improves it through trade taxes that consists of income from taxes on international trade. Both could be invested in efficient technology. In contrast, in the LGC, in the long-run, economic globalisation *de jure* reduces energy efficiency. This effect could be explained by investment restrictions that could stipulate investment in efficient technology and be directed to cheaper technology. The measures of political globalisation reveal opposite effects on the groups of countries under analysis. In the short-run, political globalisation *de facto* affects the efficiency index, improving energy efficiency in the HGC while decreasing it in the LGC. In the long-run political globalisation *de jure* affects the efficiency index, decreasing the energy efficiency in the HGC and improving it in the LGC. With an improving effect on energy efficiency, the effect of political globalisation *de jure* in the LGC could be explained by strong energy efficiency and sustainability goals established by international treaties for these countries. In contrast, in the HGC, political globalisation *de jure* decreases energy efficiency, which could be due to bilateral investment treaties. High globalised countries have a high number of bilateral investment treaties.

6.5.2 Sustainable Economic Welfare (ISEW)

The ISEW was used as a proxy to measure sustainable development. The results of the estimations with the ISEW as the dependent variable, shown in Table 6.10, reveal diverse drivers of sustainable development. In both groups of countries, and in both the short- and long-run, renewable energy consumption decreases sustainable development. This effect could reveal the high implementation costs associated with renewables, such as noted by Menegaki et al. (2017). Furthermore, the strategy of green hydrogen development, which may consist of a high burden for the economies, could aggravate this effect. This finding is rather alarming, and consequently, policymakers should rethink the strategies for renewables penetration. In turn, the efficiency index reveals a negative effect on the ISEW in both the short- and long-run in the HGC, which means that a decrease in the efficiency index (which represents an improvement in energy efficiency) increases the ISEW. This effect denotes that energy efficiency, producing the same output with less energy, saving economic input, and promoting environmental quality, is beneficial for sustainable development in the HGC. In turn, in the LGC, the efficiency index does not seem to be affecting the ISEW, which could reveal that the LGC should invest more in energy efficiency and efficient technology.

On the whole, globalisation is beneficial for sustainable development in both HGC and LGC. Economic globalisation is the only dimension with a harmful effect on sustainable development. In the HGC, economic globalisation *de jure* decreases sustainable development, while in the LGC, it is economic globalisation *de facto* that decreases it. In the HGC, the negative effect of economic globalisation *de jure* could be explained by trade regulation that includes import and export costs. In the LGC, the negative effect of economic globalisation *de facto* could be explained by an increase in economic activity through FDI and trade in goods, which consequently provokes an increase in environmental damage and energy depletion, which leads to a reduction in the ISEW. In contrast, social and political globalisation are drivers of the ISEW, encouraging sustainable development in both groups of countries under analysis. Regarding social globalisation, in the HGC, social globalisation *de facto* improves the ISEW, as well as improving energy efficiency. Improving energy efficiency results in a reduction in environmental damage or defensive costs, consequently increasing sustainable development. In the LGC, social globalisation *de jure* induces sustainable development, which could reflect the expenditure on education. Incidentally, political *globalisation de jure* in the HGC and political globalisation *de facto* in the LGC improve sustainable development. This could reflect the diffusion of governmental policies, such as education and health. Overall, globalisation is a driver for sustainable growth.

6.6 Conclusion

This essay was undertaken to evaluate three current and relevant research issues: globalisation, energy efficiency, and sustainable development, for which a comprehensive debate of the literature is provided. To do that, this essay provides new empirical insights into the analysis of energy efficiency and sustainable development. It does this by assessing the role of the phenomenon of globalisation through each dimension, economic, social, and political, and by using the measures, *de jure* and *de facto*, for each. To the best of our knowledge, this approach is innovative. This analysis is performed for the time span from 1995 to 2017 for energy efficiency and from 2000 to 2017 for sustainable development. The top 20 energy consumers per capita countries were chosen for the study. This analysis provides insights to policymakers to develop suitable and assertive measures and policies to achieve sustainable development. This research reveals that most globalisation dimensions and measures improve energy efficiency in the HGC and sustainable development in both HGC and LGC.

Concerning energy efficiency, measured by the efficiency index, GDP assumes a driving role in improving energy efficiency in both groups of countries. Considering this, both HGC and LGC might continue to invest and direct part of GDP towards efficiency measures and efficient technology. Additionally, considering energy efficiency as a tool to mitigate environmental degradation, a reduction in CO2 emissions leads to an increase in energy efficiency. Regarding globalisation, in order to improve energy efficiency, measures should be developed to manage political globalisation *de jure* in the HGC and economic globalisation *de jure* in the LGC. The LGC might reconsider investment restrictions in order to combat the detrimental effect of economic globalisation *de jure* on energy efficiency. In turn, in the HGC, to combat the detrimental effect of political globalisation *de jure*, bilateral investment treaties should ensure environmental preservation and promote energy efficiency measures.

Concerning sustainable development, measured through the ISEW, renewable energy consumption reveals an unexpected effect, reducing sustainable development. With this in mind, the strategy of renewables penetration should be reconsidered in both HGC and LGC. In regard to the globalisation phenomenon, the results suggest that most of the dimensions and measures of globalisation are beneficial for sustainable development; that is, overall, globalisation is a driver of sustainable development. However, economic globalisation *de jure* in HGC and economic globalisation *de facto* in LGC undermine sustainable development. Therefore, both HGC and LGC should focus their measures and policies on economic globalisation in order to promote sustainable development. In the case of HGC, it is suggested that trade regulations could be improperly designed and should be redesigned. While in the case of LGC, it is suggested that FDI and trade in goods and services induce economic activity, which consequently could increase defensive and environmental damage costs.

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Chapter 7

Does Climate Finance and Foreign Capital Inflows Drive De-Carbonisation in Developing Economies?

Sustainable development requires high investment, and developing economies need external aid to afford it. Developed economies are committed to providing financial support to fight climate change to those with fewer resources suffering the severest consequences. Climate finance consists of financial activities focusing on mitigating and adapting to climate change effects. In this paper, two critical perspectives were addressed: the role of climate finance on environmental degradation and human development and climate finance determinants. This research compiled a panel covering 36 developing economies from 2001 to 2019. Panel-corrected Standard Errors and Feasible Generalized Least Squares estimators were applied. The Seemingly Unrelated Regressions method was carried out to provide robustness of the empirical findings. The empirical results show that climate finance contributes to environmental degradation mitigation, and this effect is more notable in lower-middle-income countries. In these countries, regulatory quality contributes to environmental quality. Moreover, climate finance and human development have a positive bilateral relationship. However, the results suggest that foreign capital inflow slows down human development. These findings provide useful information for policymakers to design and implement environmental policies and strategies to maximize the allocation of climate finance funds and thus help to improve environmental quality.

7.1 Introduction

From 1900 to 2020, 12.386 climate-related disasters occurred worldwide, according to the International Disaster Database. These disasters resulted in 20 million deaths and US$4.130 trillion in reported economic losses in affected countries. Having catastrophic consequences for human life and natural ecosystems (IPCC, 2021), mitigating environmental degradation has become more urgent than ever before. At this point, environmental degradation is high on everyone's agenda. Global warming and climate change are global matters and affect the biggest and lowest carbon dioxide emitters. Indeed, many developing economies produce a fraction of the emissions of developed economies but are more exposed to climate change consequences. Wealthy economies are focused on the economic cost and benefits, while often the environmental costs of development are mostly incurred by poor economies (Hao, Chen, & Zhang, 2016). Differences in geographical location and economic power are two of the main reasons for the substantial differences in the intensity of exposure to environmental degradation between developed and developing economies (Angelsen & Dokken, 2018).

In order to achieve environmental sustainability, diverse methods have been implemented, such as the global carbon trading market based on international emissions trading and clean development mechanism and low-carbon technologies. However, while traditional solutions to climate-related environmental quality have been discussed, the emerging area of climate finance has been overlooked (Lee, Li, Yu, & Zhao, 2022). Climate finance has been considered one of the leading priorities in international climate negotiations. According to the United Nations Framework Convention on Climate Change, (UNFCCC, 2020), climate finance is defined as “local, national or transnational financing drawn from public, private and alternative sources of financing that seeks to support mitigation and adaption actions that will address climate change”. Climate finance, distinct from traditional financial activities, is connected to ecological benefits and is concerned about the environmental protection industry. In short, climate finance helps developing countries in two ways. Firstly environmental pollution can be reduced by funding projects which, for example, provide renewable power infrastructure. Secondly, biotechnologies such as climate resilient seeds that grow regardless of the weather and provide food and income can be developed to adapt to climate change impacts.

According to recent estimations of adaptation needs, $1.8 trillion from 2020 to 2030 might be needed to invest. Furthermore, this amount could generate $7.1 trillion in total net benefits (Global Commission on Adaptation, 2019). The Green Climate Fund, founded in 2010, is the world’s largest fund established to provide further support to developing economies to face the challenge of climate change and improve their capability to respond to climate issues (Amighini, Giudici, & Ruet, 2022). The Paris Agreement in 2015 reinforced the need for financial assistance from Parties with more financial resources to Parties that are more susceptible and have less financial capacity. Recently, climate finance flows took a focal point in the discussion during 26th Conference of Parties (COP), and two distinct points of view arose. Despite focusing on the benefits of an increasing climate finance flow to developing countries, some world leaders believe that a strict agreement on climate finance could impair the market.

Developed countries are committed to providing financial support of $100 billion per year for developing economies. However, they have been missing the target. In the past couple of years, developed nations spent trillions to deal with the COVID-19 pandemic, which consequently makes the mid-to-long-term predictions of climate finance uncertain. Recently, during COP27, a new agreement was established, the “loss and damage” fund for climate disasters in developing economies. Developing countries have been suffering from climate-related disasters, and this fund will provide financial support for recovery and rebuilding. Recovery is crucial and much needed. However, funding recovery is treating the symptoms and not the causes. So, climate finance (mitigation and adaptation finance) should be the main focus of funding. That means the loss and damage fund must not divert attention away from the even more urgent priority, a low-carbon and climate-resilient transition.

Financial support for developing nations exposed to the effects of climate change and also concerned about air quality, poverty, and infectious diseases, could be crucial to enable these economies to achieve the most urgent goal (carbon neutrality by 2050). Beyond the need for resources and efforts to achieve environmental goals and mitigate environmental degradation, developing economies need financial support to suppress poverty, premature death, food shortage and enhance the standard of living. Therefore, for these economies, climate finance might be not only a financial resource to mitigate environmental degradation but a subsistence resource that might allow these economies to improve life quality and overcome poverty.

The research questions that arise are: Is climate finance effective in environmental degradation mitigation and contributing to improving the standard of living in developing economies?; Is Foreign Capital Inflow (FCI) conducting environmental sustainability in developing economies?; and Are human development and globalisation drivers of climate finance? The research’s main objective goes beyond just assessing if climate finance is an effective tool for reducing environmental degradation. This research also highlight that lower-middle and upper-middle-income economies face severe obstacles in the sustainable development path that need further attention. Therefore, this research intends to provide evidence that climate finance improves the standard of living in these economies and that, consequently, this improvement contributes to attracting more climate finance funds.

