THE IMPACT OF ECONOMIC AND FINANCIAL DEVELOPMENT ON CARBON EMISSIONS: EVIDENCE FROM SUB-SAHARAN AFRICA

By

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DECLARATION

I, ONANUGA Olaronke Toyin, declare that this research work is my own and all the sources that I used or quoted have been indicated and acknowledged by means of completed references. This thesis has not, either in whole or part, been submitted for a degree or diploma at another university.

______________ 08 September, 2017

Signature Date

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Be that as it may, I take full responsibility for all the views and opinions expressed in this thesis. Any error(s) and shortcoming that may exist are mine and not of the above-mentioned individuals.

DEDICATION

This thesis is dedicated to God Almighty; my father, Abayomi ONANUGA (PhD, ACIB) and my mother, Mrs Folashade ONANUGA.

ACRONYMS

AAU – Assigned Amount Units

ACCF – Africa Climate Change Fund

ADR – African Development Report

ADF – Augmented Dickey-Fuller

AfDB – African Development Bank

AFREC – African Energy Commission

AGEP – African Green Economy Partnership

AGIR – Global Alliance for Resilience Initiative

AMCEN – African Ministerial Conference on Environment

AMG – Augmented Mean Group

AOSIS – Association of Small Island States

AR4 – Fourth Assessment Reports

AR5 – Fifth Assessment Reports

ARDL – Autoregressive Distributed Lag

AREF – Africa Renewable Energy Fund

AUC – African Union Commission

BASIC – Brazil, South Africa, India and China

BAU – Business as Usual

BCE – Biogas Construction Enterprises

BDEAC – Central African States Development Bank

BioCF – BioCarbon Fund

BRICS – Brazil Russia India China and South Africa

BRT – Bus Rapid Transit

C2ES – Centre for Climate and Energy Sources

CAR – Central African Republic

CBFF – Congo Basin Forest Fund

CBN – Central Bank of Nigeria

CCAP – Climate Change Action Plan

CCDA – Climate Change and Development in Africa

CDCF – Community Development Carbon Fund

CDIAC – Carbon dioxide Information Analysis Center

CDKN – Climate and Development Knowledge Network

CDM – Clean Development Mechanism

CDP – Carbon Disclosure Project

CDSF – ClimDev-Africa Special Fund

CEE – Central and Eastern Europe

CER – Certified Emissions Reductions

CFE – Carbon Fund for Europe

Ci-Dev – Carbon Initiative for Development

CIESIN – Centre for International Earth Science Information Network

CIF – Climate Investment Fund

ClimDev-Africa – Climate for Development in Africa

CMG – Common Correlated Effects Mean Group Estimator

CO_2 – Carbon dioxide

COMESA – Common Market for Eastern and Southern Africa

COP – Conference of Parties

CRMA – Climate Risk Management and Adaptation Strategy

DFE – Dynamic Fixed Effect Model

DOLS – Dynamic Ordinary Least Squares

DRC – Democratic Republic of Congo

EAC – East African Communities

ECA – Economic Commission for Africa

ECM – Error Correction Model

ECOWAS – Economic Community of West African States

ECREEE – ECOWAS Regional Centre for Renewable Energy and Energy Efficiency

EIA – Energy Information Administration

EKC – Environmental Kuznets Curve

ERU – Emission Reduction Units

EU ETS – European Union Emissions Trading Scheme

FANRPAN – Food, Agriculture and Natural Resources Policy Analysis Network

FAO – Food and Agriculture Organisation

FDI – Foreign Direct Investment

FFS – Fossil Fuel Subsidy

FGLS – Feasible Generalised Least Squares

FIP – Forest Investment Program

FMOLS – Fully Modified Ordinary Least Squares

FONERWA – Fund for Environment and Climate Change

FOREX – Foreign Exchange

FSF – Fast-Start Finance

FSU – Former Soviet Union

G-77 – Group of 77

GAM – Generalised Additive Model

GCCA – Global Climate Change Alliance

GCF – Green Climate Fund

GDP – Gross Domestic Product

GEE – Generalised Estimating Equations

