MASTERS THESIS

INVESTIGATING THE EXISTENCE OF THE ENVIRONMENTAL KUZNETS CURVE IN SELECTED MIDDLE-INCOME AFRICAN COUNTRIES

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PLAGIARISM DECLARATION

I, Liyema Dosini, do declare that except for references specifically indicated in the text and such help as has been provided by my supervisors, this thesis is wholly my original work and has not been submitted at any other University or Technikon for any degree purposes.

Signed by *L. Dosini* on this 09th day of July 2025.

ABSTRACT

This study investigated the Environmental Kuznets Curve (EKC) hypothesis for five middle-income African countries: Algeria, Angola, Morocco, Nigeria, and South Africa. The EKC hypothesis explores the relationship between economic growth and environmental degradation, suggesting an inverted U-shaped curve where environmental degradation rises during the early stages of growth but decreases once a certain income level is reached. This research employed annual panel and time series data from 1990 to 2019, excluding the post-2019 period, to avoid distortions caused by the COVID-19 pandemic.

The study applied a range of econometric models, including Fixed Effects (FE), Random Effects (RE), Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL), and time-series Autoregressive Distributed Lag (ARDL) models. These models were used to estimate both short-run and long-run effects while accounting for heterogeneity across countries. In addition to GDP per capita and its square term to capture non-linearity, the analysis incorporated key structural control variables: trade openness, energy use and the human development index (HDI).

The study aimed to contribute to the growing literature on the EKC within the African context. The panel models (PMG-ARDL) supported an inverted U-shaped EKC in most model specifications where the coefficients of GDP per capita and its squared term were statistically significant with the expected signs: a positive coefficient on GDP per capita and a negative coefficient on GDP per capita squared.

The time-series ARDL findings revealed a U-shaped relationship between GDP per capita and CO_2 emissions for Algeria, Nigeria and South Africa, implying that continued economic growth is associated with increasing carbon emissions. For Angola, no evidence of the EKC was found as the GDP per capita squared coefficient was statistically insignificant in the best-fitting model, indicating a linear rather than quadratic relationship. The time-series ARDL results for Morocco provided weak and inconsistent evidence for the EKC hypothesis.

These results highlight the need for context-specific environmental policies and suggest that economic growth alone may be insufficient to reduce emissions. The study contributes a deeper understanding of sustainable development challenges in African middle-income countries.

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LIST OF ABBREVIATIONS

AMG	augmented mean group
ADF	Augmented Dickey Fuller
AfCFTA	African Continental Free Trade Area
AIHSRN	African High-Speed Rail Network
AMCEN	African Ministerial Conference on the Environment
AMCU	Association of Mineworkers & Construction Union
AMU	Arab Maghreb Union
ARDL	autoregressive distributed lag
AREI	African Renewable Energy Initiative
ASGI-SA	Accelerated and Shared Growth Initiative for South Africa
AUC	African Union Commission
AUGRAP	African Union Green Recovery Action Plan
ASCC	African Strategy on Climate Change
CCS	carbon capture storage
CO_2	carbon dioxide
CCE-PMG	common correlated effects pooled mean group
CGE	computable general equilibrium
CoC	certificate of compliance
COMESA	Common Market for Eastern & Southern Africa
COP	Conferences of the Party
CSP	concentrated solar power
DOLS	dynamic ordinary least-squares
ECOWAS	East African Community of West African States
EKC	Environmental Kuznets Curve
ESP	Economic Sustainable Plan
FDI	foreign direct investment
FE	fixed effects
FFF	Fridays for Future
FMOLS	fully modified ordinary least-squares
GCG	Green Climate Fund
GDP	gross domestic product

GDPPC	gross domestic product per capita
GEAR	Growth, Employment and Redistribution
GGW	Great Green Wall
GHG	greenhouse gas
GLS	Generalised Least-Squares
GMM	generalised method of moments
HDI	human development index
IDC	Industrial Development Corporation
IGOs	intergovernmental organisations
IPCC	Intergovernmental Panel on Climate Change
IPPs	independent power producers
IEA	International Energy Agency
JETP	Just Energy Transition Partnership
JIPSA	Joint Initiative for Skills Acquisition
KPSS	Kwiatkowski Phillips-Schmidt-Shin
MDGs	Millennium Development Goals
MW	Megawatts
NAFTA	North American Free Trade Agreement
NCV	national certification vocational
NEPAD	New Partnership for Africa's Development
NO_X	nitrogen oxide
OECD	Organisation for Economic Co-operation and Development
NWSAS	Northwestern Sahara Aquifer System
OLS	ordinary least-squares
PAYG	pay-as-you-go
PCC	Presidential Climate Commission
PHH	Pollution Haven Hypothesis
PMG	pooled mean group
PPPs	public-private partnerships
PV	Photovoltaic
R & D	research & development
RDP	Reconstruction and Development Programme
RE	random effects

RECs	regional economic communities
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REMP	Renewable Energy Master Plan
SACCCS	South African Centre for Carbon Capture & Storage
SADC	Southern African Development Community
SANEDI	South African National Energy Development Institute
SARS	South African Revenue Services
SSA	Sub-Saharan Africa
SDGs	Sustainable Development Goals
SO_2	sulphur dioxide
SPM	suspended particulate matter
SSEG	Small-Scale Embedded Generators
TSP	total suspended particulate
TVET	technical and vocational education and training
UNFCCC	United Nations Framework Convention on Climate Change
UNDP	United Nations Development Programme
VECM	vector error correction model
WDI	World Development Indicators

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CHAPTER 1
INTRODUCTION

1.1 Research background

The Environmental Kuznets Curve (EKC) hypothesis is widely debated and there is mixed evidence of its existence (Tabash et al, 2023). The hypothesis explores the relationship between economic growth and environmental degradation, suggesting an inverted U-shaped curve where environmental degradation rises during the early stages of growth but decreases once a certain income level is reached (Barbier, 1997; Martinez-Navarro et al, 2020). Climate change has emerged as one of the most pressing global challenges, with its effects disproportionately impacting developing regions, particularly Africa. This study investigates the EKC framework for middle-income African countries, where evidence remains limited.

Africa is regarded as the continent most vulnerable to the effects of climate change and there is a need for more studies to investigate the EKC. This is due to the continent's high exposure, sensitivity and low adaptive capacity to climate change (IPCC, 2022). Africa faces increasing recurrent droughts, floods and rising temperatures, which threaten food security, water resources and livelihoods. Structural factors such as widespread poverty, reliance on climate-sensitive sectors such as rain-fed agriculture, limited institutional and financial capacity further constrain adaptation options (IPCC, 2022).

According to the IPCC (2022), African countries are among the hardest hit by climate-induced losses despite contributing the least to global emissions. Similarly, the World Bank (2021) and UNEP (2022) highlight that Africa's infrastructure, urban settlements and health systems are especially vulnerable, making the continent disproportionately affected relative to other regions. This underscores the urgency of investigating sustainable growth pathways, such as those explored under the EKC framework, to balance development and environmental protection.

While the EKC hypothesis has been widely tested in developed countries, empirical evidence for Africa is limited and often yields mixed results. For example, Baek and Kim (2013), Al-Mulali and Ozturk (2016), and Maranzano et al. (2022) confirm an inverted U-shaped EKC in

Korea, OECD countries, and a panel of developed economies, respectively. By contrast, African studies such as Ogundipe et al (2014) and Demissew-Beyene and Kotosz (2020) find no consistent evidence of the EKC. This study therefore contributes to closing this gap by testing the EKC hypothesis in a panel of middle-income African countries and at the country level, providing a more nuanced understanding of the growth–environment nexus in the region.

According to Bah et al (2020), African countries urgently need to reassess their economic and environmental policies. The paper found the existence of an inverted U-shaped EKC for seventeen African countries. It emphasised the importance of accounting for income heterogeneity when estimating the EKC. The paper claims that studies that have found limited evidence of the EKC for African countries failed to categorise countries according to income levels. Bah et al (2020) categorised countries into lower-middle and upper-middle countries and found the existence of the EKC for both categories.

Other studies by Ogundipe et al (2014), Demissew-Beyene and Kotosz (2020) and Bibi and Jamil (2021) investigated the EKC for the Western African region, twelve East African countries and the Sub-Saharan region, respectively. In their analysis, these studies did not find evidence of an inverted U-shaped curve. Demissew-Beyene and Kotosz (2020) found a bell-shaped curve rather than an inverted U-shape when they used the Pooled Mean Group estimation method between 1990 and 2013, which indicates a potential rise in degradation with subsequent growth post GDP per capita turning point. Several factors may lead to rising degradation beyond the turning point, such as rapid industrialisation, inadequate environmental regulations and dependency on non-renewable sources, further discussed in Chapter 2.

It is important to investigate the EKC hypothesis to highlight the relationship between per capita income and environmental protection policies (Chen et al, 2019). The thesis contributes to existing knowledge by investigating the EKC for middle-income African countries with limited available literature. In addition to investigating the EKC for the panel of countries, the thesis will also account for country-specific results. This provides more insight into the growth-environment nexus for these countries still in their developing stages.

1.2 Research objectives

The overarching goal is to investigate the existence of the EKC for five selected middle-income African countries: Algeria, Angola, Morocco, Nigeria and South Africa. These countries were selected based on regional diversity, emission levels and data availability (discussed in more detail in Chapter 4). The following sub-goals of the research will be addressed:

- The research will investigate the relationship between environmental degradation and GDP per capita and estimate the EKC curve's turning point.
- Research will estimate the influence of other relevant economic and development variables on the EKC shape and size.
- The thesis will conclude with a discussion of the implications of the findings for the selected African countries.

1.3 Methods, procedures, techniques and ethical considerations

The thesis follows a positivist approach based on its use of secondary quantitative data (Caldwell, 2015). It investigates the existence of the EKC from 1990 to 2019 for the five selected middle-income African countries, also categorised as high CO_2 emitters. The start of the period is motivated by data availability, while the end is by the objective of observing a long-term pattern. Beyond 2019 is COVID-19 and economic patterns would have been disrupted from regular activity. While Chapter 4 sets out and justifies the data and methods used in the study in detail, a brief introduction to the variables and techniques employed is provided here.

1.3.1 Variables and data sources

Environmental degradation is the dependent variable in the study, proxied by CO_2 emissions per capita. Explanatory variables include GDP per capita and GDP per capita squared. GDP per capita squared captures the curvilinear relationship between degradation and growth, where the sign (+/-) of its slope coefficient β_2 determines whether the EKC hypothesis holds. Control variables employed by the study are trade openness, energy use and the Human Development Index (HDI). Trade openness and energy use are proxied by trade as a percentage of GDP and energy use in kg of oil equivalent per capita, respectively.

Data for CO_2 emissions, GDP per capita and its squared term, trade openness, energy use and the HDI are obtained from the World Development Indicators (WDI) provided by the World Bank (2024). All the data sourced is secondary, collected annually from 1990 to 2019 and transformed into a natural logarithm. Annual frequency is chosen to observe long-term environmental dynamics because the variables of interest are available annually.
This study complies with ethical guidelines by accurately referencing data sources and methodologies to ensure transparency in analysis.

1.3.2 Estimation methods

Following Grossman and Krueger (1995), Stern (2004), Tamazian and Rao (2010) and Maranzano et al (2022), this study uses the log-log model to estimate the relationship between environmental degradation and GDP per capita growth. The model effectively captures the non-linear relationship between environmental degradation and economic growth. It also allows for a more straightforward interpretation of the slope coefficient results.

A stepwise estimation approach is followed to ensure robustness and address potential econometric challenges, such as multicollinearity. The methodology begins with simpler models and progresses to more complex techniques.

In the first instance, panel data modelling is undertaken. The initial models are fixed effects (FE) and random effects (RE) models, accounting for heterogeneity across the countries. The Hausman test is used to determine whether FE or RE is the most appropriate of the two approaches. Building on studies by Tenaw and Demissew-Beyene (2021) and Sanli et al (2023), which employed the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model, this study proceeds to estimate a PMG-ARDL model for the panel of five countries over the period 1990 to 2019. This technique allows for cointegration testing and analysis of the short-run and long-run relationships between the variables. Cointegration testing is necessary due to non-stationarity in the data series observed in the preliminary data analysis.

Following the PMG estimation, time-series analysis is conducted using Autoregressive Distributed Lag (ARDL) models to generate country-specific results and capture time-series dynamics. While PMG-ARDL provides a long-run relationship across the panel, it assumes homogeneity in long-run coefficients, which may overlook country-specific variations in the

EKC relationship. Therefore, individual time-series models are employed to capture heterogeneity in the economic-environmental interactions of each country, allowing for a more nuanced analysis of turning points and policy implications.

Goodness of fit for the various models is assessed, and significance testing is used to determine whether the quadratic term β_2 is statistically significant. Where relevant, the EKC turning point is estimated, as explained in Chapter 4.

1.5 Outline of the research

This study is organised into seven chapters, each contributing to the overall objective of investigating the EKC for the selected middle-income African countries: Algeria, Angola, Morocco, Nigeria, and South Africa. The chapters are outlined as follows. Chapter 2 is the first of two literature review chapters, discussing environmental sustainability and theoretical factors contributing to environmental degradation. This is done by reviewing existing literature, particularly for African countries and helps to establish the study's motivation.

Chapter 3 provides a comparative empirical review of previous research on the EKC. Studies with different methodologies and findings are reviewed. The chapter also discusses the role of policy in examining the EKC and whether policy contributes to or reduces degradation.

Chapter 4 outlines the methods, procedures and data used in this study to investigate the existence of the EKC for the chosen countries. It outlines the research approach, the data sources, period and the variables used in the study. The econometric methods used in the study are discussed in detail and their relevance to achieving the study's goals is discussed.

Chapter 5 is the socioeconomic and environmental policy context, providing an original analysis of economic and environmental factors influencing degradation levels in the selected countries. Chapter 5 conducts an in-depth examination of background data and policy documents to assess the real-world implications of environmental policies.

Chapter 6 provides the results of the EKC estimations and a discussion of the findings. Results of the econometric analysis are interpreted and the turning points for the individual countries are estimated, where relevant. The results are interpreted within the context of the literature

covered in Chapters 2 and 3, as well as the country-specific and policy context discussed in Chapter 5.

Chapter 7 is the concluding chapter. This final chapter summarises the key findings concerning the primary goals of the thesis. It also briefly discusses limitations and areas for future research that could expand understanding of the EKC hypothesis. The chapter also suggests policy recommendations.

CHAPTER 2
THE ENVIRONMENTAL KUZNETS CURVE: THEORETICAL FOUNDATIONS AND CONTEXTUAL DETERMINANTS

2.1 Introduction

As defined in Chapter 1, the Environmental Kuznets Curve hypothesises an inverted U-shape relationship between economic growth and environmental degradation (Barbier, 1997; Martinez-Navarro et al, 2020). It is named after Simon Kuznets, who developed the initial hypothesis of an inverted U-shaped curve relationship between income inequality and economic growth (Kuznets, 1955). Kuznets (1955) paper states that income inequality is high during the early stages of income growth and that the distribution moves back towards income equality when economic growth per capita reaches the "turning point".

The EKC hypothesis, popularised by Grossman and Krueger (1995), states that environmental degradation is high during the early stages of development but slows down when growth has reached its peak. This is because, at high-income levels, individuals demand improved environmental quality (Barbier, 1997; Ajmi et al, 2023; Dkhili, 2023). Their preferences shift from survival needs to environmental improvements. A GDP per capita turning point indicates the level of income at which countries begin experiencing environmental improvement. The EKC shows the relationship between economic growth and environmental degradation, which serves as a guideline to policymakers to set appropriate targets and prioritise environmental regulations (Dkhili, 2023).

Understanding the EKC is essential for several reasons. Firstly, it provides insights into the dynamic relationship between growth and degradation, offering a framework for formulating policies that balance development with sustainability (Stern, 2004; Wang et al, 2024). Secondly, it helps identify the stage at which environmental regulation becomes critical, especially for middle-income countries experiencing structural transformation. This is particularly relevant for African nations, which face acute climate-related vulnerabilities. Lastly, the EKC facilitates cross-country comparisons, fostering international dialogue and cooperation on sustainable development (Wang et al, 2024).

This chapter provides a theoretical and empirical background to the EKC hypothesis, emphasising climate change, environmental degradation and their intersection with economic and social development. It particularly highlights the relevance of the EKC for African countries, which are disproportionately affected by climate change.

The rest of the chapter is organised as follows: Section 2.2 begins with a broad framework, discussing the relationship between climate change and environmental degradation. Section 2.3 explains the roles of environmental sustainability, social development and socio-economic indicators in the EKC context. Section 2.4 introduces the EKC hypothesis in more detail, beginning in Section 2.4.1 with a discussion of the economic theory behind the curve. This is followed by a review of environmental degradation measures and the key determinants that influence the shape of the EKC, including the energy fuel mix, trade openness, corruption, financial development, and the informal sector (Sections 2.4.2 to 2.4.6). Section 2.5 concludes the chapter.

2.2 Climate change and environmental degradation

Climate change is one of the most pressing global challenges, closely linked to environmental degradation and unsustainable economic activities. The Intergovernmental Panel on Climate Change (IPCC, 2023) defines climate change as long-term alterations in temperature, precipitation and other atmospheric conditions resulting from natural processes and anthropogenic activities. These shifts have far-reaching consequences, including biodiversity loss, extreme weather events, and food and water systems disruptions. Human activities are reported as the primary driver of climate change impacts because they cause extra heat in the climate system. Activities which release greenhouse gases, such as carbon dioxide (CO_2 emissions), methane (CH4), and nitrous oxide (N20), are the drivers of climate change (Ziervogel et al, 2014, Friedlingstein et al, 2022).

Environmental degradation refers to the deterioration of the environment through the depletion of natural resources, pollution, and the destruction of ecosystems. It often accompanies economic growth in the early stages of development when industries expand and environmental regulations are weak or poorly enforced. This dynamic aligns with the early segment of the EKC, where rising income is associated with increased pollution and environmental harm (Stern, 2004; Sarkodie and Strezov, 2019).

In Africa, the consequences of climate change are particularly severe due to the continent's heavy reliance on natural resources, rain-fed agriculture and limited adaptive capacity (UNEP, 2022). Many African economies face high vulnerability to climate-induced shocks, such as droughts, floods, and declining crop yields. According to the African Development Bank (2023), climate change could push 40 million people into poverty by 2030 if left unaddressed.

The Sahel region, stretching across ten African countries (Nigeria, Senegal, Cameroon, Niger, Burkina Faso, Chad, Guinea, Gambia, Mauritania and Mali), suffers extreme desertification as a result of drought and changing patterns of precipitation caused by climate change (Lewis and Buontempo, 2016). According to the United Nations, approximately 80% of the Sahel's farmland is degraded, with temperatures rising 1.5 times faster than the global average, leading to more prolonged and frequent droughts undermining food production (World Economic Forum, 2019). Practical strategies, such as sustainable land management practices and reforestation initiatives, are critical for reversing land degradation and ensuring the region's long-term agricultural productivity (World Economic Forum, 2019).

Reducing the drivers of climate change is important for mitigation purposes and also for assisting countries in reaching the GDP per capita turning point on the EKC (Apergis and Ozturk, 2015; Balsalobre-Lorente et al, 2022). Countries may need to address climate change to escape the early stages of the EKC, where environmental degradation continues to increase as economic activity expands. Hence, climate change strategies must be integrated into economic policies to foster growth without compromising future environmental sustainability (Apergis and Ozturk, 2015; Balsalobre-Lorente et al, 2022). The following section discusses how active involvement by stakeholders can lead to more effective climate action and sustainable solutions.

The following sections move from this broader context to discuss how economic growth influences environmental degradation. In particular, Section 2.4 discusses the EKC hypothesis as one framework for investigating the relationship between GDP per capita and environmental quality. This is followed in Sections 2.4.2 to 2.4.6 by a discussion of key factors, such as the energy fuel mix, trade openness, corruption, financial development and the informal sector, which mediate this relationship, along with a review of past studies that have tested the EKC hypothesis in various contexts.

2.2.1 Climate awareness and the role of stakeholders

The increasing awareness of climate change over recent decades can be traced back to the early 1980s when scientific understanding and media coverage of environmental issues began to grow (Capstick et al, 2015). Since then, public concern about climate change has intensified, driven by landmark events such as the publication of the IPCC's Third Assessment Report in 2001, the adoption of the Kyoto Protocol in 2005 and the rising frequency of extreme weather events (UNFCCC, 2005). The process of societal engagement with climate change has thus evolved gradually, influenced by scientific evidence, international agreements and environmental activism.

Climate awareness levels vary across continents and nations (Lee et al, 2015). This is because it is influenced by factors such as access to education, investments in renewable resources and economic development. Developed countries, mainly in Europe and North America, are more climate-aware and richer. Hence, they have made good progress with the factors mentioned. In contrast, less developed nations in Africa and Latin America may be less climate aware and have not made as much progress with these factors. However, as discussed in Chapter 5, there is growing evidence of significant climate awareness in several developing countries. What varies more widely is their ability to implement mitigation and adaptation strategies, given competing development priorities and resource limitations (Kasa et al, 2022.). It is also important to note the high degree of heterogeneity among developing countries in terms of education, governance and renewable energy adoption, which shapes both awareness and responsiveness to climate challenges (Lee at al, 2015).

For African countries, stakeholder collaboration is critical to overcoming institutional weaknesses and resource constraints. Public-private partnerships can accelerate investment in green infrastructure, while community-based initiatives can strengthen local adaptation. Enhanced climate literacy, integrated into education systems and media platforms, contributes to long-term environmental stewardship (Opuku et al, 2022). Stakeholders, including governments, civil society, private sector actors and international organisations, play complementary roles in enhancing environmental governance (Opuku et al, 2022). Governments are responsible for policy formulation, regulation and enforcement. Civil society organisations raise public awareness and hold institutions accountable. The private sector, particularly in energy, transport and manufacturing, is pivotal in adopting clean technologies

and improving production efficiency (Opuku et al, 2022). Development partners and multilateral institutions provide technical assistance, climate finance and capacity-building support, especially for low and middle-income countries.

Innovation, investments and operational shifts within the private sector are important to addressing climate change (Whelan and Fink, 2016). More businesses are embracing sustainable practices, including minimising their carbon footprint and enabling green technologies in their systems (Opuku et al, 2022). Businesses like Microsoft have committed to being carbon-negative by 2030 and are developing carbon capture and storage technologies to meet this goal (Microsoft, 2020). Other multinational companies, such as Unilever, focus on reducing emissions across their supply chain. This means, for example, sourcing sustainable palm oil, improving energy efficiency in manufacturing and reducing plastic waste in packaging.

The communities most impacted by climate change are also key to ensuring that climate policies are inclusive and equitable. Such communities can work with local municipalities to propose context-relevant strategies and community-based solutions (McCarthy, 2001; Schlosberg et al, 2017). In addition, environmental activists and youth movements, like Fridays for Future (FFF), have gained worldwide visibility, compelling governments and corporations to take decisive action on climate change. Fridays for Future is a global grassroots youth-led climate movement that began in 2018 and has since mobilised millions of young people worldwide through weekly climate strikes. FFF gave rise to other initiatives like School Strike for Climate (2018) and Youth for Climate (2019), amplifying calls for accountability and action (Fridays for Future, 2022; UNFCCC, 2015).

Individuals can also impact the battle against climate change by making more sustainable lifestyle changes (IEA, 2022). Actions to reduce carbon footprint include reducing energy consumption, reducing waste, saving water and using public transport. For instance, replacing conventional appliances with energy-efficient ones, switching off devices not in use and using renewable energy at home can dramatically reduce household emissions (IEA, 2022).

2.2.2 Climate mitigation and adaptation strategies

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Mitigation and adaptation are the two principal strategies for responding to climate change and both significantly influence how countries manage the relationship between economic growth and environmental degradation as outlined in the EKC hypothesis (Klein et al, 2005; Rogelj et al, 2021). While mitigation aims to reduce or prevent greenhouse gas emissions, adaptation focuses on adjusting systems to withstand the adverse effects of climate change (Klein et al, 2005). By integrating these approaches into national and local policies, nations can effectively address immediate and long-term environmental challenges.

Mitigation strategies address the root causes of climate change and include transitioning to renewable energy, improving energy efficiency, curbing deforestation, and promoting sustainable agriculture (Rogelj et al, 2021). These efforts aim to reduce future climate risks by lowering cumulative emissions. In the EKC context, mitigation becomes more viable as countries move beyond the initial stages of industrialisation and acquire the fiscal and institutional capacity to implement cleaner technologies.

Adaptation, by contrast, seeks to reduce vulnerability to climate impacts that are already occurring or inevitable. This includes building climate-resilient infrastructure, upgrading water management systems, planting drought-resistant crops, and enhancing early warning systems. Adaptation is especially critical for low and middle-income countries that face immediate exposure to climate shocks but often lack the capacity for large-scale mitigation efforts (IPCC, 2022).

Sharifi (2020) highlights the importance of integrating mitigation and adaptation strategies, particularly in urban areas, which are economic hubs and high emitters of GHGs but also vulnerable to climate risks. Integrated approaches can maximise efficiency, reduce trade-offs, and ensure coherence in policy implementation. For instance, investing in green urban infrastructure can reduce emissions and enhance resilience to extreme weather (Sharifi, 2020). International funding for climate projects is often targeted at urban areas as they have the governance structures required to implement policies and programs at scale (Restrepo-Mieth et al, 2023).

This often makes urban areas ideal candidates for demonstrating how collaborative strategies can work in practice. Moreover, urban areas serve as testing grounds for scalable solutions. Successful implementation of integrated strategies in cities can be replicated in other urban and

even rural contexts, amplifying their impact on regional, national, and global scales (Restrepo-Mieth et al, 2023).

Mitigation strategies also reduce the extent of future climate impacts, making adaptation efforts less costly and more manageable (Qi and Terton, 2022). Adaptation strategies improve resilience towards climate impacts, creating the stability needed to implement mitigation strategies effectively. Combining efforts also allows governments and organisations to allocate resources more efficiently, avoiding duplication of efforts and maximising impact. Integrated strategies attract funding from international organisations that prioritise holistic approaches to climate action (Qi and Terton, 2022).

However, collaboration is often challenging for many reasons, including resource allocation trade-offs. Mitigation and adaptation require significant capital investments for implementation but their timelines for benefits often differ. Mitigation strategies, such as transitioning to renewable energy, are more suited for long-term emission reduction. Contrarily, adaptation strategies, such as building flood defences, reduce immediate vulnerabilities. Developing countries often struggle to balance allocating scarce resources between these priorities (Shaw et al, 2010).

Another collaboration challenge is a lack of coordination. Separate government departments often implement mitigation and adaptation, leading to a less effective approach. For instance, an industrial growth policy to reduce emissions might increase water use, which adaptation strategies aim to reduce (Grafakos et al, 2019).

The challenge of collaboration is compounded further by weak institutions. Many countries, especially developing countries, often lack skilled workers, technology and strong policies to integrate their strategies. Governments often struggle to attract funding or enforce climate laws effectively. Resistance to change within organisations also further slows down progress (Sovacool and Linnér, 2016).

Furthermore, community-based adaptation complements national mitigation and adaptation goals by reducing the burden on centralised interventions. It accelerates progress toward the EKC turning point by fostering grassroots innovation, improving resilience, and reinforcing environmental stewardship from the bottom up. However, successful implementation requires

consistent funding, institutional support, and stakeholder coordination. Without this, localised efforts risk being fragmented or unsustainable in the long run (Selje et al, 2024).

The localisation of climate change initiatives allows for strategies suitable for the specific environmental, social, and economic contexts (Badji et al, 2022). For example, region-specific adaptation and mitigation strategies are needed for African countries due to their climate change vulnerability and reliance on natural resources. Localised responses can tackle constraints from varied ecosystems, socio-economic conditions and development stages. They also promote community involvement in sustainability efforts.

Collaborative implementation of mitigation and adaptation strategies enables countries to address climate change comprehensively and effectively. This approach balances immediate needs with long-term goals, ensuring progress toward environmental sustainability and economic resilience (Badji et al, 2022).

Community adaptation strategies are essential for addressing climate change, particularly in regions with diverse socio-economic and environmental contexts (Selje et al, 2024). Adaptation strategies at the community level are increasingly being seen as necessary for tackling climate change, especially in areas with varying socio-economic and environmental conditions (Selje et al, 2024).

These strategies involve localised, community-driven actions designed to enhance resilience to climate impacts while promoting sustainable development. Unlike top-down national policies, community adaptation focuses on local populations' specific needs and conditions, making it more contextually appropriate and effective (Selje et al, 2024).

A significant benefit of community adaptation is harnessing local knowledge and resources (Kirkby et al, 2018). Communities in vulnerable areas often have traditional knowledge and experience managing environmental risks, such as droughts, floods, and soil erosion. Integrating this local expertise with modern scientific approaches can result in more sustainable and culturally appropriate solutions. For example, in drought-prone areas of sub-Saharan Africa, farmers have adopted climate-resilient agricultural practices, such as agroforestry and water conservation techniques, to enhance food security and reduce vulnerability (Kirkby et al, 2018).

2.2.3 The role of international climate organisations

International climate organisations facilitate global cooperation in addressing climate change by coordinating efforts among nations, providing financial and technical support, and promoting sustainable practices (Keohane and Victor, 2016). These organisations operate at global and continental levels, as discussed in Chapter 5. There are also different types of international climate organisations, such as Intergovernmental Organisations (IGOs), the United Nations Framework Convention on Climate Change (UNFCCC) and the Intergovernmental Panel on Climate Change (IPCC). The IGOs refer to formal organisations of multiple countries working together to address climate change (Keohane and Victor, 2016). UNFCCC facilitates international climate negotiations, while the IPCC provides scientific assessments on climate change to guide policy decisions.

Financial institutions can also be viewed as international climate organisations due to their significant role in mobilising financial resources and promoting sustainable investments in climate finance (Park and Kim, 2020). International financial institutions are intermediaries linking developed and developing countries in global climate management efforts. Climate change is a transboundary issue requiring collective action, and financial institutions facilitate this by pooling resources from various countries and distributing them to regions that need them most. Examples include the World Bank and the Green Climate Fund, discussed in Chapter 5. It is important to note that several financial institutions are signatories to agreements such as the Paris Agreement. This means that they align their investment strategies with global climate targets, which involves phasing out investments in high-carbon industries and increasing funding for sustainable projects (Park and Kim, 2020).

The primary purpose of international climate organisations is to set climate targets and monitor the progress of participating countries. For example, the UNFCCC oversees global climate negotiations, ensuring nations collaborate to reduce emissions and build resilience. This also helps to maintain transparency and accountability in global climate action (UNFCCC, 2023).
Another primary role is to foster collaborations between countries. Institutions such as the United Nations Framework Convention on Climate Change (UNFCCC) provide a platform for nations to negotiate and commit to climate action. Key agreements, such as the Paris Agreement, set global targets for reducing emissions and adapting to climate impacts. By

encouraging countries to work together, these organisations help align national efforts with global goals, accelerating progress toward sustainability (Opuku et al, 2022).

The role of international climate organisations goes beyond providing financial support and policy guidance; it is central to fostering long-term environmental sustainability and promoting equitable social development (Du et al, 2023). These organisations help bridge the gap between economic growth and environmental protection by facilitating partnerships and aligning global climate goals with national priorities. Their collaborative efforts not only drive progress towards enabling economic growth without environmental damage, as hypothesised by the EKC after the turning point is reached (Du et al, 2023).

While these institutions aim to bridge the gap between economic growth and environmental sustainability, practical and structural challenges often constrain their effectiveness. For instance, although climate finance mechanisms exist, access remains highly unequal. Many developing countries face complex application procedures, stringent reporting requirements, and institutional capacity constraints that limit their ability to absorb and manage funding effectively (Du et al, 2023).

Moreover, global climate negotiations are frequently marked by tensions between developed and developing countries, particularly regarding historical emissions responsibility and financial commitments' adequacy. This has led to delayed implementation of agreements and diluted targets, weakening the collective impact of climate diplomacy (Keohane and Victor, 2016).

There are also concerns about the governance and accountability of some financial institutions. Critics argue that climate finance is often channelled through large-scale infrastructure projects that may overlook local context or produce unintended social and environmental consequences (Park and Kim, 2020). In some cases, geopolitical considerations influence funding flows more than climate vulnerability or need.

Despite these limitations, international climate organisations remain central in aligning national actions with global goals. The Paris Agreement, for instance, encourages countries to submit and update nationally determined contributions (NDCs), fostering a process of iterative

ambition. However, the enforcement mechanisms are weak, relying mainly on peer pressure and reputational incentives rather than binding commitments (Opoku et al, 2022).

Ultimately, while international climate organisations offer essential platforms, knowledge, and resources, their ability to deliver transformative change depends on deeper structural reforms, equitable governance, and stronger accountability mechanisms. For countries seeking to move beyond the EKC turning point, particularly in Africa, these limitations must be considered when designing national climate strategies that depend on international cooperation and finance.

Environmental sustainability and social development are interlinked pillars of sustainable progress. Environmental sustainability seeks to balance ecological preservation and resource management. At the same time, social development addresses quality of life, equitable access to resources, education, healthcare and economic opportunities for current and future generations (Yan, 2024). Achieving both environmental sustainability and social development requires an integrated approach to ensure that economic growth does not come at the expense of environmental degradation or social equity.

Environmental sustainability occurs when natural resources are used in a manner which does not deplete their future use (Singh et al, 2021). Petraru and Gavrilescu (2010) and Sachs et al (2022) claim that environmental sustainability is a multidimensional concept that encompasses social, economic and ecological aspects. This means that the promotion of sustainability should integrate economic activity with environmental protection and social development.

Ekins et al (2003) define environmental sustainability as processes that maintain all components of the environment. Sustainability in economics is defined according to strong versus weak sustainability. Achieving (strong) sustainability is essential for mitigating climate change impacts and for countries to shift to renewable sources (Ekins et al, 2003).

According to strong sustainability principles, a minimum amount of natural capital stock must be preserved. Natural capital refers to the world's stock of natural resources, such as land, water, air, renewable and non-renewable resources (Ekins et al, 2003). Natural capital stock is regarded as an essential input for production and consumption and under the strong definition

of sustainability, it cannot be substituted for physical and human capital. A declining natural capital stock signals environmental unsustainability (Dasgupta, 2021).

Strong sustainability means that the current flow of value from the use of resources should be maintained for future generations. For example, Morocco has invested in its solar energy sector to reduce reliance on fossil fuels, such as coal and oil. The Noor Ouarzazate Solar Complex Power Station was built in phases beginning in 2016 to assist Morocco's transition to renewable energy (Power Technology, 2020). The power station represents a strong sustainability model because it encourages the preservation of natural capital.

Weak sustainability allows for the substitution of natural capital stock (Camporeale et al, 2021). According to Ekins et al (2003), natural capital stock can be substituted for manufactured capital under weak sustainability. For example, deforestation can be compensated for by investing in technology to repair environmental damage. Under weak sustainability principles, economic growth is prioritised at the expense of degradation if the latter is compensated for in later stages (Camporeale et al, 2021). Developing countries rich in natural resources like oil and natural gas often follow weak sustainability practices. For example, it is reported that the Algerian economy's oil and natural gas accounted for 18% of total GDP and 93% of exports between 2016 and 2022 (World Bank, 2023). This indicates a weak sustainability model that relies on non-renewable resources to achieve economic growth at the cost of environmental degradation.

Although the EKC focuses primarily on the relationship between environmental degradation and GDP per capita, a growing body of research highlights the importance of incorporating socio-economic indicators into the analysis. These indicators, including education levels, healthcare access, income inequality, and social well-being, are increasingly recognised as mediators in the relationship between economic growth and environmental outcomes (Martinez-Zarzoso and Maruotti, 2011). Socio-economic factors influence not only consumption patterns and energy demand but also the capacity of populations to adopt sustainable practices. Therefore, understanding the role of social development and socio-economic indicators is critical for developing effective policies promoting economic prosperity and environmental sustainability (Martinez-Zarzoso and Maruotti, 2011).