This research brings an innovative contribution to the current literature by (i) assessing the contribution of climate finance on achieving sustainable development goals through an analysis of the role of climate finance on environmental degradation; (ii) evaluating the determinants of climate finance, among them human development, governance indicators, vulnerability, readiness, FCI, and globalisation *de jure* and *de facto*; and also (iii) assessing the contribution of climate finance to the improvement of the standard of living. To the best of our knowledge, this study innovates by analysing both perspectives of climate finance, its effectiveness on environmental degradation mitigation and human development, and its drivers. Our empirical results show that climate finance improves environmental quality by reducing carbon emissions.

Hereinafter, this paper includes six sections. Section 7.2 presents a literature debate about the central topics, namely climate finance and FCI. Section 7.3 consists of the data, preliminary tests, and methods used. Section 7.4 describes the results. In Section 7.5 and 7.6, the discussion and conclusions of the main results, respectively, are found.

7.2 Literature Background

The role of finance on environmental performance has been intensively assessed. This relationship has been studied using diverse financial measures, such as financial sector (Wen, Lin, & Zhou, 2021), financial flow such as Foreign Direct Investment (FDI) (P. H. Leal, Caetano, & Marques, 2021; Opoku, Adams, & Adewale, 2021), and also green finance (Q. J. Wang, Wang, & Chang, 2022). From green finance, diverse financial instruments were developed, such as green credit (Song, Xie, & Shen, 2021), green bonds (Sinha, Mishra, Sharif, & Yarovaya, 2021), and green investment (Shen et al., 2021). Briefly, green finance includes all the investments that address environmental benefits (IFC, 2017). Financial decisions are increasingly prompted by climate change (Calvet, Gianfrate, & Uppal, 2022). In line with this, besides the diversity of conventional techniques in international environmental agreements for improving environmental sustainability, such as carbon trading market, technology transfer, and clean development mechanisms (see Lee et al. 2022), climate finance has arisen as a new form of financial cooperation. According to the Right Honourable Alok Sharma, President of the COP26, "Unless we get finance flowing, we cannot and will not see the action we need, to reduce emissions, to adapt, and to rise to the growing challenges of loss and damage" (McDonald, ODI, & FCDO, 2021). According to Yeo (2019), trillions of dollars will be needed to achieve a transition toward a climate-resilient and low-carbon global future.

Throughout a close look into the recent literature, climate finance has been assessed from diverse perspectives, such as climate finance allocation (Islam, 2022), global response to climate change (Carfora & Scandurra, 2019), how climate finance contributes to improving all parties (Kotchen, 2020), mechanisms and instrument of climate finance (Kapoor & Malviya, 2021), strategies to increase climate funds from public sources

(Böhringer, Schneider, & Springmann, 2021), climate finance policies (Bhandary, Gallagher, & Zhang, 2021), policy barriers (Mungai, Ndiritu, & Da Silva, 2022), economic risks (Zhao, Zhou, & Li, 2022), vulnerability and distributive justice (Islam, 2022), and environmental sustainability (Lee et al., 2022). From the currently developed climate finance literature, two strands can be found. On the one hand, the assessment of the drivers of climate finance (Ellen, Burton, Zahl-thanem, & Piroschka, 2021). On the other hand, the evaluation of the effectiveness of climate finance (Lee et al., 2022). The last is a less explored field.

Climate finance is a complex concept, with no a single commonly accepted definition. Shishlov and Censkowsky (2022) developed comprehensive research about the theoretical background of climate finance, addressing its definitions and architecture, dimensions, approaches (counting methods and accounting frameworks), and comprehensively explaining the Economic Co-operation and Development (OECD) Development Assistance Committee (DAC) Rio markers (the measure used in this study). Even though the literature on the field of climate finance is still scarce, Giglio et al. (2021) synthesize its existing empirical and theoretical literature. The effect of climate finance on environmental performance remains unclear. Climate finance involves diverse departments stretching from development, finance, foreign relationships, and the environment. Consequently, it results in a complex decision-making process for both sides of this multilateral flow; the donor and the recipient economies (CPI, 2021). Therefore, some climate finance flows could be worthlessly applied to less relevant projects and programs.

Climate finance aims to support the pathway of sustainability and low-carbon development, focusing on developing nations. Compared with developed economies, developing ones have few financial resources and do not have the economic and technological development needed to deal with climate change and environmental degradation (Carfora & Scandurra, 2019). Also, developing economies are a big concern for climate policy due to the early stages of industrialization (Q. Wang & Zhang, 2020). In line with this, developing economies are the major recipients of climate finance flows (CPI, 2021). At this point, developing countries receive further attention from the climate finance literature (Lee et al., 2022; Mungai et al., 2022).

To the best of our knowledge and highlighted by other researchers in the climate finance field (Lee et al. 2022), there is a gap in the literature about the relationship between climate finance and low emissions, and this relationship is still ambiguous. In line with this, less is known about the effect of climate finance on the environmental performance of recipient economies. Therefore, this study makes four main contributions. Primarily, distinguishing it from the previous studies in the climate finance field focused on climate funds allocation, the present study considered the increasing importance of climate finance by assessing how climate finance impacts the environmental performance of developing economies - an assessment that previous literature has rarely performed. At this point, the present research provides insight into how climate finance (as a financial aid tool) can help developing nations improve their progress toward environmental sustainability. Secondly, to provide a more comprehensive evaluation and knowledge of this topic, a close look at the determinants of climate finance was undertaken. The analysis considered the roles of globalisation *de jure* and *de facto*, human development, and FCI. Additionally, this research provides insights into how climate finance contributes to improving the standard of living in these economies. Finally, to further understand the inherent channel, the role played by mitigation finance and its determinants were also analysed.

7.3 Data and Methodology

7.3.1 Data

This research compiled a panel database covering 36 developing economies from 2001 to 2019. The countries were selected under the criterion of data availability for all the variables used. In order to consider the countries' income level as a potential influencing feature on climate finance flow, the initial group of 36 developing nations was categorised into lower-middle-income and upper-middle-income countries (according to the classification of the World Bank). Accordingly, the 21 lower-middle-income countries (LMIC) analysed were: Algeria, Bangladesh, Benin, Cabo Verde, Cambodia, Cameroon, Cote d'Ivoire, Egypt, Ghana, India, Indonesia, Iran, Kenya, Morocco, Nepal, Nigeria, Pakistan, Philippines, Tanzania, Tunisia, and Vietnam. The 15 upper-middle-income countries (UMIC) analysed were: Argentina, Azerbaijan, Botswana, Brazil, China, Colombia, Gabon, Guatemala, Malaysia, Mexico, Namibia, Peru, South Africa, Thailand, and Turkey. The data period used (using all the years available in concordance between the variables used) allowed the assessment of how much climate finance progress can improve environmental quality. This analysis was focused on developing economies considering their financial features and climate finance flow (supported in the literature review section). Variables used, description, and sources are disclosed in Table 7.1.

Table 7.1 - Variables

Variable description	Description	Source
CF	Climate Finance (constant 2019 US$)	OECD DAC External Development Finance Statistics
MF	Mitigation Finance (constant 2019 US$)	
AF	Adaptation Finance (constant 2019 US$)	
CO_2 Emissions	Carbon Dioxide Emissions (MMtons)	U.S. Energy Information Administration
HDI	Human Development Index	UNDP, Human Development Reports
GDP	Gross Domestic Product (constant 2015 US$)	World Bank Development Indicators
FDI	Foreign direct investment, net inflows (current US$)	
PR	Personal remittances, received (current US$)	
ODA	Net official development assistance and official aid received (current US$)	
RQ	Regulatory Quality	World Bank, Worldwide Governance Indicators
GE	Governance Effectiveness	
RD	Readiness	Notre-Dame Global Adaptation Index (ND-GAIN) database
VUL	Vulnerability	
EI	Energy intensity level of primary energy (MJ/$2017 PPP GDP)	World Bank Development Indicators
FF	Non-Renewable energy consumption (quad Btu)	U.S. Energy Information Administration
RES	Renewable energy consumption (quad Btu)	
KOFF	KOF Globalisation Index *de Facto*	KOF Swiss Economic Institute
KOFJ	KOF Globalisation Index *de Jure*	
KOFEF	KOF Globalisation Index Economic Dimension *de Facto*	
KOFEJ	KOF Globalisation Index Economic Dimension *de Jure*	
KOFSF	KOF Globalisation Index Social Dimension *de Facto*	
KOFSJ	KOF Globalisation Index Social Dimension *de Jure*	
KOFPF	KOF Globalisation Index Political Dimension *de Facto*	
KOFPJ	KOF Globalisation Index Political Dimension *de Jure*	

Notes: MMtons denotes Million Metric tonnes; quad Btu denotes quadrillion British thermal unit.

Climate finance was collected from the OECD DAC's climate-related funding database. This is one of the most comprehensive data sources and has been widely used in previous studies (Islam 2022, Lee et al. 2022). The present analysis considered the three categories of climate funds, namely overall climate funds (CF), climate mitigation funds (MF), and climate adaptation funds (AF). Accordingly, with the definitions provided by the OECD DAC, climate finance consists of investments and financing activities to address climate change and achieve low-carbon development goals. Climate finance is the sum of mitigation finance and adaptation finance. Therefore, on the one hand, mitigation finance promotes efforts to reduce or limit greenhouse gas (GHG) emissions or to improve GHG sequestration. The main target consists of the stabilization of GHG concentrations in the atmosphere at a level that inhibits dangerous anthropogenic interference with the climate system. On the other hand, adaptation finance aims to reduce the vulnerability of human and natural systems to the current and expected impacts of climate change. It is focused on enhancing adaptative capacity and increasing resilience in critical areas such as agriculture, water resources, ecosystems, oceans, and disaster prevention.

Regarding country-level factors that may influence environmental performance and/or the climate finance flow, the present analysis included human development, globalisation, regulatory quality, governance effectiveness, vulnerability, and readiness. Globalisation is a channel of capital flow and promotes the connection between economies. Therefore, globalisation was analysed from two perspectives using the two recently developed measures, *de jure* and *de facto* (Aluko et al. 2021, Gygli et al. 2019, Leal and Marques 2019, Leal et al. 2020). Globalisation *de jure* captures policies that lead to actual flows, as well as governmental regulations that influence international transactions. In turn, globalisation *de facto* measures real flows and activities (Gygli et al., 2019). Developing economies are more susceptible to facing governance obstacles, which may influence the application of received funds and consequently tamper with the desired effect. Moreover, developing countries have an urgent desire and need for growth which could surpass the need for action to fight climate change and environmental degradation mitigation. Therefore, regulatory quality and governance effectiveness were integrated into both estimations following the definition provided by the World Bank. Regulatory quality consists of the ability of the government to develop and execute policies and regulations that stimulate private sector development. Governance effectiveness is briefly described as the quality of policy formulation and implementation.