GEF – Global Environment Facility

GEMS – Global Environmental Monitoring System

GEO4 – Global Economic Outlook fourth publication

GGBP – Green Growth Best Practices

GGGI – Global Green Growth Institute

GGKP – Green Growth Knowledge Platform

GGND – Global Green New Deal

GGS – Green and Growth Strategy

GHG – Greenhouse gases

GIZ – Gesellschaft für Internationale Zusammenarbeit

GLS – Generalised Least Squares

GLM – Generalised Linear Model

GMM – Generalised Method of Moments

GoR – Government of Rwanda

GoS – Government of Swaziland

GSI – Global Subsidy Initiative

GW – Gigawatt

HCFC – Hydrochlorofluorocarbon

HIC – High-Income Countries

Ibid. – in the same place

ICPAC – IGAD Climate Prediction and Applications Centre

IEA – International Energy Agency

IET – International Emissions Trading

IGAD – Intergovernmental Authority on Development

IPS – Im-Pesaran-Shin

IMF – International Monetary Fund

IPCC – Intergovernmental Panel on Climate Change

IPP – Independent Power Producer

IUCN – International Union for Conservation of Nature

IV – Instrumental Variables

JSE – Johannesburg Stock Exchange

LDC – Least Developed Countries

LIC – Low-Income Countries

LMIC – Lower-Middle-Income Countries

LNG – Liquefied natural gas

LSDV – Least Squares Dummy Variables

MDG – Millennium Development Goals

MEA – Multilateral Environmental Agreements

MENA – Middle East and North African countries

MIGA – Multilateral Investment Guarantee Agency

MRV – Measurable, Reportable and Verifiable

NAMA – Nationally Appropriate Mitigation Actions

NDC – Nationally Determined Contributions

NEPAD – New Partnership for Africa's Development

NGO – Non-governmental organisation

NRG4SD – Network of Regional Governments for Sustainable Development

NRDC – Natural Resources Defence Council

OECD – Organisation for Economic Cooperation and Development

OLS – Ordinary Least Squares

OPEC – Organisation of the Petroleum Exporting Countries

ORNL – Oak Ridge National Laboratory

PAGE – Partnership for Action on Green Economy

PBL – Planbureau voor de Leefomgeving Netherlands Environmental Agency

PCF – Prototype Carbon Fund

PCSE – Panel Corrected Standard Errors

PES – Payment for Ecosystem Services

PHEV or PEV – Plug-in hybrid Electric Vehicles

PLM – Partially Linear Model

PPM – Parts Per Million

PRIA – Regional Agricultural Investment Program

REC – Regional Economic Communities

REDD – Reduce Emissions from Deforestation and Forest Degradation

REDD+ – Reduce Emissions from Deforestation and Forest Degradation plus

REES – Rural Energy and Environmental Systems

SADC – Southern African Development Community

SCF – Spanish Carbon Fund

SEED – Social and Environmental Entrepreneurship In Developing countries

SEFA – Sustainable Energy Fund for Africa

SRI – Socially Responsible Investment

SSA – Sub-Saharan Africa

STIRPAT – Stochastic Impacts by Regression on Population, Affluence and Technology

TAR – Third Assessment Report

TSLS – Two Stage Least Squares

UAE – United Arab Emirates

UECM – Unrestricted Error Correction Model

UMIC – Upper-Middle-Income Countries

UNCCD – United Nations Convention to Combat Desertification

UNCITRAL – United Nations Commission on International Trade Law

UNCTAD – United Nations Conference on Trade and Development

UN DESA - United Nations Department of Economic and Social Affairs

UNDP – United Nations Development Programme

UNECA – United Nations Economic Commission for Africa

UNEP – United Nations Environment Programme

UNFCCC – United Nations Framework Convention on Climate Change

UNIDO – United Nations Industrial Development Organisation

UN-REDD – United Nations Reducing Emissions from Deforestation and forest Degradation

UNSD – United Nations Sustainable Development

UNSD – United Nations Statistics Division (Chapter three)