Social development refers to the enhancement of a population's overall well-being and quality of life (Lai and Chen, 2020). It is often underpinned by a minimum level of human development, including access to healthcare, education, and income opportunities (Opoku et al, 2022). Improvements in these areas not only support socio-economic advancement but also contribute positively to environmental sustainability, as healthier and more educated populations are more likely to adopt environmentally responsible behaviours. These dimensions are captured in the Human Development Index (HDI), which serves as a useful indicator of broader development progress and can offer insight into how development influences environmental quality (Lai and Chen, 2020).

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According to Opuku et al (2022), human development is essential for sustainable growth. This is because it plays a crucial role in a nation’s technological progress, attracting foreign direct investment (FDI) and the switch to renewable forms of production. Higher education levels mean that the population is more aware of environmental policies and regulations (Lai and Chen, 2020). Individuals who earn higher incomes are more prone to demand improved environmental quality. This conforms to the EKC hypothesis, which postulates an increased demand for environmental quality at higher income levels. Educated individuals are more productive, responsible towards the environment and innovative. Educated individuals also understand that reducing degradation is a shared duty and they support the government in its projects (Opuku et al, 2022).

According to Shahbaz et al (2023), socio-economic indicators also play an essential role in explaining the shape of the EKC. This is in addition to economic variables. Social and political indicators, such as political stability, education, urbanisation, economic structure, poverty and inequality, are significant in determining the shape of the EKC. Including socio-economic indicators as control variables within the EKC framework highlights policy implications that may have been overlooked (omission bias). It is important to carefully select socio-economic

indicators to fit the context in which they are analysed. Socio-economic indicators have been mainly used to investigate the EKC with CO_2 emissions as a proxy for environmental degradation (Shahbaz et al, 2023).

The relationship between CO_2 emissions and the HDI has been studied to understand the impacts of both economic and social development on environmental sustainability. The HDI is a sophisticated measure of human well-being that includes important dimensions such as life expectancy, levels of education and income (UNDP, 2019). Studies report that improvements in HDI can drive environmental awareness, cleaner technologies and sustainable practices (UNDP, 2019). Therefore, evaluating the relationship between CO_2 emissions and HDI is important for identifying policy interventions that promote human development and minimise environmental degradation.

The following sections explore how global frameworks like the SDGs and national development strategies interact with these dual priorities.

2.3 The Millennium Development Goals and Sustainable Development Goals

The Millennium Development Goals (MDGs) adopted in 2000 were a set of developmental goals set to be achieved in 2015 (Lomazzi et al, 2014). The MDGs aimed to address poverty, education, gender equality and disease. Environmental sustainability is the seventh goal, which aims to reduce biodiversity loss while maintaining natural resources (strong sustainability principle). This meant integrating sustainability principles into national policies to reverse the loss of environmental degradation (Sachs, 2012).

Target 7.b of MDG seven focused on reducing biodiversity loss, a key indicator of environmental degradation. Loss of biodiversity accelerates environmental degradation by weakening ecosystems' ability to regulate climate, support agriculture and protect against natural disasters. In response, the government, in partnership with international organisations such as the United Nations Development Programme (UNDP), launched mangrove restoration programs to address the issue. These initiatives aimed to restore coastal ecosystems, reduce biodiversity loss, and protect communities from rising sea levels and extreme weather events (UNDP, 2015). The restoration efforts helped mitigate environmental degradation and

enhanced Indonesia's climate resilience by providing natural carbon sinks and reducing coastal erosion.

Nigeria is an example of a country that did not meet the seventh MDG target. The country was unable to significantly reduce biodiversity loss due to degradation in the Niger Delta (Jeremiah et al, 2022). The Niger Delta is a region in Nigeria known for its significant oil and gas reserves, which contribute considerable revenue to the economy. However, the region has proven to be an obstacle for Nigeria in achieving MDG seven because of the exploitation of resources in the area, which has led to severe environmental degradation. This is degradation in the form of deforestation, oil spills and gas flaring (Jeremiah et al, 2022).

The Sustainable Development Goals (SDGs) of 2015 were introduced as a continuation of the MDGs and were set as an international agenda for 2030 (Hak et al, 2016). The SDGs refer to interlinked global objectives that aim to end poverty, increase growth and development and protect the environment. A paper by Guang-Wen et al (2022) highlights SDGs seven, eight and thirteen as specific to environmental sustainability and economic growth.

SDG seven promotes affordable and clean energy for all. This encourages the reduction of CO_2 emissions and a shift towards renewable energy sources (Guang-Wen et al, 2022). Climate Action is SDG thirteen, which has been integrated into national environmental policies for Algeria, Angola, Morocco, Nigeria and South Africa, as discussed in Chapter 5. The eighth SDG encourages sustainable economic growth.

Given the global significance of sustainable development, assessing the progress of African countries toward achieving environmentally focused SDGs is essential. Africa faces unique socio-economic and environmental challenges that influence its progress toward these goals, including high levels of poverty, dependence on natural resources, limited infrastructure and vulnerability to climate change (UN, 2019). Despite these hurdles, several African nations have progressed in key areas such as clean energy adoption, biodiversity conservation and climate action. However, significant gaps remain, particularly in access to clean water, sanitation and sustainable urban development. Evaluating this progress is critical for identifying areas that require further intervention and fostering policies that enhance resilience and environmental sustainability across the continent (UN, 2019).

The progress of African countries toward the SDGs has been varied, reflecting significant achievements and persistent challenges (Oleribe and Taylor-Robinson, 2020). While notable advancements have been made in areas such as access to clean energy (SDG 7) and improved health outcomes (SDG 3), environmental sustainability (SDG 13) and poverty eradication (SDG 1) remain critical areas requiring more significant focus. Achieving the SDGs in Africa requires addressing environmental degradation, economic inequality and social development through coordinated efforts and strategic policies (Oleribe and Taylor-Robinson, 2020). Innovative financing mechanisms often support progress in funding the SDGs. Instruments such as green and social impact bonds have gained recognition, enabling countries to mobilise their private capital for sustainable development (Marbuah, 2020).

Many African countries have advanced significantly in adopting renewable energies and made progress in SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Morocco, for example, has made good progress through projects like the Noor Ouarzazate Solar Complex, the world's largest concentrated solar power plant with a capacity of 580 MW (Power Technology, 2020). This is expected to reduce greenhouse gas emissions by an estimated 760,000 tonnes a year and promote sustainable economic growth, emphasising the interdependence of environmental protection and economic development. Another country that has seen a rise in small-scale solar deployment is South Africa, where solar generation capacity grew from 500 MW in 2019 to 5,700 MW in the first quarter of 2023. This growth has enhanced access to energy and boosted green industries, promoting economic stability (Nana, 2024).

However, challenges remain across the continent. The absence of comprehensive renewable energy policies and regulations in many African countries poses barriers to investors, hindering the energy sector's growth (Oleribe and Taylor-Robinson, 2020). The renewable energy sector needs highly specialised technical knowledge, which is scarce in some regions, posing barriers to progress. Addressing these challenges through coordinated efforts and strategic policies is essential for achieving the SDGs in Africa. By investing in renewable energy infrastructure, enhancing regulatory frameworks and building local capacity, African nations can continue to advance toward sustainable economic development and environmental protection (Oleribe and Taylor-Robinson, 2020).

Achieving the SDGs in Africa requires continued effort to balance economic growth with environmental sustainability. Studies by Sachs et al (2022) suggest that SDGs must also be funded by internally generated revenue rather than depending on financial aid from developed countries. International aid should be used to mobilise national resources (IMF and World Bank, 2024).

The interconnectedness of social development with environmental sustainability highlights that various socio-economic factors influence the shape of the EKC (Lai and Chen, 2020). It is important to note that economic variables also influence the EKC hypothesis. These variables include the energy fuel mix, trade openness, financial development, corruption and the informal sector, which are discussed next in Section 2.4.

2.4 The EKC: Measures of degradation and its theoretical determinants

As noted in Section 2.1, the EKC depicts the relationship between per capita income and environmental degradation, with the latter increasing during the early stages of development but slowing down after per capita income has reached a turning point. The turning point indicates the per capita income level at which environmental improvements occur (Ajmi et al, 2023).

While Chapter 3 presents a focused review of empirical EKC studies, this section includes selected empirical references to support the theoretical discussion. These examples help illustrate how specific determinants influence the EKC's shape and are used to connect theory with real-world evidence.

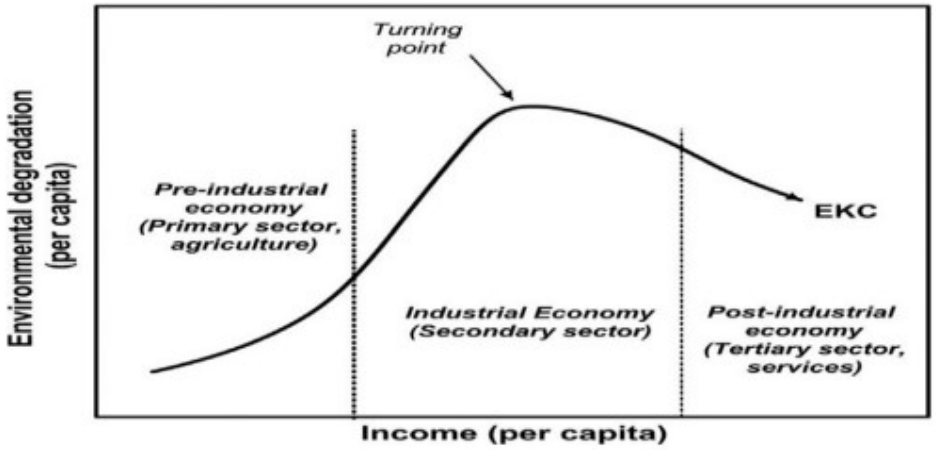

Figure 2.1: The Environmental Kuznets Curve

Source: Gill et al (2018)

Figure 2.1 depicts the EKC relationship between economic growth (income per head) and environmental degradation per head (denoted by a specific pollutant). Per capita degradation is proxied a by the selected pollutant divided by a country's population. The pollutant can be a type of emission (carbon dioxide) or an alternative measure of environmental degradation, such as deforestation (Dimitra and Efthimios, 2012).

The neoclassical income distribution theory supports the original Kuznets curve and the EKC (Barbier, 1997; Dinda, 2004; Chow and Li, 2014). This theory explains individual preference shifts concerning environmental awareness. Preferences shift between levels of development from basic survival needs (in the earlier stages of growth) towards increased demand for improved environmental quality in the later stages, as stated by EKC theory. Individuals beyond a certain income level are more incentivised to adopt environmentally sustainable practices (Chow and Li, 2014).

The transition of economies explains the stages of the EKC hypothesis, where economies typically evolve through three primary phases: agriculture, manufacturing, and services (Inglesi-Lotz and Bohlmann, 2011). In the early stages of development, the agricultural sector dominates, relying heavily on natural resources such as land, water, and forests. This phase is characterised by significant environmental degradation due to deforestation, soil erosion, and water pollution caused by intensive farming practices. As economies grow and industrialise, they shift towards manufacturing, intensifying environmental pressure. The manufacturing sector demands large quantities of energy, water and raw materials, leading to high emissions

levels, resource depletion and waste generation. A positive relationship between economic growth and environmental degradation persists during this stage, as industrial output increases without adequate environmental regulations (Barbier, 1997; Inglesi-Lotz and Bohlmann, 2011).

As economies mature and income increases, they become service-based (Parrique et al, 2019). The services sector generally has a lower environmental impact per output unit than agriculture and manufacturing, as it is less resource-intensive. At this stage, high-income earners, particularly in the services sector, begin to demand environmental improvements and stricter environmental regulations, supporting the earlier explanation by Barbier (1997). Increased public awareness, technological innovation, and better governance contribute to decoupling economic growth from environmental degradation (Parrique et al, 2019). Hence, environmental degradation starts to decline at this stage, marking the turning point of the EKC.

This shift to the services sector is further accelerated by investments in cleaner technologies, sustainable business practices and green infrastructure (Ullah et al, 2024). For example, renewable energy projects and eco-friendly urban planning reduce the environmental footprint of economic activities in advanced economies. However, such a transition requires significant policy interventions, including enforcing environmental regulations, market-based instruments and international cooperation. Resource depletion and environmental degradation may persist without these measures, delaying the EKC turning point (Ullah et al, 2024).

The EKC pattern can also be attributed to various other factors. These include shifts in technological progress, environmental regulations, globalisation, market mechanisms and institutional factors (Raymond, 2004). For example, institutional factors such as secure property rights encourage sustainable resource management by providing long-term incentives for individuals and businesses to invest in maintaining and enhancing natural resources (Inglesi-Lotz and Bohlmann, 2011). When property rights are well-defined and enforced, stakeholders are less likely to overuse resources, knowing they can reap future benefits.

Market-based instruments, such as carbon pricing and emission trading schemes, encourage businesses to adopt cleaner technology in production (Raymond, 2004). However, the success of these instruments depends on their design and implementation. When firms prioritise profit

maximisation or operate in jurisdictions with weak enforcement, the transition to renewable energy can be delayed.

Technological progress is critical in transforming energy production by making it quicker, cleaner and more efficient (IEA, 2021). For example, advancements in renewable energy technologies, including solar Photovoltaic (PV) systems, wind turbines and battery storage, have lowered the price of renewable energy over the past decade, allowing developed and developing nations to afford clean energy. Furthermore, the development of smart grids and energy management technologies is enhancing energy efficiency by improving the distribution and consumption of energy. These systems allow for better energy use monitoring and control, reducing waste and lowering emissions (IEA, 2021).

With improved technology, there is an increase in demand for environmental quality and the government responds by implementing policies and regulations (Stern, 2004; Haseeb et al, 2018). Leading industries will also become cleaner under the new, stricter regulations and policies. Environmental degradation decreases after the turning point, even when income per capita increases, as shown in Figure 2.1 above.

According to Dimitra and Efthimios (2012), environmental regulation is the dominant factor for developed countries that decreases pollution past the turning point. This is because developed countries regulate the environment more strictly, leading to higher levels of environmental improvement beyond the turning point. Developed countries also possess more resources, which they heavily invest in their education and health sectors.

Industrialisation, often a key driver of economic growth, particularly for developing countries, is typically pollution-intensive (Grossman and Krueger, 1995; Stern, 2004). After agricultural development, many countries move into an energy and pollution-intensive phase of industrialisation, where rapid economic expansion relies heavily on extracting and consuming natural resources. Sectors such as manufacturing, mining and construction require large amounts of energy, often from fossil fuels, leading to greater greenhouse gas emissions and environmental damage (Purcel, 2020). During early industrialisation, there were often limited alternatives for cleaner technologies and the high costs of adopting sustainable practices deterred firms from shifting toward greener production methods.

Governments in developing countries mainly focus on stimulating industrial growth rather than enforcing strict environmental regulations (Seri and de Juan Fernandez, 2021). As a result, firms operate with minimal regard for environmental protection, leading to significant air, water and soil pollution. The absence of robust regulatory frameworks and enforcement mechanisms also disadvantages environmental considerations as industries expand rapidly before accounting for their environmental impact (Seri and de Juan Fernandez, 2021).

Industrialisation also triggers rapid urbanisation as people migrate from rural areas to cities for employment opportunities (Purcel, 2020). This urbanisation often overburdens existing infrastructure, leading to inadequate waste management systems, overcrowded public services, and increased pollution from transportation. The surge in economic activities, energy consumption, and urbanisation places additional pressure on natural ecosystems, resulting in increased environmental degradation, as predicted by the EKC hypothesis (Purcel, 2020).

2.4.1 Measures of environmental degradation

Empirical evidence for the existence of the EKC largely depends on the context of the study, the explanatory variables employed and the pollutants used to proxy the dependent variable, environmental degradation (Raymond, 2004; Purcel, 2020). Pollutants are mainly grouped into categories: global and local pollutants. Proxies for degradation include CO_2 emissions, energy intensity, renewable energy consumption, Sulphur dioxide (SO_2), Total Suspended Particulates (TSP) and other greenhouse gases (Purcel, 2020). The turning point occurs at a different level of income per capita for each indicator and is not universal across indicators (Raymond, 2004). The number of environmental indicators is increasing as the world becomes more globalised and new emissions emerge.

There is empirical support for the EKC for local pollutants. These include SO_2, nitrogen oxide (NO_x), Suspended Particulate Matter (SPM) and water pollution. Local pollutants damage the area in which they are generated. According to Shafik and Bandyopadhyay (1992) and Mehmud et al (2021), local pollutants are easier to contain and have relatively low control costs. Local pollutants often follow an inverted U-shaped relationship with income. When income rises, these pollutant levels decrease. Deacon and Norman (2006) analysed data for both developed and developing countries. The study found an inverted U-shaped EKC for local pollutants (such as SO_2) for developed, wealthier countries. According to Deacon and Norman

(2006), wealthier nations have effective regulations for local pollutants. Brajer and Mead (2008) also found proof of the existence of EKC for SO_2 in China.

In contrast, global pollutants, such as CO_2 emissions, are not as damaging to their local environment but cause global warming (Gill et al, 2018). Wang et al (2013) and Miah and Masum (2010) tested the EKC for global pollutants, but their results were inconclusive. A paper by Cole et al (1997) examined the relationship between economic growth and CO_2 emissions per capita. Findings stated that CO_2 emissions increase monotonically with economic growth. High-income per capita turning points with significant standard errors were also predicted.

Most studies use CO_2 emissions to investigate the EKC because of global pressures to address climate change and reduce global warming (Htike et al, 2021). Majeed and Mazhar (2020) argue that the ecological footprint, a broader composite measure covering land use, carbon absorption, and resource consumption, offers a more holistic proxy for environmental degradation than CO_2 emissions alone. They advocate for its adoption in EKC studies, especially where degradation results from both global and local pressures. For middle-income African countries dealing with deforestation, overgrazing and urban expansion, this approach can help capture sources of degradation sources beyond emissions. However, its limited availability and interpretability remain a constraint in African empirical applications.

Papers which used the ecological footprint as a proxy include Destek and Sarkodie (2019) and Mahmoodi and Dahmardeh (2020). Destek and Sarkodie (2019) investigated the EKC for G20 countries from 1977 to 2013. The study used economic growth, energy consumption, financial development and ecological footprint as variables and found evidence of an inverted U-shaped EKC. The estimation techniques employed were the Augmented Mean Group (AMG) estimator and the heterogeneous panel causality method.

Ulucak and Bilgili (2018) state that the ecological footprint highlights the direct and indirect impacts of production and consumption activities on the environment. With indirect impacts, the ecological footprint allows for considering hidden ecological costs. Other studies which have used ecological footprint as a proxy for degradation include Baghai et al (2008), Hervieux and Darne (2015), Ozturk et al (2016) and Charfeddine and Mrabet (2017). Charfeddine and Mrabet (2017) investigated the EKC for 1995-2007 using an ecological footprint as the proxy for degradation. The study found that energy use worsens the ecological footprint. Real GDP

per capita exhibits an inverted U-shaped relationship with the ecological footprint of oil-exporting countries. Real GDP per capita exhibits a U-shaped relationship with the ecological footprint of non-oil exporting countries.

Mahmoodi and Dahmardeh (2020) investigated the EKC with economic growth, ecological footprint, renewable energy and governance quality as their variables. This was for a panel of emerging European and Asian countries from 1995 to 2015. An inverted U-shaped EKC was found. Estimation models were the Dynamic Ordinary Least Squares (DOLS) and the Fully Modified Ordinary Least Squares (FMOLS).

Charfeddine and Mrabet (2017) also investigated the EKC for 1995-2007 using ecological footprint as the proxy for degradation. The study found that energy use worsens the ecological footprint. Real GDP per capita exhibits an inverted U-shaped relationship with the ecological footprint of oil-exporting countries. Real GDP per capita exhibits a U-shaped relationship with the ecological footprint of non-oil exporting countries.

However, the ecological footprint is not widely used in existing literature for various reasons, including data availability limitations (Majeed and Mazhar, 2020). Since the indicator is a comprehensive measure, it is more difficult to interpret. It is also more difficult to econometrically estimate the EKC with the ecological footprint since it encompasses different ecological aspects. Considering the ecological footprint's comprehensiveness, it is also essential to account for specific factors influencing environmental degradation. The energy fuel mix is another factor discussed in the following section.

2.4.2 Environmental sustainability and the energy fuel mix

The energy fuel mix of a country plays a pivotal role in determining its environmental sustainability. As economies grow and industrialise, energy demand increases, leading to greater reliance on various sources of energy (Stern, 2011). The predominant energy source (fossil or renewable) determines how much the environment is degraded. A country highly dependent on fossil fuels will have higher greenhouse gas emissions and environmental degradation, while by contrast, a country moving towards cleaner energy will have lower carbon emissions (Stern, 2011). Evaluating the composition of the energy fuel mix is important for assessing its contributions to sustainable development and environmental quality. This

section explores how the energy fuel mix mediates the EKC relationship and contributes to sustainable growth.

The energy fuel mix refers to a combination of different fuels to meet the energy demands of a country (Akidiri et al, 2019). It varies across countries depending on availability, fuel cost, and government policies. It also depends on the environmental concerns of that specific country. Different energy fuels refer to fossil fuels, renewable energy sources and nuclear power (Akidiri et al, 2019).

The most common energy sources are fossil fuels, which are coal, oil and natural gas (Richards and Dalidowicz, 2015). Fossil fuels are a non-renewable energy source from dead plants and animals buried and compressed over millions of years (Richards and Dalidowicz, 2015). Countries abundant in fossil fuels generally possess well-established infrastructure and technologies that make generating electricity relatively inexpensive. For example, Algeria and Nigeria are oil-rich, while South Africa is coal-rich (World Bank, 2023). However, these low costs only apply in the short term because of externalities that arise. Burning fossil fuels releases greenhouse gases into the atmosphere, contributing to climate change and air pollution. Fossil fuels are also depleting resources and will eventually run out (Akidiri et al, 2019). Due to the rising costs of fossil fuels over time and the pollution they cause, there is a global shift to renewable energy sources.

The presence and size of the GDP per capita turning point in the EKC thus depends on including the fuel energy mix (Shahbaz et al, 2013). The mix determines a country's ability to achieve environmental sustainability. A well-balanced energy fuel mix reduces the level of CO_2 emissions in a nation, while one reliant on fossil fuels leads to increased emissions (Shahbaz et al, 2013). Considering the energy mix while investigating the EKC hypothesis is important because energy production significantly contributes to global emissions.

Dogan and Seker (2016) state that there should be cooperation between developed and developing countries to reduce global warming and dependency on fossil fuels for energy. This means a transfer of environmentally friendly technological innovations from developed to developing nations. Dependency on fossil fuels will be reduced and renewable energy will be implemented on a broader scale. Other strategies include financial support for developing countries to participate in multilateral organisations against global warming. Al-Mulali and

Ozturk (2016) suggest the government implement an energy tax on fossil fuels to speed up the transition. For example, South Africa implemented the carbon tax in 2019 (discussed in Chapter 5). The tax serves as a tool to discourage producers from emitting large amounts, thereby reducing CO_2 emissions.

Renewable energy sources include wind, solar and hydropower (Twidell and Weir, 2015). These sources are crucial for achieving environmental sustainability because they produce little to no carbon emissions. This allows countries to comply with international plans, such as the Paris Agreement of 2015. When countries reduce their emissions, they also become eligible for government subsidies for green energy. Renewable energy reduces dependence on fossil fuels for energy production and allows economic growth with less environmental degradation (Twidell and Weir, 2015). Ellabban et al (2014) report that although renewable resources have higher start-up costs than fossil fuels, their long-term costs are lower as they require minimal operational costs and no fuel costs.

Nuclear energy is the third component of the energy fuel mix. Nuclear energy is generated by splitting atoms in a process called nuclear fission (World Nuclear Association, 2021). Nuclear energy is highly reliable as it provides a continuous supply of energy. A small amount of nuclear fuel can produce large amounts of energy while it does not produce greenhouse gas emissions. However, using nuclear energy produces radioactive waste, which, if stored and disposed of unsafely, can have hazardous consequences lasting decades (Akidiri et al, 2019).

Using nuclear energy also reduces dependence on fossil fuels and allows developing countries to diversify their energy production (Sovacool, 2008). Implementing nuclear energy alongside renewable energy mitigates the risks associated with its disposal while making environmental sustainability an achievable goal. According to the World Nuclear Association (2023), currently, South Africa is the only African country with an operational nuclear plant (Koeberg Nuclear Power Station), generating around 5% of the nation's electricity. The power plant has been in operation since 1984 and there are plans to build more plants. Algeria, Morocco and Nigeria have explored the possibility of including nuclear energy in their fuel mix. According to the International Atomic Energy Agency (2020), these countries have signed agreements with Russia to develop a power plant strategy and have developed national research reactors to train and educate specialists in nuclear. Angola is the only country selected in this study which has yet to have an immediate plan for nuclear.

Studies in various contexts and periods have found that a shift to renewable energy sources reduces CO_2 emissions (Apergis and Payne, 2010). Earlier studies on the relationship between renewable energy consumption and CO_2 emissions were by Richmond and Kaufmann (2006). They analysed thirty-six countries, twenty of which were OECD nations and the remaining sixteen were developing countries. The study period was from 1973 to 1997, and an inverted U-shaped EKC was found with a turning point between US$29,687 and US$110,599.

Subsequent studies include Iwata et al (2011), Baek and Kim (2013), Al-Mulali and Ozturk (2016), Dogan and Seker (2016) and Shahbaz et al (2023). Iwata et al (2011) analysed twenty-eight countries from 1960 to 2003, of which seventeen were OECD countries and the remaining eleven were developing nations. When panel regression was used, an inverted U-shaped EKC was found, with a turning point of US$ 141,682.59 GDP per capita. When Pooled Mean Group was used, the inverted U-shaped curve had its turning point at US$ 77,126.73 (US dollars). However, no EKC or turning points were found when the Mean Group was used.

Papers by Baek and Kim (2013), Al-Mulali and Ozturk (2016) and Dogan and Seker (2016) analysed South Korea, twenty-seven developed economies and a panel of twenty-three OECD countries, respectively. The trend in these studies is that the EKC hypothesis holds for developed and OECD countries. These papers analysed CO_2 emissions, income and renewable energy consumption as their variables. Most developed countries are reported to have primarily shifted to renewable energy production processes beyond the income peak, where their CO_2 emissions have decreased.

Dogan and Seker (2016) tested the EKC hypothesis for a panel of countries with high renewable energy usage, employing advanced econometric methods to assess the impact of renewable energy, trade, and economic growth on CO_2 emissions. They found strong support for the inverted U-shaped EKC, with emissions peaking and then declining at higher income levels. The key driver was the transition toward renewables and service-oriented economies, supported by technological innovation. Although the study focuses on developed economies, the findings offer critical insights for middle-income African countries aiming to transition to cleaner technologies and reduce reliance on fossil fuels in their industrialisation phase.

Most empirical evidence on the EKC is for developed countries but Shahbaz et al (2023) analysed the EKC for India. India is analysed because it is developing and because the country is shifting from non-renewable to renewable energy sources. More than 40% of its total energy consumption is renewable. Using data from 1971 to 2015, the study employed CO_2 emissions, renewable energy consumption, and trade volume as key variables. Evidence of the EKC was found, with GDP per capita and its squared term showing the expected signs, positive and negative, respectively. However, the estimated turning point of US$2,937.77 GDP per capita fell outside the sample range, suggesting that India had not yet reached the income level at which CO_2 emissions begin to decline.

The study also found a statistically significant negative relationship between renewable energy consumption and CO_2 emissions in both the short and long run, indicating that expanding renewable energy use contributes directly to emissions reduction (Shahbaz et al, 2023). However, without further policy intervention and investment in clean energy, economic growth alone may not be sufficient to bring about the EKC's expected environmental improvements within the current income range

Many studies have found that energy from fossil fuels increases CO_2 emissions in the economy (Farhani and Ozturk, 2015). Shafiei and Salim (2014) conducted a long-run panel analysis on twenty-nine OECD countries between 1980 and 2011. They found that a 1% increase in non-renewable energy use resulted in a 1.038% increase in CO_2 emissions. This elasticity suggests a link between fossil fuel dependence and environmental degradation. While their sample focuses on developed economies, the results offer an important message for middle-income African countries: continuing to rely heavily on fossil fuels without transitioning to renewables could trap them on the upward slope of the EKC and delay reaching the turning point.

Saboori et al (2014) tested the EKC hypothesis for Malaysia using the ARDL bounds testing approach from 1980–2009. Their findings supported the inverted U-shaped EKC, indicating that CO_2 emissions increased with GDP per capita at lower income levels but declined once a threshold was passed. This study is particularly relevant to African middle-income countries like Nigeria and South Africa, which share structural similarities with Malaysia in terms of industrialisation patterns and energy dependency. The research demonstrates that countries undergoing rapid growth with targeted energy and environmental policies can eventually decouple emissions from income.

Ahmad et al (2021) claim that many developing countries experience rapid economic growth that is unsupported by environmentally friendly technological advancements. This means these countries continue to rely on fossil fuel energy for their production processes. Beyond the GDP per capita turning point, their CO_2 emissions continue to increase and the inverse relationship between income and environmental degradation is not achieved. Ahmad et al (2021) state that without appropriate policies against global warming, developing countries will not achieve the turning point hypothesised by the EKC.

Several studies have investigated the EKC with nuclear energy as a variable (Acaravci and Ozturk, 2010; Topcu and Tugcu, 2020; Sarkodie and Strezov, 2018). All the studies found evidence of the EKC hypothesis. Acaravci and Ozturk (2010) used panel cointegration techniques to investigate the EKC hypothesis in several European countries from 1960 to 2004. Their study confirmed the existence of the EKC and found that nuclear energy consumption significantly contributed to reducing CO_2 emissions. While their analysis centres on developed countries, it provides strong backing for diversifying energy portfolios with nuclear energy, an option currently being explored by countries like South Africa, Nigeria and Morocco. Their findings support the case for expanding clean energy options in Africa to reach environmental targets more efficiently.

Topcu and Tugcu (2020) analysed G7 countries from 1965-2013 and used the panel ARDL model. Sarkodie and Strezov (2018) used panel cointegration techniques for a combination of developed and developing countries. It is important to note that across all the studies, including nuclear energy as a variable, it was found to reduce CO_2 emissions, even when GDP per capita increased.

Other factors influencing the relationship between economic growth and environmental degradation are trade openness, corruption, financial development and the informal sector, which will be discussed next.

2.4.3 Environmental sustainability and trade openness

Trade openness refers to a country's level of participation in the global economy (Sachs and Warner, 1995). It is measured through trade volume as a percentage of GDP, tariff rates and

non-tariff barriers. It is crucial to account for trade openness while pursuing environmental sustainability because it can influence the relationship between economic growth and environmental degradation (Gill et al, 2018). Trade barriers influence the level of economic activities within a country, which affects the environment (Grossman and Krueger, 1991). For example, reducing trade barriers expands the scale of economic activities, which means there are more emissions to regulate.

According to classical (Ricardian) and neoclassical trade theory, trade liberalisation encourages countries to focus on goods with a comparative advantage (Kirkpatrick and Scrieciu, 2008). This affects the pollution level depending on whether the comparative advantage good is in a pollution-intensive industry. Environmental quality improves when a country's comparative advantage has low pollution levels (Kirkpatrick and Scrieciu, 2008).

Reduced trade and investment barriers allow developed countries to shift “dirty” industries to developing countries (Levinson and Taylor, 2008). This causes developing countries to be trapped in a vicious cycle of specialising in pollution-intensive industries. Developing countries thus incur pollution costs on behalf of the developed world while the latter imports goods without increasing local pollution (Levinson and Taylor, 2008). This is known as the Pollution Haven Hypothesis (PHH), where developed countries shift their pollution to developing countries with less strict environmental regulations.

However, trade openness can also lead to changes in production methods (Kirkpatrick and Scrieciu, 2008). Open trade can lead to environmentally friendly technological innovations, improving environmental quality. This is because it allows for environmentally friendly technologies to be transferred to developing nations (Kirkpatrick and Scrieciu, 2008). This is known as the technique effect.

The scale effect explains how reduced trade barriers can lead to increased economic activity, which encourages investments and industry growth (Dogan and Seker, 2016). Economies develop when economic opportunities are exploited on a larger scale and income rises. Countries with higher income levels demand improved environmental quality. This income effect can lead countries to achieve the EKC hypothesis turning point earlier than expected. Many countries are signatories to trade agreements such as the African Continental Free Trade Area (AfCFTA) and the North American Free Trade Agreement (NAFTA), which include

environmental clauses. This means members of these agreements are obligated to comply with specific environmental regulations (Dogan and Seker, 2016).

Papers by Cole (2003), Jalil and Mahmud (2009) and Dogan and Inglesi-Lotz (2020) claim that the EKC shape is affected by international trade. Cole (2003) used a cross-country panel between 1975 and 1998. The study used the fixed effects model and found that trade openness has a mixed effect on degradation. Both Cole (2003) and Dogan and Inglesi-Lotz (2020) found that trade leads to higher pollution levels in developing countries while it reduces pollution in developed nations.

Trade openness can positively or negatively affect environmental sustainability depending on a country's level of development and regulatory framework (Levinson and Taylor, 2008; Gill et al, 2018). Environmental clauses in trade agreements are crucial to ensure that trade openness supports environmental sustainability. However, the effectiveness of such measures is heavily influenced by the quality of governance institutions. The following section explores how corruption can undermine environmental policies, further complicating the relationship between economic growth and environmental sustainability.

2.4.4 Environmental sustainability and corruption

As a continuation of the discussion of trade openness in Section 2.4.3, it is essential to examine how corruption influences environmental sustainability. High levels of corruption may postpone the EKC turning point, prolonging environmental degradation even as economies grow. Contrarily, low corruption levels can facilitate the enforcement of environmental standards and promote sustainable development. This section explores the relationship between environmental sustainability and corruption, discussing the impact of governance quality on the EKC trajectory.

Corruption refers to the abuse of a professional position for personal gain (Welsch, 2004; Akhbari and Nejati, 2019). Corruption can influence the EKC hypothesis trajectory because it influences the timing of environmental policies. It also influences the level of enforcement of environmental regulations. According to Lisciandra and Migliardo (2017), there are two types of corruption: grand and petty.

Grand corruption is when businesses and high-level public officials attempt to influence national policy planning. This is often conducted using bribery, misappropriation of funds, state capture and nepotism (Fredriksson and Svenisson, 2003). When high-level officials accept large sums of money from businesses, these are often in return for misallocating public funds that could have funded natural resource programmes. Officials in resource-rich countries may also grant extraction rights in exchange for financial gain (Fredriksson and Svenisson, 2003). Grand corruption undermines governance in countries, hinders economic development, and delays the implementation of strict environmental regulations (Singh, 2021).

Petty corruption refers to businesses and lower-level public officials attempting to avoid the consequences of an already-implemented environmental policy (Lisciandra and Migliard, 2017). For example, officials may accept business bribes to avoid penalties for environmental violations (Lisciandra and Migliard, 2017). Petty corruption weakens the enforcement of environmental regulations at the local level.

According to Akhbari and Nejati (2019), both types of corruption are equally important in evaluating the effectiveness of environmental policy. Studies such as Welsch (2004) suggest that the EKC turning point occurs much later than expected in highly corrupt countries. For example, Masron and Subramaniam (2018) found that corruption has delayed the turning point of the EKC for Indonesia. This is because corruption exacerbates environmental degradation sources, such as deforestation and land degradation.

High levels of corruption also discourage international cooperation in mitigating climate change impacts (Akhbari and Nejati, 2019; Swain et al, 2020). This is because corruption creates distrust between countries, where developed nations become more reluctant to provide financial assistance to developing countries for fear that public officials will divert funds. Reduced financial assistance means it will be more difficult for developing countries to implement environmentally friendly policies, further delaying the turning point of the EKC (Swain et al, 2020). It also means more difficulty contributing to global efforts to reduce climate change, such as the Paris Agreement.

Studies by Cole (2007) and Leitao (2010) reported that the EKC turning point is delayed in countries with high corruption levels. Cole (2007) examined the impact of corruption perceptions (measured using the corruption perceptions index) on pollutants such as sulphur

dioxide (SO_2) and carbon dioxide (CO_2). The study found that higher perceived corruption levels are positively associated with per capita emissions of SO_2 and CO_2, indicating that governance quality plays a key role in environmental outcomes. Leitao (2010) investigated how corruption influences the income level at the turning point of the EKC for sulphur emissions across various countries. The study revealed an inverted U-shaped relationship between income and sulphur emissions, supporting the EKC hypothesis.