Both regulatory quality and governance effectiveness are measured in a range between -2.5 and 2.5. Lower values indicate permissive governance, and higher values indicate strong one. In addition to the challenging governance situation in these economies, developing countries are also considered more vulnerable to climatic changes and consequently in need of more climate funding (Islam, 2022). In line with this, vulnerability and readiness indicators were integrated into the present analysis. On the one hand, vulnerability consists of a country's sensitivity and capacity to adapt to adverse climate change effects. On the other hand, readiness consists of the country's ability to accept investments and convert them into adaptation actions. These indicators were evaluated as potential determinants of climate finance. Developing countries cannot afford expensive mitigation emissions measures, fighting climate change, and promoting sustainability without external aid (D. T. Wang & Chen, 2014). Thus, in order to capture potential technology effects from other sources of investment, FCI was considered. FCI represents a significant financial help to developing economies. FCI could be defined as all sorts of capital received by a country from another, taking place through government, private and international organizations. Foreign Direct Investment (FDI), Personal Remittances (PR), and Official Development Assistance (ODA) are considered the most significant FCI sources in most of the recipient countries (Mowlaei, 2018). The respective variables were collected in the current US$. The first step was to transform them into constant US$. Also, these variables were converted into per capita in order to consider the population size of each country under analysis.

To ascertain the influence of the FCI on environmental degradation and as a determinant of climate finance flows, a Principal Component Analysis (PCA) was carried out. This method is one of the most widely used statistical techniques for compressing the dimensionality of large datasets. PCA allows one to obtain the essential information on each variable and convert it into a single variable. Furthermore, information loss is minimized (preserving as much information as possible) while dimensionality is reduced. PCA was applied to create an indicator of FCI (Foreign Capital Inflow) by compressing the information on Foreign Direct Investment (FDI), Personal Remittances (PR), and Official Development Assistance (ODA).

Through the Bartlett's test of sphericity and the Kaiser-Meyer-Olkin Measure of sampling adequacy, the suitable application of the PCA was evaluated. The results displayed in Table-7.2 sustain the rejection of the null hypothesis wherein the variables are not intercorrelated. Therefore, it indicates that the variables are sufficiently correlated for PCA usage. Regarding the Kaiser-Meyer-Olkin Measure of sampling adequacy, according to Kaiser (1974), values above 0.5 are acceptable.

Table 7.2 - Adequacy of PCA

	UMIC	LMIC
Bartlett's test of sphericity	7.226*	379.219***
Kaiser-Meyer-Olkin Measure of sampling adequacy	0.533	0.700

Notes: ***, * denotes statistical significance at 1% and 10%, respectively.

Therefore, the value of 0.535 and 0.700 reveal the suitability of applying PCA to these variables. Table-7.3 displays the variables' descriptive statistics.

Table 7.3 - Descriptive Statistics

	Mean	Std. Dev.	Min.	Max.	Obs.
Lower-Middle Income Countries (LMIC)					
CF	4.90E+08	1.06E+09	20726.92	1.09E+10	399
MF	3.61E+08	8.27E+08	20726.92	8.00E+09	399
CO2_pc	0.0013	0.0016	0.0001	0.0078	399
GDP_pc	2097.019	1210.116	515.5754	5657.97	399
HDI	0.5896	0.0913	0.406	0.789	399
FCI	1.48E-09	1.4642	-1.3809	8.6874	399
RQ	-0.5371	0.375	-1.7092	0.1914	399
GE	-0.4673	0.3848	-1.3448	0.6951	399
RD	0.3361	0.0627	0.1814	0.4921	399
VUL	0.489	0.0622	0.3788	0.6003	399
EI	5.0348	1.822	2.3	12.01	399
EC	2.4741	5.0401	0.0052	31.7827	399
KOFF	51.3631	8.1321	32.5874	69.7113	399
KOFJ	56.7518	8.3367	31.7037	73.6242	399
KOFEF	45.4423	14.6749	19.2232	79.9189	399
KOFEJ	44.2787	10.3558	19.5718	77.2745	399
KOFSF	37.4077	12.3931	10.0863	66.1583	399
KOFSJ	49.652	11.4944	24.7019	75.2989	399
KOFPF	70.8386	16.4413	13.2811	90.9085	399
KOFPJ	76.4106	11.6589	44.3529	94.1844	399
Upper-Middle Income Countries (UMIC)					
	Mean	Std. Dev.	Min.	Max.	Obs.
CF	3.39E+08	6.22E+08	5337.177	3.30E+09	285
MF	2.89E+08	5.36E+08	5337.177	3.02E+09	285
CO2_pc	0.0035	0.0021	0.0008	0.0086	285
GDP_pc	6658.276	2633.079	1614.792	14200.27	285
HDI	0.7071	0.0703	0.543	0.852	285
FCI	1.75E-10	1.087751	-3.129348	7.270728	285
RQ	0.0587	0.4224	-1.0662	0.9002	285
GE	-0.0095	0.4863	-0.9852	1.2543	285

RD	0.3871	0.0601	0.261	0.5794	285
VUL	0.4275	0.0364	0.348	0.5079	285
EI	4.711	2.2177	2.14	13.33	285
EC	9.8707	27.3613	0.0411	151.6089	285
KOFF	59.4726	9.838	37.5782	85.9894	285
KOFJ	65.7317	7.6018	48.1865	78.362	285
KOFEF	51.6468	13.952	27.739	83.8515	285
KOFEJ	55.0967	10.9405	28.7535	78.2745	285
KOFSF	55.4732	10.7043	30.4281	87.2706	285
KOFSJ	62.8297	8.4808	41.4742	80.2068	285
KOFPF	71.3423	19.0477	23.2365	92.6716	285
KOFPJ	79.2108	12.1643	42.3909	96.9098	285

Notes: Max. – Maximum; Min. – Minimum; Std. Dev. – Standard deviation; Obs – Observations.

7.3.2 Model Specification

To accomplish the main objectives of this research, three main models were structured. Firstly, to assess the role of climate finance on environmental degradation, it is crucial to understand the factors affecting environmental performance. According to the theoretical framework, the environmental impact is decomposed into population, technology, and wealth (Lee et al., 2022). Notwithstanding, as suggested in the literature, other relevant explanatory variables can be considered. Therefore, the determinants of CO2 emissions are shown in Equation 7.1.

$$CO_{2_{it}} = f(CF, GDP, HDI, FCI, RQ, GE, EI, KOFDJ, KOFDF) \tag{7.1}$$

Secondly, diverse potential determinants were considered in order to analyse their roles in the climate finance flow, shown in Equation 7.2.

$$CF_{it} = f(CO_2, HDI, FCI, RQ, GE, RD, VUL, KOFECDF, KOFECDJ, KOFSODF, KOFSODJ, KOFPODF, KOFPODJ) \tag{7.2}$$

The last main model was structured to analyse the role of climate finance on human development. In light of this, the determinants of Human Development Index (HDI) are shown in Equation 7.3.

$$HDI_{it} = f(GDP, CF, FCI, EC, KOFDJ, KOFDF) \tag{7.3}$$

Most variables are in natural logarithms (hereafter prefix ‘L’), except ones with negative values, included as raw data. These are the three main models of the present research. Additionally, Equations 7.1 and 7.2 were estimated by replacing climate finance with mitigation finance. Models I and II (Equation 7.1) were estimated with CO_2 emissions as the dependent variable and climate finance and mitigation finance as independent variables, respectively. Models III and IV (Equation 7.2) were estimated with climate finance and mitigation finance as the dependent variable, respectively. Model-V (Equation 7.3) was estimated with the human development index as the dependent variable and climate finance as an independent variable.

7.3.2 Methodology

The estimation procedure for accomplishing the purpose of this study required the use of an extensive battery of tests. Firstly, to verify the adequacy of the data for panel data techniques application, the presence of correlation and multicollinearity was assessed. Through the values of the correlation matrix and the Variance Inflation Factor (VIF), the suitability of the data for the estimations was supported. After that, the presence of cross-section dependence was verified. The existence of cross-section dependence is frequent in panel data settings. Its presence can lead to inconsistent results of the first-generation unit root tests. In light of this, the Cross-section Dependence test (CD-test) developed by Pesaran (2004) was performed, under the null hypothesis of cross-sectional independence, to assess the presence of cross-sectional dependence in each variable (see Table 7.4).

Table 7.4 - Cross-Section Dependence Test (CD – Test)

	LMIC				UMIC		
	CD-Test	Corr	Abs (corr)		CD-Test	Corr	Abs (corr)
LGDP_pc	57.85***	0.916	0.916	*LGDP_pc*	32.21***	0.721	0.857
LCF	41.96***	0.664	0.664	*LCF*	25.36***	0.568	0.568
LMF	33.31***	0.527	0.527	*LMF*	20.66***	0.463	0.472
LCO2_pc	41.75***	0.661	0.78	*LCO2_pc*	12.79***	0.286	0.552
LHDI	61.39***	0.972	0.972	*LHDI*	43.47***	0.973	0.973
FCI	23.66***	0.375	0.444	*FCI*	8.43***	0.189	0.326
RQ	1.34	0.021	0.355	*RQ*	-1.21	-0.027	0.411
GE	3.21***	0.051	0.384	*GE*	-0.92	-0.021	0.331
LRD	2.34**	0.037	0.505	*LRD*	10.55***	0.236	0.539
LVUL	35.5***	0.562	0.599	*LVUL*	32.5***	0.728	0.728
LEI	21.28***	0.337	0.717	*LEI*	14.11***	0.316	0.51
LEC	55.65***	0.881	0.881	*LEC*	37.49***	0.839	0.839
LKOFF	43.79***	0.693	0.697	*LKOFF*	31.11***	0.696	0.696
LKOFJ	49.05***	0.777	0.777	*LKOFJ*	35.57***	0.796	0.796
LKOFEF	0.37	0.006	0.384	*LKOFEF*	1.37	0.031	0.416
LKOFEJ	6.1***	0.097	0.348	*LKOFEJ*	0.78	0.017	0.367
LKOFSF	57.01***	0.902	0.902	*LKOFSF*	40.58***	0.908	0.908
LKOFSJ	58.65***	0.929	0.929	*LKOFSJ*	38.21***	0.855	0.855
LKOFPF	17.55***	0.278	0.461	*LKOFPF*	18.36***	0.411	0.466
LKOFPJ	56.43***	0.893	0.893	*LKOFPJ*	39.75***	0.89	0.89

Notes: *** denotes statistical significance at 1% level.

The presence of cross-sectional dependence was confirmed for almost all variables. Consequently, a panel unit root test that considered the presence of cross-sectional dependence was performed.

The cross-section Im-Pesaran-Shin (CIPS) test proposed by Pesaran (2007) was computed to inspect the stationary properties of the variables. Table 7.5 displays the results of the second-generation CIPS unit root test.