VAR – Vector Autoregression

VAT – Value Added Tax

VECM – Vector Error Correction Model

WACIP – West African Common Industrial Policy

WAEMU – West African Economic and Monetary Union

WCED – World Commission on Environment and Development

WDI – World Development Indicators

WDR – World Development Report

WEO – World Economic Outlook

WEC – Wave Energy Converter

WRI – World Resource Institute

ABSTRACT

In the literature, some studies argue that affluence and the financial sector encourages low-carbon investments which result in lower emissions while others find that they enhance emissions. Contemporary studies barely consider agriculture, employment generation and the degree of financial development as determinants of emissions. In view of these, the thesis investigates the impact of economic and financial development on CO_2 emissions in sub-Saharan Africa (SSA). Applying the EKC and STIRPAT framework, the study modelled three functional forms which were estimated using an unbalanced panel data of 45 SSA countries by employing static and dynamic analytical methods. The models were re-estimated for 24 low (LIC), 13 lower-middle (LMIC), six upper-middle (UMIC) and two high-income countries (HIC).

The study found evidence that empirical results differ in terms of the (sub-) sample of countries, estimation methods and functional forms. In detail, the study found different CO_2 emissions-economic development relationships for the income groups. However, there is evidence of a linkage between later developments of the economies with lower emissions in LIC and UMIC while this linkage does not exist in LMIC and HIC. The study also found that financial development lowers CO_2 in UMIC while it enhances emissions in LIC, LMIC and HIC. Despite this, there is evidence of a linkage between later developments of financial sectors with higher emissions in LIC and HIC and a linkage between later developments of financial sectors with lower CO_2 in UMIC in SSA meanwhile no linkage was found for LMIC.

The study concludes that not all economic development increases the level of CO_2 emissions and not all financial development limits CO_2 emissions in SSA during the study period. Generally, the main contributory variables to CO_2 emissions are income, trade openness, energy consumption, population density and domestic credit to private sector to GDP. The main reducing factors of CO_2 emissions are agriculture and official exchange rate. The thesis recommends that SSA needs to be more responsive to a cleaner CO_2 environment by moving away from the conduct of unclean development strategy to intensified green investments.

KEYWORDS

Carbon Dioxide Emissions; Climate Change; Economic Development; Financial Development; Carbon Finance Mechanism; Low-Carbon Development; Green Economy; Green Growth; Sub-Saharan Africa; Low-Income Countries; Lower-Middle-Income Countries; Upper-Middle-Income Countries; High-Income Countries

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CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Carbon dioxide (CO_2) is the most concentrated greenhouse gas (GHG) in the atmosphere and it has over a century atmospheric lifespan (Cunha-e-Sá 2008).[1] As a result, the Brundtland Commission report has since 1987 declared the accumulation of CO_2 as one of the environmental threats to the planet (GEO4 2007). Without a doubt, CO_2 (also called carbon as part of the generic term to all GHG emissions) has its natural occurrence through photosynthesis, animal grazing, respiration of humans and rock weathering (Goodland and Anhang 2009). The highest concentration is human-induced through combustion, the use of fossil fuels for energy as well as deforestation and land-use practices (GEO4 2007). The clearing of forest for agriculture and urban development releases the stored CO_2 in trees and soil and reduces the environment's future capacity to absorb CO_2 (IPCC 2007).

The increasing CO_2 concentration causes a gradual heating of the atmosphere, oceans and the earth's surface which is called global warming and leads to global climate change (Raghbendra and Whalley 2001; Cunha-e-Sá 2008). Climate change, in the opinion of the United Nations Framework Convention on Climate Change (UNFCCC), is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (GEO4 2007:517).

The Brundtland Commission report of 1987 concluded that "humanity has the ability to make development sustainable". This conclusion suggests that there is a link between environmental quality and development (GEO4 2007:6). In response to this conclusion, the debate on the link between CO_2 emissions and development was initiated amongst economists. This study contributes to this debate by exploring the impact of economic development and financial development on the level of CO_2 emissions in sub-Saharan Africa (SSA).