Apergis and Ozturk (2015) confirmed the existence of the EKC for countries with better governance, further confirming the trend. The study used panel data from fourteen Asian countries to investigate the EKC, with corruption perceptions as a variable. The study confirmed the presence of the EKC in countries with better governance. Better governance, characterised by lower corruption levels, facilitates the earlier onset of the turning point in the EKC. Countries with effective governance structures experience environmental improvements at lower income levels than those with higher corruption.

Understanding and addressing the different types of corruption and their determinants is important for developing anti-corruption measures. For example, promoting transparency in the implementation process of environmental regulations will encourage officials to be accountable for funds allocated to environmental protection (Akhbari and Nejati, 2019). Aligning developed anti-corruption measures with environmental rights will also help reduce corruption's impact on achieving environmental sustainability. When corruption is managed effectively, financial support will increase from developed nations due to increased trust.

2.4.5 Environmental sustainability and financial development

Financial development is critical in shaping the relationship between economic growth and environmental degradation. It acts as a double-edged sword, capable of accelerating environmental harm or fostering sustainable practices, depending on how financial resources are mobilised and utilised (Ozturk et al, 2016). The dual impact of financial development makes it a crucial factor in determining whether an economy remains on the upward slope of the EKC or reaches its turning point, where economic growth coincides with environmental improvement. This section discusses the relationship between financial development and environmental sustainability, emphasising its positive and negative implications.

Financial development refers to improving and expanding a country's financial system, encompassing the development and integration of financial institutions such as banks, insurance companies and capital markets, including bond and equity markets (Ozturk et al, 2016). A well-developed financial system enhances the mobilisation of savings, efficient allocation of resources and availability of credit, which are essential for driving economic growth. The depth and sophistication of financial institutions, indicated by metrics such as credit-to-GDP ratio, financial market capitalisation and the diversity of financial products, serve as key indicators of a country's financial development level (Beck et al, 2018).

Financial development is important in addressing environmental challenges and providing more access to capital for green investments. Access to well-functioning financial markets allows firms to invest in cleaner technologies, renewable energy projects, and sustainable infrastructure (Nasir and Rehman, 2019). Moreover, financial institutions can provide products suited to support environmental sustainability, such as green bonds, environmental impact funds and sustainability-linked loans. These instruments reduce the capital cost for green projects and encourage businesses to implement sustainable practices (Nasir and Rehman, 2019).

Finally, financial development also promotes risk-sharing and diversification, which is important in hedging the uncertainty surrounding investments in renewable energy and other green technologies. Countries with advanced financial systems can better attract FDI aimed at sustainable development, further bolstering their capacity to address environmental issues (Shehzad et al, 2022). The impact of financial development on environmental sustainability depends on regulatory frameworks and governance quality. Without adequate environmental regulations, increased financial activity may lead to greater industrialisation and pollution, delaying progress toward achieving environmental goals (Shehzad et al, 2022).

For financial development to positively contribute to environmental sustainability, it must be accompanied by incentives for green investments and regulatory oversight (Shehzad et al, 2022). Policymakers must promote financial activities while ensuring that financial activities align with long-term sustainability objectives. Through coordinated efforts, financial development catalyses sustainable economic growth and environmental protection (Shehzad et al, 2022).

Several studies have linked financial development with increased renewable energy consumption (Eren et al, 2019; Mushtaq and Ahmed, 2021; Usman et al, 2021). Mushtaq and Ahmed (2021) found that countries with better financial systems can use renewable energy to reduce CO_2 emissions by facilitating investments in renewable energy infrastructure, lowering borrowing costs and improving financial inclusion. A well-developed financial system enables the efficient mobilisation of capital for renewable energy projects, reducing reliance on fossil fuels and reducing emissions.

Mushtaq and Ahmed (2021) applied the panel ARDL model to a dataset covering twenty-five countries from 1995 to 2017, focusing on the moderating role of financial development in the EKC framework. Their results revealed a long-run inverted U-shaped relationship between GDP per capita and CO_2 emissions, confirming the EKC hypothesis. Importantly, financial development enhanced the ability of countries to invest in renewable energy infrastructure, reducing emissions over time. This finding underscores the importance of strengthening financial systems in African middle-income economies, as better access to green finance can help accelerate the transition to sustainable development.

Abdouli and Hammami (2017) argue that not all foreign direct investment (FDI) forms benefit environmental quality in developing countries. While FDI is generally seen as a driver of economic growth, technology transfer, and job creation, it can also have adverse environmental consequences depending on the nature of the investment. FDI directed toward pollution-intensive sectors, such as mining, oil extraction, and heavy manufacturing, often results in increased natural resource exploitation and environmental degradation. This occurs because foreign firms motivated by profit maximisation may engage in resource-intensive activities without prioritising sustainable practices, particularly in host countries with weak environmental regulations (Abdouli and Hammami, 2017).

This is known as the Pollution Haven Hypothesis (PHH), discussed earlier in Section 2.4.3. Wang et al (2022) highlight that FDI in environmentally harmful sectors can exacerbate pollution, disrupt ecosystems, and delay improvements in environmental quality, undermining the expected trajectory of the EKC hypothesis. Instead of reaching the turning point of the EKC, where environmental degradation begins to decline as income levels rise, countries receiving FDI in pollution-intensive sectors may experience prolonged periods of environmental harm (Wang et al (2022).

Additionally, the rapid increase in industrial activities associated with such FDI leads to higher emissions of greenhouse gases and other pollutants (Zhou et al, 2023). This harms local ecosystems and contributes to global environmental challenges, such as climate change (discussed in Section 2.2). Moreover, the over-reliance on FDI-driven resource extraction can leave host countries Vulnerable to the depletion of critical natural resources, further complicating their path toward sustainable development (Zhou et al, 2023).

Therefore, while FDI has the potential to drive positive environmental outcomes when directed toward clean technologies and sustainable industries, the lack of proper governance and regulatory enforcement can result in significant environmental harm (Zhou et al, 2023). Policymakers must carefully assess the sectors attracting FDI and create incentives for investments in renewable energy, green infrastructure and environmentally friendly industries to minimise the adverse effects of FDI on environmental quality.

2.4.6 Environmental sustainability and the informal sector

Dada et al (2022) define the informal sector as the production and distribution of goods and services that are unaccounted for in a country's national accounts. This means all economic activities which occur outside of the official economy. The informal sector is regarded as a significant influence on environmental degradation and it is essential to account for it in environmental sustainability studies for the following reasons.

In developing countries, the informal sector employs a large portion of the population (International Labour Organisation, 2018). According to the International Labour Organisation (2018), 70% of the population in Africa is employed in the informal sector. For example, 85% of new work generated in 2023 was in the informal sector of Kenya (KNBS, 2024). The informal sector mainly employs economically disadvantaged people in developing countries and for this reason, the government is reluctant to enforce regulations for the informal market (Chen et al, 2007).

However, it is reported that a large part of the informal sector is concentrated in pollution-intensive industries. Such industries include subsistence farming, transport services and small-scale mining (Srivastava et al, 2016). These industries are pollution-intensive because they are

loosely regulated and often use inefficient technologies. For example, small-scale mining often uses harmful materials such as mercury and cyanide to mine gold (Esdaile and Chalker, 2018). These harmful materials contaminate the soil and water. Another example is subsistence farming, where the overuse of chemical fertilisers and pesticides leads to soil degradation (Srivastava et al, 2016).

Informal businesses are also highly competitive, which leads to them adopting cost-cutting strategies at the expense of the environment (Bose, 2010). This is prevalent in the transport industry, where 'minibus taxis' are often poorly maintained and contribute to air pollution when they release carbon monoxide and other harmful pollutants (Lutchman and Bickford-Smith, 2015). Another example is when recycling (initially thought to be environmentally friendly) is carried out unethically. This releases harmful pollutants into the atmosphere. For example, burning electronic e-waste is an unethical way of disposal (Bose, 2010).

The informal sector often acts as a pollution leakage due to its lack of compliance with government regulations (Ihrig and Moe, 2004). When environmental regulators set an emission target, the informal sector can avoid compliance (Baksi and Bose, 2010). This is because regulators focus on the formal sector to comply and ignore the informal sector for various reasons. Firstly, there are minimal ties between the informal sector and the state (Chadhun, 2005). Secondly, there is difficulty in monitoring small businesses as they are geographically dispersed.

Studies with the informal sector as a variable while investigating the EKC include Chaudhuri and Mukhopadhyay (2006), Bose (2010), Bhattacharyya and Hodler (2010) and Goel and Saunoris (2020). Estimation techniques used in these papers include the Computable General Equilibrium (CGE) model, the dynamic panel data approach and the Generalised Method of Moments (GMM) estimator. All the studies found that the EKC turning point was delayed for countries with large informal sectors in their analysis.

According to Frynas (2010), efforts to control pollution in the informal sector should be coordinated more than just nationally. Individual municipalities must also contribute with a variety of strategies. Local municipalities can strengthen enforcement by closely monitoring the pollution sources of informal businesses. For example, municipalities can monitor how informal businesses dispose of waste (Frynas, 2010).

In conclusion, the informal sector is a significant factor in environmental sustainability, particularly in developing countries where it largely contributes to economic activity (Dada et al, 2022). While it provides many essential livelihoods and economic opportunities, its unregulated nature and prevalence in pollution-intensive industries exacerbate environmental degradation. Addressing the environmental impact of the informal sector requires a multi-level governance approach involving not only national governments but also local municipalities (Bose, 2010). Through targeted policies and strengthened regulatory frameworks, policymakers can mitigate the environmental harm caused by the informal sector while preserving its economic benefits.

2.5 Conclusion

This chapter reviewed the theoretical foundations and contextual determinants of the EKC hypothesis, emphasising its relevance in understanding the relationship between economic growth and environmental degradation, particularly in middle-income African countries.

The chapter began in Section 2.2 by establishing the broader context of climate change and environmental degradation, highlighting how these issues disproportionately affect Africa and set the stage for the EKC discussion. This section also introduced the importance of climate awareness, stakeholder involvement, and climate mitigation and adaptation strategies, and ended by considering the role of international climate organisations in shaping national climate action.

Section 2.3 linked the EKC to social development and environmental sustainability, outlining how sustainable development goals (SDGs), particularly SDG 7, 8, and 13, interact with the EKC framework. It also emphasised the integration of socio-economic indicators, such as education and human development, in understanding the shape of the EKC.

The chapter's main theoretical focus was presented in Section 2.4, which discussed the determinants of the EKC in detail. This included the energy fuel mix (2.4.2), trade openness (2.4.3), corruption (2.4.4), financial development (2.4.5), and the informal sector (2.4.6). These

sub-sections provided a nuanced exploration of how structural and institutional variables shape the EKC's trajectory.

Theoretical support for the EKC was provided through discussions on income distribution theory, structural transformation of economies, and the influence of market mechanisms and technology in promoting sustainable growth.

In summary, this chapter moved from a broad contextual foundation in Sections 2.2 and 2.3 to a focused theoretical framework in Section 2.4, illustrating the flow from general environmental concerns to the specific economic and institutional drivers of the EKC. These insights lay the groundwork for the empirical investigation in the following chapter.

CHAPTER 3
EMPIRICAL EVIDENCE FOR THE EKC: A LITERATURE REVIEW

3.1 Introduction

The EKC hypothesis has become an important framework for understanding the relationship between economic development and environmental degradation. The emergence of climate change as a global crisis has highlighted the need for policymakers to harmonise economic growth with environmental protection (Limmeechokchai et al, 2023). The EKC hypothesis has been widely tested using various econometric methodologies, environmental indicators and datasets across different country classifications.

Empirical evidence on the EKC varies significantly depending on factors such as the pollutants analysed, estimation techniques and institutional frameworks within different economies (Raymond, 2004; Purcel, 2020). While some studies confirm an inverted U-shaped EKC, others challenge its validity, especially in developing economies where structural and policy constraints influence environmental outcomes. This chapter critically reviews the empirical literature on the EKC, focusing on evidence from developed and developing economies, cross-country comparisons and sectoral perspectives. It aims to highlight variations in findings, methodological approaches and policy implications.

The rest of the chapter is organised as follows: Section 3.2 begins with an analysis of previous empirical investigations, focusing on evidence from developed and developing economies and cross-country comparisons. Section 3.3 discusses general critiques of the EKC hypothesis and outlines policy interventions commonly recommended in the broader literature where economic growth alone may not lead to environmental improvements. By contrast, the policy implications in Chapter 6 are directly informed by this study's empirical findings and are tailored to the specific environmental and developmental circumstances of the five middle-income African countries examined. Section 3.4 concludes the chapter.

3.2 Empirical investigations of the EKC: Methodologies and evidence

The empirical investigation of the EKC originated in the early 1990s when researchers sought to understand the relationship between economic growth and environmental quality. The concept gained prominence through a study by Grossman and Krueger (1991), who provided early empirical evidence suggesting an inverted U-shaped relationship between income levels and environmental degradation. These studies laid the foundation for subsequent research exploring variations in EKC patterns across different pollutants, countries and methodological approaches.

Grossman and Krueger (1991), in their assessment of the environmental impacts of the North American Free Trade Agreement (NAFTA), used air pollutant proxies such as sulphur dioxide (SO_2) and suspended particulate matter (SPM), initially discussed in Chapter 2. Their study using panel data techniques, including pooled OLS and fixed effects (FE) approaches, found evidence that pollution increased with economic growth up to a certain income level before declining, supporting the EKC hypothesis. Grossman and Kruger (1991) inspired a large body of literature that applied more advanced econometric techniques to test the robustness of the EKC across various countries and environmental indicators.

Building on these early contributions, the focus of empirical research gradually shifted. While Grossman and Krueger (1991) analysed air pollutants like SO_2 and SPM, subsequent studies increasingly adopted CO_2 emissions per capita as the primary dependent variable. This shift was driven by growing concerns over global climate change and the recognition of CO_2 emissions as a major contributor to environmental degradation (Sarkodie and Strezov, 2019). The following sections review key studies that have tested the EKC hypothesis using CO_2 emissions, highlighting variations in findings, methodological approaches and policy implications.

3.2.1 Methods and functional forms in EKC empirical studies

This section discusses the primary methods and techniques used to investigate the EKC, focusing on cross-sectional, time-series and panel data techniques. These methods provide insights into the short-term and long-term dynamics between economic growth and environmental degradation (Adebayo et al, 2022). The section then reviews empirical findings from both developed and developing economies, highlighting key patterns and implications for policy and sustainability.

Cross-sectional studies analyse the EKC across multiple countries or regions simultaneously. These studies often employ OLS and Generalised Least Squares (GLS) regressions to estimate the EKC relationship (Wooldridge, 2016). OLS is commonly used due to its simplicity and interpretability. However, it may be susceptible to heteroskedasticity and omitted variable bias, while GLS addresses issues of heteroskedasticity by adjusting the variance structure (Wooldridge, 2016). By comparing economies at different income levels, cross-sectional analysis can reveal patterns that indicate whether environmental degradation initially increases with income and later declines.

Time-series methodologies, including Autoregressive Distributed Lag (ARDL) models, Johansen cointegration tests and Vector Error Correction Models (VECM), allow for the examination of the EKC hypothesis within individual countries over time (Wooldridge, 2016). These techniques assess the dynamic relationship between economic growth and environmental quality, capturing short and long-term effects.

Panel data models are considered the most common EKC analysis technique (Wooldridge, 2016; Baltagi, 2021). These models allow for a more robust investigation of the EKC hypothesis by accounting for country-specific effects and changes over time. Some commonly used panel techniques include fixed effects (FE) and random effects (RE) models. The FE and RE models control for unobserved heterogeneity among countries, helping to establish whether economic growth consistently influences environmental outcomes across different national contexts (Baltagi, 2021).

Other panel techniques such as Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model, Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) have been widely adopted in cross-country studies. Pooled Mean Group (PMG) and Mean Group (MG) models allow for country-specific differences in EKC trajectories while maintaining a typical long-run relationship (Baltagi, 2021). They are particularly effective in studying heterogeneous regions where environmental policies, industrial structures and economic conditions differ significantly.

Previous papers investigating the EKC have used different functional forms (Dinda, 2004; Hasanov et al, 2019). Theoretical expectations, empirical patterns and econometric

considerations inform the choice of functional form in EKC studies. Different functional forms include linear, quadratic and cubic functional forms. Each functional form is associated with a different expected EKC shape, which implies specific expectations for the signs of the estimated coefficients (Dinda, 2004; Hasanov et al, 2019). These relationships are summarised below in Table 3.1

The quadratic model is the most common form used in EKC studies, where environmental degradation initially rises with economic growth but declines after a certain income level (Ungwanitban et al, 2020). This study also adopts the quadratic functional form to estimate the GDP per capita turning point and assess the EKC hypothesis. While the quadratic specification remains dominant, other studies adopt cubic forms, particularly in regions with a rebound effect. The cubic specification allows for more complex relationships, such as inverted N-shaped or N-shaped patterns, where environmental degradation may decline and rise again at higher income levels or vice-versa (Ungwanitban et al, 2020).

Linear models, though less common, assume a constant relationship between economic growth and environmental quality without any turning point. Lastly, monotonic decreasing models capture scenarios where environmental degradation consistently declines as income rises, reflecting strong environmental policies and structural transformations in the economy (Dong et al, 2016; Ungwanitban et al, 2020; Cheikh et al, 2021).

Table 3.1 below summarises the expected relationships between economic growth and environmental degradation across different functional forms.

Table 3.1: Relationship between coefficient signs and EKC curve shapes

β_1	β_2	B_3	EKC shape
> 0	< 0	-	Inverted U-shaped EKC curve
< 0	> 0	-	U-shaped EKC curve
> 0	> 0	< 0	Inverted N-shaped EKC curve
< 0	> 0	< 0	N-shaped EKC curve

Note: B_3 represents the coefficient on the cubic term of GDP per capita, included in studies testing for N-shaped EKC relationships

Source: Compiled by the author based on Dinda (2004) and Acheampong (2019)

These functional forms represent different versions of the EKC hypothesis, each with distinct assumptions about the relationship between GDP per capita and environmental degradation.

3.2.2 Empirical evidence of the EKC

Empirical evidence for the existence of the EKC largely depends on the study's context, the variables employed and the pollutants used to proxy environmental degradation, as discussed in Chapter 2 (Raymond, 2004; Purcel, 2020).

Table 3.2 summarises these studies, outlining key methods and techniques, countries or regions analysed and the direction and shape of the EKC relationship reported. It provides a comparative view of how the EKC manifests across different economic contexts and identifies patterns or inconsistencies in empirical findings.

Many developed countries exhibit an inverted U-shaped EKC, where environmental degradation first increases and then decreases as income rises (Apergis, 2016). Studies on OECD countries (Richmond and Kaufmann, 2006; Iwata et al, 2011; Dogan and Inglesi-Lotz, 2020) consistently found evidence of an inverted U-shaped EKC, suggesting that economic growth initially degrades the environment but later leads to improvements. Richmond and Kaufmann (2006) analysed twenty OECD countries from 1973 to 1997 using OLS regression and found an inverted U-shaped EKC with turning points discussed in Section 3.2.3.

Iwata et al (2011) examined seventeen OECD countries from 1960 to 2003 using MG and PMG estimators and found strong support for the inverted U-shaped EKC. The study further confirmed that higher income levels are associated with declining CO_2 emissions after a specific turning point. Similarly, Dogan and Inglesi-Lotz (2020) studied seven European nations from 1980 to 2014, employing the FMOLS model. Their results confirmed the EKC hypothesis when industrial structure was excluded as a variable. However, when included, they revealed a U-shaped relationship, highlighting the significant influence of structural economic changes on environmental outcomes.

Baek and Kim (2013) investigated the EKC hypothesis for South Korea from 1971 to 2007. The study employed the ARDL bounds testing approach to investigate the EKC. The study's results confirmed the existence of an inverted U-shaped EKC in Korea, with turning points discussed in Section 3.2.3. Additionally, the study found that electricity generation from fossil fuels and rising energy consumption contributed to increased CO_2 emissions, while nuclear power significantly mitigated environmental degradation. These findings underscore the role

of structural energy policies and technological shifts in achieving environmental improvements alongside economic growth.

Other studies, such as Bilgili et al (2017), focused on the influence of renewable energy on the EKC in OECD countries. Using panel data analysis across seventeen OECD countries from 1977 to 2010 and employing the PMG model, the study investigated the long-run and short-run relationships between renewable energy consumption, economic growth and CO_2 emissions. Their findings indicate that increasing renewable energy consumption contributes to an earlier turning point in the EKC, reducing environmental degradation at lower income levels (Bilgili et al, 2017). Furthermore, the study highlighted that renewable energy plays a significant role in decoupling economic growth from carbon emissions, suggesting that policy interventions promoting clean energy adoption can accelerate environmental improvements and help countries achieve sustainability targets more efficiently.

While empirical studies from developed and high-income countries largely confirm the existence of an inverted U-shaped EKC, evidence from developing economies, particularly African countries, remains less conclusive (Lee et al, 2015). More investigation of the existence of the EKC for African countries needs to be conducted. This is because of an urgent need for African countries to reassess their economic and environmental policies (Bah et al, 2020). According to Bah et al (2020), Africa is the continent most affected by climate change (further discussed in Chapter 5). This highlights the importance of more country-specific empirical studies to confirm the existence and shape of the EKC in African economies.

Most African studies on the EKC did not find evidence of an inverted U-shaped curve. For example, Kohler (2013) investigates the EKC using the ARDL bounds testing approach and Johansen cointegration techniques from 1960 to 2009. The study does not find evidence of the EKC because its GDP per capita and GDP per capita square coefficients were statistically insignificant determinants of CO_2 emissions per capita. Similarly, Ogundipe et al (2014) examined the EKC hypothesis for fifteen West African countries and found a U-shaped relationship, where environmental degradation initially declines with income, but then rises. The study applied panel data regression techniques, specifically FE and RE models, while incorporating factors such as population density, external debt, manufactured exports and regulatory quality to determine the drivers of environmental degradation. The findings indicate that the EKC hypothesis does not hold for the selected African countries.

Conversely, using the FE and RE models, Sarkodie (2018) found an inverted U-shaped EKC for seventeen African countries from 1971 to 2013. The countries were selected due to data availability and their geographical locations, which position them as representatives of the African continent. Variables employed in the study included CO_2 emissions per capita, GDP per capita and its squared term, total fertility rate, food production index and permanent cropland. An inverted U-shaped EKC curve with turning points was observed (further discussed in Section 3.2.3).

Bah et al (2020) emphasised the importance of accounting for income heterogeneity in estimating the EKC for African nations. The paper claims that studies which found limited evidence of the EKC for African countries have failed to group them according to income levels. Bah et al (2020) thus categorised the selected countries into lower-middle and upper-middle-income groups from 1971 to 2012. The study found evidence of an inverted U-shaped EKC for both groups using OLS and panel DOLS techniques. Variables employed in the study included CO_2 emissions, GDP per capita, population, urbanisation rate and fossil fuel energy use.

In a related study, Tenaw and Beyene (2021) examined the EKC hypothesis across twenty Sub-Saharan African countries from 1990–2015. The study applied the Common Correlated Effects-Pooled Mean Group (CCE-PMG) estimator, which accounts for cross-sectional dependence. Their results confirmed the existence of the EKC, showing that CO_2 emissions initially rise with income but eventually decline as countries invest in human development and renewable energy. Notably, including the HDI highlighted that broader social development (not just income) is critical in driving environmental improvements. This is especially relevant for middle-income African countries, where strengthening education and health infrastructure can reinforce low-carbon growth trajectories.

Complementing this, Maranzano et al (2022) investigated a modified educational EKC from 1950 to 2015. Variables included CO_2 emissions, GDP per capita and its squared term, education and its squared term, energy use and trade openness. Using both FE and RE models, they identified turning points at approximately $4.60 and $5.35 per capita educational expenditure, respectively. This suggests that improvements in education beyond a certain level contribute to environmental quality. While this study was not focused on Africa, its findings

are relevant for middle-income African countries pursuing green development through education reforms.

Bibi and Jamil (2021) investigated the EKC based on a regional approach. The study used six regions, namely Europe and Central Asia, Latin America and the Caribbean, the Middle East and North Africa, South Asia, Sub-Saharan Africa, East Asia and the Pacific, for the period 2000-2018. Their variables included CO_2 emissions, FDI, GDP per capita, trade openness, financial development, institutional quality and primary school enrolment. The latter variable was included to capture the influence of education on environmental awareness and sustainable consumption patterns. This highlights the broader role of human development in shaping environmental outcomes. As discussed in Chapter 2, education, particularly at the foundational level, fosters environmental awareness, supports technological adoption and strengthens institutional quality, all critical for sustainable economic growth (Lai and Chen, 2020). Using FE and RE models, Bibi and Jamil (2021) found evidence of an inverted U-shaped EKC for most regions, except for Sub-Saharan Africa.

The mixed results for developing regions suggest that factors such as income heterogeneity, governance quality and industrial structure influence the presence and shape of the EKC. Among developing countries, Malaysia represents a rapidly industrialising, upper-middle-income economy whose environmental dynamics are mainly influenced by energy composition. The study by Saboori and Sulaiman (2013) tested the EKC hypothesis for Malaysia over the period 1980 to 2009. The ARDL bounds testing approach and Johansen cointegration techniques were employed and the study found no evidence of the EKC when aggregated energy consumption was used. However, when disaggregated energy sources (coal, gas, and electricity) were considered, the results supported an inverted U-shaped EKC relationship, with turning points ranging from US$5,378 to US$8,267, although these were mainly outside the sample range.

Table 3.2: A summary review of the selected empirical literature on the EKC relationship

Study	Countries	Period	Variables	Method	EKC shape	Turning Point
Richmond and Kaufmann (2006)	20 OECD 16 non-OECD	1973- 1997	CO_2 emissions; GDPPC; $GDPPC^2$; Energy consumption; Total population	OLS	Inverted U-shaped	$29,687 - $110,599
Iwata et al (2011)	17 OECD 11 non-OECD	1960 -2003	CO_2 emissions; $GDPPC^2$; GDPPC; Electricity produced from nuclear sources	MG PMG Panel regression	No EKC Inverted U-shaped Inverted U-shaped	 $77,126.73 $141,682.59
Baek and Kim (2013)	Korea	1975- 2006	CO_2 emissions; GDPPC; $GDPPC^2$; Electricity production from conventional thermal sources	ARDL bounds test	Inverted U-shaped	TP is too large, outside the sample size.
Kohler (2013)	South Africa	1960-2009	CO_2 emissions; GDPPC; $GDPPC^2$; Energy consumption; Trade openness	ARDL bounds test Johansen cointegration VECM Granger Causality	No EKC found	N/A
Sulaiman et al (2013)	Malaysia	1980 - 2009	CO_2 emissions; GDPPC; $GDPPC^2$; Energy consumption; Trade openness	ARDL bounds test	Inverted U-shaped	$8,77
Inglesi-Lotz & Bohlmann (2011)	South Africa	1960 - 2010	CO_2 emissions; GDPPC; $GDPPC^2$; Energy intensity; Renewable energy production	ARDL bounds test	No EKC found	N/A
Jebli et al (2015)	24 SSA	1980 -2010	CO_2 emissions; GDPPC; $GDPPC^2$; Renewable energy consumption per capita; Real exports per capita; Real imports per capita	Unit root tests Panel cointegration test FMOLS and DOLS Granger Causality test	Inverted U-shaped	$244,65
Boluk and Mert (2015)	Turkey	1961 –2010	CO_2 emissions; GDPPC; $GDPPC^2$; Electricity production from renewable sources per capita	ARDL bounds test	Inverted U-shaped	$9,920, TP is too large and outside sample size
Jebli and Youssef (2015)	Tunisia	1980-2009	CO_2 emissions; GDPPC; $GDPPC^2$; Renewable electricity consumption; Non-renewable energy consumption; Real merchandise exports; Real merchandise imports	ARDL bounds test VECM Granger Causality	U-shaped	$2,878.60 - $3,259.37

Bah et al (2020)	10 middle-income Sub-Saharan African countries	1971-2012	CO_2 emissions; GDPPC; $GDPPC^2$; Total Population	Panel cointegration Panel DOLS	Inverted U-shaped (6 countries)	N/A
Beyene and Kotosz (2020)	12 East African countries	1990-2013	CO_2 emissions; GDPPC; $GDPPC^2$; Globalisation; FDI; Population density; Political stability	PMG	Bell-shaped	$177.35 (short run) $128.95 (long run)
Bibi and Jamil (2021)	6 Regions (Latin America; Europe & Central Asia; East Asia & The Pacific; Middle East & North Africa; South Africa; Sub-Saharan Africa)	2000-2018	CO_2 emissions; GDPPC; $GDPPC^2$; Financial development; Institutional quality; Trade; FDI; School enrolment	FEM REM	Inverted U-shaped (5 regions except Sub-Saharan Africa)	$ 36,315.50 (Latin America) $13,226.70 (Europe & Central Asia) $12,571.70 (East Asia & The Pacific) $89,321.70 (Middle East & North Africa) $15,521.79 (South Asia)
Maranzano et al (2022)	17 European OECD countries 6 GCC region countries	1950-2015	CO_2 emissions; GDPPC; $GDPPC^2$; Education; $Education^2$; Energy use; Trade openness	FEM REM	Inverted U-shaped	FEM - $64,320 REM - $55,157
Tabash et al (2023)	6 GCC region countries	2001 -2019	CO_2 emissions; GDPPC; $GDPPC^2$; Education; $Education^2$; Energy use; Trade openness	FMOLS	No EKC found	FEM - $64,320 REM - $55,157

Source: Compiled by the author

In summary, empirical studies demonstrate that the existence and shape of the EKC are susceptible to country-specific factors such as industrial structure, energy composition, income levels, and econometric methods (Apergis, 2016). While many developed economies show evidence of an inverted U-shaped curve, results from developing regions remain mixed and context-dependent. In those studies that find a significant relationship, a critical component in interpreting these findings is understanding the GDP per capita turning point: the income level at which environmental degradation begins to reverse (Dkhili, 2023). The following section delves deeper into the significance of this turning point and its implications for sustainable development and policymaking.

3.2.3 The role of the turning point

Empirical estimates of the turning point vary widely across countries and regions, reflecting differences in economic structure, energy use, industrial composition and institutional capacity. The turning point is critical for understanding how GDP growth affects environmental degradation (Tanti et al, 2020). The turning point of an inverted U-shaped curve identifies the income level at which economic growth transitions from worsening emissions to improving environmental outcomes. The turning point of a U-shaped curve, where emissions shift from declining to rising, signals a developmental phase requiring careful policy intervention (Tanti et al, 2020).

When the case of an inverted U-shaped is observed and the traditional EKC exists, the GDP per capita turning point in logarithmic terms is given by:

Turning point (log form) = $-\beta_1 / 2\beta_2$

where β_1 is the coefficient of the logarithm of GDP per capita and β_2 is the coefficient of the square of the logarithm of GDP per capita.

The GDP per capita turning point in real terms is given by:

Turning point (in real terms) = $\exp(-\beta_1 / 2\beta_2)$

where β_1 is the coefficient of GDP per capita and β_2 is the coefficient of the square of GDP per capita.

A detailed derivation and interpretation of this formula, including the significance of its coefficients, is discussed in Chapter 4.

In OECD countries, the turning point typically occurs at high-income levels, often above US$30,000. For instance, Iwata et al (2011) estimated turning points between US$77,126 and US$141,683, while Richmond and Kaufmann (2006) reported similar values between US$29,687 and US$110,599. These findings suggest that environmental improvements in developed nations generally emerge after reaching advanced stages of industrialisation, driven by structural shifts and technological innovations.

By contrast, developing countries where an inverted U-shape is found reach their turning points at much lower income levels, typically from US$5,000 to US$15,000. For example, Baek and Kim (2013) examining South Korea during its development phase (1971–2007), identified turning points of approximately US$10,119 and US$11,711, both within the study's sample range. Similarly, Sarkodie (2018) estimated a turning point of US$5,702 for a group of African countries and Saboori and Sulaiman (2013) reported values between US$5,378 and US$8,267 for Malaysia. These turning points are also summarised in Table 3.2.

These empirical variations indicate that the GDP per capita turning point is highly context-specific (Dogan and Inglesi-Lotz, 2020). As the following section explores, these findings necessitate a critical examination of the EKC's theoretical assumptions, the role of policy interventions and the limitations of the methods and techniques used to investigate the EKC.

3.3 Critiques of the EKC hypothesis and the role of policy interventions

While the EKC hypothesis presents a helpful framework for understanding the relationship between economic growth and environmental degradation, empirical testing faces data

challenges and method constraints. These critiques suggest that the EKC is not a universal law but a pattern that depends on country-specific conditions and policy frameworks (Stern, 2004; Gill et al, 2018).

One of the primary critiques of the EKC hypothesis is its simplistic assumption that economic growth automatically leads to improved environmental quality after a GDP per capita turning point (Kaika and Zervas, 2013; Gill et al, 2018). Critics argue that this assumption ignores structural economic changes, institutional quality and policy interventions, which are crucial in shaping environmental outcomes. Without proactive and targeted environmental policies, economic growth may continue to drive environmental degradation rather than reversing it (Kaika and Zervas, 2013; Gill et al, 2018).

According to Gill et al (2018), the EKC hypothesis does not account for the time lag between the onset of economic growth and the decline in environmental degradation. In this view, countries only attain environmental improvements when they implement appropriate policies rather than as a natural consequence of rising income levels. This critique, known as the temporal factor, suggests that countries with weak institutional capacity or slow policy responses may experience prolonged environmental deterioration before any improvements occur (Cao et al, 2022). Developing economies, in particular, face delays in implementing and enforcing environmental policies due to limited financial resources, political instability or conflicting economic priorities. Stronger policy coordination, international funding for sustainability programs, and capacity-building initiatives are needed to ensure a faster transition to cleaner economic growth (Cao et al, 2022).

Additionally, the EKC hypothesis assumes a uniform relationship between growth and emissions across all countries, ignoring the context-specific factors influencing environmental quality, such as industrial composition, technological adoption and governance effectiveness. Ul Husnain et al (2021) argue that developed nations achieved rapid industrialisation by exploiting colonial markets, benefiting from cheap primary goods extracted from their colonies to fuel their industries. Current developing nations must follow a different growth trajectory,

as they do not have colonies to exploit. As a result, the EKC process for developed and developing countries differs significantly. Developing countries face unique constraints, such as lower technological capabilities and financial limitations, that delay their transition to environmental sustainability (Ul Husnain et al, 2021).

According to Rao and Min (2018), the EKC theory often does not account for income inequalities when calculating the turning point. This is because the turning point is typically estimated based on average income levels, which do not reflect disparities in wealth distribution. In highly unequal economies such as South Africa, with a Gini coefficient of 0.63, much of the population may still have income levels far below what is needed to drive demand for environmental quality improvements (World Bank, 2024).

Another critique of the EKC is that it ignores the income elasticity of demand for dirty goods. If the demand for pollution-intensive products remains high even at higher income levels, developed countries may outsource pollution to developing nations through international trade (Gill et al, 2018). This phenomenon, known as the pollution haven hypothesis (discussed in Chapter 2), suggests that developed economies maintain their environmental quality by reducing consumption and shifting production to regions with more relaxed environmental regulations.

These critiques emphasise the need for deliberate, well-designed policy interventions to complement economic growth. The following section explores how policy has influenced the EKC relationship and highlights strategies supporting environmental improvement.

3.3.1 The role of policy

A fundamental distinction exists between environmental policy and regulation. Policies provide strategic direction and frameworks for environmental management, including incentives for clean energy, emissions taxation and support for sustainable industrial practices (further discussed in Chapter 5) (Gupta and van der Grijp, 2010). Regulations are legally

binding enforcement mechanisms that impose limits on pollution, set environmental standards and penalise non-compliance. The distinction between regulation and policy is crucial because countries that rely solely on regulatory enforcement without integrated policy frameworks may struggle to realise the environmental improvements implied by the EKC hypothesis (Kaika and Zervas, 2013; Gill et al, 2018).