Table 7.5 - Second-Generation Unit Root Test (CIPS)

	LMIC			UMIC	
	Without trend	With trend		Without trend	With trend
LGDP_pc	1.367	1.624	*LGDP_pc*	2.085	0.735
DLGDP_pc	- 5.062***	- 4.382***	*DLGDP_pc*	- 5.48***	- 4.788***
LCF	- 10.783***	- 8.565***	*LCF*	- 7.525***	- 5.595***
DLCF	- 16.842***	- 14.616***	*DLCF*	- 12.934***	- 10.69***
LMF	- 10.242***	- 7.366***	*LMF*	- 6.771***	- 5.135***
DLMF	- 16.169***	- 14.063***	*DLMF*	- 12.716***	- 10.475***
LCO2_pc	- 1.177	1.676	*LCO2_pc*	- 0.507	1.821
DLCO2_pc	- 8.01***	- 6.469***	*DLCO2_pc*	- 8.126***	- 8.458***
LHDI	0.739	3.543	*LHDI*	- 0.317	1.177
DLHDI	- 5.167***	- 3.242***	*DLHDI*	- 6.834***	- 6.997***
FCI	- 4.005***	- 4.886***	*FCI*	- 4.053***	- 5.884***
DFCI	- 14.291***	- 11.495***	*DFCI*	- 13.28***	- 11.757***
RQ	- 0.218	- 0.177	*RQ*	- 1.638*	- 2.201**
DRQ	- 11.681***	- 9.889***	*DRQ*	- 10.553***	- 8.471***
GE	- 1.002	- 1.293*	*GE*	0.171	0.359
DGE	-12.233***	- 10.362***	*DGE*	- 7.459***	- 5.688***
LRD	4.194	2.359	*LRD*	- 0.888	0.674
DLRD	- 6.926***	- 5.600***	*DLRD*	- 9.053***	- 6.909***
LVUL	- 1.921**	- 0.142	*LVUL*	- 1.946**	- 0.202
DLVUL	- 11.627***	- 11.078***	*DLVUL*	- 9.276***	- 9.177***
LEI	- 1.374*	0.686	*LEI*	- 1.573*	0.639
DLEI	- 9.22***	- 7.819***	*DLEI*	- 9.592***	- 8.758***
LEC	- 1.551*	0.795	*LEC*	- 0.636	1.066
DLEC	- 10.59***	- 10.104***	*DLEC*	- 7.762***	- 6.8***
LKOFF	- 0.482	- 1.631*	*LKOFF*	- 4.207***	- 2.913***
DLKOFF	- 10.597***	- 7.278***	*DLKOFF*	- 10.526***	- 8.895***
LKOFJ	- 4.23***	- 6.39***	*LKOFJ*	- 3.352***	- 3.762***
DLKOFJ	- 14.342***	- 11.931***	*DLKOFJ*	- 10.927***	- 8.852***
LKOFEF	0.198	1.33	*LKOFEF*	0.871	1.282
DLKOFEF	- 9.076***	- 6 .994***	*DLKOFEF*	- 8.944***	- 8.156***
LKOFEJ	- 3.232***	- 3.539***	*LKOFEJ*	- 1.399*	- 1.241
DLKOFEJ	- 12.684***	- 10.325***	*DLKOFEJ*	- 9.960***	- 8.293***
LKOFSF	- 1.628*	- 0.493	*LKOFSF*	- 5.722***	- 6.328***

DLKOFSF	- 9.155***	- 8.678***	*DLKOFSF*	- 12.402***	- 10.466***
LKOFSJ	- 4.586***	- 3.571***	*LKOFSJ*	- 3.039***	- 2.722***
DLKOFSJ	- 11.752***	- 11.299***	*DLKOFSJ*	- 9.489***	- 8.522***
LKOFPF	- 1.963**	0.4	*LKOFPF*	- 1.454*	- 0.377
DLKOFPF	- 9.274***	- 8.676***	*DLKOFPF*	- 9.728***	- 8.703***
LKOFPJ	- 4.546***	- 3.741***	*LKOFPJ*	- 2.873***	- 1.779**
DLKOFPJ	- 13.999***	- 12.678***	*DLKOFPJ*	- 10.152***	- 9.172***

Notes: *, **, *** denotes significance level at 10%, 5% and 1%, respectively; prefix D denotes Differences; prefix L denotes Logarithm.

Accordingly, almost all variables are integrated of order one, i.e. stationary at first differences. Therefore, following the standard econometric procedure (Oteng-abayie, Duodu, Mensah, & Boakye, 2022), the cointegration among the variables was tested using the Pedroni (2004) and Westerlund (2005) tests. The cointegration test establishes how the variables are included in the estimations. Once cointegration is verified, the variables are included in the estimation at that level (Afonso, Marques, & Fuinhas, 2021). Table 7.6 displays the results of the cointegration tests. The results suggest the existence of a long-run relationship in all models.

Table 7.6 - Cointegration test

		Model I	Model II	Model III	Model IV	Model V
	Pedroni					
	Panel v	- 2.832***	- 2.761***	- 4.28***	- 4.114***	- 0.3593
	Panel rho	5.455***	5.382***	4.144***	4.258***	5.735***
	Panel t	- 7.147***	- 7.402***	- 16.93***	- 17.08***	1.494
LMIC	Panel ADF	9.89***	5.595***	- 0.4845	- 0.8847	5.845***
	Group rho	7.16***	7.016***	5.933***	6.097***	7.569***
	Group t	- 6.799***	- 7.623***	- 18.7***	- 18.93***	2.794***
	Group ADF	7.974***	5.304***	1.512	- 0.5942	6.503***
	Westerlund	1.4072*	1.3189*	- 1.2964*	- 1.6409*	4.3240***

	Pedroni					
	Panel v	- 1.888	- 1.889	- 3.605***	- 3.708***	- 0.524
	Panel rho	4.374***	4.459***	4.118***	4.399***	4.014***
	Panel t	- 3.129***	- 3.217***	- 10.34***	- 10.28***	- 2.329***
UMIC	Panel ADF	2.27***	- 0.724	2.954***	6.55***	5.898***
	Group rho	5.716***	5.781***	5.55***	5.812***	5.342***
	Group t	- 3.944***	- 3.984***	- 11.45***	- 11.64***	- 2.284***
	Group ADF	3.974***	0.08991	2.162***	2.01***	5.375***
	Westerlund	2.2912**	2.3343***	- 1.9579**	- 1.8465**	3.9998***

Notes: *** denotes significance level at 1%. In both tests, the null of no cointegration is tested against the alternate of cointegration.

The traditional Hausman test (Hausman, 1978) was conducted to identify the most suitable estimator. The test was carried out under the null hypothesis of difference in coefficients is not systematics (i.e. the random effects estimator is appropriate). The results of the Hausman test are displayed in Table 7.7.

Table 7.7 - Hausman test and F - test

		F - test	Hausman test
LMIC	Model I - CO2 (CF)	147.51***	59.00***
	Model II - CO2 (MF)	139.93***	37.10***
	Model III – CF	14.26***	162.32***
	Model IV - MF	14.10***	170.76***
	Model V - HDI	235.93***	30.56***
UMIC	Model I – CO2 (CF)	82.12***	34.50***
	Model II - CO2 (MF)	81.11***	40.24***
	Model III – CF	13.26***	173.13***
	Model IV - MF	11.69***	87.09***
	Model V - HDI	121.49***	85.25***

Notes: *** denotes significance level at 1%.

Accordingly, the null hypothesis was rejected, i.e. fixed effects are suitable for all the estimated models. After that, panel data specification tests were accomplished. A battery of model specification tests was carried out in order to detect the presence of contemporaneous correlation, heteroskedasticity, and first-order serial autocorrelation. Therefore, displayed in Table 7.8 are the outcomes of the following tests: (i) Frees (1995), Friedman (1937), and Pesaran (2004) tests to assess the presence of contemporaneous correlation, (ii) Modified Wald test to assess the presence of heteroskedasticity, and (iii) Wooldridge test to assess the presence of first-order serial autocorrelation.

Table 7.8 - Specification tests

	Pesaran test	Frees test	Fiedman test	Modified Wald test	Wooldrige test
LMIC					
Model I - CO2 (CF)	4.669***	3.288***	33.474**	2864.73***	69.651***
Model II - CO2 (MF)	4.293***	3.34***	31.059*	2755.68***	70.413***
Model III – CF	1.037	0.055	19.296	141.28***	3.788*
Model IV - MF	- 0.173	-0.13	16.006	128.49***	2.823
Model V - HDI	2.336**	2.879***	25.29	406.56***	208.278***
UMIC					
Model I - CO2 (CF)	0.406	1.843***	23.592*	1652.72***	20.422***
Model II - CO2 (MF)	0.63	1.93***	25.179**	3135.5***	20.503***
Model III – CF	2.978***	0.487***	29.044**	178.42***	3.397*
Model IV - MF	2.022**	0.387***	25.844**	198.52***	5.667**
Model V - HDI	2.201**	1.26***	33.419***	1105.81***	93.753***

Notes: ***, **, * denotes significance level at 1%, 5% and 10%, respectively.

Accordingly, the outcomes suggest the presence of contemporaneous correlation for all the estimations of the UMIC and the Models I, II and V of the LMIC. Regarding heteroskedasticity, the outcomes suggest its presence for all the estimations for both groups of countries. Lastly, the presence of first-order serial autocorrelation is evidenced for all the estimations for both groups of countries, excluding Model-IV of the LMIC.

Considering the features disclosed through the specification tests, Panel Corrected Standard Errors (PCSE) or Feasible Generalized Least Squares (FGLS) estimators are suitable to be applied. The FGLS is robust and suitable to be applied when the time dimension (T) is larger than the cross-sectional dimension (N). As opposed to the PCSE, which is robust when N>T (Hoechle, 2010; Reed & Ye, 2011). Both PCSE and FGLS estimators are robust in the presence of heteroskedasticity, cross-section dependence, and serial correlation in all panels (Afonso et al., 2021; Ji, 2020). Additionally, alternative estimators were employed in order to ensure the robustness of the estimations, namely the FE model and Driscoll-Kraay with Fixed Effects (DK-FE). The

DK estimator is robust in the presence of heteroskedasticity, serial correlation and cross-sectional dependence.

7.4 Empirical Results

The results of the estimated models are displayed in this section. Considering the size of both groups of countries, LMIC (21 countries) and UMIC (15 countries), and the time span (19 years) under analysis, the PCSE estimator was applied for all the estimated models for both groups of countries. Meanwhile, when analysing the UMIC, the condition of T>N is verified, so the FGLS estimator is also applied. The PCSE estimator is widely used in the literature and under similar features such as the ones revealed through the pre-estimation procedure. In light of this, the application of the PCSE estimator is in concordance with the literature (Zakari, Khan, Tan, Alvarado, & Dagar, 2022; Zakari, Tawiah, Khan, Alvarado, & Li, 2022). The PCSE model was estimated using diverse available options to deal with the features detected by the specification tests, namely heteroscedasticity, first-order serial correlation, and contemporaneous correlation. Four structures for the PCSE estimator were specified. A PCSE estimator to deal with contemporaneous correlation (CORR(IND)), heteroscedasticity (HET), first-order serial correlation (AR1), and both heteroscedasticity and first-order serial correlation (HET-AR1) was applied. Regarding the FGLS estimator, three structures were specified. An FGLS estimator to deal with contemporaneous correlation (CORR(IND)), heteroscedasticity (HET), and first-order serial correlation (AR1). Considering the results of the Hausman test (Table 7.7), fixed effects were included in the estimations by recurring to a dummy variable for each country. The results of Model-I - CO2 (CF) and Model-II - CO2 (MF) for LMIC and UMIC are shown in Tables 7.9 and 7.10, respectively.