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[1] Other GHGs include water vapour, methane, nitrous oxide and ozone.

1.1.1 Carbon dioxide emissions and Income

There is a divide on the debate that explains the link between environmental quality and development. Panayotou (2000:1; 2003:45) submits that "on one side are those who argue that economic growth must cease and the world must take a transition to a steady-state economy" (see for example, Meadows *et al.* 1972; Daly 1991; Jansson *et al.* 1994). On the other side are those who demonstrate that the fastest road to environmental improvement is the path of economic growth (see for example, Beckerman 1992; Bartlett 1994). Beckerman attributed that the strong correlation between income and environmental protection measures indicates that in the long run, the surest way to improve the environment is by becoming rich (Panayotou 2003).

Poor countries like those in SSA attract 'dirty' and material intensive domestic and industrial activities which would generate high CO_2 emissions while richer countries specialise in 'clean' and material extensive domestic and industrial activities which would generate low CO_2 emissions (Hoffmann 2011). That is, industrialised countries have the economic and financial muscle to generate clean, low-carbon, greener and energy-efficient technology innovations while developing countries do not have such capabilities. Thus, many developing countries still use traditional technologies which are considered dirty (Hoffmann 2011). At least 80% of the population in countries like Afghanistan, Chad, Ghana, India and China use cheap and dirty fuel including kerosene, coal and traditional fuel wood stoves to meet their domestic energy needs (Duflo *et al.* 2008). As observed, the outdated 1950s Multilith machines and analogue lathe machines which are no more used in Britain are still being imported and widely used by Nigerians.

Studies have been conducted using CO_2 emissions and income to investigate the link between environmental quality and economic development (see for example, Moomaw and Unruh 1997; Pauli 2003; Bertinelli and Strobl 2005; Piaggio and Padilla 2012; Mazzanti and Musolesi 2013). These studies, nonetheless, are argued to be vulnerable to the problem of omitted variables bias (Stern 2004). As such, the question of whether the level of income is the only development-related variable that matters (Panayotou 1997) became pertinent. For this reason, other scholars, in the conduct of their investigation, considered other economic variables like the share of industry in GDP (gross domestic product), debt as a share of GDP, population density, trade openness, illiteracy rate and energy consumption as additional explanatory variables. Examples of these other scholars are Shafik and Bandyopadhyay (1992), Panayotou, Peterson and Sachs

(2000), Carvalho and Almeida (2010) and Onafowora and Owoye (2013). The explanatory variables (economic and financial) considered for this study are as itemised in section 1.6 of this chapter.

1.1.2 Carbon dioxide emissions and financial development

Lanoie, Laplante and Roy (1998) and Dasgupta, Laplante and Mamingi (1998) are credited with introducing financial development into the debate of development variables that matter for environmental quality. Lanoie *et al.* (1998) and Dasgupta *et al.* (1998) argue that an organised financial sector may provide adequate incentives for firms to reduce their CO_2 emissions in developing countries. For instance, if the capital markets and communities are properly and deliberately informed that a firm has adopted a more pollution controlled effort, this may lead to a positive response. Such a positive response may provide financial incentives like the rise in the firm's market capitalisation. However, adverse environmental news like court actions on violations of environmental regulations would lead to a negative response from the capital markets and communities (Ibid.).

Financial institutions may also provide incentives by giving priority and preferential treatments to firms that seek funds for the procurement of cleaner technologies and low-emission driven investments via a reduction in administrative charges and interest on loans (Shahbaz, Solarin and Mahmood 2012b). The sector can also facilitate foreign capital inflows and offer to hedge for financially weak firms that would like to procure environmental-friendly types of machinery (Claessens and Feijen 2007). Therefore, the reason why financial development matters to the link between a cleaner CO_2 environment and development is that the financial sector has the ability to render superior financial services to eco-friendly programs that would reduce CO_2 emissions in developing countries (Tamazian, Piñeiro and Vadlamannati 2009).