The role of policy in achieving environmental improvements has been extensively analysed in recent literature. Studies by Jebli et al (2016) and Bilgili et al (2017) argue that policies such as economic restructuring, green production and trade liberalisation with environmental safeguards are necessary for long-term sustainability. Economic restructuring, often through shifts from heavy industries to service-based or knowledge economies, has been linked to reduced pollution levels in developed countries. Green production and consumption incentives, including subsidies for renewable energy and environmentally friendly technologies, accelerate the decoupling of emissions from growth (Bilgili et al, 2017). Moreover, trade liberalisation and strong environmental regulations can facilitate technology transfer and cleaner production methods, contributing to long-term sustainability without sacrificing economic growth (Shapiro, 2021).

However, for many developing economies, particularly in Africa, a direct leap to a service-based or knowledge-intensive economy may not be feasible without undergoing a phase of industrialisation (UNECA, 2016). Green industrialisation has gained traction as a pathway that balances economic transformation with environmental sustainability in this context. Rather than replicating the pollution-intensive industrialisation paths of the past, green industrialisation promotes low-emission manufacturing, renewable energy adoption and resource-efficient technologies as a foundation for structural change (UNECA, 2016; Pegels and Altenburg, 2020). This approach leverages sectors such as agro-processing, ICT and tourism, which are regarded as industries that can drive growth and employment while maintaining a lighter environmental footprint (Newman et al, 2016; Abdychev et al, 2018).

Recent literature argues that tailored green industrial policies, including targeted subsidies, carbon pricing and strategic investment in green technologies, can support Africa's structural transformation while avoiding the environmental degradation typically associated with late industrialisation (Altenburg and Rodrik, 2017; Black et al, 2023). These insights highlight the importance of context-specific policy frameworks that manage emissions and support inclusive development through environmentally sustainable industrial growth.

According to Jebli and Youssef (2015), proactive policies are also essential for developing economies that have yet to reach the EKC turning point to accelerate the transition to sustainable development. Jebli and Youssef (2015) argue that these economies should focus on reforming fossil fuel subsidies and redirecting funds towards clean energy initiatives. Governments should also expand investment in green technologies by establishing industrial hubs near export zones to reduce transportation emissions and integrate environmental considerations into trade policies. Kirkpatrick and Scrieciu (2008) and Shapiro (2021) also suggest that trade policies should support environmental sustainability by distinguishing between protectionist and ecological conservation policies. Furthermore, public awareness campaigns and educational initiatives are critical in fostering environmental consciousness and behavioural shifts towards sustainability.

In summary, while regulations are essential for enforcing environmental standards, the design and implementation of coherent and proactive policy frameworks determine whether countries can successfully navigate the environmental challenges associated with economic growth (Kaika and Zervas, 2013; Gill et al, 2018). The following section concludes the chapter by synthesising the empirical and theoretical insights presented and reflecting on the implications for EKC applicability across diverse economic settings.

3.4 Conclusion

This chapter has reviewed the empirical evidence surrounding the EKC hypothesis. The discussion has explored the various econometric methods used to investigate the EKC,

including cross-sectional, time-series, and panel data techniques. While these methods offer valuable insights, they also present certain limitations that influence the robustness of EKC findings. The empirical evidence suggests that while the EKC holds in many developed economies, its applicability in developing countries remains highly conditional on institutional quality, income distribution, and policy effectiveness (Apergis, 2016).

The chapter has also highlighted key critiques of the EKC, including its theoretical oversimplifications and the limitations of previously used methods and techniques. The EKC hypothesis assumes a universal relationship between economic growth and environmental quality, but this relationship is highly context-dependent. Factors such as income inequality and industrial dependency on pollution-intensive sectors challenge the assumption that growth alone leads to environmental improvements. Additionally, the study of EKC must consider international trade dynamics, as the pollution haven hypothesis suggests that developed economies may outsource environmental degradation to lower-income countries (Gill et al, 2020).

Furthermore, this chapter has emphasised the critical role of policy in shaping environmental outcomes. Contrary to the assumption that economic growth naturally leads to sustainability, evidence suggests that proactive policy interventions are necessary to accelerate the transition to environmental improvement (Kaika and Zervas, 2013; Gill et al, 2018). Policies such as carbon pricing, investment in renewable energy, and regulatory enforcement play a key role in ensuring that economic expansion does not come at the cost of long-term environmental degradation.

While the EKC remains a valuable framework for understanding the relationship between economic development and environmental sustainability, its applicability is far from universal. Future research must refine EKC models by incorporating country-specific factors, technological advancements and global policy efforts. The conclusions of the studies reviewed in this chapter provide a foundation for the subsequent discussion on the econometric estimation techniques used to analyse the relationship between economic growth and environmental quality in the present study, which are set out in the following chapter.

CHAPTER 4
METHODS, PROCEDURES AND DATA

4.1 Introduction

This chapter describes the techniques employed to conduct the research and data sources for the empirical analysis. In addition, the limitations of the methods and data are also discussed. The thesis contributes to existing knowledge by investigating the EKC for middle-income African countries with limited available literature. In addition to investigating the EKC for the panel of countries, the thesis will also account for country-specific results. This provides more insight into the income growth-environmental degradation nexus for these countries, which are still developing. As stated in Chapter 1, the study's primary goal is to investigate the existence of the EKC in Algeria, Angola, Morocco, Nigeria and South Africa. Sub-goals include estimating each country's turning point and the influence of other relevant economic and development (control variables) on the EKC size and shape. It is important to investigate the EKC hypothesis to highlight the relationship between economic growth and environmental protection policies (Chen et al, 2019).

The chapter is organised as follows: Section 4.2 discusses the research approach and the methods used to address each sub-goal. Section 4.3 discusses the model specifications, variables and data sources used in the study. Section 4.4 outlines the research limitations and concludes the chapter.

4.2 Research approach and methods

The thesis follows a positivist approach based on its use of secondary quantitative data (Caldwell, 2015). It investigates the existence of the EKC from 1990-2019 for selected middle-income African countries. The start of the period is motivated by data availability, while the end is by the objective of observing a long-term pattern. The onset of the COVID-19 pandemic in 2020 would have disrupted economic patterns from regular activity.

The selected countries are Algeria, Angola, Morocco, Nigeria and South Africa. The World Bank (2024) classifies the chosen panel as middle-income countries. This means these countries are at a crucial stage of economic development where the EKC is relevant (Bah et al, 2020). The countries were also chosen to represent different regions in Africa. Algeria and Morocco are in North Africa, Nigeria is in West Africa, and Angola and South Africa are in Southern Africa. This diverse selection aims to highlight how diverse economic contexts influence environmental decisions. Economic structures are also different where Angola, Algeria and Nigeria are classified as oil-rich economies (World Bank, 2024). Morocco is rich in agricultural resources, while South Africa is mineral-rich.

The selected panel has different environmental governance structures. For example, South Africa is the only country on the panel that has an implemented carbon tax policy (discussed in more detail in Chapter 5). This policy variation is crucial for future recommendations regarding formulating continental and country-specific environmental policies. Lastly, the panel of countries was chosen because of data availability. Reliable and comparable data on the dependent variable (CO_2 emissions per capita), explanatory variable (GDP per capita) and control variables (trade openness, energy use and HDI) are available for these countries over the studied period.

The study's empirical analysis is set out and discussed in Chapters 5 and 6 of the thesis. Chapter 5 provides empirical context for the econometric analysis to follow in Chapter 6. Chapter 5 provides a comparative discussion of the socioeconomic characteristics of the selected countries. These characteristics provide information on key economic and environmental indicators in each country. In addition, the research also consulted relevant policy documents to provide a comparative analysis of the environmental policies of the five selected countries. Chapter 5 thus provides a comparative background analysis to outline the environmental progress of the panel of countries, within the context of environmental policies on the African continent.

Chapter 6 presents the econometric analysis that addresses all the sub-goals of the study. First, it investigates the relationship between environmental degradation and economic growth and estimates GDP per capita turning point. Second, it examines the effects of relevant control variables, such as trade openness, energy use and the HDI. Finally, the chapter discusses the policy implications of the findings, offering insights for sustainable development strategies in the selected middle-income African countries.

Following the methodology of Grossman and Krueger (1995), Stern (2004), Tamazian and Rao (2010) and Maranzano et al (2022), the study uses the log-log model functional form for its econometric modelling. The model effectively captures the non-linear relationship between environmental degradation and economic growth. It also allows for a more straightforward interpretation of the slope coefficient results. This is because, with the log-log model, slope coefficients represent percentage changes and illustrate the elasticity of environmental degradation concerning growth. According to Manning and Mullahy (2001; Liddle, 2022), the log-log model reduces the impact of heteroscedasticity in the data, which facilitates robust estimation results.

A combination of panel and time-series econometric models addresses the research objectives. Unit root tests were conducted for both panel and time-series data to determine the stationarity properties of the variables used in this study. For the panel data, panel unit root tests, including Levin, Lin & Chu (2002), Im, Pesaran & Shin (2003), and Fisher-type tests (Maddala and Wu, 1999), were employed. These tests investigate whether the series share a standard unit root process across countries or individually, which provides a foundation for cointegration analysis. For time-series modelling, the Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests were applied to investigate the non-stationarity or stationarity of variables and confirm their orders of integration.

The outcomes of these tests, presented in Chapter 6, guided the selection of appropriate econometric models for both panel and time-series analyses. In addition to the unit root tests, a correlation analysis was conducted to examine the relationships between the dependent and

explanatory variables on the one hand, as well as those between the explanatory variables themselves. The latter is important in assessing the potential for multicollinearity. The results of the correlation matrix are presented and discussed in Chapter 6.

For the panel data analysis, the Fixed Effects (FE), Random Effects (RE) and Pooled Mean Group Autoregressive Distributed Lag (PMG-ARDL) models are used. Studies which have previously used the FE and RE models to investigate the EKC include Wang et al (2024) and Oshin and Ogundipe (2015). The FE and RE models capture heterogeneity across the selected countries. The FE model accounts for unobserved, time-invariant country-specific characteristics, such as geographical or institutional factors. The RE model assumes these characteristics are random and uncorrelated with the explanatory variables (Baltagi, 2008). Previous empirical applications of the FE and RE models in EKC studies were reviewed in Chapter 3, highlighting their relevance and effectiveness in capturing the non-linear relationship between economic growth and environmental degradation.

After the FE and RE models are estimated, the Hausmann test is performed to choose between the two model types. The test was introduced by Hausmann (1978) and has been used in subsequent studies on the EKC, such as those by Hussain et al (2023) and Stern (2003). The test's null hypothesis states that differences in the coefficients estimated by the FE and RE models are not statistically significant. When the null hypothesis is rejected, the FE model is preferred because it accounts for the potential correlation between unobserved country-specific effects and the explanatory variables, ensuring consistency of the estimates. When there is a failure to reject the null hypothesis, the RE model is preferred because it is more efficient, provided that the assumptions of no correlation between the unobserved effects and explanatory variables hold (Gujarati and Porter, 2009).

While the FE and RE models are useful, they have significant limitations in the presence of non-stationary data series. Given the outcome of the panel unit root tests, the PMG-ARDL model is then estimated to facilitate panel cointegration testing. The PMG model was introduced by Pesaran et al (1999) and has been used in subsequent studies to investigate the

EKC, such as Shahbaz et al (2023) and Destek and Sinha (2020). The model is particularly appropriate for this study as it assumes long-run parameter homogeneity while allowing short-run dynamics to vary across countries (Pesaran et al, 1999). It allows for a rich understanding of short and long-term economic-environmental interactions.

The bounds test for cointegration is applied to the PMG-ARDL models to investigate the presence of a long-run equilibrium relationship among the variables across the panel. The bounds test compares the computed F-statistic to critical value bounds at various significance levels (Pesaran et al, 2001; Sam and Apergis, 2021). The test's null hypothesis states no cointegration exists, meaning the variables do not share a stable long-term relationship. If the F-statistic exceeds the upper critical bound, the null hypothesis is rejected, indicating cointegration and a stable long-run relationship among the variables. If the F-statistic falls below the lower critical bound, there is a failure to reject the null hypothesis, suggesting no evidence of cointegration (Nkoro and Uko, 2016). When the F-statistic lies between the two bounds, the inconclusive results require additional analysis.

The panel data set for the study was compiled by the author for the five countries over thirty years from 1990 to 2019, yielding 150 observations for each variable. The measure of environmental degradation used for the study's dependent variable is CO_2 emissions per capita, following Richmond and Kaufmann (2006), Iwata et al (2011), Shafiei and Salim (2014), Jebli and Youssef (2015) and Shahbaz et al (2023). The prominent influence of CO_2 emissions on environmental degradation determines the choice of the dependent variable. CO_2 emissions significantly contribute to climate change and are regarded as a global pollutant,as discussed in Chapter 2.

The main explanatory variables are GDP per capita and GDP per capita squared, which investigate for the existence of the EKC. Control variables include trade openness, energy use, and the HDI, all of which are described in more detail in Section 4.3.[1]

[1] While the literature review in Chapter 2 identified other important determinants of environmental degradation, such as corruption, financial development and the informal sector. These variables were excluded due to data

Chapter 6 also estimates time-series models for individual country-level analysis, using Autoregressive Distributed Lag (ARDL) modelling. This model provides insights into the country-specific dynamics of the EKC. The ARDL model helps estimate country-specific results, even when the variables exhibit mixed orders of integration (I(0) and I(1)) (Nkoro and Uko, 2016). While individual country time series regressions were also estimated using the OLS method, cointegration testing using the Engle-Granger approach is unsatisfactory in the multiple regression context. Hence, the OLS results are included in Appendix B. This is further discussed in the presentation of the results in Chapter 6.

The time-series ARDL models are applied individually to each country, facilitating the estimation of both short-run and long-run relationships. Cointegration testing using the bounds test for the ARDL results is undertaken for the time series section.

4.3 Model specifications, variables and data sources

Annual data for CO_2 emissions per capita, GDP per capita, trade openness, energy use and the HDI were obtained from the World Bank (2024). All the data sourced were transformed into natural logarithms for the log-log model, which forms the basis for all estimation approaches used in this study. These data transformations and modelling techniques apply consistently across all models employed. The basic EKC equation specification for the panel models (FE, RE and PMG-ARDL) is as follows:

$$\ln CO_2PC_{it} = \beta_{0i} + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \varepsilon_{it} \qquad \text{(Equation 1)}$$

CO_2PC, the dependent variable, refers to carbon dioxide emissions stemming from the burning of fossil fuels and the manufacture of cement. Emissions include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring. CO_2 emissions are measured as metric tons per capita.

unavailability across the full study period. Their absence is acknowledged as a limitation of the study and may partly explain why the results did not consistently confirm the inverted U-shape of the EKC.

GDPPC refers to a country's average income per person. GDP per capita assists policymakers in gaining insights into overall economic well-being and the standard of living for the population. It allows for comparisons between countries over time regarding economic growth and development. GDP per capita is measured in US dollars at 2015 constant prices.

GDPPC_SQ is the squared term capturing the diminishing marginal utility of income (Suki et al, 2020). It accounts for non-linear relationships between economic variables. Including the variable relationship is necessary for investigating the curvature relationship of EKC. GDP per capita squared is based on GDP per capita measured in US dollars at 2015 constant prices.

Variations of the basic equation above will include the following control variables commonly included in the literature: trade openness, energy use and the HDI. The exact specifications are discussed in more detail further below, with reference to Tables 4.2 to 4.4.

TRADE refers to trade openness as measured by the proportion of a country's GDP that is accounted for by international trade activities, which includes exports and imports. Trade openness indicates a country's reliance on international trade for economic growth and development. A high percentage indicates that a significant portion of a nation's economic output is derived from international trade. Trade openness is measured as the sum of exports plus imports as a percentage of total GDP (Tabash et al, 2023).

ENE standardises energy use across all forms by converting them into equivalent amounts of energy in a specific oil quantity. Conversion allows for comparisons of different energy forms across countries over time. Different energy forms converted include coal, natural gas, nuclear and renewable energy (Jebli and Youssef, 2012; Dogan and Turkekul, 2016; Bano and Zhang, 2020). Energy is measured in kilograms of oil equivalent per capita.

HDI assesses and compares the overall level of human development across countries. It considers three dimensions: health, education and income (Kpolovie et al, 2017). By

incorporating different dimensions, the human development index provides a holistic measure of human well-being. The human development index does not have a specific unit of measurement. It is an index that ranges between zero and one, where a higher value indicates a higher level of human development. Countries with a higher HDI score are generally characterised by longer life expectancy, better access to education, and higher income levels per capita. A lower HDI score indicates poorer human development outcomes and challenges in achieving higher living standards, health, and education than countries with higher HDI scores (Hussain and Dey, 2021).

Table 4.1 below outlines the theoretical expectations for the estimated coefficients of the variables in this study, providing a framework for interpreting the econometric results discussed in Chapter 6. The following prior expectations are based on theoretical considerations and prior studies.

Table 4.1: Prior expectations

Variable	**Sign**	**Rationale**
LNGDPPC	Positive	Economic growth initially increases emissions due to industrialisation.
LNGDPPC_SQ	Negative	Quadratic relationship between GDP per capita and CO2 emissions. Initially, it increases at a diminishing rate, peaks, and potentially decreases as GDP per capita grows.
LNTRADE	Mixed	Trade openness facilitates environmentally friendly technology transfer, which reduces emissions. Trade may also attract polluting industries to countries with relaxed regulations, which increases emissions.
LNENE	Positive	Higher energy consumption, mainly from fossil fuels, increases CO_2 emissions.
LNHDI	Negative	Higher development levels support sustainable practices and reduce emissions.

Source: Compiled by the author

The initial specifications exclude the HDI variable for the FE and RE models (Models 1 and 2). This is due to constraints in the number of variables that can be included in the RE specification, given the number of cross-sectional units (countries) in the study. The basic specification for Models 1 and 2 (FE and RE) is as follows:

$$\ln CO_2PC_{it} = \beta_{0i} + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \beta_4 \ln ENE_{it} + \varepsilon_{it}$$

After performing the Hausman test, which indicated that the FE model is preferred, the HDI was included in the estimation of an expanded FE model (Model 3). The modified FE specification for Model 3 (to include HDI) is as follows:

$$\ln CO_2PC_{it} = \beta_0 i + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \beta_4 \ln ENE_{it} + \beta_5 \ln HDI_{it} + \varepsilon_{it}$$

The PMG-ARDL model is estimated incrementally using a stepwise regression approach, where explanatory variables are progressively added. The approach is adopted to evaluate the incremental impact of each explanatory variable on CO_2 emissions.

With the incremental approach employed, PMG-ARDL specifications for Models 4-11 are in Table 4.2 below.

Table 4.2: PMG-ARDL model specifications

Model	**Specification**
Model 4	Basic model: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \varepsilon i_t$
Model 5	Adds LNTRADE: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln TRADEi_t + \varepsilon i_t$
Model 6	Adds LNENE: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln ENEi_t + \varepsilon i_t$
Model 7	Adds LNHDI: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln HDIi_t + \varepsilon i_t$
Model 8	Adds LNTRADE and LNENE: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln TRADEi_t + \beta_4 \ln ENEi_t + \varepsilon i_t$
Model 9	Adds LNTRADE and LNHDI: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln TRADEi_t + \beta_4 \ln HDI_t + \varepsilon i_t$
Model 10	Adds LNENE and LNHDI: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln ENEi_t + \beta_4 \ln HDIi_t + \varepsilon i_t$
Model 11	Complete model: $\ln CO_2PCi_t = \beta_{0i} + \beta_1 \ln GDPPCi_t + \beta_2 \ln GDPPC\_SQi_t + \beta_3 \ln TRADEi_t + \beta 4 \ln TRADEi_t + \beta_5 \ln HDI_t + \varepsilon i_t$

Source: Compiled by the author

The time-series analysis, conducted after the panel data modelling, includes ARDL time series estimations for each country. The ARDL models are estimated incrementally, using a stepwise regression approach to assess explanatory variables' individual and combined impacts on CO_2 emissions.

For the ARDL time series models (Models 12-16), the basic specification is as follows:

$$CO_2PC_t = \beta_0 + \beta_1 GDPPC_t + \beta_2 GDPPC\_SQ_t + \varepsilon_t$$

With the incremental approach employed, the model specifications for Models 12-16 are set out in Table 4.3 below.[2]

Table 4.3: ARDL time series specifications

Model	Specifications
Models 12-16	Basic model: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \varepsilon_{it}$
Models 12a-16a	Adds LNTRADE: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \varepsilon_{it}$
Models 12b-16b	Adds LNENE: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln ENE_{it} + \varepsilon_{it}$
Models 12c-16c	Adds LNHDI: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln HDI_{it} + \varepsilon_{it}$
Models 12d-16d	Adds LNTRADE and LNENE: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \beta_4 \ln ENE_{it} + \beta_5 \ln HDI_{it} + \varepsilon_{it}$
Models 12e-16e	Adds LNTRADE and LNHDI: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \beta_4 \ln HDI_{it} + \varepsilon_{it}$
Models 12f-16f	Adds LNENE and LNHDI: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln ENE_{it} + \beta_4 \ln HDI_{it} + \varepsilon_{it}$
Models 12g-16g	Complete model: $\ln CO_2PC_{it} = \beta_0 + \beta_1 \ln GDPPC_{it} + \beta_2 \ln GDPPC\_SQ_{it} + \beta_3 \ln TRADE_{it} + \beta 4 \ln TRADE_{it} + \beta_5 \ln HDI_{it} + \varepsilon_{it}$

Source: Compiled by the author

The bounds test for cointegration is also applied to the ARDL models (12–16, including each version) to investigate the presence of a long-run equilibrium relationship among the variables. In this instance, the time series ARDL cointegration testing determines whether a long-run relationship exists among the variables for each country (Narayan, 2005).

The GDP per capita turning point for the time series ARDL models is also calculated using the formula exp $(-\beta_1/2\beta_2)$, where applicable.

β_1 is the coefficient of lnGDPPC, the linear term.
β_2 is the coefficient of lnGDPPC_SQ, the quadratic term.
exp is the exponential function is used to reverse the natural logarithm transformation.

[2] Each model number applies to an individual country, with the five countries considered in alphabetical order. Hence Model 12 and its various iterations (12a to 12g) are for Algeria, while Model 13 and versions 13a to 13g apply to Angola. Next, Model 14 together with versions 14a to 14g are for Morocco, while Model 15 plus 15a to 15g are estimated for Nigeria. Finally, Model 16 and its various versions (16a to 16g) are for South Africa. The time series results are presented in clearly labelled tables for each country in Section 6.5 of Chapter 6.

In each case, a goodness of fit for the model is assessed and significance testing is used to determine whether the quadratic term β_2 is statistically significant. This is crucial because the sign (+/-) of slope coefficient β_2 determines whether the hypothesis of the EKC holds.

4.4 Conclusion and limitations

This chapter discussed the methodology employed to investigate the existence of the EKC for five middle-income African countries. The study uses both panel data modelling, including FE, RE and PMG-ARDL approaches, as well as individual time series analysis using the ARDL approach. Basic and modified specifications for each of the models were provided. Annual data from 1990 to 2019 is analysed for Algeria, Angola, Morocco, Nigeria, and South Africa, which are classified as middle-income African countries and high CO_2 emitters by the World Bank (2024). The dependent variable (CO_2 emissions per capita), explanatory variables (GDP per capita and GDP per capita squared) and control variables (trade openness, energy use and human development, as measured by the HDI) were also discussed. The data source for the variables is the World Bank (2024).

Alternative methods the study could have used are nonparametric models, such as the kernel and spline regression. These regressions allow for flexibility in exploring variable relationships that are non-linear, such as the EKC relationship (Wang, 2010). However, interpreting variable relationships with the kernel and spline regressions is often challenging. This is because these models require large datasets to estimate relationships accurately. Additionally, interpreting coefficients in these models can be difficult, as they provide smooth estimates of the EKC relationship, with coefficients that vary across the range of the explanatory variable (Fakih and Marrouch, 2019). The relationship between GDP per capita and CO_2 emissions is modelled as a continuous curve rather than a set of fixed, interpretable coefficients.

Apart from CO_2 emissions, other proxies for degradation that could have been used include sulphur dioxide, nitrogen oxide, total suspended particulate and other greenhouse emissions (Purcel, 2020). These are classified as local pollutants, which are more accessible and less

costly to manage (as discussed in Chapter 2). However, these pollutants only capture specific geographical impacts that must be translated globally. This study proxies degradation with CO_2 emissions per capita to illustrate the country's environmental and growth progress where future recommendations can be made and countries can conform to international treaties. Understanding the influence of global pollutants, such as CO_2 emissions, allows individual countries to analyse further the impact of these local pollutants in their respective economies. This study, in alignment with the paper by Purcel (2020), suggests that future studies can complement global pollutants with local pollutants.

The selected control variables (trade openness, energy use and the HDI) are chosen because of data availability. These variables are also supported by economic theory and previous studies, which identify them as important mediating factors between GDP growth and environmental degradation. For the educational variable, there was a limitation in finding an appropriate proxy to account for the socioeconomic impacts of the EKC. The most accurate proxy is the mean years of schooling because it reflects long-term investments in human capital. Mean years of schooling are crucial for understanding education's broad impacts on environmental outcomes (Maranzano et al, 2022). However, the proxy is only available for some of the selected five countries over the studied period. Therefore, the study uses the Human Development Index as its educational proxy, as discussed in Section 4.2.

The following chapter provides a comparative analysis of the socioeconomic characteristics and environmental policies of the selected countries to contextualise the econometric analysis in Chapter 6.

CHAPTER 5
THE SOCIOECONOMIC CONTEXT AND ENVIRONMENTAL POLICY CONTEXT OF THE SELECTED COUNTRIES

5.1 Introduction

As defined in Chapter 2, the EKC hypothesises a quadratic relationship between economic growth and environmental degradation, suggesting that environmental pressures initially increase with economic growth but eventually decline as economies develop and adopt cleaner technologies (Barbier, 1997; Martinez-Navarro et al, 2020). However, this relationship is often shaped by country-specific factors, including environmental policies, institutional capacity and commitments to international climate change mitigation frameworks, such as the Paris Agreement. Understanding these contextual influences is crucial for understanding the EKC in middle-income African countries.

Building on the methodological framework outlined in Chapter 4, this contextual chapter provides the socioeconomic and environmental backgrounds of Algeria, Angola, Morocco, Nigeria and South Africa. Chapter 5 is the empirical context, providing an original analysis of economic and environmental factors influencing degradation levels in the selected countries. Chapter 5 conducts an in-depth examination of background data and policy documents to assess the real-world implications of environmental policies.

The rest of the chapter is organised as follows: Section 5.2 begins with a discussion of the environmental framework for Africa, Agenda 2063. Section 5.3 discusses specific continental policies, such as the African Strategy on Climate Change and the African Renewable Energy Initiative. Section 5.4 provides a detailed examination of the economic and environmental backgrounds of the selected countries. Section 5.5 discusses the country-specific environmental policies implemented to combat climate change impacts. Section 5.6 concludes the chapter.

5.2 An environmental policy framework for the African continent

A continental environmental policy framework is crucial in fostering coordinated efforts to control pollution, mobilising financial resources and establishing globally recognised environmental standards (Ndizera and Muzee, 2018). Continental policies are also important for Africa as it has transboundary ecosystems that can benefit from joint management frameworks (Kamath et al, 2023). Transboundary ecosystems refer to natural ecological systems that span the political boundaries of two or more countries, including shared rivers, lakes, forests, wetlands and mountain ranges. Examples in the African context include the Nile River, the Congo Basin and the Great Rift Valley (among others), which require coordinated policies for their protection and sustainability (Ndizera and Muzee, 2018; Kamath et al, 2023). Effective management of the ecosystems prevents critical natural resources from overexploitation and ensures that local communities who depend on them continue to benefit economically and environmentally (Kamath et al, 2023). A coordinated continental approach attracts international support (Ndizera and Muzee, 2018).

Global partnerships and funding mechanisms, such as the Green Climate Fund GCF (discussed in Section 5.5.2), are more accessible when Africa presents a unified policy stance on environmental issues (AUC and AUDA, 2022). The importance of continental policy frameworks is exemplified by Agenda 2063, Africa's blueprint for sustainable development and transformation. Agenda 2063 provides a strategic framework for aligning environmental governance with economic and social priorities (Nwozor et al, 2021). The following section delves deeper into the role of this framework initiative in shaping Africa's environmental policies and its implications for sustainable development.

5.2.1 The impact of Agenda 2063 as a policy framework

Agenda 2063, endorsed by the African Union Commission (AUC), serves as Africa's strategic framework for achieving inclusive economic growth, social development and environmental sustainability over fifty years, from 2013 to 2063 (AU, 2024). While Agenda 2063 is not

necessarily an environmental policy, it provides a blueprint for addressing economic and environmental challenges. Environmental sustainability is a vital component of the plan, where specific goals are set and the measures to address them (African Peer Review, 2023).

Agenda 2063 aims to position Africa as a leader in innovation, industrialisation and sustainable development, leveraging its abundant natural resources, youthful population and cultural diversity to achieve transformation (AU, 2024;). This is done by encouraging full participation by all the continent's stakeholders. It is reported that all fifty-five member states of the African Union have agreed to participate in implementing the plan (AU, 2024;). However, most member states are in a critical phase of development where balancing economic growth with environmental sustainability is vital. This phase is marked by the need to prioritise industrialisation and infrastructure development to stimulate economic progress while simultaneously addressing environmental challenges such as the impacts of climate change. To support member states in achieving the balance, Agenda 2063 is implemented in phases, allowing them to align their strategies incrementally and address priorities in a structured and sustainable manner (AU, 2024).

The first ten-year implementation plan (2014-2023) focuses on short-term, immediate priorities and actions to kick-start the broader Agenda 2063 (AU, 2024). In this phase, specific targets include increasing renewable energy use, enhancing food security through sustainable agriculture and advancing regional integration through infrastructure projects like the African Integrated High-Speed Rail Network (AIHSRN). The AIHSRN aligns with environmental sustainability goals by promoting rail transport as a greener alternative to road and air travel, with higher carbon footprints (Rajab, 2019). High-speed rail systems such as the AIHSRN use advanced technologies and electrification, which allow for reduced reliance on fossil fuels when paired with renewable energy sources like solar or wind power. Additionally, the rail network's ability to transport large volumes of passengers and freight simultaneously reduces congestion on highways and airports, further contributing to a decrease in overall air pollution (Rajab, 2019; Liu et al, 2022).

Initial phases of the AIHSRN began in 2014 with feasibility studies and pilot projects in Kenya, Ethiopia, and Morocco (AU, 2015; Deel-Smith, 2022). Morocco's high-speed rail system, the Al Boraq, developed in 2018, serves as a model for other African nations, showcasing such infrastructure's economic and social benefits. The Al Boraq rail project has facilitated technological transfers, particularly in railway engineering, infrastructure design and operational management (AU, 2015; Deel-Smith, 2022). These transfers occurred through collaborations with international partners such as the French National Railways, which played a key role in the project's development. Moroccan engineers and technicians worked closely with foreign experts, gaining invaluable knowledge in high-speed rail technology, construction practices and maintenance protocols (AU, 2015; Deel-Smith, 2022). This collaboration has built local capacity, equipping Morocco with the technical expertise required to manage and expand its rail network independently in the future. The technological transfers associated with the Al Boraq project align with environmentally friendly practices rather than the Pollution Haven Hypothesis, as discussed in Chapter 2.

The second ten-year plan (2024-2033) builds on the first phase by focussing on medium-term strategic objectives and initiatives, which include reducing Africa's dependency on raw material exports (AU, 2024). It prioritises harmonising national policies and aligning them with the Sustainable Development Goals (discussed in Chapter 2). The phase also emphasises sustainable land use practices to combat deforestation, desertification and soil erosion, aligning with continental efforts such as the Great Green Wall (GGW) initiative (Chevallier and Chesterman, 2022). The GGW initiative launched in 2007 refers to Africa's land restoration program aimed at combating desertification, restoring degraded land and enhancing climate resilience in the Sahel region (Chevallier and Chesterman, 2022).

Nigeria is the only county from the Sahel region included on the panel and it has made significant strides in implementing the GGW (CISLAC and TI, 2024). The initiative addresses critical environmental challenges, specifically in the northern regions of Nigeria, particularly in states such as Borno, Sokoto, Katsina, Yobe, and Jigawa, which are heavily affected by desertification and drought (CISLAC and TI, 2024). According to Chevallier and Chesterman

(2022), Nigeria has restored over 5 million hectares of degraded land under the GGW initiative and created 20,000 jobs through planting drought-resistant tree species such as Acacia and Neem. This has improved land fertility, restored lands to become arable, increased agricultural productivity and reduced dependence on food imports.

In the context of the Great Green Wall (GGW) initiative, the trees and vegetation planted to act as natural carbon sinks by removing CO_2 emissions from the atmosphere and storing it in their biomass (trunks, branches and leaves) and the surrounding soil (Sacande and Berrahmouni, 2016). This function helps mitigate the impacts of climate change by offsetting carbon emissions. Carbon sinks are natural or artificial systems that absorb and store more carbon dioxide (CO_2 emissions) from the atmosphere than they release, helping to reduce the concentration of greenhouse gases in the atmosphere. This supports Nigeria's climate goals under its Nationally Determined Contribution (NDC) and contributes to global efforts to reduce greenhouse gas emissions.

Agenda 2063 is structured around five ten-year implementation plans designed to contribute to the overarching vision of transforming Africa by 2063. This thesis focuses on the first (2014–2023) and second (2024–2033) phases to provide a foundation for understanding the environmental and economic context leading up to Agenda 2063 and the progress made during its formative years. The following section delves into how the framework has been operationalised and examines its implementation strategies.

5.2.2 Implementation of Agenda 2063

Multiple stakeholders implement Agenda 2063 at different levels. The chairperson of the AU, in collaboration with Regional Economic Communities (RECs), the African Development Bank (AfDB) and other development agents, is responsible for overall coordination (A U, 2024). The primary responsibility of the AU is to ensure alignment by guiding implementation and monitoring.

At the regional level, RECs are the primary implementers of Agenda 2063 (Uzodike, 2009; Nwozor et al, 2021). RECs refer to regional groupings of African states and include the East African Community (EAC), the Economic Community of West African States (ECOWAS), the Southern African Development Community (SADC) and the Common Market for Eastern and Southern Africa (COMESA). The selected countries belong to different RECs: Algeria and Morocco belong to the Arab Maghreb Union (AMU), Nigeria belongs to ECOWAS, while Angola and South Africa belong to SADC (Uzodike, 2009; Nwozor et al, 2021).

The primary tools national governments use are RECs to communicate their achievements, constraints and policy needs to the AU. This process identifies implementation gaps and ensures that necessary adjustments are made (Amani Africa, 2023). For example, ECOWAS regularly assesses economic development and climate action efforts, providing recommendations for policy improvements (ECOWAS, 2020). Another example is SADC, which has worked closely with international partners to fund large-scale renewable energy projects in Southern Africa, advancing the region's transition to sustainable energy. For example, the Redstone Concentrated Solar Power (CSP) Plant, a 100 MW CSP plant located in the Northern Cape, uses molten salt technology to store energy, enabling power generation even at night (ACWA Power, 2023). It is a flagship project under SADC's renewable energy initiatives.

Algeria’s position within UMA presents unique challenges due to limited regional cooperation. This is because UMA, comprising of Algeria, Morocco, Tunisia, Libya and Mauritania, has struggled with regional integration due to political tensions and weak institutional frameworks (Chabbouh, 2018). This lack of coordination has led to missed opportunities for environmental sustainability, preventing the region from effectively addressing climate change and green economic development. For example, North Africa faces severe water scarcity, yet no formal transboundary agreements exist between UMA states (Zarhloule et al, 2019). Algeria and Morocco share the Northwestern Sahara Aquifer System (NWSAS), one of the largest groundwater reserves in North Africa. However, due to long-standing political tensions between the two countries, there is no formal bilateral agreement on managing this critical

water resource (Zarhloule et al, 2019). As a result, over-extraction and inefficient use threaten its sustainability, exacerbating water scarcity in both nations.

In contrast, East African nations (Burundi, Egypt, Ethiopia, Kenya, DRC, Rwanda, Sudan, Tanzania and Uganda) cooperate on managing the Nile Basin, ensuring sustainable water use (Nile Basin Initiative, 2013). This emphasises the role of coordination between countries in achieving effective environmental governance, as collective management of natural resources enables better policy harmonisation, shared infrastructure development and improved climate resilience (Nile Basin Initiative, 2013).