Table 7.9 - Model-I – CO2(CF) and Model-II – CO2(MF) for LMIC

Model-I - CO2 (CF)						
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1
LGDP_pc	1.0523***	1.0523***	1.0523***	1.2***	1.0523***	1.2***
LHDI	0.8489***	0.8489**	0.8489***	0.8056***	0.8489***	0.8056***
LCF	- 0.0115**	- 0.0115*	- 0.0115*	- 0.0002	- 0.0115**	- 0.0002
FCI	0.0453***	0.0453**	0.0453***	0.0141	0.0453***	0.0141*
RQ	- 0.0854*	- 0.0854*	- 0.0854**	- 0.0015	- 0.0854*	- 0.0015
GE	0.0852*	0.0852*	0.0852**	0.0398	0.0852*	0.0398
LEI	0.5967***	0.5967***	0.5967***	0.7385***	0.5967***	0.7385***
LKOFJ	0.4845***	0.4845*	0.4845**	0.0853	0.4845***	0.0853
C	-17.2347***	- 17.2347***	-16.8189***	-16.779***	-16.8189***	-16.779***
Model-II - CO2 (MF)						
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1
LGDP_pc	1.0482***	1.0482***	1.0482***	1.1993***	1.0482***	1.1993***
LHDI	0.8329***	.8329**	0.8329***	0.801***	0.8329***	0.801***
LMF	- 0.0125**	- 0.0125*	- 0.0125**	- 0.0001	- 0.0125**	- 0.0001
FCI	0.0454***	0.0454**	0.0455***	0.0143	0.0454***	0.0143*
RQ	- 0.0853*	- 0.0853*	- 0.0853**	- 0.0022	- 0.0853*	- 0.0022
GE	0.088*	0.088*	0.088**	0.0401	0.088*	0.0401
LEI	0.5918***	0.5918***	0.5918***	0.7377***	0.5918***	0.7377***
LKOFJ	0.4746***	0.4746*	0.4746**	0.0892	0.4746***	0.0892
C	-17.1502***	-17.1502***	-16.7294***	-16.7912***	- 16.7294***	-16.7912***

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Table 7.10 - Model-I – CO2(CF) and Model-II – CO2(MF) for UMIC

				Model-I - CO2 (CF)					
			PCSE				FGLS		
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1	CORR(IND)	AR1	HET
LGDP_pc	0.6425***	0.6425***	0.6425***	0.7386***	0.6425***	0.7386***	0.6425***	0.7386***	0.8446***
LHDI	1.105***	1.105***	1.105***	0.2195	1.105***	0.2195	1.105***	0.2195	0.211
LCF	- 0.0089**	- 0.0089***	- 0.0089**	- 0.0037	- 0.0089*	- 0.0037	- 0.0089**	- 0.0037	- 0.0012
RQ	0.2144***	0.2144***	0.2144***	0.0856**	0.2144***	0.0856**	0.2144***	0.0856**	0.0474**
LEI	0.459***	0.459***	0.459***	0.4191***	0.459***	0.4191***	0.459***	0.4191***	0.6427***
LKOFF	- 0.4969***	- 0.4969***	- 0.4969***	- 0.2399*	- 0.4969***	- 0.2399	- 0.4969***	- 0.2399**	- 0.2391***
C	- 9.5519***	- 9.5519***	- 9.6011***	- 11.8751***	- 9.6011***	- 11.8751***	- 9.6011***	-11.8751***	-13.2145***
				Model-II - CO2 (MF)					
			PCSE				FGLS		
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1	CORR(IND)	AR1	HET
LGDP_pc	0.678***	0.678***	0.678***	0.7475***	0.678***	0.7475***	0.678***	0.7475***	0.8223***
LHDI	0.8121***	0.8121**	0.8121**	0.1032	0.8121**	0.1032	0.8121***	0.1032	0.1817
RQ	0.1993***	0.1993***	0.1993***	0.0784**	0.1993***	0.0784**	0.1993***	0.0784**	0.0506**
LEI	0.4565***	0.4565***	0.4565***	0.416***	0.4565***	0.416***	0.4565***	0.416***	0.6145***
LKOFF	- 0.5487***	- 0.5487***	- 0.5487***	- 0.2447*	- 0.5487***	- 0.2447*	- 0.5487***	- 0.2447**	- 0.2412***
C	- 9.9049***	- 9.9049***	- 9.9331***	- 12.0246***	- 9.9331***	-12.0246***	- 9.9331***	- 12.0246***	- 12.9841***

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Overall, there is considerable consistency and stability between the estimators used. Models I and II focus on assessing the role of climate finance and mitigation finance on environmental degradation. In light of this, climate and mitigation finance could be considered valuable tools to mitigate environmental degradation in the LMIC. On the other hand, in the UMIC, mitigation finance does not influence environmental degradation. Only climate finance reveals as a driver of environmental quality. Economic growth and human development are by far the greatest boosters of environmental degradation, followed by energy intensity, mainly in the LMIC. Moreover, the negative effect of regulatory quality on the LMIC and the opposite effect, a positive one, on the UMIC should also be highlighted. Regarding globalisation, there is notably a difference between LMIC and UMIC related to the influence of globalisation measures. Only one measure of globalisation is statistical significance in each group of countries. Globalisation *de jure* influences environmental degradation of the LMIC, while in the UMIC is globalisation *de facto*. Besides that, globalisation measures have opposite signs. The same PCSE and FGLS structure specified above for the estimation of Model-III and Model-IV was applied. Tables 7.11 and 7.12 display the results of Model-III – Climate Finance and Model-IV – Mitigation Finance, for LMIC and UMIC, respectively.

Table 7.11 - Model-III – CF and Model-IV – MF for LMIC

Model-III - Climate Finance						
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1
LHDI	20.3518***	20.3518***	20.3518***	20.3506***	20.3518***	20.3506***
RQ	0.6445*	0.6445**	0.6445*	0.7422*	0.6445*	0.7422*
LKOFEF	- 1.2839**	- 1.2839**	- 1.2839**	- 1.1241*	- 1.2839**	-1.1241*
LKOFSJ	1.9662**	1.9662*	1.9662**	1.8775**	1.9662**	1.8775**
LKOFPF	- 1.9072***	- 1.9072***	- 1.9072***	- 1.9146***	- 1.9072***	-1.9146***
C	34.6277***	34.6277***	28.5976***	28.4797***	28.5976***	28.4797***
Model-IV - Mitigation Finance						
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1
LHDI	16.8508***	16.8508***	16.8508***	16.9***	16.8508***	16.9***
RQ	0.9034**	0.9034***	0.9034**	0.9511**	0.9034**	0.9511**
LRD	- 1.0118*	- 1.0118**	- 1.0118**	- 0.9594*	- 1.0118*	- 0.9594
LKOFEF	- 1.387**	-1.387**	- 1.387**	- 1.2784**	- 1.387**	-1.2784**
LKOFSJ	1.7991**	1.7991	1.7991**	1.7269**	1.7991**	1.7269**
LKOFPF	- 2.237***	- 2.237***	- 2.237***	- 2.234***	- 2.237***	- 2.234***
C	33.8435***	33.8435***	28.5735***	28.5644***	28.5735***	28.5644***

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Table 7.12 - Model-III – CF and Model-IV – MF for UMIC

	Model-III - Climate Finance								
				PCSE				FGLS	
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1	CORR(IND)	AR1	HET
LHDI	16.3035***	16.3035***	16.3035***	16.8367***	16.3035***	16.8367***	16.3035***	16.8367***	15.3257***
LVUL	- 16.6212*	- 16.6212*	- 16.6212**	- 15.3875*	- 16.6212**	- 15.3875*	- 16.6212**	- 15.3875	-20.0879***
LCO2_pc	- 2.6199***	- 2.6199***	- 2.6199***	- 2.5444***	- 2.6199***	- 2.5444**	- 2.6199***	- 2.5444***	- 2.4823***
LKOFEF	1.7595	1.7595**	1.7595*	1.6771	1.7595	1.6771	1.7595	1.6771	2.2897**
LKOFSF	3.1269**	3.1269**	3.1269**	2.8744*	3.1269**	2.8744**	3.1269**	2.8744**	2.5354**
C	- 25.6545**	- 25.6545*	- 28.8967**	- 25.9094*	- 28.8967**	- 25.9094*	- 28.8967**	- 25.9094*	- 31.0301***

	Model-IV - Mitigation Finance								
				PCSE				FGLS	
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1	CORR(IND)	AR1	HET
LHDI	18.7687***	18.7687***	18.7687***	18.8625***	18.7687***	18.8625***	18.7687***	18.8625***	16.8792***
LCO2_pc	- 1.4502*	- 1.4502	- 1.4502*	- 1.4635*	- 1.4502*	- 1.4635	- 1.4502*	- 1.4635	- 1.364**
LKOFEF	3.1402***	3.1402***	3.1402***	2.947**	3.1402**	2.947**	3.1402***	2.947**	3.3113***
LKOFSJ	6.5819***	6.5819**	6.5819**	5.9921**	6.5819***	5.9921**	6.5819***	5.9921**	8.3129***
LKOFPJ	- 5.6336*	- 5.6336***	- 5.6336**	- 5.1105	- 5.6336**	- 5.1105	- 5.6336**	- 5.1105	- 7.2831***
C	0.4222	0.4222	- 2.5396	- 1.6703	- 2.5396	- 1.6703	- 2.5396	- 1.6703	-3.0572

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Throughout the objective of assessing the determinants of climate and mitigation finance, the Model-III and Model-IV outcomes reveal that human development is a highly significant driver of climate and mitigation finance in both groups of countries. However, contrary to what occurs in the LMIC, quite similar determinants of climate finance and mitigation finance, in the UMIC, there are considerable differences between the determinants of climate and mitigation finance. The differences are mainly in the dimensions and measures of globalisation. Regarding the LMIC, the effect of regulatory quality that increases climate and mitigation finance and the impact of readiness that reduces mitigation finance stands out. In turn, in the UMIC stand out the effect of environmental degradation, which reduces both climate and mitigation finance and the impact of vulnerability, which also decreases climate finance.