The lack of coordination in UMA also limits environmental funding opportunities (Tippmann et al, 2013). While SADC and ECOWAS secure regional climate finance partnerships, UMA states must compete individually, reducing their ability to access international sustainability grants. For example, SADC's Climate Change Adaptation Strategy has enabled countries like South Africa and Angola to access climate resilience funding from the AfDB and GCF, supporting projects in renewable energy, disaster risk reduction and sustainable agriculture (SADC, 2021).

The AfDB is crucial in mobilising financial resources to support climate resilience and sustainable development across Africa (AfDB, 2021; Bah and Azadi, 2021). Its primary function is to provide funding, secure international investments and coordinate financial partnerships to help African nations transition toward low-carbon economies and adapt to climate change. The financial role of the AfDB will be discussed in greater detail in Section 5.5.2, which focuses specifically on funding mechanisms for climate policies.

5.3 Specific African environmental policies

Africa is particularly vulnerable to the impacts of climate change due to its reliance on climate-sensitive sectors such as agriculture, forestry and fisheries, as well as its limited adaptive capacity. Despite this vulnerability, the continent contributes only around 4% of global

greenhouse gas emissions, highlighting its imbalanced burden in addressing global climate challenges (Rumble, 2019). Continental policies are critical in ensuring that Africa's unique vulnerabilities and priorities are addressed in international negotiations and agreements, such as the Paris Agreement.

The AU serves as both a continental policy framework and the key driver behind implementing other significant continental policies addressing climate change and environmental challenges (Obah-Akpowoghaha et al, 2022). While the African Union introduced the African Union Green Recovery Action Plan (AUGRAP) in 2021 to address post-pandemic sustainability challenges, this thesis focuses on earlier continental environmental policies, particularly the African Strategy on Climate Change (ASCC) and the African Renewable Energy Initiative (AREI), which were launched within the study period (1990–2019) and play a central role in shaping Africa's climate agenda.

5.3.1 The African Strategy on Climate Change

The ASCC is an African continental policy adopted in January 2015 (AU, 2024). The policy's objectives include resource mobilisation, strengthening climate resilience and promoting low-carbon development across African countries. The ASCC is firmly aligned with environmental frameworks such as the Paris Agreement, the Sustainable Development Goals (SDGs) and Agenda 2063, ensuring its relevance in continental and international contexts (AU, 2024).

A just green transition is a significant focus of the ASCC to address the socioeconomic inequalities exacerbated by climate change. The strategy acknowledges that the most vulnerable communities are often disadvantaged by climate change whilst contributing the least to global emissions (Presidential Climate Commission, 2022). To address this, the ASCC promotes the development of ambitious, context-specific climate plans tailored to national circumstances. These plans aim to create green jobs, support sustainable livelihoods and reduce economic disparities by fostering inclusive and equitable climate solutions.

Several African countries have made notable progress in implementing just transition policies under the ASCC framework. South Africa is an example, having developed a Just Transition Framework in 2022 that integrates climate action with economic restructuring (Presidential Climate Commission, 2022). The country has committed to phasing out coal dependency while ensuring that workers in the fossil fuel sector are retrained and integrated into new employment opportunities within the renewable energy sector. Through initiatives such as the Presidential Climate Commission (PCC) and partnerships with the Just Energy Transition Partnership (JETP), South Africa has secured substantial international funding, an initial commitment of $8.5 billion from the International Partners Group, comprising the United Kingdom, United States, France, Germany, and the European Commission (Tyler and Mgoduso, 2022). This funding is intended to support South Africa's transition to a low-carbon economy by investing in renewable energy, electric vehicles and green hydrogen projects. The funding will also ensure that workers currently employed in coal mines, power plants and related industries are equipped with new skills that align with the country's green economy priorities (Tyler and Mgoduso, 2022).

According to Tyler and Mgoduso (2022), training will be provided to reskill workers through Technical and Vocational Education and Training (TVET) colleges and partnerships with renewable energy firms. TVET colleges such as False Bay TVET College, Nkangala TVET College and Port Elizabeth TVET College have been identified as suitable institutions for reskilling workers. False Bay TVET College, for instance, offers specialised training in photovoltaic systems and renewable energy technologies, equipping students with skills in solar panel installation and maintenance (False Bay TVET College, 2022).

Nkangala TVET College has launched industry-accredited renewable energy training programs as part of a Reskilling Lab initiative, focusing on solar photovoltaic (PV) installation and entrepreneurship (Nkangala TVET College and RES4Africa Foundation, 2023). Port Elizabeth TVET College provides a National Certificate Vocational (NCV) program in Renewable Energy, covering subjects such as Electrical Principles and Practice, Electronic Control and

Digital Electronics and Workshop Practice, preparing students for careers in the renewable energy sector (Port Elizabeth TVET College, 2024).

5.3.2 The African Renewable Energy Initiative

As part of the ASCC's commitment to sustainable development, the African Renewable Energy Initiative (AREI) was introduced in 2015 during the 21st Conference of the Parties (COP21) in Paris (AREI, 2018; AfDB, 2020). AREI is a continental policy framework designed to accelerate the transition to clean and sustainable energy across Africa. The policy aligns with Agenda 2063 and the ASCC objectives by facilitating large-scale solar, wind and hydro energy investments. The policy also recognises Africa's energy challenges, including limited electricity access and dependence on fossil fuels and seeks to unlock the continent's vast renewable energy potential (Federal Government of Nigeria, 2021).

Specific goals of the AREI include generating 10GW of new renewable energy capacity by the 2020 initial phase, which spanned from 2016 to 2020 (AREI, 2018; Haidi and Cheddadi, 2022). The initiative also aims to scale up renewable energy to 300GW by 2030, providing universal access to electricity across Africa (AREI, 2018). Nigeria has leveraged AREI to expand off-grid solar energy solutions, mainly through the Solar Power Naija initiative introduced in 2020 to electrify rural communities. The initiative, launched under Nigeria's Economic Sustainability Plan (ESP), is designed to increase energy access, reduce reliance on fossil fuels, and support economic growth in off-grid areas (Federal Government of Nigeria, 2021).

Through public-private partnerships (PPPs) and international funding, Solar Power Naija seeks to deploy 5 million solar home systems and mini-grids, ultimately electrifying over 25 million people across Nigeria's rural regions (Federal Government of Nigeria, 2021; World Bank, 2022). The project prioritises regions with low electrification rates, such as parts of Kano, Kebbi, Adamawa, and Taraba states, where grid infrastructure is weak or non-existent (Federal Government of Nigeria, 2021).

The initiative also supports job creation and local enterprise development, intending to generate 250,000 direct and indirect jobs in solar panel installation, maintenance and distribution networks. Small businesses, schools and healthcare centres in rural areas benefit from clean, reliable power, improving education, healthcare delivery, and local commerce (Federal Government of Nigeria, 2021; World Bank, 2022).

5.3.3 The implementation process of the ASCC and AREI

The ASCC and AREI are guided by the AU and supported by institutions such as the African Ministerial Conference on the Environment (AMCEN), the AfDB and the New Partnership for Africa's Development (NEPAD). AMCEN plays a policy and advisory role, ensuring that environmental sustainability remains a priority for African governments (NEPAD, 2015; AMCEN**,** 2021). It provides guidelines for climate governance and facilitates continental dialogue on climate change policies. AMCEN also ensures that Africa's collective climate agenda is represented in international negotiations, such as the UNFCCC Conferences of the Parties (COPs). NEPAD ensures climate initiatives align with Agenda 2063 by working with governments to scale up investments in clean energy and institutional frameworks for climate governance (NEPAD, 2015).

Continental initiatives such as AREI and ASCC are backed by multilateral funding agencies like the GCF and AfDB, which are crucial in channelling resources and technical support. The AfDB, accredited by the GCF, finances infrastructure resilience, early warning systems, and renewable energy transitions across member states while providing research and regulatory guidance (AfDB, 2024).

The ASCC and AREI are not legally binding and countries may demonstrate varying degrees of commitment to achieving their objectives. However, the development of such policies serves a crucial role as they encourage member states to develop more binding national plans (Sparks, 2016).

Progress of the AREI to accelerate the transition to clean energy has often been hindered by several institutional, financial and infrastructural challenges. A significant challenge for AREI is the inconsistent implementation of renewable energy policies across African countries (Sparks, 2016; Haidi and Cheddadi, 2022). Many governments have set ambitious renewable energy targets, but policy execution remains fragmented due to weak regulatory frameworks that delay project approvals.

Regulatory uncertainty has also affected policy delays, where frequent government policy changes discourage long-term private investment. According to Sparks (2016), Nigeria's national grid cannot handle large-scale solar integration, causing frequent electricity blackouts. Another example of regulatory delays is permit delays, where projects take years to obtain necessary approvals, reducing investor confidence and investments in large-scale solar projects.

5.4 Overview of selected countries: Economic and environmental context

As discussed in Chapter 4, the five selected countries, Algeria, Angola, Morocco, Nigeria, and South Africa, were chosen for this study based on their shared economic and environmental characteristics, which align with the research objective of investigating the EKC hypothesis in middle-income African nations. These countries represent diverse economic structures yet share key similarities, including their classification as middle-income economies and status as major CO_2 emitters in Africa (Bah et al, 2020). This section explores their economic profiles, key industries, energy consumption patterns and environmental challenges, offering insight into how their development trajectories influence CO_2 emissions and sustainability efforts.

5.4.1 Economic background

According to the World Bank (2024), Algeria, Angola, Morocco, Nigeria and South Africa operate as mixed economies, where both the government and private sector play active roles in

economic activities. However, state intervention and private sector involvement vary significantly across the countries.

In Algeria, Angola and Nigeria, the government maintains significant control over key sectors, particularly oil and gas, which are the backbone of these economies. State-owned enterprises (SOEs) such as Algeria's Sonatrach, a major energy company founded in 1963, limit private sector participation in the hydrocarbon sector (Entelis, 1999; Black, 2014). The SOE remains fully operational despite being founded over half a century ago. In recent years, it has been actively involved in various projects to enhance its operations and expand its energy portfolio. For example, in October 2024, Sonatrach signed a memorandum of understanding with Cepsa**,** a Spanish multinational energy company specialising in oil, gas and renewable energy, to explore the development of green hydrogen production in Algeria (Cepsa, 2024).

Green hydrogen production refers to generating hydrogen using renewable energy sources through electrolysis (Maka and Mehmood, 2024). Unlike grey hydrogen (produced from fossil fuels) and blue hydrogen (which captures carbon emissions), green hydrogen is considered completely carbon-free because it is produced using clean energy sources such as solar, wind, or hydropower (Tuluhong et al, 2024). Green hydrogen is important for environmental sustainability because it helps reduce CO_2 emissions in heavy industries (steel, cement, and chemicals), power generation, and transportation. It also acts as an energy carrier, allowing excess renewable energy (from wind or solar) to be stored and used later (Tuluhong et al, 2024).

Similarly, Angola's oil industry (petroleum and natural gas resources) is primarily managed by the state-owned Sonangol, founded in 1976 (Sonangol USA Company, 2023). The company maintains a near-monopoly over production and distribution, which has historically restricted foreign direct investment (FDI) by limiting entry for private and international energy firms. This lack of competition may reduce the potential for technological innovation and efficiency improvements in the sector. However, as a large SOE operating within a natural monopoly, Sonangol also has the potential to drive innovation due to its scale and capacity to invest in Research and Development (R and D). Such firms can pioneer technological improvements

and infrastructure development when appropriately funded and managed. Nevertheless, in Angola's case, inefficiencies and limited competition have often constrained this potential, resulting in underinvestment in cleaner technologies and slow progress toward energy sector diversification (Moti, 2019). The over-reliance on oil and gas exports makes Angola highly susceptible to volatility in global commodity prices, affecting its economic stability, investment climate, and environmental policy implementation (Leao and Shetty, 2022).

Morocco and South Africa have more diversified economies with more substantial private sector participation, particularly in finance, manufacturing and renewable energy (OECD, 2011). South Africa, despite its historical legacy of Apartheid and state control, is Africa's most industrialised economy and has Independent Power Producers (IPPs) contributing significantly to the electricity market (Montmasson-Clair and Ryan, 2014). These IPPs must be licensed and sell their generated electricity back to the national utility, Eskom, which retains a monopoly on electricity distribution (NBI, 2024). Although this framework has attracted private investment in generation, it limits the full liberalisation of the electricity sector, and regulatory challenges have slowed progress in renewable energy adoption (de la Rue du Can and Covary, 2023).
South Africa's mining sector is highly energy-intensive with large-scale extraction and processing operations requiring substantial amounts of electricity, water and fossil fuels (Majola and Langerman, 2023). The country's reliance on coal-fired power plants for electricity generation contributes to its high carbon footprint, making it one of the largest CO_2 emitters in Africa. The platinum, gold, and manganese industries require high-temperature smelting and refining processes, which depend on electricity from coal-fired plants, further exacerbating emissions (Majola and Langerman, 2023). This dependence on fossil fuel-based energy makes transitioning toward a more sustainable, low-carbon economy challenging.

Morocco has actively promoted public-private partnerships (PPPs) in agriculture, tourism and renewable energy industries, making it a leading country in attracting FDI for renewable energy projects (Boudoudouh, 2024). An example of a PPP supporting renewable energy is the Tarfaya Wind Farm, one of Africa's most significant onshore wind energy projects. The project was developed through a public-private partnership between the Moroccan government and private

sector stakeholders, including Engie (a French multinational energy company) and Nareva Holding (a Moroccan private energy firm). It was financed with $500 million in investment (ENGIE Newsroom, 2014; Climate Action, 2017). The wind farm supplies 300 megawatts (MW) of clean electricity, meeting the energy needs of 1.5 million households while reducing CO_2 emissions by 900,000 tons annually (Climate Action, 2017). These large-scale PPP-driven projects highlight Morocco's ability to attract private capital and FDI into renewable energy infrastructure, accelerating its transition toward a low-carbon economy.

Nigeria presents a hybrid model, where the government has historically controlled key sectorsbut economic reforms have led to partial liberalisation in industries such as telecommunications, banking and energy (U.S. Department of State, 2023). The privatisation of energy generation through the Electricity Sector Reform Act (2005) has increased private sector engagement to approximately 60% of the electricity distribution market (Babatunde et al, 2023). However, bureaucratic inefficiencies, policy inconsistencies and corruption hinder full private investment, particularly in oil refining and infrastructure projects (Onuh et al, 2024).

Table 5.1 below shows the economic characteristics of the selected countries, including population size, life expectancy, GDP per capita, GDP growth rate, urbanisation rate, access to electricity and literacy rate. These indicators provide a basis for comparing the selected countries' economic structures and development levels, helping to understand their economic and environmental contexts.

The countries exhibit significant differences in economic output, as measured by GDP per capita. South Africa has the highest GDP per capita at US$6 006.5, followed by Algeria US$4,660.9), Morocco (US$3,403.3), Nigeria (US$2,416.4), and Angola (US$2,332.9 (World Bank, 2024). This suggests South Africa and Algeria benefit from more diversified economies and industrial development. In contrast, despite their resource wealth, Angola and Nigeria exhibit lower GDP per capita due to economic inefficiencies and governance challenges (Olayungbo and Adediran, 2017).

Table 5.1: Economic Background of Selected Countries (Data for 2023, unless otherwise specified)

Characteristics	Algeria	Angola	Morocco	Nigeria	South Africa
Population size (millions)	46	36	37	227	63
Life expectancy (years)	77	62	75	54	61
GDP per capita (US$ 2015 constant prices)	4 660.90	2 332.90	3 403.30	2 416.40	6 006.5
GDP per capita growth rate (annual %)	2.6	-2.1	2.3	0.7	-0.6
Gini coefficient (year of most recent data available shown in brackets)	27.6 (2011)	51.3 (2018)	50.6 (2019)	35.1 (2018)	63.0 (2014)
Urbanisation rate (%)	75	69	65	54	69
Population with access to electricity (%)	100.0	48.5	100.0	60.5	86.5
Literacy rate (% of people aged 15+)	81	72	77	63	90

Source: Compiled by the author based on the World Bank (2024) and World Economics (2019)

The GDP growth rates further illustrate economic variations. In 2024, Algeria (2.6%) and Morocco (2.3%) recorded a moderate annual growth rate, indicating relative stability, while Nigeria (0.7%) and Angola (-2.1%) struggled with low or negative growth. South Africa's economy contracted at -0.6% per annum in 2024, reflecting structural weaknesses, policy uncertainty and energy supply crises (World Bank, 2024). These disparities in growth rates suggest differing levels of economic resilience and sustainability.

The Gini coefficient is a widely used measure of income inequality, indicating how income is distributed across a population. It ranges from 0 to 1, where 0 represents perfect equality and 1 represents perfect inequality (Catalano et al, 2023). The Gini coefficient is also expressed as a percentage (0 to 100) in economic analyses, including this thesis. A higher Gini coefficient indicates greater income inequality, meaning wealth is concentrated among a small portion of the population, while a lower Gini coefficient suggests a more equitable income distribution (Catalano et al, 2023). South Africa (63.0) has one of the highest Gini coefficients in the world, highlighting severe income disparity where a small segment of the population controls a significant share of wealth. Angola (51.3) and Morocco (50.6) also show high inequality, though slightly lower than South Africa. In contrast, Nigeria (35.1) and Algeria (27.6) exhibit

relatively lower levels of inequality, indicating that income is more evenly distributed (World Bank, 2023).

Access to electricity remains a critical economic indicator. Algeria and Morocco report universal electricity access (100%), while South Africa (86.5%) still has gaps in energy availability. Nigeria (60.5%) and Angola (48.5%) face significant infrastructure challenges, with limited electricity access hampering economic diversification, industrial expansion and overall development (World Bank, 2024). This disparity highlights the importance of energy investment and policy interventions to bridge the gap.

Life expectancy further reflects disparities in healthcare access, living conditions and social development. Life expectancy and literacy rates can also be indicators of socioeconomic disparities between the countries. Algeria (77 years) and Morocco (75 years) have higher life expectancies, while South Africa (61 years) and Angola (62 years) have lower averages, likely due to healthcare access and social inequalities (World Bank, 2024). In South Africa's case, the lower life expectancy is also influenced by the high HIV/AIDS infection rate, which has historically placed a heavy burden on the healthcare system and affected mortality rates (UNAIDS, 2024). Nigeria (54 years) has the lowest life expectancy, reflecting severe health and developmental challenges. Similarly, literacy rates vary, with South Africa (90%) and Algeria (81%) leading, whereas Nigeria (63%) and Angola (72%) lag. Higher literacy rates are linked to better economic opportunities, workforce development and innovation capacity.

5.4.2 Environmental Background

All the selected countries face significant environmental challenges due to their energy-intensive economies, reliance on fossil fuels and vulnerability to climate change impacts (Amakoh, 2022). The following section examines these environmental factors, providing insight into how economic activities contribute to environmental degradation and the extent to which each country is working toward sustainability goals.

Angola, situated in Southern Africa, has natural resources, such as oil, diamonds and vast amounts of arable land (Amakoh, 2022). However, environmental challenges in the country include deforestation, soil erosion, poor water quality, climate change and pollution from mining and oil production. The country's main sectors affected by climate change include energy, fisheries, agriculture and forestry (Amakoh, 2022).

Morocco is vulnerable to extreme climate conditions, such as droughts, floods, soil erosion, water scarcity and heat waves (Abderebbi, 2020). Nigeria is regarded as one of the most climate-vulnerable countries in the world due to its large population, frequent natural disasters and poor infrastructure (Abderebbi, 2020). Climate change impacts the country, including heat waves and floods.

South Africa faces environmental challenges such as air and water pollution, habitat loss, and climate change impacts. It is reported that the national average temperature has increased more than twice the global temperature increases (Ndoma, 2024). This has resulted in more frequent droughts and extreme weather conditions. The country's carbon tax implemented in 2019 (discussed in Section 5.5.6) aims to reduce greenhouse gas emissions and transition to a low-carbon economy. Despite these efforts, socioeconomic disparities and implementation gaps remain significant challenges (Ndoma, 2024).

As indicated in Table 5.2 below, all the selected countries are signatories to the Paris Agreement and the SDGs of 2030, which is indicative of their commitment towards reducing their greenhouse gas emission levels. All the selected countries also submitted their first Intended Nationally Determined Contributions (INDCs) in 2015, complying with the Paris Agreement (Clémençon, 2016).

Table 5.2: Environmental Background of Selected Countries

Characteristics	Algeria	Angola	Morocco	Nigeria	South Africa
Paris Agreement Signatory	Yes	Yes	Yes	Yes	Yes
SDG aligned	Yes	Yes	Yes	Yes	Yes
Carbon Tax Implemented	No	No	No	No	Yes
First INDC submitted	Yes	Yes	Yes	Yes	Yes
Primary energy source	Oil and gas	Oil	Solar and wind	Oil	Coal
CO_2 emissions per capita (metrics per ton per capita)	3.7	0.6	1.8	0.5	6.7
Renewable energy targets	27% by 2030	50% by 2025	52% by 2030	30% by 2030	17.8 GW by 2030
Green investment (% of GDP)	0.5	0.2	0.6	0.3	1.0

Source: Compiled by the author based on UNFCC (2015), Republic of South Africa National Treasury (2024) and the World Bank (2024)

The table also highlights the importance of environmental targets. Transitioning to renewable energy is central to each country's climate strategy. Morocco leads with a 52% renewable energy target by 2030, reflecting its significant investments in solar and wind power. Angola aims for 50% by 2025, strongly emphasising hydropower development. Algeria and Nigeria have set 30% renewable energy targets by 2030, indicating a moderate commitment to clean energy. South Africa's target is framed in capacity terms (17.8 GW by 2030), highlighting a shift towards integrating wind and solar energy into its electricity grid (World Bank, 2024).

The selected countries' environmental challenges highlight the need for effective climate policies. While commitments to sustainability exist, their implementation varies due to economic constraints and energy dependencies. The following section explores how each country addresses these challenges through national climate policies and regulatory frameworks.

5.5 National climate policies

National climate policies are crucial in translating global climate commitments into actionable strategies for reducing greenhouse gas emissions (Resources for the Future, 2022). These

policies provide the framework for governments to implement legislative, regulatory and financial mechanisms that support climate action at the national level. By integrating climate considerations into economic planning, national policies help align domestic sustainability efforts with international agreements such as the Paris Agreement and the Sustainable Development Goals (SDGs) (Roelfsema et al, 2020).

As noted above, all the selected countries developed and submitted their first INDCs between September and November 2015 as part of their commitment to the Paris Agreement (Clémençon, 2016). INDCs are voluntary climate action commitment plans outlining how each country intends to reduce greenhouse gas emissions and adapt to climate change impacts based on national circumstances (Jernnäs, 2023). Under the Paris Agreement, countries are required to update and strengthen their INDCs every five years to ensure alignment with evolving global climate targets, such as limiting global warming to well below 2°C, preferably 1.5°C (UNFCCC, 2015; Jernnäs, 2023). Angola submitted its updated INDC in 2021, while Morocco, Nigeria and South Africa **s**ubmitted their updated INDCs by 2022. Algeria has not submitted an updated INDC (Jernnäs, 2023).

In addition to the INDCs, each country has developed its national policy to mitigate and adapt to climate impacts. All policies align with international agreements, such as the Paris Agreement, the African Union Agenda 2063 and the Sustainable Development Goals for 2030. These policies cover sectors most affected by climate change, such as energy, transportation, infrastructure and agriculture.

5.5.1 Algeria's National Climate Policy of 2013

Algeria has the National Climate Policy of 2013 as its primary national policy but later updated it in 2015 with the Renewable Energy and Energy Efficiency Development Plan, which increased the target for installed renewable capacity by 2030 from 12 GW to 22 GW (Ministry of Environment and Renewable Energy, 2013). The policy's primary purpose is to build the

country's renewable energy capacity and reduce greenhouse gas emissions. Algeria uses solar resources, such as its vast desert areas, to build capacity for solar farming.

A key component of Algeria's climate strategy is the development of its renewable energy sector, leveraging the country's vast solar resources to diversify its energy mix (Leaders in Energy, 2024). With more than 2,500 hours of annual sunshine in some regions, such as Tamanrasset, which experiences approximately 3,686 hours of sunshine per year and the Sahara Desert, where certain areas receive up to 3,900 hours of sunshine annually (Leaders in Energy, 2024) Algeria is well-positioned to harness solar energy for sustainable development. The National Climate Policy sets a target of generating 27% of its electricity from renewable sources by 2030, primarily through the deployment of photovoltaic and wind power, as well as thermal solar energy, biomass, and geothermal projects. Additionally, Algeria has committed to reducing gas flaring to less than 1% by 2030, a significant step toward curbing industrial emissions (IMF**,** 2024).

The government has introduced several policy initiatives to facilitate this transition, including The National Reforestation Plan of 2000, which aims to restore 1.2 million hectares of degraded land to enhance carbon sequestration and biodiversity conservation (Merdas et al, 2017). Energy efficiency programs promote building insulation, efficient lighting systems and sustainable urban planning to reduce energy consumption. To cut methane emissions, sustainable waste management strategies focus on organic waste composting and methane recovery from landfill sites (Cheniti et al, 2024).

Algeria's first INDC covers the 2021-2030 period. It outlines emission goals, stating that the nation aims to reduce emissions by 35% in 2030 (Ministry of Environment and Renewable Energy, 2013). An additional 15% will be reduced through international funding assistance. Algeria has historically relied on hydrocarbon exports, with oil and natural gas contributing more than 90% of its total export revenues but national plans have outlined efforts to diversify the economy (Benhamiche et al, 2014).

5.5.2 Angola's National Strategy for Climate Change

Angola implemented a National Strategy for Climate Change between 2018 and 2030 (Ministry of Environment Angola, 2018). The policy is built on five pillars: climate mitigation, adaptation, capacity building, financing and research analysis. The strategy focuses on climate change mitigation and on building climate-resilient infrastructure. This means integrating climate assessment risk when building infrastructure in areas prone to climate impacts, such as coastal areas (Ministry of Environment Angola, 2018).

For example, flood-resistant infrastructure and sustainable drainage systems have been implemented in Luanda and Namibe, coastal cities facing rising sea levels and storm surges (AfDB, 2015). In Luanda, the government has invested in the Luanda Drainage Master Plan, which includes constructing flood barriers and rainwater harvesting systems to reduce the impact of flash floods (AfDB, 2015).

Namibe, a region affected by droughts and desertification, has projects such as the Namibe Desalination Plant, which provides a reliable freshwater supply to communities and reduces reliance on unpredictable rainfall (Constantino et al, 2022). Additionally, the government has promoted climate-smart agricultural practices, such as drought-resistant crop irrigation systems, to help farmers adapt to water scarcity challenges.

These projects demonstrate Angola's commitment to integrating climate adaptation measures into infrastructure development, ensuring that cities and communities are more resilient to flooding, sea-level rise and droughts (AfDB, 2015).

5.5.3 The Moroccan Climate Change Policy of 2014

Morocco's Climate Change Policy of 2014 serves as the country's primary framework for climate mitigation, adaptation and sustainable development (Ministry of Energy, Mines, Water, and Environment, 2014). The policy integrates international climate commitments, including

Morocco's INDC under the Paris Agreement, which sets an ambitious target of reducing greenhouse gas (GHG) emissions by 45.5% by 2030, with 18.3% of the reductions being unconditional and the remaining dependent on international financial and technical support (UNFCCC, 2015). Unconditional commitments refer to emission reduction targets Morocco aims to achieve using its national resources without relying on external support. Conditional targets depend on the availability of international financial assistance from global climate funds and bilateral agreements (World Bank Group, 2021).

The policy aims to reduce emissions, promote renewable energy and strengthen adaptation plans for vulnerable areas, such as coastal areas (Ministry of Energy, Mines, Water and Environment, 2014). Renewable energy is promoted through public campaigns, educational programs, and community outreach initiatives (Ministry of Energy, Mines, Water and Environment, 2014; World Bank Group, 2021). Initiatives include environmental education curricula, training programs and awareness-raising events to foster a culture of environmental stewardship (Abderebbi, 2020). The Green Schools Program, launched by the Mohammed VI Foundation for Environmental Protection in 2006, educates students on environmental conservation, energy efficiency, and waste management through interactive learning (World Bank Group, 2021). Another example is the Earth Hour Morocco campaign, organised annually on the last Saturday of March, which encourages individuals and businesses to switch off non-essential lights for one hour to raise awareness about energy conservation and climate action (WWF, 2019).

5.5.4 Nigeria's National Climate Change Policy Response and Strategy of 2012

Nigeria's policy is the National Climate Change Policy Response and Strategy (NCCPRS) of 2012, later updated with the National Climate Change Act (NCA) of 2021. The NCCPRS of 2012 aimed to improve adaptation to climate impacts, such as flooding and food insecurity (Federal Ministry of Environment Nigeria, 2012). For example, strengthening flood management systems, particularly in coastal areas like Lagos, where rising sea levels pose a serious risk. The NCA encourages private sector involvement in climate adaptation and

mitigation. It also emphasises that climate change and gender equality (SDG five) are interlinked (Federal Government of Nigeria, 2021).

Nigeria's NCA is linked with gender equality by emphasising gender-responsive climate policies and ensuring women's participation in climate adaptation and mitigation efforts (Federal Government of Nigeria, 2021). The Act recognises that women, particularly in rural communities, are disproportionately affected by climate change, facing challenges such as decreased agricultural productivity, water scarcity and displacement due to extreme weather events. Environmental sustainability relies on the equitable use of resources and resilience-building strategies that empower vulnerable communities, especially women in rural areas who depend on natural resources for their livelihoods (Federal Government of Nigeria, 2021).

Nigeria submitted its INDC in 2015, later updated in 2021 as an NDC. The updated commitment aims to reduce greenhouse gas emissions by 20% unconditionally and up to 47% conditionally by 2030, depending on international climate finance and technological support (UNFCCC, 2021). These commitments align with Nigeria’s goal of transitioning to a low-carbon economy while ensuring socioeconomic resilience.

Nigeria also has a Solar Power Naija Initiative implemented in 2020 as part of the Economic Sustainability Plan (ESP) to accelerate the deployment of off-grid solar energy solutions across the country (Ojomo and Sanchez, 2023). This is a government-led but private-sector-supported initiative aimed at deploying off-grid solar solutions to five million households, particularly in rural communities without reliable access to the national grid. This reduces reliance on diesel generators and lowers carbon emissions (Ojomo and Sanchez, 2023). The Solar Power Naija Initiative is implemented through public-private partnerships, attracting investments from local and international financial institutions to support the expansion of solar mini-grids and home solar systems. Financing models, such as pay-as-you-go (PAYG) solar systems, make renewable energy more accessible to low-income households, addressing energy poverty and climate change mitigation (IRENA, 2020).

For example, Nigeria introduced its Renewable Energy Master Plan (REMP) in 2005, aiming to increase the share of renewable energy in electricity generation and reduce reliance on fossil fuels. In 2011, the Nigerian government updated the REMP to align with evolving climate commitments. More recent frameworks have taken precedence. The 2021 Energy Transition Plan and the Renewable Energy and Energy Efficiency Policy (REEEP). These policies aim to achieve net-zero emissions by 2060, scale up solar deployment, and improve energy access while reducing dependence on fossil fuels (Federal Government of Nigeria, 2021; IEA, 2022) Additionally, Nigeria has partnered with the World Bank, AfDB and private investors to secure financing for off-grid projects, ensuring long-term sustainability. The program is aligned with Nigeria's REMP and NDCs under the Paris Agreement, reinforcing the country's commitment to reducing greenhouse gas emissions and transitioning to a low-carbon energy system.

Nigeria was the first African country to issue a sovereign green bond in 2017, raising $29 million for solar and afforestation projects (Oche, 2019). A second issuance in 2019 raised $42 million to finance INDC-aligned projects, including clean energy and low-carbon transport. Aiming to raise $250 million by 2024, Nigeria continues to leverage green bonds to fund national projects in solar, hydropower, and waste management (Cortelline and Panetta, 2021). These initiatives complement Nigeria's broader funding sources, including AfDB support and limited domestic public financing.

Despite these investments, the country continues to rely heavily on fossil fuels, particularly natural gas and crude oil, which remain the backbone of the economy. Addressing this dependence on hydrocarbons while scaling up renewable energy investments is a key challenge for the long term.

5.5.5 South Africa's National Climate Change Response of 2011

The National Climate Change Response Policy of 2011 is South Africa's national environmental policy (Department of Environmental Affairs RSA, 2011; International Emissions Trading Association, 2023). It provides a framework to deal with nation-specific

climate impacts. This is through efforts such as the carbon tax and greenhouse gas emissions targets, which aim to peak emissions between 2020-2025 and then decline them after. The policy also endorses the carbon tax as a climate action instrument.

As part of its commitment to the Paris Agreement, South Africa submitted its INDC in 2015, later updated as an NDC in 2021. Key climate mitigation strategies under the NCCRP and NDC include introducing a carbon tax (effective from 2019) and incentivising renewable energy through the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP).

Despite these commitments, South Africa remains one of the world's highest per capita carbon emitters, mainly due to its heavy reliance on cheap and abundant coal reserves (Climate Transparency, 2023). The trade-off between economic growth, energy security and environmental protection remains a key challenge in implementing climate policies effectively. Eskom relies heavily on coal despite the expansion of renewable energy projects.

Among these projects, wind energy has emerged as one of South Africa's most important utility-scale renewable sources, outpacing solar PV in grid-connected capacity under the REIPPPP. Major wind farms in the Eastern Cape, Northern Cape and Western Cape have significantly contributed to the country's clean energy mix, helping diversify the energy portfolio and reduce dependence on fossil fuels (IPP Projects, 2023).

To address dependency on fossil fuels, President Cyril Ramaphosa appointed South Africa's first Minister of Electricity and Energy in 2023, a role created to address the nation's ongoing energy crisis characterised by frequent rolling blackouts, referred to in South Africa as load shedding (de la Rue du Can and Covary, 2023).

Regarding residential renewable energy, South African citizens must obtain permission from local authorities before installing solar systems (National Business Initiative, 2024). Homeowners must apply to become Small-Scale Embedded Generators (SSEG) with their

respective municipalities. This process involves submitting detailed plans and adhering to specific regulations, which can vary between municipalities.

Additionally, all solar installations must be performed by individuals or companies registered as electrical contractors with the Department of Employment and Labour (National Business Initiative, 2024). A certified electrician must issue a Certificate of Compliance (CoC) upon completion of the installation to ensure it meets safety and regulatory standards. This requirement underscores the importance of building a skilled workforce to support South Africa's renewable energy goals (National Business Initiative, 2024). As discussed earlier, TVET colleges such as False Bay TVET College and Nkangala TVET College have been instrumental in retraining workers during the transition.

These regulatory requirements aim to ensure the safety and reliability of solar installations. However, they can also pose challenges for widespread adoption, as the need for permissions and compliance with varying municipal regulations may deter some homeowners from transitioning to solar energy (National Business Initiative, 2024).

The South African government also works with state-owned enterprises such as Eskom to retrain mineworkers for construction and maintenance roles in renewable energy infrastructure projects (DMRE, 2021). This initiative is part of the broader Just Energy Transition, ensuring that coal, oil, and gas workers are not left behind as the country shifts towards clean energy sources. Beyond formal employment, the government also fosters entrepreneurship opportunities, enabling former fossil fuel workers to establish sustainable businesses (Tyler and Mgoduso, 2022). These initiatives include government-backed start-up grants and microfinancing options to support small-scale renewable energy ventures. For instance, former coal miners are encouraged to start solar microgrid businesses, providing off-grid communities with affordable and reliable clean energy solutions (Tyler and Mgoduso, 2022).

South Africa also benefits from international climate financing through institutions such as the Green Climate Fund (GCF) and the AfDB, both of which provide grants and technical

assistance to support national climate strategies (AfDB, 2024). However, despite this multi-channel funding approach, project implementation is often hindered by bureaucratic delays and policy uncertainty.

5.5.6 South Africa's carbon tax policy and its implementation

South Africa is the only African country with a fully implemented carbon tax. The Carbon Tax Act of 2019 is an instrument to reduce South Africa's greenhouse gas emissions and a component of the country's INDC (National Treasury, 2024; Masondo and Nwosimiri, 2023). South Africa has specifically chosen to introduce a carbon tax rather than an emission trading scheme because it aligns more with the implemented national policy, the National Climate Change Response Policy of 2011. Economic theory suggests that an ETS can more efficiently reduce CO_2 emissions. However, a carbon tax provides greater predictability in pricing, making it more suitable for South Africa's regulatory and economic environment (Parry et al, 2022). This is because emission schemes are more fixed in their design, while the carbon tax is more simplistic in its administration.

The carbon tax was implemented on the 1st of June 2019 to transition the South African economy to a low carbon as per the Paris Agreement. Effectively implemented, the tax is expected to cover 86% of the country's total emissions (National Treasury, 2024). The tax applies to various sectors, such as energy, transportation, industry, waste and agriculture, forestry and land use (National Treasury, 2024). All businesses within the sectors that emit greenhouse gas emissions (GHG) above the threshold must pay the carbon tax. Businesses operating their facilities with a combined installed thermal capacity of 10 megawatts (MW) or more are liable to pay the carbon tax (National Treasury, 2024).

Implementation of the carbon tax is divided into two phases for gradual adaptation. The first phase, between 2019-2022, focuses on introducing the tax and allowing businesses to adjust to it (National Treasury, 2024). Phase two, between 2023 and 2030, focuses on reviewing the tax structure to adjust it for potential tax rate and allowances amendments. Adjustments in tax rates

and sectoral allowances will be based on emission trends, technological advancements and economic conditions, ensuring that the tax remains a compelling incentive for businesses to transition toward low-carbon alternatives (National Treasury, 2024).

South Africa's carbon tax rate has steadily increased since its introduction in 2019, reflecting the government's commitment to strengthening carbon pricing as a climate mitigation tool (YellowTree Consulting, 2024). Following its introduction, the carbon tax rate has been adjusted annually to account for inflation and to strengthen its effectiveness. In 2020, the tax increased from R120 to R127 per tCO_2e; by 2021, it had risen to R134 per tCO_2e and in 2022, it was further adjusted to R144 per tCO_2e (IETA,2023; National Treasury, 2024). In 2023, the carbon tax rate reached R159 per tCO_2e, reflecting the government's intent to scale up climate action and push industries toward sustainable alternatives. In 2024, the rate substantially increased to R190 per tCO_2e, reinforcing South Africa's commitment to meeting its INDC under the Paris Agreement. National Treasury (2024) has projected that the tax will continue to rise, reaching R236 per tCO_2e in 2025 and R308 per tCO_2e by 2026 (YellowTree Consulting, 2024).

These incremental increases were implemented to ensure businesses had time to adapt to the new tax structure. The carbon tax is charged on fossil fuel inputs, such as coal, gas and oil. The government initially introduced tax-free allowances ranging from 60% to 95% of total emissions, allowing specific sectors to gradually transition to lower-carbon alternatives (SARS, 2020; National Treasury, 2024). These allowances effectively reduce the tax burden, resulting in an effective tax rate between R9.50 and R76 per tCO_2e, depending on the specific allowances applicable to each sector. For example, the energy sector's rate is R47.50 per tCO_2e after a 60% allowance (National Treasury, 2024). Starting in 2026, there are plans to gradually reduce these allowances to strengthen the carbon price signal and encourage further emissions reductions.

South Africa's carbon tax revenue supports the transition to a low-carbon economy. This includes funding for renewable energy projects and emissions reduction initiatives in key sectors such as public transportation (National Treasury, 2024). One of the programs aligned

with this transition is REIPPPP, which facilitates electricity procurement from private renewable energy producers. Rather than directly investing in renewable projects, the government uses REIPPPP to purchase electricity from independent power producers (IPPs), supplying wind, solar, and biomass-generated electricity to the national grid operated by Eskom. This program is crucial in expanding South Africa's renewable energy capacity, diversifying the energy mix and reducing reliance on coal-fired power generation.

Carbon revenue also funds research and development programs, such as Research in Carbon Capture and Storage (CCS), which is critical in mitigating greenhouse gas emissions from industrial processes (National Treasury, 2024; Dhansay et al, 2022). CCS technology is designed to capture CO_2 emissions at the source, mainly from coal-fired power plants, cement factories, and heavy industries, before they are released into the atmosphere. The captured CO_2 emissions are then transported and stored underground in geological formations, such as depleted oil and gas reservoirs or deep saline aquifers, preventing them from contributing to climate change (Dhansay et al, 2022). The South African Centre for Carbon Capture and Storage (SACCCS), established under the South African National Energy Development Institute (SANEDI), has been leading pilot projects and feasibility studies to explore the scalability of CCS technology (Viebahn et al, 2015).

The South African Revenue Service (SARS) is the primary administrative authority responsible for implementing the carbon tax (National Treasury, 2024; SARS, 2023). SARS collects the carbon tax and ensures businesses follow the tax regulations. Through tax collection, SARS ensures that entities make payments according to the stipulated rates and timelines. For compliance, SARS ensures that businesses accurately report their emission reductions and comply with the tax requirements (National Treasury, 2024; SARS, 2023). SARS is also responsible for conducting audits to ensure integrity within the carbon tax system and penalises non-compliance where necessary. This means transparency is a crucial component of the system and SARS publishes regular updates and reports on the performance of the carbon tax (National Treasury, 2024).

SARS collects the carbon tax and ensures businesses adhere to tax regulations by enforcing compliance measures. This involves registering taxable entities, verifying emissions data and ensuring that companies pay their dues within stipulated timelines. By collecting the tax, SARS aims to incentivise emission reductions while generating revenue to support climate mitigation initiatives (SARS, 2023; YellowTree Consulting, 2024).

SARS requires businesses to accurately report their greenhouse gas (GHG) emissions and submit detailed carbon tax returns to ensure compliance. Companies must calculate their emissions based on verified data, following the methodologies outlined in South Africa's Greenhouse Gas Emissions Reporting Regulations. SARS audits tax returns and cross-checks emissions reports to verify whether businesses comply with reduction targets and tax obligations (National Treasury, 2024; SARS, 2023).

Additionally, non-compliance penalties play a key role in enforcement. Businesses which fail to submit accurate emissions data or underpay their carbon tax liabilities face financial penalties and interest charges. SARS has mechanisms to detect fraud and tax evasion, ensuring that the system operates transparently (SARS, 2023).

Transparency is a critical component of the carbon tax framework. SARS publishes regular reports outlining tax revenues collected, emission reductions achieved, and the effectiveness of tax incentives in reducing carbon footprints (SARS, 2023). These reports also help inform policy adjustments, ensuring that the tax remains aligned with South Africa’s broader climate commitments under the Paris Agreement and the National Climate Change Response Policy.

In recent years, SARS has expanded its digital reporting platforms to streamline tax submissions and integrate real-time GHG emissions monitoring systems (SARS, 2023). These efforts contribute to enhanced enforcement, increased compliance and improved transparency in the carbon tax regime.

5.5.7 Challenges in implementing climate policies

Despite significant progress in climate policy adoption across Africa, several structural and economic barriers hinder effective implementation. These challenges vary by country but broadly fall into four key categories: infrastructure deficiencies, financial constraints, dependency on fossil fuels and lack of climate change awareness (Bengoa et al, 2021). While countries like Morocco and South Africa have made strides in renewable energy expansion, others like Algeria and Angola struggle with fossil fuel reliance. The following section provides a comparative analysis of these challenges, highlighting country-specific obstacles with practical examples.

Insufficient infrastructure for renewable energy generation is a significant obstacle for climate policy implementation (Liu et al, 2023). Countries with weak electricity grids, limited water management systems and outdated transport networks struggle to meet their INDCs and climate resilience goals. In Nigeria, renewable energy expansion is hampered by grid instability and insufficient transmission networks. Failure to modernise energy infrastructure by government authorities, energy utility companies and private sector stakeholders slows the integration of solar and wind power into the national grid (Liu et al, 2023). For example, Nigeria's climate policy enforcement gaps were evident in the failure to curb illegal gas flaring in the Niger Delta, despite legislation prohibiting the practice (Climate Change News, 2022).

In South Africa, although the energy infrastructure is relatively well developed, the country’s reliance on ageing coal-fired power stations and recurring load shedding, combined with delays in expanding solar and wind farms due to bureaucratic approvals, continue to limit a smooth transition to renewable energy (de la Rue du Can and Covary, 2023). Load shedding could act as an incentive for transitioning to renewables. However, it has led to short-term responses such as increased reliance on private diesel generators, especially following the 2022 reform by the Department of Mineral Resources and Energy that removed the 100 MW licensing cap for private generation (DMRE, 2022). While this reform was designed to accelerate private energy investment, the urgency to secure an immediate electricity supply has often favoured quicker-to-deploy diesel solutions over longer-term renewable infrastructure.

The selected countries also struggle to finance large-scale renewable energy and adaptation. For example, Morocco relies heavily on external financing from international climate funds and bilateral agreements to meet its renewable energy targets (Moroccan Ministry of Energy, Mines, Water, and Environment, 2018). While Nigeria has accessed green bonds to support off-grid solar projects, a significant portion of climate investments still depends on foreign donors, making long-term sustainability uncertain (Cortelline and Panetta, 2021). South Africa secured $8.5 billion from the JETP initiative (discussed in Section 5.3), but delays in fund disbursement and regulatory approvals have slowed renewable energy development.

Most of the selected economies rely heavily on fossil fuels, creating a policy conflict between economic growth and climate sustainability (IEA, 2022). Governments face pressure to maintain fossil fuel production due to employment, revenue generation and energy security concerns. Algeria and Angola are major oil and gas exporters, making it challenging to prioritise renewable energy over fossil fuel revenues (IEA, 2022). In Nigeria, fossil fuels account for a significant share of GDP, with oil and gas exports making up 90% of foreign exchange earnings. This reliance slows the shift toward cleaner energy sources. South Africa remains dependent on coal, which supplies over 75% of its electricity. The coal industry's political influence has slowed the pace of phasing out coal-fired power plants. For example, labour unions, such as the National Union of Mineworkers (NUM) and the Association of Mineworkers and Construction Union (AMCU), strongly oppose rapid coal phase-outs, fearing mass unemployment and economic hardship for coal-dependent communities (Creamer, 2022; SEI, 2024).

Corruption also limits the efficiency of financial assistance from organisations such as the Green Climate Fund (IRENA, 2020). South Africa faces challenges that include socioeconomic disparities, such as income inequalities, where lower-income households will not have much opportunity to switch to renewable alternatives (Winkler et al, 2011).

Another important constraint to effective national policies is the lack of public awareness towards climate change (Leao and Shetty, 2022). Effectively implementing climate change policy also depends on local populations' support and awareness of such policies. The data in Table 5.3 below is derived from the Afrobarometer ninth-round survey conducted in 2021/2023. The table reflects responses to the question: "Have you heard about climate change, or haven't you had the chance to hear about this yet?" which measures awareness levels of climate change across the selected countries (Afrobarometer, 2023). While a tenth round of the Afrobarometer survey is underway for the 2024/2025 period, it only includes Angola and Morocco from the panel of countries examined in this thesis. As such, this thesis uses data from the ninth round (2022/2023), which covers Angola, Morocco, Nigeria and South Africa, ensuring a more comprehensive comparison of public awareness levels across the selected countries.

The responses reveal that awareness levels are highest in Morocco, where 54.3% of respondents are aware of climate change, followed by Angola (45.8%) and South Africa (42.7%). Nigeria reports the lowest awareness levels, with only 29.8% of respondents familiar with climate change (Afrobarometer, 2023). These findings have significant implications for policy implementation. Countries with higher public awareness, such as Morocco, are more likely to have a population that actively supports and engages in climate initiatives. For example, Morocco's extensive renewable energy targets and public education campaigns align with its relatively higher public awareness (Abderebbi, 2020). On the other hand, Nigeria's low awareness level indicates a significant barrier to policy success.

Table 5.3: Public awareness of climate change among respondents in Angola, Morocco, Nigeria, and South Africa

Category	**Total**	**Country**			
	Algeria	Angola	Morocco	Nigeria	South Africa
No	53.7%	49.%	43.3%	67.5%	51.2%
Yes	42.2%	45.8%	54.3%	29.8%	42.7%
Refused to answer	0.1%	0.1%	0.1%	-	0.2%
Do not know	4.0%	4.9%	2.4%	2.7%	5.9%
N	5 580 (100%)	1 200 (100%)	1 200 (100%)	1 600 (100%)	1 580 (100%)

Source: Compiled by the author based on Afrobarometer (R9 2021/2023**)**

Moreover, the data highlights an urgent need for tailored public education campaigns to address gaps in awareness, particularly in countries like Nigeria and South Africa. These campaigns include integrating climate education into school curriculums, leveraging media outreach and engaging local communities in discussions about the risks of climate change and the benefits of sustainable practices (UNFCCC, 2015). For example, South Africa's carbon tax policy may face resistance or low compliance without a widespread understanding of its environmental and economic objectives (National Treasury, 2024). Similarly, Nigeria's reliance on green bonds (discussed in Section 5.5.2) to fund renewable energy projects may encounter challenges without sufficient public support for such initiatives (Cortelline and Panetta, 2021).

5.6 Conclusion

This chapter examined the national and continental environmental policies across the selected panel. While all five countries are signatories to international frameworks such as the Paris Agreement and Agenda 2063, their implementation pathways differ significantly due to variations in governance, energy structures, and institutional capacity.

South Africa and Morocco, with more diversified economies and advanced regulatory mechanisms, demonstrate stronger policy frameworks and relatively higher private sector participation in renewable energy projects. In contrast, Algeria and Angola remain heavily reliant on fossil fuels and state-controlled energy sectors, with limited progress in diversifying energy sources or securing climate finance. Nigeria presents a hybrid case, where state-led initiatives coexist with emerging market-based mechanisms like green bonds and private solar programs, although bureaucratic and infrastructural barriers persist.

Continental initiatives such as the African Renewable Energy Initiative (AREI) and the African Strategy on Climate Change (ASCC) offer structured frameworks for collective climate action. However, these initiatives face common challenges, including fragmented implementation, financial constraints, and inconsistent national commitment. Despite receiving support from international institutions such as the Green Climate Fund and the African Development Bank,

many projects are delayed by policy uncertainty and weak institutional coordination at the national level.

The following chapter presents the econometric analysis of the EKC hypothesis using panel and time-series models, assessing the relationship between economic growth and environmental degradation across the five selected countries.

CHAPTER 6
RESULTS AND DISCUSSION OF THE ECONOMETRIC ANALYSIS

6.1 Introduction

As noted in Section 1.2 of Chapter 1, the main objective of this thesis is to investigate the EKC theory for five middle-income African countries: Algeria, Angola, Morocco, Nigeria and South Africa between 1990 and 2019. This chapter addresses this goal by estimating the relationship between GDP per capita and environmental degradation (proxied by CO_2 emissions). Where a statistically significant quadratic relationship between GDP per capita and CO_2 emissions is found, the turning point (at which the relationship between CO_2 emissions per capita and GDP per capita changes) is estimated. The econometric analysis also estimates the influence of other relevant economic and development variables on the relationship between GDP per capita and CO_2 emissions. The chapter thus assesses whether the data obtained supports the EKC theory.

As discussed in Chapter 4, the econometric analysis follows a two-stage approach. First, panel data models are estimated to identify general trends across the five countries. This is followed by individual time-series analysis to explore country-specific dynamics. In addition to addressing the core empirical objectives, this chapter also responds to the final sub-goal of the study by discussing the implications of the findings for environmental sustainability in the selected African countries.

The rest of Chapter 6 is organised as follows: Section 6.2 graphically represents the variables included in the econometric analysis and briefly discusses their trends and patterns across the selected five countries. Section 6.3 provides the results of the correlation analysis and panel unit root tests performed. Section 6.4 reports the findings for the panel data estimations. Section 6.4.1 provides the preliminary panel data analysis results based on the fixed effects (FE) and random effects (RE) models. Section 6.4.2 provides the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) estimation results with the bounds test findings for cointegration. Section 6.5 presents the results of the time-series ARDL models for individual

countries and discusses the findings. Section 6.6 provides a comparative discussion of EKC patterns and the implications of the findings for the selected African countries. Section 6.7 concludes the chapter.

6.2 Key variable trends over time

This section presents a graphical overview of the key variables used in the analysis, including CO_2 emissions per capita, GDP per capita, trade openness, energy use and the HDI. These visuals illustrate long-term trends across the selected countries. While the graphs in this section depict the variables in level terms for ease of trend interpretation, Appendix A contains the log-transformed versions for econometric analysis consistency.

Figure 6.1 below graphs CO_2 emissions per capita levels across the selected countries from 1990 to 2019. The first striking feature of the graph is the significantly higher emissions per capita recorded in South Africa, followed by Algeria to a lesser but still notable extent, relative to the other three countries.

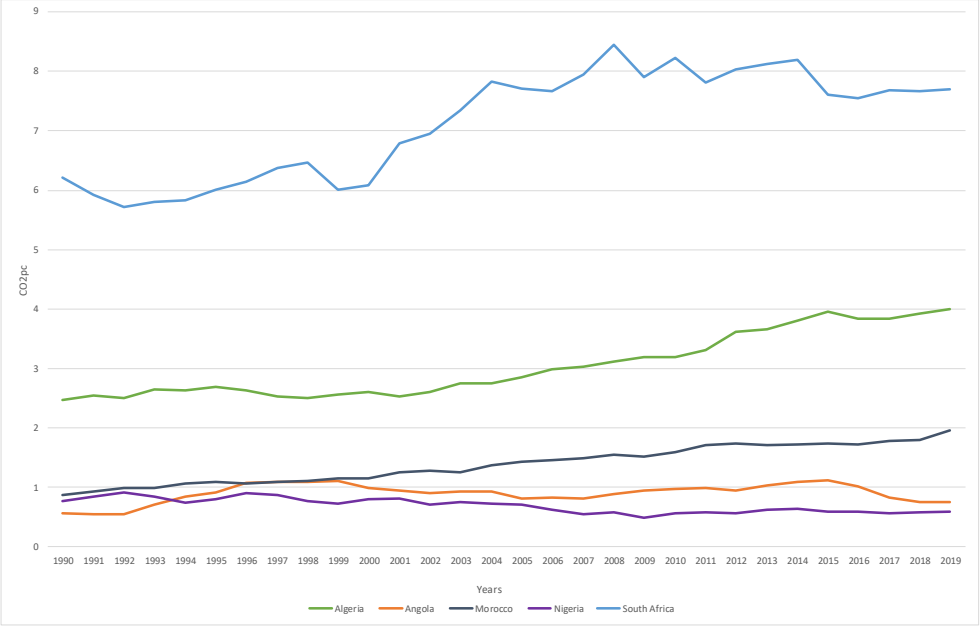

Figure 6.1: CO_2 per capita (metric tons per capita)
Source: Compiled by the author based on the World Bank Data (2024)

Algeria demonstrates a steady rise in emissions per capita, starting at 2.5 metric tons per capita in 1990 and rising to 4 metric tons per capita by 2019. Algeria's heavy reliance on fossil fuels, particularly natural gas, accounting for over 90% of electricity generation, contributes to the upward trend (IEA, 2024). Angola shows relatively low CO_2 emissions per capita across the entire period with only slight fluctuations over time.

Moroccan CO_2 emissions gradually rose from 0.87 metric tons per capita in 1990 to 1.96 metric tons per capita by 2019. According to Amegankpoe et al (2021), this increase is primarily driven by industrialisation, including the expansion of manufacturing and construction sectors and growth in tourism-related activities, which have increased energy demand and fossil fuel consumption. Contrarily, Nigeria displays fluctuating emissions, reflecting its dual economy as an oil producer with persistent infrastructure challenges (Amegankpoe et al, 2021).

South Africa is the most industrialised of the selected countries and exhibits consistently higher emissions levels, which peaked in 2008 at 8.4 metric tons per capita. The leading cause of the higher emissions is the country's over-reliance on coal-based energy and a spike in economic growth (following Apartheid) that further increased energy consumption (Eberhard, 2011; Awodumi and Adewuyi, 2016). Emissions slowed after 2008 because of the consequences of the global financial crisis of 2008, including less industrial activity, less energy use and lower overall economic production. Additionally, persistent electricity generation problems, particularly those affecting the state utility Eskom, have led to recurring load shedding (rolling blackouts), disrupting industrial production and contributing to lower emissions levels (Climate Transparency, 2020).

Figure 6.2 below illustrates the GDP per capita trajectories of the selected countries over the study period.

South Africa has consistently higher GDP per capita than the other countries in the sample, followed by Algeria. Algeria's GDP per capita rose consistently, starting at US$3,153.48 in

1990 and reaching US$4,246.24 by 2016. The steady growth reflects the country's reliance on its oil and gas sector, which has driven industrialisation and income (Khan et al, 2021). However, income growth declined slightly between 2016 and 2019, due at least in part to lower global oil prices, coupled with domestic economic challenges such as fiscal tightening and reduced public investment (Bouzidi, 2019).

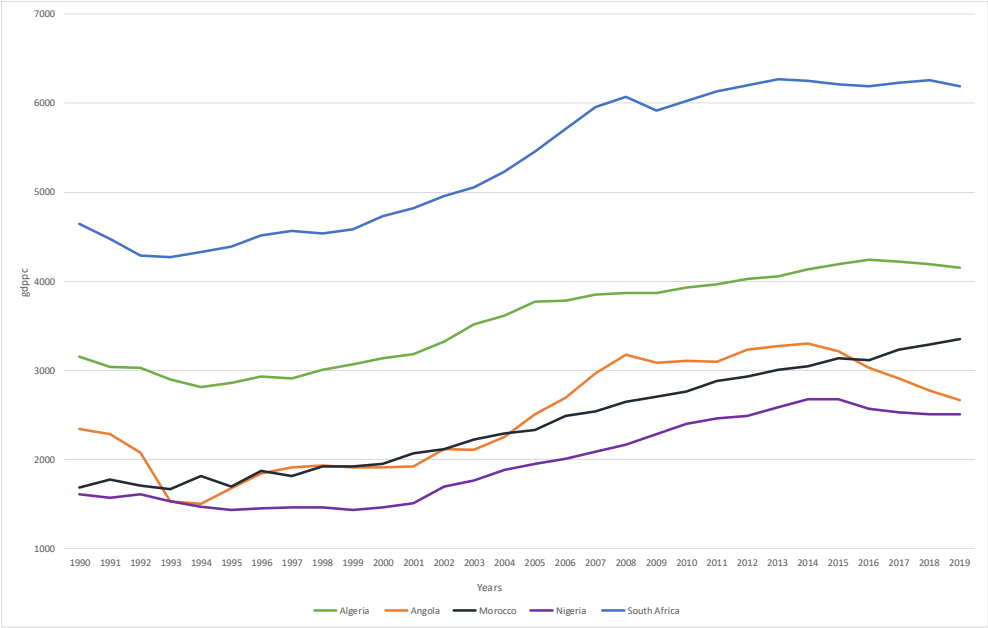

Figure 6.2: GDP per capita (2015 constant prices, US$)
Source: Compiled by the author based on the World Bank (2024)

Angola's fluctuating income levels highlight the structural fragility of its economy, which is heavily reliant on a single commodity (oil), leaving it vulnerable to external shocks such as oil price volatility (Ngoma and Ismail, 2020). The absence of economic diversification limits resilience and exacerbates the risk of severe economic contractions during periods of declining global oil demand.

On the other hand, Morocco is persistent in GDP per capita growth, from US$1,682.33 in 1990 to US$3,355.61 in 2019. Its relatively diversified economy, including agriculture, manufacturing and investments in renewable energy, has contributed to this stability (Jebli et al, 2016). Although Morocco's GDP per capita remains lower than that of South Africa and

Algeria, its steady economic performance and structural transformation suggest progress toward potentially attaining upper-middle income status soon (Haddadi, 2024).

Nigeria's GDP per capita fluctuates within a relatively low range, from US$1,429.01 in 1995 to US$2,679.55 in 2015. According to Sarkodie and Strezov (2018), this indicates dependence on oil exports and challenges managing a rapidly growing population. South Africa exhibits the highest GDP per capita among the five countries, with a generally upward trend until the mid-2000s that has since largely stagnated. GDP per capita grew from US$4643,22 in 1990 to US$6188,70 in 2019. Effects from post-Apartheid growth policies increased GDP growth from -0.1% to 5.4% between 1990 and 2007 (World Bank, 2024). Such policies included the Reconstruction and Development Programme (RDP), the Growth, Employment and Redistribution Strategy (GEAR), the Accelerated and Shared Growth Initiative for South Africa (ASGI-SA) and the Joint Initiative on Priority Skills Acquisition (JIPSA).[3]

However, economic growth slowed significantly after 2008, dropping from 3.2% in 2008 to 0.3% by 2019. While the global financial crisis (GFC) played a substantial role in this deceleration, domestic constraints further compounded the slowdown. These included recurring electricity supply issues, such as load shedding and price hikes by Eskom, logistics bottlenecks in rail and ports, high port tariffs and deteriorating infrastructure at both municipal and national levels (DTI, 2018). These constraints undermined industrial output, reduced competitiveness and contributed to stagnating income levels.

Figure 6.3 below depicts trade openness, measured as the ratio of trade (exports plus imports) to GDP, expressed as a percentage. This indicator provides insights into the degree of integration of the selected countries into the global economy. However, it is important to note that changes in this ratio reflect not only shifts in trade volumes but also fluctuations in GDP. As such, variations in trade openness may result from increased trade activity, declining or

[3] [3] The RDP focused on growth through public investment in infrastructure and basic services. GEAR aimed to promote macroeconomic stability and attract investment. ASGI-SA targeted higher economic growth through infrastructure expansion and regulatory reform. JIPSA supported economic growth by addressing skills shortages in key economic sectors (JIPSA, 2007; Padayachee and Van Niekerk, 2019).

stagnating GDP, or a combination of both (Bleaney and Tian, 2022). The observed trends reveal significant variation among the countries, reflecting differences in economic structures, trade policies and levels of resource dependency.

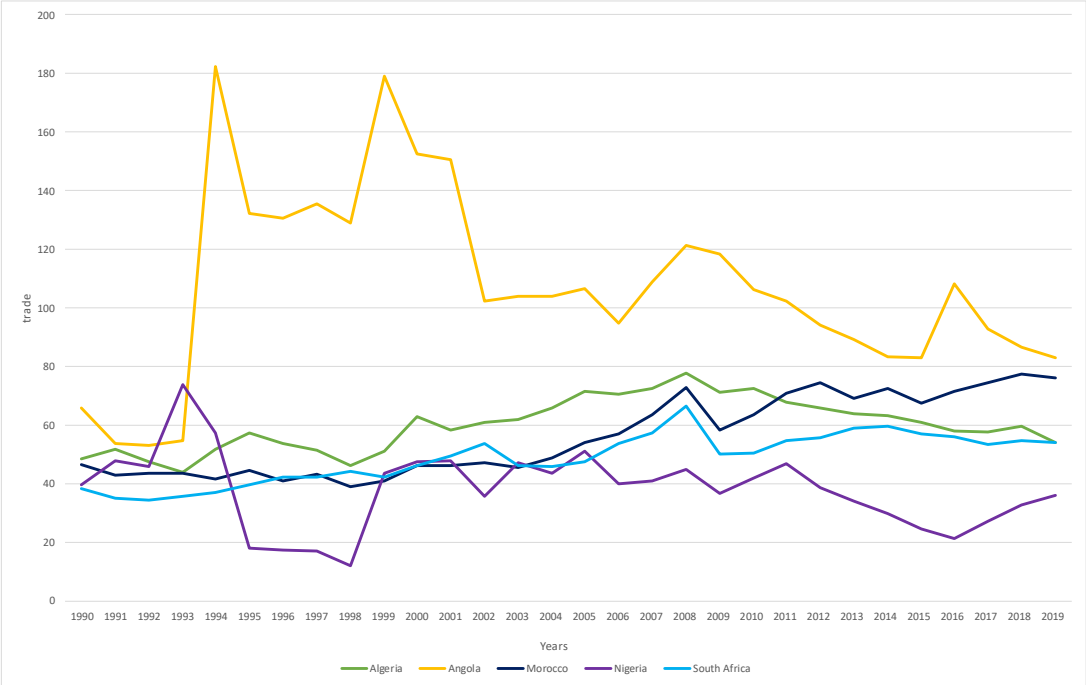

Figure 6.3: Trade openness (trade as a percentage of GDP)
Source: Compiled by the author based on the World Bank data (2024)

Angola's trade openness has been substantially higher than the other countries since 1994, although it has moved closer to the average in the last 5 years of the study period (2015 – 2019). This underscores the country's dependence on crude oil exports and its vulnerability to global price shocks. By 2019, trade openness had stabilised at 82.93%, reflecting recovery efforts after the 2014 oil price crash. Between 1993 and 2010, the level of trade openness increased in Algeria from 43.83% to 77.76%, partly due to hydrocarbon exports. Peaks align with periods of high oil prices, highlighting the country's dependence on oil and gas revenues (Benhabib and Maliki, 2014).

Trade openness has gradually grown in Morocco, from 38.74% in 1998 to 77.46% by 2018. This upward trend reflects successful diversification with key exports, including agricultural

products, textiles and renewable energy technologies (Yousef and Boubacar, 2021). Morocco's trade agreements and policies supporting export growth contribute to its consistent progress.

Nigeria exhibited a relatively volatile trend in trade openness over the period. From the early 1990s, its trade openness fluctuated due to shifting oil production levels and policy changes. Nigeria showed a declining trend in trade openness over most of the period, especially steep from around 2000 onward, reaching its lowest point between 2015 and 2017, before slightly recovering by 2019.

South Africa’s trade openness remained relatively stable from 1992 until the global financial crisis of 2008/9. The country’s diversified economy, with substantial contributions from mining, manufacturing and services, provides a degree of resilience to external shocks (Nyasha and Odhiambo, 2020). The global financial crisis marked a turning point, triggering a decline in trade openness. After this period, trade openness stabilised at around 60%, reflecting slower domestic economic growth. This pattern reflects persistent domestic constraints affecting trade performance (DTI, 2018).

Figure 6.4 below illustrates the trends in energy use per capita. The observed trends reflect differences in energy policies, resource availability and levels of industrial activity across the five countries.

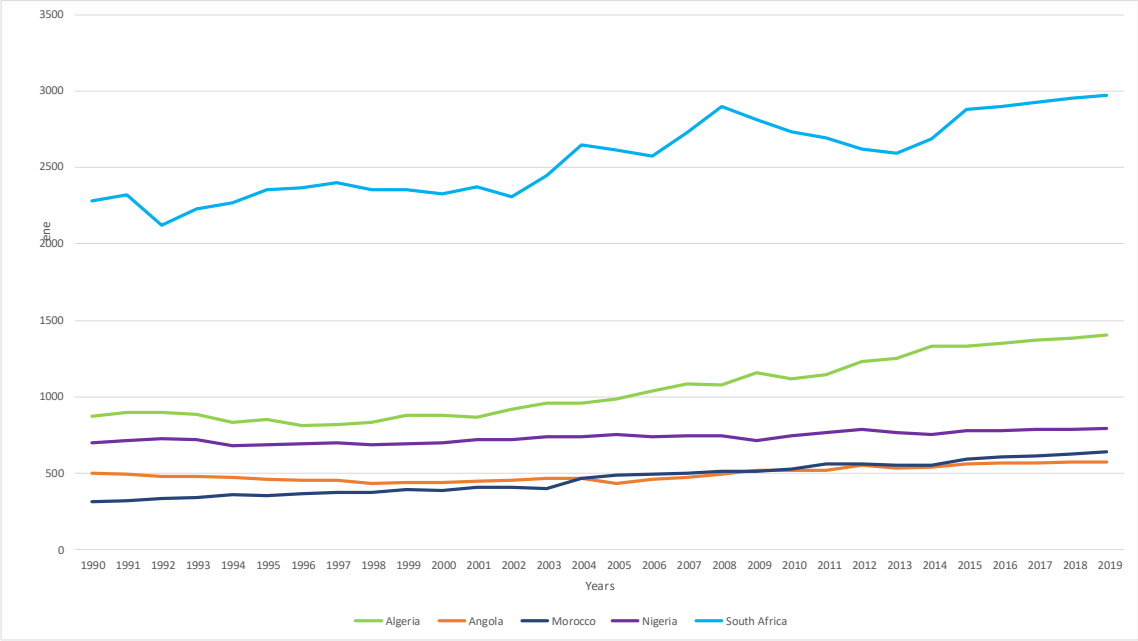

Figure 6.4: Energy use (kg of oil equivalent per capita)
Source: Compiled by the author based on the World Bank (2024)

South Africa has by far the highest energy use per capita of any of the countries in the sample. Algeria's total energy consumption per capita doubled from 800 kg of oil equivalent per capita in 1990 to 1,500 kg in 2019. This increase is due to Algeria's dependence on fossil resources, especially natural gas, for power generation and fusion processes (IEA, 2020). The government's commitment to building its hydrocarbon sector has increased energy consumption.

Angola exhibits comparatively low and stable energy use, fluctuating from around 600 to 800 kg of oil equivalent per capita between 1990-2019. The relatively low energy consumption is due to Angola's underdeveloped industrial sector. While Angola is a major oil exporter, domestic energy consumption remains low due to inadequate infrastructure and a large rural population with limited access to electricity (IEA, 2020).

Morocco's energy use per capita increased steadily from 500 kg of oil equivalent per capita in 1990 to around 900 kg by 2019. Despite this rise in consumption, the country has managed to

limit emissions growth by shifting its energy mix towards renewables. Morocco has emerged as a leader in renewable energy development in Africa. The country's flagship project, the Noor Ouarzazate Solar Complex, is one of the world's largest concentrated solar power plants, as discussed in Chapter 2. This project represents a key component of Morocco's strategy to reduce its reliance on imported fossil fuels and curb emissions growth (Jebli and Youssef, 2015).

Nigeria's energy use per capita fluctuates between 500 and 700 kg of oil equivalent per capita, with minimal overall growth. Despite being a significant oil producer, Nigeria's low domestic energy use per capita reflects inadequate energy infrastructure, frequent power outages and high dependence on traditional biomass for cooking and heating, especially in rural areas (IEA, 2021).

South Africa records the highest energy use per capita among the five countries, peaking at 3,000 kg of oil equivalent per capita in 2008 before declining to 2,500 kg by 2019. The high energy consumption is driven by South Africa's abundant coal reserves and the early development of an extensive electricity infrastructure centred around coal-fired power generation (Bekun et al, 2019). The post-2008 decline reflects slower economic growth and ongoing issues with power supply reliability, including frequent load shedding by Eskom, the national utility provider (Winkler et al, 2020).

Figure 6.5 below graphs the HDI as a composite indicator of life expectancy, education and income per capita. The trends reveal varying levels of progress among the selected countries and reflect differences in social policies, economic structures and governance.