Table 7.13 - Model-V – HDI for LMIC

Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1
LGDP_pc	0.1358***	0.1358***	0.1358***	0.1761***	0.1358***	0.1761***
LCF	0.0067***	0.0067***	0.0067***	0.0018***	0.0067***	0.0018***
FCI	- 0.0096***	- 0.0096***	- 0.0096***	- 0.0048***	- 0.0096***	- 0.0048***
LEC	0.0696***	0.0696***	0.0696***	0.0586***	0.0696***	0.0586***
LKOFJ	0.1362***	0.1362***	0.1362***	0.1464***	0.1362***	0.1464***
C	- 2.1845***	-2.1845***	- 2.1726***	- 2.459***	- 2.1726***	- 2.459***

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Table 7.14 - Model-V – HDI for UMIC

				PCSE				FGLS	
Variable	FE	DK-FE	CORR(IND)	AR1	HET	HET-AR1	CORR(IND)	AR1	HET
LGDP_pc	0.0642***	0.0642***	0.0642***	0.0872***	0.0642***	0.0872***	0.0642***	0.0875***	0.0662***
LCF	0.0036***	0.0036***	0.0036***	0.0009*	0.0036***	0.0009**	0.0036***	0.0009**	0.0024***
FCI	- 0.005***	- 0.005***	- 0.005***	- 0.0027*	- 0.005**	- 0.0027*	- 0.005***	- 0.0027**	- 0.006***
LEC	0.1162***	0.1162***	0.1162***	0.1039***	0.1162***	0.1039***	0.1162***	0.1037***	0.1093***
LKOFF	0.0323	0.0323*	0.0323	0.0436**	0.0323	0.0436**	0.0323	0.0435**	0.0613***
LKOFJ	0.1957***	0.1957***	0.1957***	0.1368***	0.1957***	0.1368***	0.1957***	0.1361***	0.132***
C	- 1.9669***	-1.9669***	- 1.9656***	-1.9185***	- 1.9656***	- 1.9185***	- 1.9656***	- 1.9175***	- 1.8051***

Note: ***, ** and * denotes significance level at 1%, 5% and 10%, respectively.

Tables 7.13 and 7.14 show that the results are similar for all estimators. Through Model-V, this research intends to provide evidence that climate finance goes further than fighting climate change, demonstrating that climate finance could be a valuable source for developing countries to increase their standard of living. Therefore, the outcomes of Model-V reveal that climate finance is a highly significant driver of human development in both groups of countries. Moreover, the effect of FCI decreasing human development in both groups of countries stands out. All the results deserve further attention in the discussion subsection. During the period under analysis, historical events occurred that may have influenced mainly climate and mitigation finance, such as the Paris Agreement in 2015. For that reason, a temporal impulse dummy for 2015 was tested in the climate and mitigation finance models. However, the dummy proved to be not a statistically significant determinant of climate and mitigation finance.

The role played by adaptation finance on environmental performance was also checked. However, adaptation finance only came into effect in 2010. Therefore, the models were estimated from 2010 to 2019. However, this is a short amount of time to catch an effective effect on environmental degradation, as it takes several years for recipient countries to complete the projects and apply the funds received. Consequently, adaptation finance does not reveal statistically significant for environmental performance in both groups of countries.

7.4.1 Robustness Check

In order to guarantee that the results obtained by using the PCSE estimator are robust and reliable, this subsection is dedicated to carefully assessing the robustness of the main findings. Therefore, the models were estimated using the Seemingly Unrelated Regressions (SUR). This method allows for the variable's parameter estimation by using a system of equations, and it has advantages over the use of the single equation methods. The SUR estimates the parameters of all equations simultaneously, which allows the parameters of every single equation to consider the information provided by the other equations. Thus, additional information is used to describe the system and consequently conducts to the higher efficiency of the parameters estimates (Cadavez & Henningsen, 2012; Mufutau Opeyemi, 2021). Moreover, the system of equations used by SUR permits the presence of heteroscedasticity and contemporaneous correlation, and it also allows for the error term of the equation to be correlated when properly specified (Cameron & Trivedi, 2010). Therefore, the equations should have differences in the explanatory variables in order to guarantee that the models are robust to endogeneity; otherwise, when the regressors are the same, the SUR runs an OLS, which is not able to deal with endogeneity. The results of the estimated SUR are displayed in Table 7.15 for both groups of countries.

Table 7.15 - SUR Regression Analysis

	LMIC			UMIC		
	Model-I – CO2(CF)	Model-III – CF	Model-V - HDI	Model-I – CO2(CF)	Model-III - CF	Model-V - HDI
LGDP_pc	0.8843***		0.0972***	0.5708***		0.0591***
LHDI	1.7689***	34.3831***		1.8294***	37.121***	
LCF	- 0.0247***		0.0117***	- 0.0188***		0.0064***
FCI	0.0522***	0.1148	- 0.0085***	- 0.0158*	0.2147	- 0.0053***
RQ	- 0.0828*	0.4056		0.2263***	1.075	
GE	0.0702	- 0.4858		0.0029	- 0.5034	
LRD		- 0.3802			- 1.1522	
LVUL		6.9458			- 8.0747	
LCO2_pc		- 1.3546***			- 5.1639***	
LEI	0.5532***			0.4391***		
LEC			0.0728***			0.1121***
LKOFEF		- 0.883			1.4252	
LKOFEJ		- 0.6718			0.0953	
LKOFSF		- 0.5249			0.3244	
LKOFSJ		1.18443			1.3174	
LKOFPF		- 1.7748***			- 1.0819	
LKOFPJ		- 3.252			- 4.2657	
LKOFF	- 0.035		0.0027	- 0.3272**		0.0245
LKOFJ	0.3548**		0.1119***	- 0.4622*		0.1691***
C	- 14.1777***	51.1718***	- 1.8464***	- 7.3303***	- 1.0151	- 1.814***
	Breusch-Pagan test of independence (chi-sq)					
	98.027***			35.109***		

Notes: ***, **, * denotes significance level at 1%, 5% and 10%, respectively.

The suitability of the methodology used was verified by analysing the Breusch-Pagan test of independence (see Table 7.15). Under the null hypothesis that the residuals are independent, the rejection of it corroborates the appropriate use of SUR. The results of the Breusch-Pagan test of independence sustain the rejection of the null hypothesis, denoting that the residuals are not independent and supporting the suitability of the method. The results obtained through the SUR (see Table 7.15) corroborate the main findings. The outcome of the SUR shows that climate finance is an effective tool to mitigate environmental degradation in both groups of countries. Environmental degradation is mainly driven by economic growth, human development, and energy intensity. The difference between both groups of countries lies in the role played by regulatory quality and globalisation. Regulatory quality decreases environmental degradation in the LMIC, while it has the opposite effect in the UMIC. Regarding globalisation, it is clear that the groups of countries under analysis are in different policy spectrums. On the one hand, globalisation *de jure* increases environmental degradation in the LMIC. On the other hand, globalisation *de facto* decreases environmental degradation in the UMIC. These findings are entirely in line with the results obtained by using the PCSE estimator.

Among the determinants of climate finance, the influence of environmental degradation, mainly in the UMIC, stands out. The increasing allocation of climate funds is conditioned by the level of environmental degradation. Through the human development model (Model-V), this research intends to analyse the role of climate finance on the standard of living. Once again, the results of SUR corroborate the results previously found by using PCSE, and climate finance is a highly significant driver of human development. This subsection provides support for the robustness of the main findings found previously.

7.5 Empirical Discussion

Developed and industrialised countries have contributed the most to climate change, yet these countries are the near opposite of those who face the most imminent risk of climate loss and damage. Therefore, countries unanimously agreed that industrialised nations with financial resources and technological knowledge must provide financial support for climate action in developing countries. In light of this, climate finance flow has stimulated academic research to analyse the factors that attract this financial support and if it is an effective environmental degradation mitigation tool. There is increasing pressure to accomplish global environmental goals, and it is mainly developing economies that are facing several challenges to adapt and mitigate climate change effects. Consequently, this makes the research on the field of climate finance all the more urgent, as it can be useful to help policymakers design effective environmental policies and strategies to maximise the allocation and efficacy of climate finance funds, and thus help to accelerate the drive to net zero carbon. That is, to identify strengths for the allocation and implementation of climate finance in improving environmental quality in the years that follow.

Climate finance significantly reduces the environmental degradation of the recipient developing countries and consequently improves environmental quality. This evidence suggests that climate finance is an effective environmental pollution mitigation tool and relevant in dealing with environmental issues. This outcome is consistent with Carfora and Scandurra (2019) and Lee et al. (2022). Climate finance funds may allow developing economies to invest in environmentally friendly sectors, such as renewable energy power generation (alleviating the excessive use of fossil fuels), and low-carbon manufacturing technologies, and incentivise low-carbon development. Climate finance funds avoid or smooth the dilemma developing economies face when choosing between economic development and environmental protection (Nakhooda et al., 2014). According to the outcomes, the effect of climate finance on the LMIC seems more remarkable than on the UMIC. However, in contrast to what happened in the allocation of climate finance in the LMIC, CO_2 emissions only behave as a significant discouragement of climate finance in the UMIC. That is, increasing environmental degradation decreases climate finance in the UMIC. As LMIC have fewer resources, the level of emissions is not a determinant factor of climate finance allocation. This is in contrast to what happens in the UMIC, which are bigger emitters, have more resources, and consequently have stricter environmental goals.

Climate finance is composed of mitigation finance and adaptation finance. On the one hand, mitigation finance is dedicated to reducing environmental degradation. On the other hand, adaptation finance focus on reducing the effects of climate change impacts. Mitigation finance effectively reduces environmental degradation in the LMIC. However, it seems to not significantly influence environmental degradation in the UMIC. This finding could suggest that the current amount of funds is not enough to achieve environmental goals in the UMIC. With higher levels of CO_2 emissions and as highly industrialised economies, the UMIC need even more financial resources to effectively be able to reduce emissions. In contrast, the LMIC are poorer economies, less industrialised, and with lower levels of CO_2 emissions, so they are more sensitive to environmental mitigation investments. That is, achieving the environmental goals in the UMIC requires a greater proportion of the global budget.

Adaptation finance does not reveal statistically significant for environmental performance in both groups of countries. According to the United Nations (2021) report, adaptation finance has been overlooked and is far from reaching a stable allocation. Developed countries are committed to spending $100 billion for climate action (of climate finance) in developing countries per year. Yet, adaptation finance represents about 20% of climate finance overall. In 2019 just $20 billion went to adaptation projects. According to The United Nations Environment Programme, developing countries will face estimated adaptation costs in the range of $140 billion to $300 billion per year by 2030 (United Nations, 2021). Developing economies contribute the least to climate change; however, they are the most vulnerable to its effects. In light of this, adaptation finance is essential and the most needed financial source for these countries to overcome climate change effects and to fight to survive. Regarding globalisation, distinct effects were revealed from globalisation measures on the environmental performance of the groups of countries under analysis. Beyond each group of countries´ environmental performance being affected by a different globalisation measure, the globalisation measures revealed opposite signs. Globalisation *de jure* increases environmental degradation in the LMIC, while globalisation *de facto* decreases it in the UMIC. Globalisation *de facto* consists of actual flows and activities. Globalisation *de jure* consists of policies that allow flows and activities. Considering the measure that affects the environmental performance of each group of countries, this could suggest that LMIC may fit in the policy adoption spectrum, while UMIC fits in the policy implementation spectrum.