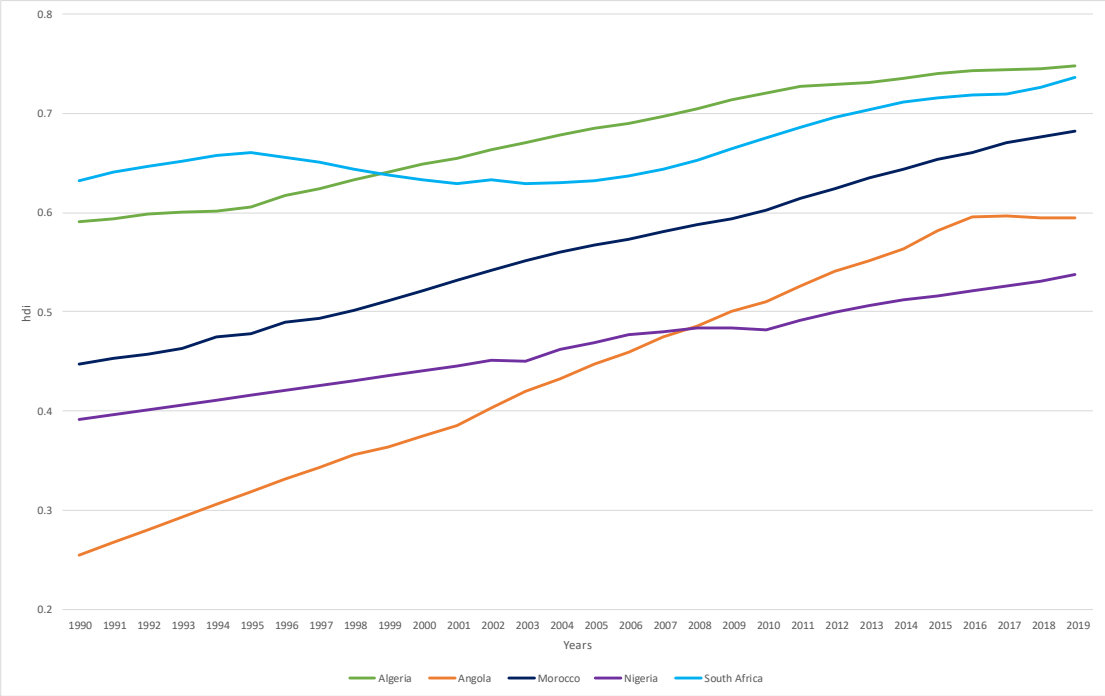

Figure 6.5: Human Development Index (0-1 scale)
Source: Compiled by the author based on the World Bank (2024)

Algeria's HDI has steadily increased, starting at 0.59 in 1990 and reaching 0.75 by 2019, reflecting significant investments in education, healthcare and income growth supported by hydrocarbon revenues (Boudarbat and Ajbilou, 2020). The absence of significant fluctuations suggests stability in development outcomes over the three decades.

Angola has the lowest initial HDI (in 1990) but overtakes Nigeria from 2009 to 2019. The country's initial low HDI represents the aftermath of the civil war of 1975-2002, which devastated infrastructure and social services (UNDP, 2020). The gradual improvement since the war reflects peace restoration and increased oil revenues, enabling reconstruction and investment in essential services. Despite this progress, Angola's HDI remains relatively low due to persistent challenges in healthcare, education and income inequality (Ferreira and Faria, 2020).

Morocco's HDI shows consistent progress, increasing from 0.49 in 1990 to 0.68 in 2019. Focused investments in education, healthcare and economic diversification drive this trend. Morocco's strong emphasis on human development policies positions it as a leader in sustainable progress. For example, policies such as the National Literacy Strategy (2004) and the National Initiative for Human Development (2005) have improved poverty, inequality and literacy rates (World Bank, 2019).

Nigeria's HDI remains relatively low, improving from 0.40 in 1990 to 0.54 in 2019. While the country has made gains in education and healthcare, these improvements are moderated by rapid population growth, regional disparities and economic challenges (Alege and Ogundipe, 2016). Population growth outpaces improvements in social services, limiting the overall rise in HDI.

South Africa had the highest HDI among the panel until 1998, when Algeria overtook it. The gap between the two countries widens and narrows as South Africa's HDI improves from the mid-2000s. Notably, South Africa's HDI has also been constrained by lower life expectancy relative to other middle-income countries, a trend largely attributed to the HIV/AIDS pandemic, which has significantly affected public health outcomes since the late 1990s (UNAIDS, 2022; UNDP, 2022). The improvement in the mid-2000s reflects relatively advanced infrastructure, a well-established education system, better income levels and the rollout of a comprehensive HIV/AIDS treatment program that began during the mid-2000s (UNDP, 2022).

6.3 Correlation analysis and panel unit root tests

Before conducting regression analysis, it is crucial to explore the characteristics of the data to ensure the robustness of econometric estimations. This section presents descriptive statistics, correlation analysis and panel unit root test results. Descriptive statistics provide insights into the data's central tendencies, dispersion and variability. Correlation analysis examines the relationships between the dependent and explanatory variables. Additionally, correlations

among explanatory variables are assessed to identify potential multicollinearity, which can bias regression results (Gujarati and Porter, 2009).

The correlation results for the variables in natural log form are presented in Table 6.1 below, where LNCO2PC = log of CO_2 emissions per capita, LNGDPPC = log of GDP per capita, LNGDPPC_SQ = squared log of GDP per capita, LNTRADE = log of trade as a percentage of GDP, LNENE = log of energy use per capita and LNHDI = log of Human Development Index. The results indicate that CO_2 emissions per capita strongly correlate with several explanatory variables, consistent with theoretical expectations derived from the EKC hypothesis, as discussed in Chapter 4.

Table 6.1: Correlation analysis for the panel dataset

	LNCO2PC	LNGDPPC	LNGDPPC_SQ	LNTRADE	LNENE	LNHDI
LNCO2PC	1.000					
LNGDPPC	0.937***	1.000				
LNGDPPC_SQ	0.936***	0.991***	1.000			
LNTRADE	0.893***	0.897***	0.896***	1.000		
LNENE	0.856***	0.921***	0.921***	0.808***	1.000	
LNHDI	0.466***	0.690***	0.693***	0.507***	0.696***	1.000

*** Significant at the 1% level
Source: Author's calculation using EViews 13

$LNCO_2PC$ is strongly positively correlated with LNGDPPC and LNGDPPC_SQ. LNCO2PC and LNENE exhibit a strong positive correlation. The correlation between $LNCO_2PC$ and LNHDI is moderate but still statistically significant.

Apart from the correlations between the study's proposed dependent and explanatory variables, it is also important to consider the correlation coefficients between the explanatory variables themselves. These can indicate to the researcher that there may be multicollinearity issues in the modelling phase of the research.

LNGDPPC is highly correlated with LNENE and LNTRADE. LNGDPPC is moderately correlated with LNHDI, indicating a positive relationship between economic growth and human development. There is also a moderate correlation between LNENE and LNHDI across the panel dataset.

While Table 6.1 provides valuable insights into the strength and direction of relationships between variables, it is critical to emphasise that correlation does not imply causation. For example, the strong correlation between LNENE and $LNCO_2PC$ does not mean energy consumption directly causes emissions. Both variables could be driven by underlying factors such as industrialisation. Another example is that the correlation between LNTRADE and $LNCO_2PC$ does not establish that trade openness increases emissions. Trade can also facilitate the adoption of cleaner technology, which might reduce emissions in the long term.

The high correlations between some explanatory variables indicate that multicollinearity may be an issue; therefore, a stepwise estimation approach is used.

The descriptive statistics for the dependent and explanatory variables are summarised in Table 6.2 below, providing further insights into their distribution and variability across the selected countries. Key measures, such as the mean, standard deviation, minimum and maximum, offer insights into the data distribution for the panel as a whole.

Table 6.2: Descriptive statistics for the panel dataset

Statistic	**LNCO2PC**	**LNGDPPC**	**LNGDPPC_SQ**	**LNTRADE**	**LNENE**	**LNHDI**
Mean	0.567898	7.969093	63.67825	4.028437	6.736856	-0.604210
Median	0.335298	7.976658	63.62707	3.988190	6.603853	-0.528484
Maximum	2.133770	8.742431	76.43010	5.206126	7.998495	-0.290352
Minimum	-0.710546	7.264739	52.77643	2.495124	5.736772	-1.366239
Std. Dev.	0.878491	0.415888	6.659380	0.440451	0.645122	0.237146
Skewness	0.444772	0.164931	0.250241	-0.063261	0.679612	-0.928885
Kurtosis	1.844312	2.124217	2.166185	4.299317	2.282574	3.489092
Jarque-Bera	13.29313	5.473778	5.910818	10.65145	14.76368	23.06574
Probability	0.0011298	0.064772	0.052057	0.004865	0.000622	0.000010
Sum	85.18465	1195.364	9551.737	604.2656	1010.528	-90.63154
Observations	150	150	150	150	150	150

Source: Author's calculation using EViews 13

$LNCO_2PC$ has a mean of 0.57, corresponding to approximately 1.77 metric tons of CO_2 per capita on average. This level is relatively moderate when compared to the global average for middle-income countries, which was around 3.6 metric tons in 2019 (World Bank, 2021). The average LNGDPPC of 7.97 translates to approximately US$2,900 GDP per capita, confirming the inclusion of countries that fall within the lower-middle to upper-middle income bracket, as

outlined in Chapter 4. LNENE, with a mean of 6.74, reflects an average energy use of about 850 kg of oil equivalent per capita, which is modest compared to the middle-income country average of around 1,500 kg (IEA, 2021). Lastly, LNHDI has a mean of –0.60, corresponding to an HDI value of approximately 0.55, indicating moderate to low levels of human development relative to the global middle-income average of 0.70 (UNDP, 2022).

The standard deviation measures the variability or dispersion of the data. LNGDPPC_SQ exhibits the highest standard deviation (6.66) followed by $LNCO_2PC$ with a standard deviation of 0.88. LNENE (0.65) and LNTRADE (0.44) show moderate variability, meaning their dispersion falls between the more volatile variables like emissions and income squared, and the more stable ones like HDI and GDP per capita. In other words, their standard deviations are neither the highest nor the lowest, reflecting intermediate levels of variation across the sample. LNGDPPC has the relatively low standard deviation (0.42) while LNHDI has the lowest standard deviation (0.24).

The minimum and maximum values provide the range of each variable in log form, which can be converted back to actual units for clearer interpretation. $LNCO_2PC$ ranges from –0.71 to 2.13, corresponding to approximately 0.49 to 8.43 metric tons of CO_2 per capita. LNGDPPC spans from 7.26 to 8.74, which translates to approximately US$1,428 to US$6,253 in GDP per capita, consistent with the World Bank's definition of lower and upper-middle-income economies. LNENE ranges from 5.73 to 7.99, equating to approximately 308 to 2,960 kilograms of oil equivalent per capita. Lastly, LNHDI ranges from –1.37 to –0.29, corresponding to HDI scores of approximately 0.25 to 0.75.

The descriptive statistics provide a comprehensive overview of the data, emphasising heterogeneity across the panel. These differences are expected to play a significant role in the relationship between economic growth and environmental degradation, as explored through the EKC hypothesis.

Finally, unit root testing is necessary to assess the stationarity or otherwise of the variables before performing regression analysis. Unit root test results for the panel dataset are presented in Table 6.3 below.

Assessing the stationarity or non-stationarity of the variables is a crucial step in econometric analysis in models with a time series dimension. Stationary variables have constant mean and variance over time, ensuring reliable and unbiased coefficient estimates. If variables are non-stationary, it is important to test for cointegration to avoid reporting spurious regression results (Gujarati and Porter, 2009). This study conducted panel unit root tests on all variables under intercept-only and intercept-with-trend specifications for the panel data analysis section.
As noted in Chapter 4, the study employs standard panel unit root tests reported in EViews, including the Levin, Lin and Chu (LLC), Im, Pesaran and Shin (IPS), and Fisher-type tests, to assess the stationarity properties of the variables. The null hypothesis for these tests is that there is a unit root in all the series. Failing to reject the null hypothesis implies that the series is non-stationary, meaning its statistical properties, such as mean and variance, change over time (Gujarati and Porter, 2009).

Table 6.3: Panel unit root test results

Variables	**Intercept**	**Intercept and trend**
LNCO2PC	I(1)	I(1)
LNGDPPC	I(1)	I(1)
LNGDPPC_SQ	I(1)	I(1)
LNTRADE	I(1)	I(0)
LNENE	I(1)	I(1)
LNHDI	I(0)	I(1)

Source: Author's estimation using EViews 13

LNTRADE is stationary in level terms [I(0)], with an intercept and trend, while LNHDI is stationary with an intercept only included. All the other variables are non-stationary in levels but become stationary at first differences [I(1)], regardless of whether the test includes just an intercept, or both an intercept and a trend. A prevalence of I(1) series is very common with economic time series data.

The mixed orders of integration in the dataset indicate that panel models capable of handling both I(0) and I(1) variables can be used for estimation. As noted in Chapter 4, following the preliminary FE and RE estimations, this study uses the PMG-ARDL model in the panel data case, which is recommended for a mix of I(0) and I(1) variables and is well-suited for capturing both short-run and long-run dynamics in the data.

The non-stationarity of these variables in level terms underscores the need for cointegration analysis to determine whether long-run equilibrium relationships exist among them. This is particularly relevant for the EKC hypothesis, where long-term interactions between GDP per capita and environmental degradation are of primary interest. The unit root results indicate the need for the subsequent cointegration analysis using the bounds test approach in the ARDL modelling, as discussed in later sections of this chapter.

6.4 Panel data analysis

As noted in Chapter 4, the econometric investigation of the EKC relationship for the countries under study begins with a panel data approach, following the method used in studies such as Shahbaz et al (2015), Haseeb et al (2018) and Gorus and Aydin, (2019). Panel data analysis is particularly suitable for this investigation because it allows for the inclusion of both cross-sectional (between-country) and time-series (within-country) variation, thereby improving the robustness and reliability of the estimated relationships.

Section 6.4.1 below reports the preliminary panel data analysis results using fixed effects (FE) and random effects (RE) models. These models serve as a useful starting point because they provide initial insights into the relationships between the variables while accounting for heterogeneity across countries. Heterogeneity in this context refers to differences in structural factors, such as economic development levels, energy policies and trade dynamics, which may influence the EKC relationship differently in each country.

6.4.1 Preliminary panel analysis: FE and RE models

Table 6.4 below presents the results of three model specifications estimated using the FE and RE approaches, with all variables in log form. As discussed in Chapter 4, the dependent variable in the study is CO_2 emissions per capita. The explanatory variables include GDP per capita, the squared term of GDP per capita, energy use per capita, trade openness and the HDI. Models 1 and 2 apply the FE and RE approaches respectively and include all explanatory variables except the HDI. Model 3 adopts the FE approach and includes the HDI as well.[4] This analysis is a foundation for understanding the relationship between economic growth and environmental degradation while accounting for heterogeneity across countries.

The Hausman test determines the most appropriate model between the FE and RE models. The results of the Hausman test for Model 1 (FE) versus Model 2 (RE) are presented in Table 6.4 below. The Hausmann test yields a chi-square statistic of 1307.81 with a p-value of 0.000, which indicates a rejection of the null hypothesis. Consequently, the FE model is deemed more appropriate for analysing the EKC relationship. The RE approach is unsuitable, as the significant test statistic suggests that country-specific random effects correlate with the explanatory variables (Gujarati and Porter, 2009).

Following the results of the Hausman test, Model 3, which includes all five explanatory variables, is estimated using the FE approach. The HDI is an additional explanatory variable to evaluate the broader socioeconomic factors influencing CO_2 emissions.

[4] The reason for omitting the HDI initially was that the RE model requires the number of explanatory variables to be less than the number of cross-sectional units. With five cross-sectional units, only four explanatory variables could be included. HDI was initially chosen for omission since the correlation coefficient between the dependent variable and HDI was the lowest in Table 6.1.

Table 6.4: Fixed effects and random effect models

Dep variable LNCO2PC	Model 1 FE	Model 2 RE	Model 3 FE
C	16.43	36.89	22.44
LNGDPPC	-5.58***	-11.13***	-6.68***
LNGDPPC_SQ	0.33***	0.78***	0.39***
LNTRADE	0.18***	0.06**	0.17***
LNENE	0.92***	0.351538***	0.89***
LNHDI			0.52***
Adj R-squared	0.982	0.822	0.984
F-statistic	1032.586***	173.965***	1087.891***
Hausman chi-sq.	1307.807***		

*** Significant at 1% level
** Significant at 5% level
Source: Author's estimations using EViews 13

A key focus of the analysis is the relationship between GDP per capita and CO_2 emissions, which is central to testing the EKC hypothesis. The results indicate a U-shaped relationship contrary to the traditional inverted U-shaped EKC. Across all Models 1-3, the coefficient of LNGDPPC is negative and statistically significant at the 1% level, while the coefficient of the LNGDPP_SQ is positive and significant at the 1% level. This pattern suggests that in the early stages of economic growth, CO_2 emissions may decline modestly as households and firms access relatively more efficient energy sources. This may involve, for instance, shifting from traditional biomass (such as wood or charcoal) to electricity or fossil fuels (Huo et al, 2021). However, as income rises, emissions begin to increase again, potentially due to expanding industrial activity, urbanisation and increased energy consumption associated with higher living standards.

Amongst the control variables, trade openness and energy use also emerge as significant factors influencing CO_2 emissions. Across all the models, the coefficient on energy use is positive and statistically significant at the 1% level, indicating that higher energy consumption contributes to greater emissions, holding all else constant. This aligns with prior expectations (see Table 4.1).

The coefficient on trade openness is significant at the 1% level in Models 1 and 3 and at the 5% level in Model 2 (RE). This finding suggests that greater trade openness is associated with higher CO_2 emissions. A plausible explanation is that expanded trade drives up industrial output and fossil energy use in resource-exporting or regulation-weak economies, thereby raising emissions. This outcome is consistent with the Pollution Haven Hypothesis (PHH), which argues that countries with more relaxed environmental regulations may attract polluting industries as trade barriers are liberalised (Cole, 2003).

The findings also reflect the mixed theoretical expectation outlined in Table 4.1, where trade can reduce emissions via cleaner technology transfer or raise them by encouraging pollution-intensive activities. In Model 3, the HDI coefficient is positive and statistically significant, suggesting a positive association between the HDI and CO_2 emissions. This result contradicts the negative sign anticipated in Table 4.1, where higher development levels are expected to support sustainable practices and reduce emissions.

The FE and RE models provide an initial understanding of the relationship between GDP per capita and environmental degradation, but they have limitations. In particular, their validity is unclear in the absence of cointegration testing. Given the findings of non-stationarity from the panel unit root tests in Section 6.3, this study estimates and discusses the PMG-ARDL model next. As noted in Chapter 4, this allows for cointegration testing and captures both long-run and short-run dynamics in the EKC relationship. The PMG-ARDL model is particularly suited to addressing cross-country heterogeneity and the mixed integration properties of the variables, as explained in Chapter 4.

6.4.2 PMG-ARDL models

Building on the preliminary FE and RE estimations, this section presents the PMG results using the ARDL framework, which is well-suited for panel data with variables at different orders of integration. As noted in Chapter 4, a stepwise approach is applied across Models 4–11 to sequentially introduce explanatory variables and examine their individual and joint effects on

CO_2 emissions. This method enhances model robustness and helps isolate how each factor influences the EKC relationship. Although the PMG-ARDL model estimates short-run and long-run dynamics, this study focuses on interpreting the long-run coefficients, which are more relevant to assessing structural trends in environmental degradation.

Model 4 is the basic PMG-ARDL model, which includes only the linear and quadratic terms of GDP per capita. Model 5 introduces LNTRADE; Model 6 adds LNENE and Model 7 adds LNHDI. Subsequent models include different combinations of the control variables to capture additional socioeconomic dynamics. Model 11 is the complete model with all the variables included. This stepwise modelling strategy is also consistently applied in the subsequent country-level time-series models, ensuring comparability and robustness across both panel and individual estimations. While multicollinearity is a potential concern, particularly when including LNHDI alongside LNGDPPC, the models were estimated incrementally to reduce overlapping variation.

In contrast to the simple FE and RE estimations, the PMG-ARDL results in Table 6.5 below provide evidence supporting the EKC hypothesis in the panel context. Across Models 4-11 (except for Models 5 and 10), LNGDPPC coefficients are consistently positive and statistically significant, while LNGDPPC_SQ coefficients are negative and significant. This indicates an inverted U-shaped relationship, indicating that carbon emissions initially increase with GDP per capita but decline once a certain income threshold is reached (Shahbaz et al, 2015). However, regarding cointegration, the validity of the results for some countries is mixed, as discussed further below.

Table 6.5: PMG-ARDL models (long-run coefficients)

Dep variable LNCO2PC	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
C	-148.37	312.69	-15.04	-49.99	-173.91	-90.12	-14.40	-29.22
LNGDPPC	34.40***	-79.99***	2.39**	11.02***	40.95***	20.44***	2.17	5.63***
LNGDPPC_SQ	-1.97***	5.12***	-0.16**	-0.58**	-2.32***	-1.13***	-0.14	-0.29***
LNTRADE		-0.15			-0.30***	-0.14***		-0.32***
LNENE			1.04***		-0.45***		1.02	0.67***
LNHDI				-0.86***		-0.74***	-0.06	-1.03***
Bounds test								
Algeria	NC	C	C	C	NC	I	C	C
Angola	C	C	C	C	I	C	C	NC
Morocco	C	C	NC	NC	NC	C	NC	C
Nigeria	NC	NC	NC	NC	NC	NC	I	NC
South Africa	C	I	I	C	I	C	C	C

*** Significant at 1% level
** Significant at 5% level
C = Cointegration present
NC = No cointegration
I = Inconclusive cointegration result
Source: Author's estimations using EViews 13

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As control variables are introduced in each model depicted in the table, the inverted U-shape largely persists (except for Model 5). However, the significance of the coefficients of LNGDPPC and LNGDPPC_SQ vary. When LNTRADE is added in Models 8, 9 and 11, the traditional EKC shape is still evident, while the trade openness coefficient is statistically significant at the 1% level in these specifications.

The introduction of LNENE in Models 6, 8, 10 and 11 suggests a strong link between energy consumption and emissions, except in Model 10. In Models 6, 8 and 11, the coefficient on LNENE is statistically significant at the 1% level, suggesting that increased per capita energy use is associated with higher CO_2 emissions, holding all else constant. This finding aligns with expectations for countries in this study, particularly Algeria, Angola and South Africa, where energy systems remain heavily reliant on fossil fuels (coal, oil, and gas) (IEA, 2023).

LNHDI is added as a control variable in Models 7, 9, 10 and 11. LNHDI has negative and statistically significant coefficients at the 1% level in three of the models (7,9 and 11). This suggests that education, health and income improvements are associated with decreases in CO_2 emissions per capita, aligning with a priori expectations in Table 4.1(Ulucak and Khan, 2020).

While most of the PMG-ARDL models in Table 6.5 support the inverted U-shaped EKC, Model 5 deviates from this pattern, suggesting a statistically significant U-shaped relationship between GDP per capita and CO_2 emissions. The coefficients on LNGDPPC and LNGDPPC_SQ are significant at the 1% level. This implies that emissions initially decrease with rising income but begin to increase again beyond a certain income threshold (Adu and Denkyirah, 2022). As noted earlier, this pattern is often associated with countries experiencing early growth through non-industrial activities or resource exports, followed by increased emissions as industrialisation deepens without adequate environmental safeguards.

According to Adams and Nsiah (2019), the U-shaped EKC curve is often observed in resource-dependent developing economies, where early economic growth is driven by primary sectors like oil and gas rather than manufacturing or services. This growth pattern is frequently associated with under-industrialisation, meaning that increases in GDP per capita do not immediately translate into higher emissions due to limited energy-intensive production (Friedrich and Basson, 2021).
Such a trajectory could characterise economies like Angola and Nigeria, which are investigated further in the time series section below. Similar findings are reported in the African context by Tenaw and Beyene (2021), whose panel study across 20 Sub-Saharan African countries confirmed a U-shaped relationship in some cases, particularly where economic gains stem from natural resource exploitation rather than diversified industrial development.

These studies highlight that in resource-reliant settings, environmental degradation may initially decrease or remain flat before rising again as delayed industrialisation and energy demand take effect. This pattern contrasts the traditional inverted U-shape commonly found in

higher-income or structurally diversified economies (Shahbaz et al, 2023; Dogan and Seker, 2016), suggesting that the EKC's shape is context-dependent.

As discussed in Chapter 4, despite the statistical significance of most of the key coefficients in the PMG-ARDL results in Models 4-11, cointegration must be tested for using the bounds test due to the non-stationary of the series. Cointegration testing determines whether a stable long-run relationship exists between the variables. If cointegration is not present, the validity of the results is questionable, as they may be spurious.

The cointegration results in Table 6.5 above are mixed across countries and models. For example, in the complete model (Model 11), in which all coefficients are statistically significant, no cointegration is found in the cases of Angola and Nigeria. To examine country specificities further in light of these findings, the study proceeded to estimate individual time series for the five countries. Section 6.5 below presents the results of the individual country-level ARDL models, emphasising the long-run relationships once again.

6.5 Time-series analysis: Findings and discussion

This section presents the results of time series estimations for each selected country: Algeria, Angola, Morocco, Nigeria and South Africa. Focusing on time series data, this section aims to provide deeper insights into how the explanatory variables influence CO_2 emissions in each country's unique economic and policy context. The ARDL approach is used for the time-series modelling undertaken in this section.[5] The section also compares findings across countries, emphasising differences in the behaviour of key variables over time.

6.5.1 Time-series unit root tests

[5] While individual country time series regressions were also estimated using the OLS method, cointegration testing using the Engle-Granger approach is unsatisfactory in the multiple regression context. Furthermore, as noted in Chapter 4, the ARDL method is more suitable for a mix of I(0) and I(1) time series. Hence, the OLS findings are not discussed here, although the OLS results are included in Appendix B.

This study applies unit root tests to investigate the stationarity or non-stationarity of the variables for each country separately. Table 6.6 below summarises the results of the five countries' Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) tests. The null hypothesis for the ADF test is that the series has a unit root, meaning it is non-stationary (Dickey and Fuller, 1979; Zivot, 2020). Rejecting the null hypothesis indicates that the series is stationary. In contrast, the null hypothesis for the KPSS test is that the series is stationary around a deterministic trend; failure to reject this null hypothesis implies stationarity, while rejection suggests non-stationarity. By applying both tests, the analysis ensures a more robust determination of stationarity or non-stationarity.

Table 6.6: Summary of unit root test results for country time series

	Algeria		Angola		Morocco		Nigeria		South Africa	
Variable	ADF	KPSS	ADF	KPSS	ADF	KPSS	ADF	KPSS	ADF	KPSS
LNCO2PC	I(1)	I(1)	I(0)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)
LNGDPPC	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(2)	I(0)	I(1)	I(0)
LNGDPPC_SQ	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(2)	I(0)	I(1)	I(0)
LNTRADE	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)	I(1)	I(1)
LNENE	I(1)	I((1)	I(1)	I(1)	I(1)	I(0)	I(1)	I(0)	I(1)	I(0)
LNHDI	I(2)	I(1)	I(2)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

Source: Author's calculation using EViews 13

The ADF and KPSS results for Algeria indicate that most variables are stationary after first differencing. The exception is LNHDI, which is stationary at second differences. However, this variable is I(1) according to the KPSS test. For Angola, the ADF and KPSS tests indicate mixed results across variables. All of the variables in the case of Angola are I(0) or I(1), except for LNHDI in the case of the ADF test, which is I(2). Once again, however, LNHDI is I(1) under the KPSS test and is retained.

In the case of Nigeria, the series are all I(1) according to the ADF test, except for LNGDPPC and LNGDPPC_SQ. However, the latter are both stationary under the KPSS test. For Morocco and South Africa, all variables are I(1) according to the ADF test and either I(0) or I(1) for the KPSS test.

In sum, most of the variables used in the individual time series modelling are I(1) or I(0), according to the ADF and KPSS tests. In the few instances where series are I(2) in the ADF test, they are found to be I(0) or I(1) in the KPSS test and are hence retained. The mix of I(0) and I(1) variables indicates the suitability of time series ARDL as the estimation method for this section.

6.5.2 ARDL time-series models

This section presents the ARDL time-series estimation results for Algeria, Angola, Morocco, Nigeria, and South Africa, with each country depicted in a separate table. As outlined in Chapter 4, the stepwise approach is used, with control variables added incrementally and cointegration is tested using the bounds test to determine the presence of stable long-term relationships between emissions and the explanatory variables.

Table 6.7: ARDL time-series model: Algeria

Dep variable LNCO2PC	Model 12	Model 12a	Model 12b	Model 12c	Model 12d	Model 12e	Model 12f	Model 12g
C	116.56	73.69	157.75	262.64	131.03	348.74	422.30	533.29
LNGDPPC	-29.09	-18.56	-39.74***	-64.16**	-76.78***	-85.07***	-92.67***	-148.19***
LNGDPPC_SQ	1.82	1.18	2.47***	3.95**	4.74***	5.23***	5.70***	9.12***
LNTRADE		0.0001	-		0.08	-0.11*		0.04
LNENE			0.65***		0.74***		0.64***	0.84***
LNHDI				-0.12		1.56	2.28	1.91
Adjusted R-squared	0.980	0.981	0.999	0.987	0.992	0.988	0.993	0.997
F-statistic	212.586***	168.123***	375.44***	212.756***	214.114***	239.478***	207.159***	479.41***
(Cointegration) Bounds test	C	C	C	C	NC	C	C	C

*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level
Source: Author's estimations using EViews 13

Table 6.7 above presents the ARDL time-series regression results for Algeria using a piecewise regression approach.

Model 12 is the basic model where the coefficients of LNGDPPC and LNGDPPC_SQ are statistically insignificant, suggesting no meaningful evidence of an EKC relationship in this model. The lack of significance likely reflects the effect of omitted variables, as this relationship changes once relevant control variables are introduced into the model.

Model 12b includes LNENE, which has a significant coefficient at the 1% level. The coefficients of LNGDPPC and LNGDPPC_SQ are also significant at the 1% level, suggesting a U-shaped EKC. This indicates that energy use plays a crucial mediating role in Algeria's income-emissions relationship.

Further support for a U-shaped relationship is found in the complete model (Model 12g), which includes all the control variables. The U-shaped EKC pattern holds, with the coefficients of the GDP terms and LNENE remaining highly significant at the 1% level. The coefficients of LNTRADE and LNHDI are statistically insignificant in this and all other model specifications where they appear. Models 12b and 12g perform best in the case of Algeria. Notably, although the coefficient of LNHDI is statistically insignificant, its t-statistic exceeds 1 in absolute terms, indicating that it contributes to the explanatory power of Model 12g.

Overall, the results indicate that a significant U-shaped EKC only emerges once energy use is included, highlighting the importance of Algeria's fossil fuel dependency in driving emissions. Among the three control variables (LNTRADE, LNENE, and LNHDI), only LNENE consistently exhibits statistically significant coefficients, affirming its dominant role in Algeria's long-run emissions trajectory. Evidence of cointegration is found in all ARDL models for Algeria, except for Model 12d.

Table 6.8: ARDL time-series model: Angola

Dep variable LNCO2PC	Model 13	Model 13a	Model 13b	Model 13c	Model 13d	Model 13e	Model 13f	Model 13g
C	110.52	132.18	107.22	115.83	135.17	35.26	101.98	-95.54
LNGDPPC	-11.11*	-11.25	-13.07	-12.83	-9.04	13.86	-12.02	59.66
LNGDPPC_SQ	0.70	0.71	0.83	0.81	0.56	-0.89	0.76	-3.80
LNTRADE		-0.04			-0.05	-0.30***		-1.04
LNENE			0.16		-0.15		0.20	1.03
LNHDI				0.06		-6.51***	-0.05	-21.39
Adjusted R-squared	0.872	0.883	0.866	0.865	0.876	0.915	0.858	0.837
F-statistic	26.197***	18.832***	21.960***	21.761***	16.338***	19.639***	18.454***	6.789*
(Cointegration) Bounds test	C	C	C	C	C	C	C	NC

*** Significant at 1% level
*Significant at 10% level
Source: Author's estimations using EViews 13

Table 6.8 above presents ARDL time-series regression results for Angola using a piecewise regression approach.

Model 13 is the basic model. The coefficient of LNGDPPC is weakly significant at the 10% level, while the coefficient of LNGDPPC_SQ is insignificant, offering no support for the EKC hypothesis. The F-statistic confirms that the model is statistically significant overall, indicating that at least one of the included variables explains variation in CO_2 emissions. However, the insignificance of the GDP per capita squared coefficient suggests that the model is likely under-specified and that including relevant control variables may improve its explanatory power.

A more informative result appears in Model 13e, where LNHDI and LNTRADE are added. The model is statistically significant overall, with a significant F-statistic at the 1% level. The coefficients of LNTRADE and LNHDI are negative and significant at the 1% level, suggesting that improvements in human development and increased trade openness are associated with lower CO_2 emissions in Angola, holding all else constant. However, the coefficients of LNGDPPC and LNGDPPC_SQ remain statistically insignificant, suggesting that income growth does not drive emissions trends in this instance. While including LNTRADE and LNHDI improves the model's specification, the absence of significance in the GDPPC coefficients means there is still no evidence of an EKC relationship in this model.

The complete model (Model 13g) includes all explanatory variables, but none are statistically significant. This reinforces Model 13e as the best-fitting and most reliable specification for Angola. In summary, no support is found for the EKC in Angola. Cointegration is confirmed in all models except Model 13g.

Across all specifications, LNHDI and LNTRADE coefficients show statistical significance only in Model 13e, suggesting their joint relevance in explaining Angola's emissions. The coefficient of LNENE remains statistically insignificant throughout, indicating that it does not meaningfully affect long-run emissions trends in the Angolan context.

Table 6.9: ARDL time-series model: Morocco

Dep variable LNCO2PC	Model 14	Model 14a	Model 14b	Model 14c	Model 14d	Model 14e	Model 14f	Model 14g
C	-14.07	-3.02	-4.55	-8.67	-3.33	-8.49	-3.87	-72.12
LNGDPPC	-2.03	-5.36	-3.82	-9.52	2.40	-6.87	-25.15**	-6.92
LNGDPPC_SQ	0.20**	0.42	0.30	0.67	-0.11	0.53	1.69**	0.56
LNTRADE		0.10			0.10	0.17*		-0.08
LNENE			0.34*		0.35*		0.47**	0.09***
LNHDI				0.60		-0.63	4.03**	-8.20*
Adjusted R-squared	0.988	0.989	0.990	0.988	0.989	0.991	0.993	0.997
F-statistic	211.976***	194.772***	228.489***	194.001***	188.400***	173.938***	239.705***	429.801***
(Cointegration) Bounds test	C	C	C	C	NC	C	C	C

*** Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimations using EViews 13

Table 6.9 above presents the ARDL time-series regression results for Morocco using a piecewise regression approach.

The basic model (Model 14) includes only LNGDPPC and LNGDPPC_SQ. While the coefficient of LNGDPPC is statistically insignificant, the LNGDPPC_SQ coefficient is significant at the 5% level. The model is statistically significant overall, with an F-statistic that is significant at the 1% level. However, the absence of significance of the GDPPC coefficient

suggests that the model is likely under-specified and that additional structural factors are needed for clearer insights.

A more informative result for Morocco appears in Model 14f, where LNENE and LNHDI are included. The coefficients for LNGDPPC, LNGDPPC_SQ, LNENE and LNHDI are all statistically significant at the 5% level. This strengthens the evidence of a U-shaped EKC. The F-statistic is highly significant, supporting the model's overall validity. LNENE's positive coefficient suggests that higher energy consumption leads to increased emissions. In contrast, the coefficient of HDI has an unexpected positive sign in Model 14f. These results strengthen support for a U-shaped EKC.

Model 14g is the complete model, incorporating all explanatory variables. The model is statistically significant overall, with a significant F-statistic and the highest adjusted R-squared, indicating a strong overall fit and improved explanatory power when structural factors are fully included. The coefficient of LNENE is statistically significant at the 1% level, reinforcing its importance as a key driver of emissions in Morocco.

The coefficient of LNHDI is weakly significant at the 10% level, and its coefficient is negative. However, both coefficients for LNGDPPC and LNGDPPC_SQ are statistically insignificant, indicating that income growth does not meaningfully explain emissions in this model. This weakens the case for the EKC hypothesis in Morocco, particularly when structural variables are accounted for.

In summary, there is no evidence for the EKC except for the U-shaped result in Model 14f. There is evidence of cointegration in all models except for Model 14d.

Table 6.10: ARDL time-series model: Nigeria

Dep variable LNCO2PC	Model 15	Model 15a	Model 15b	Model 15c	Model 15d	Model 15e	Model 15f	Model 15g
C	36.04	43.41	64.49	97.22	125.99	97.93	100.11	106.51
LNGDPPC	-9.29	-11.26	-44.01**	-0.47	-37.17***	-0.40	-31.59***	-37.45***
LNGDPPC_SQ	0.59	0.73	2.91**	0.06	2.44***	0.06	2.15***	2.49***
LNTRADE		0.03			-0.01	0.00		-0.06*
LNENE			2.60***		2.60***		2.81***	3.36***
LNHDI				8.20**		8.18**	-1.51**	-1.92***
Adjusted R-squared	0.804	0.798	0.845	0.871	0.895	0.862	0.909	0.918
F-statistic	39.369***	28.724***	26.384***	16.924***	19.454***	14.484***	27.059***	23.350***
(Cointegration) Bounds test	NC	NC	I	C	C	I	C	C

*** Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimation using EViews 13

Table 6.10 above presents ARDL time-series regression results for Nigeria using a piecewise regression approach.

In the basic model (Model 15), the coefficients of LNGDPPC and LNGDPPC_SQ are insignificant. This suggests no support for the EKC in its simplest form and likely reflects model misspecification due to omitted structural variables.

A more informative result emerges in Model 15d, which includes LNENE. All three coefficients for LNGDPPC, LNGDPPC_SQ, and LNENE are statistically significant at the 1% level. The GDP terms display a negative and positive sign respectively, confirming a U-shaped EKC.

The complete model (Model 15g) offers the most robust results. The coefficients of LNGDPPC, LNGDPPC_SQ and LNENE remain significant at the 1% level. The coefficient of HDI is negative and statistically significant at the 1% level**,** indicating that human development improvements are associated with reduced emissions, holding all else constant. The LNTRADE coefficient is weakly significant and negative at a 10% level, suggesting limited explanatory value. The model's F-statistic is significant, and Model 15g has the highest adjusted R squared.

In summary, Nigeria only shows strong evidence of a U-shaped EKC when control variables are included (Model 15g). The most robust models suggest that emissions are shaped by the interaction of GDPPC with energy use and the HDI. This reinforces the importance of multidimensional specifications in understanding Nigeria's emissions dynamics.

There is evidence of cointegration in Models 15c, 15d, 15f and 15g. There is no evidence of cointegration in the basic models (15, 15a) and an inconclusive result for Models 15b and 15e.

Table 6.11: ARDL time-series model: South Africa

Dep variable LNCO2PC	Model 16	Model 16a	Model 16b	Model 16c	Model 16d	Model 16e	Model 16f	Model 16g
C	-164.42	-88.80	159.97	372.40	-115.03	-353.03	-367.05	-225.12
LNGDPPC	-71.43**	-72.58*	-66.69*	-58.04*	-46.05	-89.23*	-58.53	-110.92*
LNGDPPC_SQ	4.19**	4.25*	3.91*	3.40*	2.69	5.22*	3.43	6.51*
LNTRADE		-0.07			-0.14	0.15		0.03
LNENE			0.19		-0.01		0.05	-0.25
LNHDI				-1.25		0.24	-1.27	0.77
Adjusted R-squared	0.943	0.944	0.944	0.966	0.951	0.979	0.963	0.978
F-statistic	44.209***	34.405***	37.795***	49.976***	34.782***	66.359***	43.257***	52.483***
(Cointegration) Bounds test	C	C	C	C	C	C	C	C

***Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimation using EViews 13

Finally, Table 6.11 above presents the ARDL time-series regression results for South Africa using a piecewise regression approach.

In the basic model (Model 16), the coefficients of LNGDPPC and LNGDPPC_SQ are significant at the 5% level. There is thus evidence of a U-shaped EKC. The F-statistic is significant at the 1% level, suggesting a significant model overall. These results indicate that emissions in South Africa initially decrease with income growth but rise again as the country progresses beyond a certain threshold.

In the complete model (Model 16g), the coefficients of LNGDPPC and LNGDPPC_SQ are weakly significant at the 10% level, suggesting a weakly U-shaped relationship once control variables have been added. In South Africa, control variables do not significantly influence the relationship between GDP and CO2 emissions. In summary, South Africa exhibits a weakly observed U-shaped EKC, supported across multiple model specifications, including Model 16g. Across all the model specifications, none of the control variables demonstrate statistical significance. This pattern suggests that these structural variables do not mediate South Africa's emissions in the long run. This suggests that South Africa's emissions trajectory is driven by GDP per capita patterns and the carbon intensity of its industrial base rather than by broader structural or developmental factors. Cointegration is confirmed across all the models (Models 16-16g).

As explained in Chapter 4, GDP per capita turning points for the ARDL models are calculated where relevant and presented below in Table 6.12.

Table 6.12: GDPPC turning point for ARDL models

Country	Turning Point	Sample range	Within sample	EKC curve
Algeria	$3 361.02	$1 510.20 - $3 294.47	No	U-shaped
Nigeria	$1 844.57	$1 422.26 - $2 670.44	Yes	U-shaped
South Africa	$5 014.05	$4 272.69 - $6 247.90	Yes	U-shaped

Source: Compiled by the author based on the World Bank (2024)

The observed turning points indicate the income level at which the relationship between GDP per capita and CO_2 emissions changes direction, where emissions stop declining and begin rising with GDP per capita. For countries where a U-shaped EKC is consistently supported, this point represents the threshold beyond which economic growth is associated with environmental deterioration.

It is important to note that the validity of these turning points depends on the statistical significance of both GDP per capita and GDP per capita squared (Destek and Sarkodie, 2019). For Morocco, the coefficients of LNGDPPC and LNGDPPC_SQ were largely statistically insignificant, with one exception, suggesting the EKC relationship is not supported. As a result,

the turning point for Morocco was not calculated, as doing so would involve dividing by an insignificant coefficient, which would be econometrically invalid. Similarly, Angola's GDP per capita squared coefficient was statistically insignificant in the best-fitting model, suggesting a linear rather than quadratic relationship. Therefore, the turning point was also not calculated for Angola.

6.6 Comparative discussion and implications of EKC patterns

The empirical results presented in this chapter offer a detailed country-by-country analysis of the income–emissions relationship for five middle-income African countries: Algeria, Angola, Morocco, Nigeria, and South Africa. This section summarises the key findings, highlights cross-country similarities and differences and discusses the implications of the EKC theory and environmental policy in Africa.

A key finding is that a U-shaped EKC is observed in Algeria, Nigeria and South Africa. The coefficients of GDP per capita and its squared term are statistically significant in the best-fitting ARDL models. In these cases, emissions initially decline as income rises but begin to increase again beyond a certain income threshold. These results challenge the traditional inverted U-shaped EKC, implying that environmental degradation decreases with sustained growth. Instead, the findings suggest that structural reliance on fossil fuels, limited green infrastructure and energy-intensive growth continue to fuel emissions even at higher income levels in these economies (Nathaniel and Iheonu, 2019).

As noted in Chapter 3, similar U-shaped patterns have been observed in other African studies, such as in Ogundipe et al (2014), who found that economic growth initially reduced emissions but later intensified them in resource-based economies, and Jebli and Youssef (2015), who documented a U-shaped EKC for Tunisia. As discussed in Chapter 3, Sarkodie (2018), however, did find an inverted U-shaped EKC for a sample of African countries using FE and RE models, highlighting that heterogeneity within Africa plays a key role in shaping environmental outcomes. These findings align with the panel-based results from this study,

which show that while some countries demonstrate EKC-like behaviour, others do not, emphasising the region-specific applicability of the hypothesis.

For Algeria and South Africa, this may be attributed to energy-intensive industrialisation strategies driven by fossil fuels, particularly coal in South Africa and natural gas in Algeria. As one of the largest gas producers in Africa, Algeria has long relied on subsidised domestic energy pricing to expand electricity access and support industrial growth (El-Katiri, 2014; Ounalli and Bachta, 2020). While this approach has helped meet energy demand affordably, it has also reduced incentives for energy efficiency and delayed diversification into cleaner energy sources.

Algeria's clean energy transition has been slow, constrained by institutional rigidity and political dependence on hydrocarbon revenues. The absence of a carbon pricing mechanism and prioritising short-term economic goals have delayed emissions mitigation efforts (Aissaoui, 2016).

South Africa's emissions pattern is shaped by a development path driven by coal-fired energy production, which accounts for more than 80% of electricity generation (World Bank, 2024). The country's industrialisation strategy, rooted in apartheid-era resource exploitation, created a highly centralised and energy-intensive economy focused on mining, steel and chemicals. While South Africa has a well-established energy grid and regulatory institutions, its energy transition is challenged by the dominance of Eskom (Baker, 2017). This state-owned power utility is burdened by debt, mismanagement and ageing infrastructure.

The case of South Africa also highlights how workforce certification requirements, such as mandatory Certificates of Compliance (CoCs) for solar installations, play a critical role in ensuring safe and scalable renewable energy adoption. As discussed in Chapter 5, such measures not only promote regulatory compliance but also strengthen the green skills workforce essential for a just and sustainable energy transition (National Business Initiative, 2024).

As noted in Chapter 5, South Africa has introduced policy frameworks like the Just Energy Transition Partnership (JETP) and carbon tax mechanisms. However, implementation remains slow due to resistance from the labour union, political contestation and concerns over energy security (Tyler and Mgoduso, 2022). As a result, emissions continue to rise alongside income despite policy ambitions to decouple growth from environmental degradation.

Nigeria presents a different but equally complex case. Its emissions pattern reflects a hybrid of oil dependence, weak infrastructure and informal energy systems (Edoja et al, 2024). Households and businesses rely heavily on diesel generators and biomass, contributing significantly to local and global emissions. The U-shaped EKC observed in Nigeria likely reflects this transition from biomass-based subsistence to fossil-fuel-based urbanisation and industrial activity. While Nigeria's HDI is improving, governance challenges, regulatory fragmentation and limited enforcement capacity hinder the effectiveness of environmental policies. Moreover, efforts to diversify the economy, such as expanding manufacturing or agriculture, have been slow and often replicate high-emissions models without integrating green standards or cleaner technologies (Ewubare and Kakain, 2022).

Across these three countries, the U-shaped EKC reflects a shared structural constraint: economic growth is not yet paired with a strategic, systemic shift towards cleaner development models. In South Africa and Nigeria, emissions rise with income due to fossil fuel dependence and infrastructural limitations. In Algeria, although the EKC turning point is not statistically confirmed, emissions remain high, reflecting continued reliance on carbon-intensive energy systems and industrial policies that have not yet transitioned toward sustainability. This emphasises the need to rethink EKC theory in African contexts, where growth alone does not lead to environmental improvement and structural transformation is required to bend the emissions curve (Adu et al, 2023). To bend the emissions curve, countries must prioritise investment in renewable energy infrastructure, adopt cleaner industrial technologies, and implement strong environmental regulations. These actions must be complemented by targeted external financing and regional cooperation (Adu et al, 2023).

The EKC is unsupported in Angola as the GDP per capita squared coefficient is statistically insignificant across all models (Models 13-13g). Angola's emissions follow a linear path, driven less by income dynamics and more by sectoral patterns such as oil extraction and inefficient energy use. The oil sector strongly shapes Angola's emissions, which account for over 90% of export revenue and dominate domestic energy production (IEA, 2021).

Although a substantial portion of the country's oil is exported, emissions occur throughout the supply chain, during extraction, processing, transport and especially when the fuel is ultimately combusted, whether domestically or abroad (Wang et al, 2023). Despite relatively high revenues, the country has low human development outcomes, limited electrification and one of the least diversified economies in Africa. The significance of the LNHDI and LNTRADE coefficients in Angola's best-fitting model (Model 13e), rather than LNGDPPC, suggests that redistributive and integrative development strategies and not GDP per capita alone are more influential in shaping the country's long-run environmental outcomes.

As noted in Chapter 3, Angola's linear emissions path mirrors findings from Kohler (2013) and Inglesi-Lotz and Bohlmann (2011), who also found no support for the EKC in their studies on South Africa, where the income–emissions relationship remained monotonic or linear.

Morocco shows weak support for the EKC, with significance for the LNGDPPC_SQ coefficient occurring only in limited models and inconsistent results across specifications. As discussed in Chapter 5, Morocco has substantially invested in renewable energy with projects such as the Noor Quarzazate Solar Complex (Benbrahim et al, 2023). The shifting significance and sign of the HDI coefficient in Morocco's models may reflect an ongoing tension between developmental gains and environmental sustainability where health, education, and infrastructure gains are not yet decoupled from emissions. Morocco's partial success in renewable energy transitions may explain the weak EKC pattern.

The inconsistent behaviour of the HDI variable in Morocco's models may reflect how different aspects of human development interact with emissions. While HDI generally improves with better education, health, and income, the relationship with CO_2 emissions depends on how these gains are achieved. For instance, expanded access to modern services and infrastructure in urban centres like Casablanca and Rabat may contribute to increased energy use and emissions (Bounoua et al, 2024). Meanwhile, rural areas with limited development may lag behind in clean energy access, leading to reliance on carbon-intensive sources (Schoelen, 2024). These dynamics suggest that improvements in HDI can either raise or lower emissions, depending on the underlying mode of development and spatial distribution of infrastructure (Bounoua et al., 2024; Schoelen, 2024).

Therefore, Morocco may be best understood as a country amid a structural shift pursuing green growth but still embedded in a hybrid energy and industrial framework. Its weak and shifting EKC pattern likely reflects this transitional reality. The results suggest that Morocco's emissions are not declining with income growth but are rising as steeply as in more fossil-dependent peers. Over time, continued investment in renewables, improvements in public transport and inclusive urban planning may enable Morocco to bend its emissions curve. However, such outcomes depend on addressing the dual challenge of economic transformation and social equity.

The findings also highlight the importance of designing climate policies that do not exacerbate existing social and economic inequalities. As discussed in Chapter 5, frameworks such as the African Strategy on Climate Change (ASCC) and national just transition plans recognise that vulnerable communities are often the most affected by climate change while contributing the least to emissions. To ensure that environmental policies are both effective and equitable, mitigation strategies must be embedded within broader social development agendas. This includes promoting inclusive access to green jobs, sustainable livelihoods and infrastructure improvements in under-served areas (Presidential Climate Commission, 2022).

A recurring theme across countries is the dominant role of energy use variables as a long-run driver of emissions. The LNENE coefficient is statistically significant in all best-fitting models for Algeria (Model 12b), Nigeria (Model 15d) and Morocco (Model 14f), reinforcing the importance of energy structure in shaping emissions. The significance of the LNENE coefficient as a driver of emissions across multiple countries in this study is consistent with findings by Bilgili et al (2017) and Beyene and Kotosz (2020), who observed that without a transition toward renewable energy, emissions are unlikely to decline.

In contrast, the LNTRADE coefficient is rarely significant, suggesting that external trade is less important than domestic production processes and energy sources in determining environmental outcomes. As noted in Chapter 2, the weak and inconsistent role of the LNTRADE coefficient in this study also aligns with the literature, where trade's effect on emissions is shown to be conditional on the presence of environmental safeguards and trade composition (Sulaiman et al, 2013; Bibi and Jamil, 2021).

The relationship with LNHDI varies: while the HDI coefficient is strongly significant and negatively signed in the best-fitting models for Nigeria and Morocco. This indicates the potential for decoupling emissions from development its behaviour across other model specifications is less stable, particularly in Morocco. This supports earlier observations that the impact of human development on emissions may depend on the nature and distribution of developmental gains, rather than income levels alone (Bibi and Jamil, 2021).

Turning point estimates in this study also corroborate prior findings. As seen in Baek and Kim (2013), Saboori and Sulaiman (2013) and (Nathaniel et al, 2021) turning points for developing countries often fall outside the sample range, as in the case of Algeria, or are not statistically valid, as in Angola and Morocco. This highlights the limited practical relevance of turning point estimates without policy support and structural reform.

Overall, this study contributes to the growing body of empirical research challenging the universal applicability of the EKC hypothesis in Africa. It supports arguments raised in

critiques by Kaika and Zervas (2013), Gill et al (2018) and Ul Husnain et al (2021) that structural transformation, energy transition and targeted policy reform (not income growth alone), are critical for environmental sustainability in African contexts.

A further implication emerging from the findings is the importance of regional coordination in climate policy and finance. As discussed in Chapter 5, mechanisms such as the Green Climate Fund (GCF) are more accessible when countries present a unified stance (AUC and AUDA, 2022). Rather than pursuing fragmented national strategies, pooling efforts through frameworks like Agenda 2063 could improve the region's bargaining power, signal long-term policy coherence, and unlock greater support for emissions reduction and sustainable development. Agenda 2063 offers a credible policy framework to align environmental action with economic and social priorities.

6.7 Conclusion

This chapter has investigated the relationship between economic growth and CO_2 emissions in five middle-income African countries: Algeria, Angola, Morocco, Nigeria and South Africa. The analysis followed a two-step approach. First, panel data models were estimated to explore regional trends, followed by country-specific time-series ARDL models that allowed for a deeper contextual interpretation of the EKC relationship.

In the panel analysis, the FE and PMG-ARDL models provided strong evidence of an EKC relationship, though their shapes varied across models. The PMG-ARDL model revealed an inverted U-shape, suggesting that CO_2 emissions rise with income at lower levels of development but begin to fall beyond a specific turning point. However, the presence and consistency of cointegration varied across countries, indicating that a one-size-fits-all interpretation may obscure critical country-level dynamics.

The ARDL time-series results reveal a U-shaped EKC in Algeria, Nigeria and South Africa, where emissions initially decline but rise again as income increases, reflecting fossil fuel-dependent industrialisation. Morocco shows weak and inconsistent evidence of the EKC, while

Angola displays no EKC, with emissions following a linear growth pattern. LNENE consistently drives emissions across countries, while LNHDI and LNTRADE have explanatory power in specific cases. Most models confirm cointegration, supporting the validity of long-run relationships.

The country-level findings reveal the limitations of applying the EKC as a universal hypothesis across African countries. Income levels, historical development paths, institutional capacity, energy systems and policy priorities shape emissions trajectories. The significance of structural variables in several models highlights the importance of broader development strategies that move beyond economic growth to address the underlying systems that generate emissions.

The following chapter presents the overall conclusion of the study, summarising key findings, and outlining areas for future research.

CHAPTER 7

CONCLUSION

7.1 Introduction

This chapter concludes the study by summarising its key findings, highlighting policy implications, outlining the main contributions and suggesting areas for future research.
The chapter is structured as follows: Section 7.2 summarises the key findings, including their policy implications. Section 7.3 discusses the study's contributions and Section 7.4 outlines its limitations. Section 7.5 offers suggestions for future research, while Section 7.6 concludes the chapter with final remarks.

7.2 Summary of key findings

This study successfully addressed its key objectives as outlined in Chapter 1. Firstly, it investigated the existence of the EKC hypothesis across five middle-income African countries: Algeria, Angola, Morocco, Nigeria, and South Africa. This was done through panel data modelling using FE, RE and PMG-ARDL approaches, and country-specific ARDL time-series models. A stepwise approach was applied for both the PMG-ARDL and ARDL modelling.

The panel PMG-ARDL results largely supported an inverted U-shaped EKC relationship, consistent with the theoretical expectation that environmental degradation initially increases with economic growth but eventually declines as income reaches a certain threshold (Martinez-Navarro et al, 2020). This pattern was confirmed in most model specifications where the coefficients of GDP per capita and its squared term were statistically significant with the expected signs: a positive coefficient on LNGDPPC and a negative coefficient on LNGDPPC_SQ.

However, Model 5, which introduced HDI as an explanatory variable, deviated from this pattern. In this model, a U-shaped EKC suggests that including HDI may capture parts of the variation previously explained by the GDP per capita variable. Furthermore, the mixed findings regarding cointegration for the PMG-ARDL results in the presence of non-stationary variables called into question the validity of the findings for some countries.

The time-series ARDL models yielded mixed support for the EKC hypothesis. Algeria, Nigeria and South Africa displayed a U-shaped curve, implying that continued economic growth beyond the turning point is associated with increasing carbon emissions, contrary to EKC expectations. This is likely due to structural reliance on fossil fuels and limited green infrastructure to fuel emissions at higher growth levels in these economies (Nathaniel and Iheounu, 2019).

As noted in Chapter 6, Morocco showed limited support for the EKC, possibly due to its slow transition toward renewable energy (Benbrahim et al, 2023). For Angola, no support for the EKC was found. Angola's inconsistent or weak results suggest that structural and institutional factors may outweigh income effects in determining emissions outcomes (Wang et al, 2023). As discussed in Chapter 6, Angola has low human development outcomes, limited electrification and is one of the least diversified economies in Africa.

The study also evaluated the effects of key control variables, such as trade openness, energy use and the HDI, on environmental degradation. Energy use was a significant driver of emissions across most models, reflecting these economies' reliance on fossil fuels. HDI and trade openness showed varying effects, with their significance and direction differing across countries and models, suggesting the importance of local policy contexts and development strategies.

For countries exhibiting linear or non-significant EKC relationships (such as Angola), targeted interventions are required to decouple economic growth from environmental degradation

(Wang et al, 2023). This includes enhancing institutional quality, promoting energy efficiency and integrating environmental considerations into national development strategies.
Across all countries, accelerating renewable energy deployment, particularly following Morocco's example of targeting 52% renewables by 2030, is essential (IEA,2021). Promoting energy-efficient technologies in residential and industrial sectors can also reduce dependence on fossil fuels.

In addition, encouraging low-carbon industrialisation through cleaner production methods and trade-aligned environmental standards will support long-term emissions reduction, as mentioned in Chapter 6. Linking human development to sustainability through environmental education and green job creation ensures that socio-economic gains reinforce climate objectives.

Finally, strengthening environmental governance by enforcing emissions regulations and incentivising cleaner technologies is critical. Regional collaboration and knowledge exchange can enable countries to share best practices and access innovations, enhancing collective progress toward sustainable development (Bilgili et al, 2017).

The findings reinforce that the EKC cannot be universally applied, even among countries with similar income levels. Instead, emissions patterns in African middle-income countries are shaped by the interactions of structural variables, institutional contexts and energy systems.

7.3 Contributions of the study

This study contributes to the existing body of literature in several meaningful ways:

Theoretically, this study investigates the EKC hypothesis in an under-researched context namely, five middle-income African countries. The findings underscore the role of key development and economic variables, particularly energy use as significant mediators of environmental outcomes across the selected countries. As noted in Chapter 6, energy use

consistently showed a strong, positive, and statistically significant relationship with CO_2 emissions across nearly all models, underscoring the central role of fossil fuel dependence in shaping environmental outcomes.

In terms of methods and techniques, the study applies both panel PMG-ARDL and country-specific ARDL models. This dual approach captures short- and long-run dynamics and allows for a more precise country-level interpretation of the income-emissions relationship. The approach addresses a key limitation of traditional panel studies, which often distort country-specific heterogeneity.

Empirically, the research contributes new evidence on the role of trade openness, energy use and human development in shaping CO_2 emissions across African middle-income countries. By incorporating these control variables, the study moves beyond simplistic income-based models and offers a more realistic and policy-relevant understanding of the development–environment nexus. The findings provide a foundation for revisiting climate and development policies, particularly in resource-rich and energy-intensive economies where standard EKC assumptions may not hold.

7.4 Limitations of the study

While this study provides valuable insights into the relationship between economic growth and environmental degradation in African middle-income countries, it has several limitations.
The study focused exclusively on middle-income economies, excluding potential comparative insights from low and high-income African countries. Future research could benefit from a broader income spectrum to better assess how environmental dynamics evolve across different development stages.

As noted in Chapter 4, the study concentrated solely on CO_2 emissions as the proxy for environmental degradation. CO_2 emissions significantly contribute to climate change and are regarded as a global pollutant. Although CO_2 is a significant greenhouse gas, it does not capture

other critical environmental concerns, such as deforestation, water pollution, or biodiversity loss, which are highly relevant in Africa.

The study was constrained by data limitations, particularly concerning the availability of an educational variable. As noted in Chapter 4, the most accurate proxy is mean years of schooling. However, the proxy is only available for some of the selected five countries over the studied period. Therefore, the study used the HDI as its educational proxy.

7.5 Suggestions for future research

Since the thesis focused solely on CO_2 emissions, future research could benefit from expanding the environmental indicators, such as water pollutants, air pollutants and the ecological footprint, discussed in Chapter 2.

The thesis investigated the conventional inverted U-shaped EKC hypothesis. However, future research could investigate the existence of an N-shaped EKC, where emissions initially rise with income, then decline as economies mature but increase again beyond a higher income threshold (Ungwanitban et al, 2020). Exploring the N-shaped relationship could offer deeper insights into long-term sustainability challenges, particularly for rapidly industrialising economies.

Future research could also explore the feasibility and impact of alternative financing models, such as pay-as-you-go (PAYG) solar systems, in expanding clean energy access across African middle-income countries. Such approaches may offer scalable solutions to both energy poverty and emissions reduction in contexts with weak grid infrastructure (RENA, 2020).

7.6 Final Remarks

This study demonstrates that emissions patterns are shaped by economic growth and broader structural variables such as the energy fuel mix, governance capacity, trade openness, institutional quality and human development outcomes (Ulucak and Khan, 2020).

The results of this study reveal that the EKC does not hold universally across the selected countries. This study demonstrates that emissions patterns are shaped by economic growth and broader structural variables such as the energy fuel mix, governance capacity, trade openness, institutional quality and human development outcomes (Ulucak and Khan, 2020). All the countries examined face common development constraints, including limited access to reliable electricity, challenges in governance and public sector capacity, and underdeveloped infrastructure (Lee et al, 2015). Although each country has adopted climate mitigation strategies on paper, public awareness of climate change remains relatively low, undermining the effectiveness of policy implementation (Afrobarometer, 2023).

The dominant U-shaped relationship between GDP per capita and CO_2 emissions per capita observed in several countries reflects structural realities of resource-dependent economies. As Adams and Nsiah (2019) note, this pattern is common in contexts where early growth is driven by extractive industries such as oil and gas, rather than by diversified or service-based economies. As a result, emissions tend to rise again beyond a certain income level due to continued fossil fuel dependence and weak institutional oversight.

The findings also indicate that the relationship between development (proxied by the HDI) and environmental degradation is not straightforward. In some specifications, such as Model 16g for South Africa, higher HDI levels are associated with increased CO_2 emissions per capita, likely due to rising energy consumption and industrial activity accompanying improved income, health, and education outcomes (Bounoua et al, 2024). This highlights a difficult trade-off: while all five countries urgently need to prioritise growth and development, they may do so at the expense of environmental quality unless decisive interventions are made.

A second turning point where emissions decline again despite continued income growth, could become achievable if certain conditions are met. This would require a deliberate shift toward green industrialisation, including the adoption of cleaner technologies and renewable energy sources, enabling countries to decouple economic growth from carbon emissions (Pegels and Altenburg, 2020). Avoiding the pollution haven effect, will also be critical to prevent emissions from escalating. Additionally, substantial external financing will be necessary to support these transitions (Wang et al, 2022).

While international climate finance mechanisms show potential, their sustainability is uncertain. As such, innovative local financing tools, such as green bonds, may provide viable alternatives. Finally, successfully implementing environmental regulations despite potential political resistance and limited public climate awareness will be essential to translate policy into real environmental outcomes (Lee et al, 2015). Achieving this future turning point will depend not only on income growth but also on targeted institutional, financial and technological reforms aligned with each country's unique context.

These findings reaffirm that the path to sustainable development in African middle-income countries requires more than economic growth. Achieving low-carbon and inclusive growth in Africa will require context-sensitive, evidence-based policies that reflect each country's unique economic structure and environmental aspirations (Dogan and Seker, 2016). With thoughtful planning and committed implementation, Africa's emerging economies can forge a socially inclusive path that safeguards both the economy and the environment.

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APPENDIX A: Logged Key Variable Trends Over Time

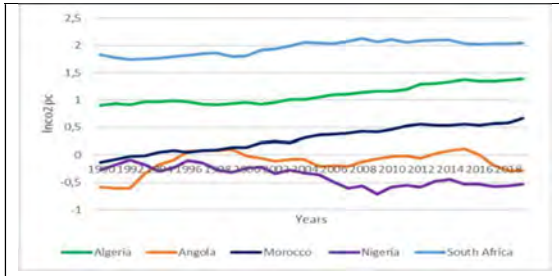

Figure 6.1: logged CO_2 per capita (metrics per ton)

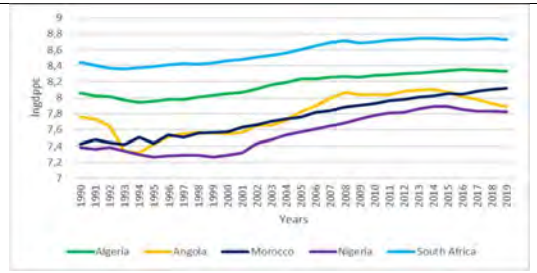

Figure 6.2: logged GDP per capita (2015 constant prices, US$)

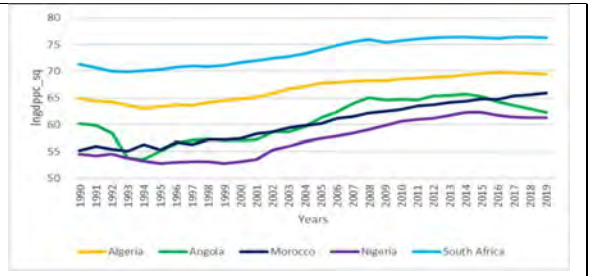

Figure 6.3: logged GDP per capita squared (2015 constant prices US$)

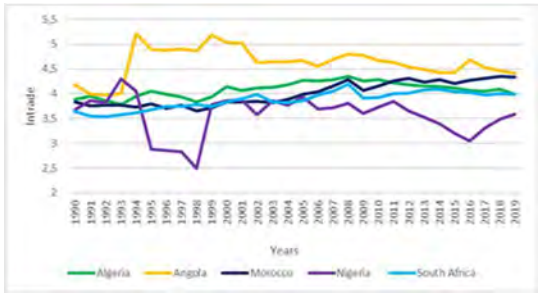

Figure 6.3: logged trade openness (percentage of GDP

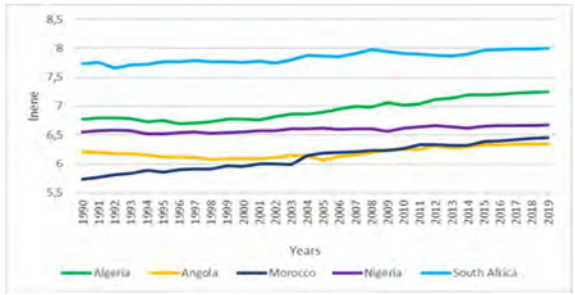

Figure 6.4: logged energy use (kg of oil equivalent per capita)

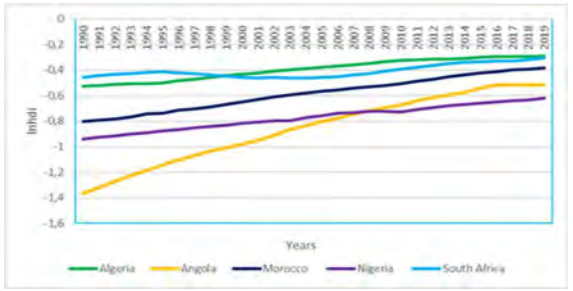

Figure 6.5: logged Human Development Index (0-1 scale)

Source: Compiled by the author based on World Bank (2024) data

APPENDIX B: COUNTRY-LEVEL OLS TIME-SERIES MODEL ESTIMATIONS

Table B1: Algerian OLS time-series model

Dep variable LNCO2PC	Model 17	Model 17a	Model 17b	Model 17c	Model 17d	Model 17e	Model 17f	Model 17g
C	342.96	333.49	215.79	336.67	213.51	316.67	199.04	200.01
LNGDPPC	-84.94***	-82.61***	-53.98***	-83.16***	-53.50***	-78.19***	-49.70***	-49.91***
LNGDPPC_SQ	5.27***	5.13***	3.34***	5.15***	3.30***	4.85***	3.06***	3.07***
LNTRADE		-0.03			0.09*	-0.06		0.06
LNENE			0.49***		0.61***		0.53***	0.60***
LNHDI				0.37		0.44*	0.46**	0.41**
Adjusted R-squared	0.974	0.973	0.984	0.975	0.985	0.975	0.987	0.987
F-statistic	536.197***	347.875***	589.54***	378.289***	481.656***	284.639***	556.59***	456.941***
(Cointegration) Engler Granger	C	C	C	C	C	C	C	C

*** Significant at 1% level
** Significant at 5% level
* Significant at 10% level
Source: Author's estimations using EViews 13

Table B2: Angolan OLS time-series model

Dep variable LNCO2PC	Model 18	Model 18a	Model 18b	Model 18c	Model 18d	Model 18e	Model 18f	Model 18g
C	69.41	42.96	109.11	50.20	48.73	38.12	99.06	65.12
LNGDPPC	-18.07	-11.95	-26.74**	-12.33	-13.22	-10.20	-22.78**	-15.85*
LNGDPPC_SQ	1.17	0.788	1.75**	0.76	0.87	0.65	1.46**	1.02*
LNTRADE		0.47***			0.46***	0.39***		0.29**
LNENE			-1.18**		-0.15		-1.54***	-0.75
LNHDI				0.70***		0.34*	0.81***	0.49**
Adjusted R-squared	0.038	0.560	0.141	0.323	0.544	0.606	0.536	0.627
F-statistic	1.568***	13.32***	2.584***	5.609***	9.671***	12.154***	9.364***	10.749***
(Cointegration) Engler Granger	C	NC	NC	C	C	C	NC	NC

*** Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimations using EViews 13

Table B3 Moroccan OLS time-series model

Dep variable LNCO2PC	Model 19	Model 19a	Model 19b	Model 19c	Model 19d	Model 19e	Model 19f	Model 19g
C	-31.20	-34.17	-23.98	-15.02	-24.83	-20.27	-17.29	-19.83
LNGDPPC	7.16**	7.92**	4.75**	3.92	4.97**	5.42**	3.61*	4.46**
LNGDPPC_SQ	-0.40*	-0.92**	-0.30**	-0.24	-0.31**	-0.35**	-0.24*	-0.30**
LNTRADE		0.07			0.02	0.20**		0.10
LNENE			0.86***		0.86***		0.68***	0.60***
LNHDI				1.31***		1.55***	0.67**	0.87**
Adjusted R-squared	0.966	0.966	0.985	0.978	0.984	0.982	0.987	0.988
F-statistic	418.896***	273.666***	637.789***	439.115***	461.255***	388.836***	554.723***	463.716***
(Cointegration) Engler Granger	C	C	C	C	C	C	C	C

*** Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimations using EViews 13

Table B4: Nigerian OLS time-series model

Dep variable LNCO2PC	Model 20	Model 20a	Model 20b	Model 20c	Model 20d	Model 20e	Model 20f	Model 20g
C	42.27	46.24	44.28	48.92	41.18	46.60	54.92	39.867
LNGDPPC	-10.64	-11.70	-14.51**	-12.83*	-13.73*	-12.22	-18.96***	-15.34**
LNGDPPC_SQ	0.66	0.73	0.89*	0.82	0.84	0.78	1.20***	0.97**
LNTRADE		0.01			-0.01	-0.01		-0.05
LNENE			2.13***		2.16***		2.76***	2.97***
LNHDI				-0.75*		-0.77*	-1.14***	-1.27***
Adjusted R-squared	0.744	0.735	0.798	0.765	0.781	0.756	0.858	0.885
F-statistic	43.124***	27.766***	39.111***	32.491***	28.266***	23.458***	44.714***	37.111***
(Cointegration) Engler Granger	C	C	C	C	C	C	C	C

*** Significant at 1% level
** Significant at 5% level
*Significant at 10% level
Source: Author's estimations using EViews 13

Table B5: South African OLS time-series model

Dep variable LNCO2PC	Model 21	Model 21a	Model 21b	Model 21c	Model 21d	Model 21e	Model 21f	Model 21g
C	-190.42	176.98	-190.14	-57.06	-177.12	-50.42	-44.63	-36.28
LNGDPPC	44.11***	40.98***	44.09***	12.72	41.05***	11.18	9.66	7.72
LNGDPPC_SQ	-2.53***	-2.35***	-2.52***	-0.68-	-2.35***	-0.60	-0.51	-0.40
LNTRADE		0.07			0.07	0.05		0.06
LNENE			-0.05		-0.03		0.11	0.12
LNHDI				-0.70**		-0.68**	-0.77	-0.76**
Adjusted R-squared	0.923	0.922	0.920	0.934	0.919	0.933	0.933	0.931
F-statistic	175.292***	115.361***	112.834***	138.821***	83.296***	101.751***	101.652***	79.591***
(Cointegration) Engler Granger	NC	NC	NC	C	NC	C	NC	NC

*** Significant at 1% level
** Significant at 5% level
Source: Author's estimations using EViews 13