Also, regulatory quality demonstrated opposite effects. The scenario of regulatory quality between the groups of economies under analysis is quite different. LMIC presents a weakness in regulations (mean negative value of - 0.54), while UMIC reveals stronger regulation (mean value of 0.058) (see Table 7.3). Regulation is a tool for the government to achieve its goals. Regulatory quality helps governments to boost economic growth, social welfare, and environmental standard (OECD, 2008). According to the main findings, an increase in regulatory quality decreases environmental degradation in the LMIC. This outcome is supported by the findings of Mesagan and Olunkwa (2022). According to the Pollution Halo Hypothesis, improving regulatory frameworks reduces environmental pollution. In other words, it is beneficial to strengthen pollution regulations to attract environmentally friendly corporations. Furthermore, according to the literature, regulation quality could help the LMIC to enhance the impacts of financial sectors on pollution mitigation (Mesagan & Olunkwa, 2022). However, the quality and success of the regulatory system are conditioned by how regulations are formulated and executed (Handoyo & Fitriyah, 2018). Regulatory quality is significantly positive on environmental degradation in the UMIC, implying that regulatory quality contributes to a rise in environmental degradation. This outcome is consistent with the findings of Ibrahim and Ajide (2021), indicating the weak nature of these economies' institutions in safeguarding the environment from the production and consumption of environmentally carbon-embodied goods. Ineffective regulation could come from different triggers, such as lack of capacity, institutional features, and bad politics. In other words, regulation quality increasing environmental degradation could occur as a result of, for instance, political decision-making, budget expansion, or private interest (private political or economic ends) (Donadelli & Heijden, 2022). This relationship suggests that institutions without the help of the principal economic agents (households and firms) are not sufficient to fight environmental pollution in the UMIC.

The relationship between FCI and environmental degradation was one of the main topics discussed recently during COP27. Foreign investment (mainly by energy and petrochemical companies) is related to some environmentally devastating consequences. Therefore, a discussion arises focused on understanding if the connection between foreign direct investment (one of the principal sources of FCI) and carbon-intensive industries can be finished. According to the main findings, FCI increases environmental pollution in the LMIC. On the one hand, FCI might stimulate economic activity and increase the production level of these economies. That consequently might increase energy demand. The increasing effect on environmental degradation suggests that the energy used to fulfil the increasing demand mainly comes from fossil fuels (mainly due to the lack of renewable energy infrastructure). Also, LMIC are on a retarded industrialization path, and they are mainly equipped with old and carbon-intensive technologies. Investing in renewable energy sources and efficient equipment is crucial to these economies' sustainable economic growth. On the other hand, according to the literature, FCI (primarily foreign direct investment) could represent pollutant industries transfer and consequently increase environmental pollution (relationship theorized by the Pollution Haven Hypothesis). This hypothesis focuses on the pollutant industries transfer from developed to developing countries, and developing economies become pollution havens for developed ones (Cai, Che, Zhu, Zhao, & Xie, 2018; P. H. Leal et al., 2021).

It might be worth noting that LMIC and UMIC face several human concerns besides climate change, such as poverty. Besides contributing to improving environmental quality in these economies, climate finance also enhances human development. That means that as well as being a financial resource to mitigate environmental degradation, it also allows these economies to improve life quality. Climate finance and human development have a positive bilateral relationship, which means that climate finance improves human development, and human development attracts climate finance. However, the same is not true of FCI, which impairs human development. As mentioned above, FCI might be related to the relocation of pollutant industries to the economies under analysis. This phenomenon is triggered mainly by the comparative advantages that developed and high-income countries have over developing. The most evident comparative advantages are the less rigorous environmental regulation context and a cheaper labour force. If employers look for a cheap and not-specialized labour force, education and knowledge are discouraged. Consequently, there is a negative effect on human development. Furthermore, FCI fosters environmental degradation that might have negative effects on health and life expectancy.

7.6 Conclusion and Policy Implications

Climate impacts are no longer just a threat to the future; they are a reality that needs to be dealt with today. The present research was undertaken with the principal objective of further understanding, on the one hand, the role of climate finance in the achieving sustainable development and on the other hand, identifying the determinants of climate finance. The main findings of this research reveal that climate finance, beyond improving environmental quality, also improves human development. Climate finance is more than just a financial resource to mitigate climate change; it also improves living standards. However, FCI reveals the opposite. Besides increasing environmental degradation, it also decreases human development. FCI is still related to carbon-intensive activities and industries. Policymakers play a crucial role in controlling investment and capital flows. Policies and measures should be implemented in order to assess the environmental impact of investments and capital inflow besides investing in renewable energy infrastructure. Countries have been experiencing increases in energy demand as a result of increased energy access and economic development, which requires improved energy efficiency and increasing renewable energy capacity. Also, regulatory quality in the UMIC needs further attention from policymakers. The regulatory scenario in these economies suggests that they are not prioritizing environmental quality. In order to promote environmental quality in these economies, it is necessary to strengthen environmental laws and regulations to protect the environment. The analysis of the determinants of climate finance reveals that, at this stage, climate finance is mainly influenced by the level of environmental degradation, more strongly reflected on the UMIC and by human development. That suggests that climate finance allocation focuses on effectively supporting the economies that suffer the most effects of climate change. However, climate finance funds have not reached the projected amount for the expected needs. For economies to make significant progress toward sustainability and reach sustainable development goals, policies and measures that do not even exist yet or exist in a form unsuitable for the purpose need to be developed, projected, and implemented.

The main findings suggest some implications for the path toward global environmental sustainability. Climate finance has a significant impact on CO_2 emissions in recipient countries, which indicates that the commitment by developed countries is vital to accomplish the goals. Therefore, climate finance needs to be increased by mobilizing diversified fund sources. Climate finance should not only be pushed by public finance, but also the private sector and regional governments should contribute to increasing climate finance and promoting global low-carbon development. The accomplishment of the global net zero carbon emissions goal comes at a financial cost. More climate finance needs to be invested, and policies have to drive these funds to clean energy technologies and low-carbon industries to guarantee environmental degradation reduction from climate finance. Climate finance has a positive bidirectional relationship with human development that could be used to enhance the potential reduction effect of climate finance on CO_2 emissions. That is, if the recipient countries receive climate finance on the basis of high economic and human development, the mitigation climate change effect from climate finance may be boosted. In light of this, governments should focus on reinforcing and improving the economic conditions in order to enlarge the absorptive capacity of climate finance. Besides, the environmental regulatory framework should be strengthened to discourage carbon-intensive investments and ensure the most efficient allocation of climate finance.

The COP and international agreements are crucial to accomplish sustainable and environmental goals. Global warming and climate change are a worldwide struggle. Individual economies' interests should not be above this most urgent fight that humanity has to win. Considering the common global interest of mitigating and adapting to climate change, it is indispensable to establish goals and mainly accomplish them. International agreements allow transparency and the commitment to a shared interest. Considering the urgent need to act, punishing those who break the agreements and do not accomplish them might be reasonable. Achieving a net carbon-zero future is vital, and now is the time to apply the most rigorous measures to reach that. Perhaps implementing penalties on economies that do not comply with the agreed treaty will discourage these economies from making decisions that maximize their profit over environmental quality. To achieve carbon neutrality targets, global efforts have to be made. Policymakers need to ensure that all policy structures endorse the implementation of climate finance, both in adapting to climate change effects and fighting climate change. Climate finance and related-climate policy should not be used as isolated tools, they should be considered as an integral part of the development path of developing economies.

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Chapter 8

Conclusions

This thesis focused on the analysis of the influence of growing globalisation on both environmental performance and sustainable development (Chapters 2, 3, and 4), considering the environmental performance assessment hypothesis (Chapter 5) and environmental degradation mitigation tools (Chapters 6 and 7). The design and implementation of policies and directives should consider two main perspectives of the role of globalisation. On the one hand, by low barriers to goods, cross-border technologies, individuals, and capital, globalisation might enable countries to achieve environmental improvements. On the other hand, globalisation might be used as a channel to access foreign markets, reduces production costs, and lead to the relocation of polluting industries. This process means that globalisation's influence on environmental performance is susceptible to the economies' features. Therefore, the intervention of policy guidance is crucial to controlling the adverse effects, discouraging technologically advanced economies from taking advantage of the poorer ones, and reducing the gap and inequality between nations.

The achievement of environmental targets is crucial to attaining Sustainable Development Goals (SDGs) and guaranteeing a safe environment for future generations. This challenge should not be restricted to a group of countries or region; it needs to be addressed on a global scale. Therefore, economies working together to accomplish the same goal should benefit from the same channels and fight with the same effort against each one's available recourses. Investments in research and development of new advanced technologies to achieve net zero carbon emissions and provide financial support to economies with capital in short supply, ensuring the accomplishment of the environmental targets, besides an auto preservation mechanism, in the long-term could even have a significant financial return. Providing guidelines and insights to help policymakers improve sustainable development has motivated this thesis.

8.1 Final Remarks

Overall, the transversal research question consisted of analysing of how globalisation has been impacting the sustainable development of economies. Considering this question, the main objective of this thesis was to provide empirical evidence considering distinct economic, social, political, environmental, and development features of the economies. To accomplish the objective of this thesis, the econometric techniques were selected in concordance with the data features and research objective of each essay. Panel data techniques were used on an annual basis to obtain as many observations as possible. Therefore, the empirical evidence of this thesis was performed by using diverse econometric methods, and the econometric procedure was focused on ensuring the use of the most suitable econometric practices.

Getting briefly into the detail of each chapter's analysis in order to discuss as a whole the main findings of this thesis, Chapter 2 focused on analysing a group of developed, high-income, high-globalised, strictly regulated, politically and economically integrated, and unified foreign and security policy economies. The main findings of this chapter suggest that the highest European Union (EU) globalised economies are more often policymakers, whereas the lowest globalised are more frequently policy takers. Chapter 3 considered economies with distinct features that allow developed economies to have comparative advantages over developing ones. Consequently, globalisation could act as a channel that allows developed economies to benefit from those advantages. Additionally, the Environmental Kuznets Curve (EKC) hypothesis was assessed. The findings of this chapter suggest that developed economies may have been taking advantage of the lax environmental regulation in developing economies. According to the EKC hypothesis assessment, the outcome suggests that there might be a flow of polluting industries relocating from developed to developing countries.

To fully accomplish the first objective of this thesis, Chapter 4 focused on a group of developing economies with low income, low globalisation, lax regulation, severe economic, political, and social context, and considerable levels of energy poverty. The findings suggest that African economies might have been pollution havens. These findings are consistent with the findings of Chapter 3 about the relocation of pollutant industries. Policymaking strategies should be focused on eliminating the advantages that a company based in a country with strict environmental regulations looks to benefit from when relocating its production to a country with lax environmental regulations. Also, complementary measures that persuade emerging economies to accept the possibility of a slowdown in economic growth and to compensate them should be implemented. Furthermore, African countries are stuck with fossil-powered technology. In order to induce environmental quality, it might be crucial to promote energy transition from fossil fuels to renewable energy sources.

Overall, the main findings of the first part of this thesis lead to brief conclusions about the role of globalisation in environmental performance. Firstly a brief note about the econometric procedure. Throughout these chapters, an Autoregressive Distributed Lag

(ARDL) approach with a Driscoll Kray estimator was carried out. This methodology has some advantages, such as it permits the capturing of short- and long-run effects individually, obtaining the magnitude of the effect through the semi-elasticities and elasticities, and dealing with the endogeneity. Additionally, considering the common objective throughout these essays, using the same methodology provides a most reliable comparison between the findings.

The most important conclusion arising from the first part of this thesis is that the contents of the three essays support the relevance of analysing each measure and dimension of globalisation separately in order to avoid biased results. In other words, they support the intuition that each measure and dimension of globalisation has a different effect in nature and magnitude. Regarding the role of globalisation in environmental performance, as suspected, globalisation is a complex phenomenon and susceptible to the economies' features. The distinct behaviour of globalisation under different development, income, economic, social, political, and environmental contextualisation is evident throughout the three essays. Furthermore, it is observed that globalisation could change its roles from the short- to the long-run. The environmental performance in developing and middle-income economies is the least benefited from globalisation.

When the findings of each dimension and measure of globalisation specifically are compared, it is observed that political globalisation *de facto* only influences developed economies and when statistically significant it improves environmental quality. This situation might suggest the advantages and benefits of policy dissemination. Regarding political globalisation *de jure*, it has the most influence on environmental performance under different economies' features. On the one hand, in the short-run, when statistically significant, it improves environmental quality. On the other hand, in the long-run, it has the same effects as in the short-run, plus it increases environmental degradation in the low EU globalised economies and the group of developed economies. Apart from international treaties that could take time to be in place, some economies have not been experiencing the desired effects, which could suggest that international treaties have not been designed with a clear environmental protection directive.

The effect of economic globalisation *de jure* deserves to be highlighted. Economic globalisation *de jure* consists of the policies that allow trade flows. In any of the analysed contexts, it is statistically significant in the short-run, only in the long-run increasing environmental degradation in high- and middle-income countries. This situation suggests that the policies that allow the trade flows also take time to be in place and need time to have an effective environmental outcome. That is, trade policies do not have immediate environmental consequences. In contrast, economic globalisation *de facto* influences the environmental degradation of diverse groups of countries (high-, middle-, low-income, developed, and developing) in the short-run and always increases environmental degradation. This measure of economic globalisation, the actual trade flows, have more immediate consequences.

Overall, the findings have indicated that environmental strategies should be delineated considering the level of income, development, and globalisation and the regulatory, economic, social, and political context of the economies. A debate on strategies that discourage developed and high-income economies from economically benefiting from increasing environmental degradation in developing and low-income countries is needed. The findings of the three essays that constitute the first part of this thesis and the structure of the essays that allow comparison suggest strong internal consistency.

The findings of the first part of this thesis evidence that it is crucial to provide the most realistic assessment of environmental performance for policymakers to design and implement the most efficient policies and directives to achieve sustainable development and the net-zero carbon goal. Understanding the gaps and the improvements that might be needed in environmental performance assessment has motivated the second part of this thesis. Chapter 5 focused on providing a highly detailed survey of the literature and a critical analysis of one of the most popular methods used to assess environmental performance, the EKC. Through that, it was evidenced that the application of the EKC hypothesis holds some gaps and econometric issues, and additionally, improvement needs were identified.

The main conclusions of Chapter 5 indicate that the EKC assessment would benefit from using econometric methods which deal with collinearity and multicollinearity. Non- or semi-parametric methods or non-econometric methods could be helpful to avoid EKC sensitivity to the approach used. Furthermore, the EKC would also benefit from integrating insights from other disciplines and research areas, such as socio-political indicators. The complexity of environmental degradation issues is increasing, and scenarios such as relocated pollution, delocalized production, energy and production goods, countries' dependence, lax environmental regulation, and comparative advantages, among others, can influence countries’ environmental performance.

At this point, it is crucial to consider these scenarios during the EKC assessment to allow policymakers to develop and implement fair and effective policies conducive to achieving the SDGs. A set of strategies and tools have been developed, and they should be included in assessing the path of environmental pollution over economic development. Technological progress, energy efficiency, energy transition, potential clean energy sources (such as nuclear), environmental regulation, and green and climate finance can influence this path and provide a realistic route to a cleaner environment. These improvements would be beneficial for economic analysis and policymaking.

Besides answering each essay's research questions, the main findings of the first and second parts of this thesis elicit further research questions. Therefore, the analysis of each measure and dimension of globalisation as a determinant of sustainable development consists of the main objective of the third part. Energy efficiency and climate finance are two of the most discussed tools to achieve the SDGs. For this reason, the analysis of the role of globalisation as a determinant of energy efficiency and climate finance could be crucial in the policymaking strategy. In fact, strategies to mitigate environmental degradation and climate change effects might go along with strategies to adapt to the climate change effects already felt.

In Chapter 6, globalisation as a driver of energy efficiency and sustainable development was evaluated. The main results reveal that the lowest globalised economies should invest more in energy efficiency and efficient technology. The high implementation costs of renewable energy sources were evidenced in the analysis. Considering the high levels of energy consumed by these countries, the findings suggest that the economic component in sustainable development is more significant than the depletion of the natural environment with respect to renewable energy consumption. Policymakers should design strategies to make energy transition economically more attractive.

Regarding globalisation, most of its dimensions and measures improve energy efficiency in the highest globalised economies and sustainable development in both groups of economies. In order to improve energy efficiency, bilateral investment treaties should ensure environmental preservation and promote energy efficiency measures in the highest globalised economies. Also, investment restrictions should induce energy efficiency. With respect to sustainable development, economic globalisation is the only dimension with a harmful effect on it, which could suggest that economic benefit could have been prioritised over environmental quality. While in the highest globalised economies, strategies should be focused on the policies that allow trade flows; in the lowest globalised economies, it should be on the real trade flows. In contrast, social and political globalisation encourages sustainable development.

Apart from supporting environmental degradation mitigation, climate finance also supports adaptation measures. Therefore, climate finance might not only help resource-poor economies to improve environmental quality but also help these economies to suppress poverty, premature death, and food shortage and enhance the standard of living. This evidence, along with the vulnerability of the developing economies, evidenced through the findings of the first part of this thesis, caught our attention and inspired the development of Chapter 7. This connection between the findings and objectives of the essays once again suggests consistency throughout this thesis.

Chapter 7 evaluated the contribution of climate finance to the environmental performance and improvement in the standard of living of developing economies and potential determinants of climate finance. The main findings indicate that climate finance effectively is a valuable mechanism to mitigate environmental degradation. Besides acting as an environmental preservation mechanism, climate finance also improves living standards in developing countries. In concordance with that, human development was seen as a major determinant of climate finance flow. In contrast, foreign capital inflow, beyond promoting environmental degradation, also dissuades human development, which could indicate that this capital is connected with carbon-intensive activities and industries. Once again, the findings throughout this thesis's essays are in concordance revealing a coherent analysis structure. The main findings of the essays in the first part also suggest the relocation of pollutant industries.

The regulatory quality in upper-middle-income economies needs further attention from policymakers. Strengthening regulatory scenarios and implementing environmental protection directives are indispensable to accomplishing the established environmental goals. In order to make significant progress toward sustainability and reach sustainable development goals, individual economies' interests should not be above the most urgent fight that humanity has to win. Considering the common global interest of mitigating and adapting to climate change, it is indispensable to establish goals and mainly accomplish them. International agreements allow transparency and the commitment to a shared interest. Perhaps implementing penalties for the economies that do not comply with the agreed treaties would discourage those economies that make decisions that maximize their profit over environmental quality.

In short, this thesis contributes to increasing the knowledge in the area of environmental sustainability. Specifically, it reveals the importance of developing and implementing environmental measures and directrices considering the specific features of economies. Also, it shows the importance of the climate change mitigation challenge to be addressed to all the countries and how each one applies its available resources to accomplish the SDGs, prioritizing global climate change mitigation and adaptation over individual economic interests. In fact, the findings of this thesis from empirical evaluation constitute support for the design of quality policies toward environmental sustainability. However, it is worth highlighting that this thesis's findings are based on the analysis of historical data. In light of this, new environmental challenges, techniques, and mechanisms will emerge in the future that will need to be incorporated into the relationships that this thesis has addressed.

8.2 Future research

The accomplishment of international environmental targets is currently the most discussed topic by world leaders. It can be said with some confidence that this thesis significantly contributes to the literature. It provides robust evidence about the role of globalisation on environmental performance and sustainable development and includes an analysis of different economies' features, a mechanism for environmental degradation mitigation, a tool of financial support for climate change mitigation and adaptation, and an environmental performance assessment hypothesis. The contribution of this thesis has already started to be recognized through already-published articles. Nevertheless, fully understanding the role of the complex phenomenon of globalisation on environmental performance and how to entirely convert it into a sustainable development driver is still a need, and additional contributions in the field are welcomed. In the near future, new mechanisms will be developed and implemented, increasing the attractiveness of it for researchers. Additionally, in the course of this thesis and giving answers to the initial research questions, new questions emerged. Although these do not entirely suit the scope of this thesis, they are examples of future research paths.

This thesis focuses on globalisation as a channel between economies characterised by low barriers to goods, cross-border technologies, individuals, and capital. Diverse phenomena could occur through that channel, such as the relocation of pollutant industries and capital flight. In fact, policies regulating and controlling these phenomena might improve the role of globalisation in environmental performance. The findings of this thesis suggest that the relocation of pollutant industries from developed to developing economies should be explored in future research. This research could provide further evidence of this phenomenon not only through financial flows, such as foreign direct investment, but also on amount of pollution transfer, imports, and exports (consumption split from production).

Globalisation and capital flight share the ability to transpose national borders. In economies with capital in short supply, capital flight induces severe economic consequences. The achievement of sustainable development goes further than improving environmental quality; thus phenomena that destabilize the economic situation of countries in already severe situations of poverty might consequently have a negative influence on achieving sustainable development. Therefore, the influence of capital flight in human and sustainable development and globalisation as a driver of capital flight should be explored in future research.

In the current context, apart from concerns about air quality, also water, and soil quality, there is an increasing source of uneasiness. Following a sustainable development path should include all of these environmental dimensions. Therefore, in the future, research should focus on different dimensions of pollution, and diversify the analysis of air pollutants. Additionally, the recent global health crisis and the current tension experienced between Ukraine and Russia have revealed economies' weaknesses and dependency on the production from countries that globalisation provokes. These issues are subjects surely worthy of future research in order to identify their environmental consequences.

Moreover, additional proof of the role of globalisation in environmental performance is needed. There are still opportunities for improvements in the analysis of this topic by using the subdimensions of each dimension of globalisation, namely the subdimensions of economic, trade, and financial globalisation, and of social, interpersonal, informational, and cultural globalisation. This research area is, and will continue to be, a hot topic for the literature and crucial for policymaking.

Further research could consider the application of other methodologies to analyse the influence of globalisation on sustainable development. According to the data characteristics, as explained in each essay of this thesis, the methodology used was to ensure robust results. Understanding the past is crucial to project the future. Therefore, the majority of the findings of this thesis, excluding Chapter 5, have resulted from econometric analysis using available historical data. Future research should apply other methodologies, such as simulation, to analyse the introduction of new mitigation mechanisms or restricted environmental regulation scenarios, game theory, and multiregional input-output analysis.