However, there is an alternate opinion as to the role that financial development plays in the link between environmental quality and development. This expresses that, since developing countries attract material-intensive commodities (Hoffmann 2011), the financial system would mostly provide financial assistance for the production and consumption of carbon-related commodities (World Bank 2000). This would increase the volume of emissions even with good environmental policies (Jensen 1996). This opinion is empirically supported by Sadorsky (2010) who found that financial development has a positive relationship with fossil energy demand, the end product of which is higher CO_2 emissions.

1.2 Statement of the problem

Answering the question of whether income is the only development-related variable that matters for a cleaner CO_2 environment, studies on the impact of economic and financial development on CO_2 emissions have been hypothesised using the Environmental Kuznets Curve (EKC) model.[2] These studies portray a disparity in findings. Some found the inverted U-shape (Pandelis 2012), some found a monotonic shape (Azomahou, Laisney and Nguyen-Van 2009) and others found an N-shape (Carvalho and Almeida 2010). Does the EKC model relation shape exist in SSA, is one of the questions this study intends to find answers to. On the issue of the turning point,[3] Stern (2004:1424) suggests that "including more low-income countries in a cross-country study might yield a higher turning point". Some studies with a higher number of low-income countries in their samples have found lower turning points than studies with a lower number of low-income countries. Agras and Chapman (1999) estimated a turning point of $13,630 per capita income for a sample of 34 developed and developing countries while Dijkgraaf and Vollebergh (2001) estimated $13,959 per capita income for 24 OECD countries. Whether this suggestion is true or false, particularly for SSA, is an empirical question this study explores. According to Nhamo (2009a:125), "Africa's Principal international trading partners continue to be its former slave masters". Probably, SSA countries' foreign incursion may have an effect on the way carbon-related resources are being exploited and managed. This study intends to find the difference in the patterns of CO_2 emissions in SSA due to the different colonial histories of its countries using the Anglophone, Francophone and Lusitanian categorisation.[4]

Applying the reasons why financial development impacts on CO_2 emissions, financial development may generally allow for the importation of clean technologies that may sequentially improve economic activities and hence influence a cleaner CO_2 environment in SSA (Frankel

[2] The EKC proposes that the indicators of environmental degradation first rise and then fall with increasing per capita income (EKC) (Stern 2004).
[3] Turning point reflects the point at which an environmental indicator starts to decline as per capita income increases (UNCTAD 2012).
[4] Anglophone countries are English-speaking countries; Francophone countries are French-speaking countries and Lusitanian countries are Portuguese-speaking countries.

and Romer 1999). However, the financial sector (under business-as-usual) provides the funds for the natural resources' exploration and exploitation which incurs more emissions into the atmosphere in SSA (Sadorsky 2010; UNCTAD 2012). Consequently, the financial sector may influence CO_2 emissions on one hand and it may stimulate the technological progress that would reduce CO_2 emissions on the other in SSA. This brings in view the deterministic and influential role of financial development in the environmental performance (Tamazian *et al.* 2009) of SSA which is also a hypothesis this study tests.

1.3 Research questions

The following pertinent research questions are to be answered in this study:

1) Does the EKC exist in sub-Saharan Africa for CO_2 emissions?
2) What is the income elasticity of demand for a cleaner CO_2 environment and the turning point in sub-Saharan Africa?
3) What is the effect of economic development on CO_2 emissions in sub-Saharan Africa?
4) What is the effect of financial development on CO_2 emissions in sub-Saharan Africa?
5) Do sub-Saharan African countries with different colonial histories have different patterns regarding CO_2 emissions?

1.4 Objectives of the study

The broad objective is to examine and analyse the impact of economic and financial development on CO_2 emissions in sub-Saharan Africa focusing on the period 1989-2012. Specifically, this study via panel analysis seeks to:

a) Evaluate the existence of the EKC in sub-Saharan Africa for CO_2 emissions.
b) Calculate and describe the income elasticity of demand for a cleaner CO_2 environment and the turning point in sub-Saharan Africa.
c) Analyse the effect of economic development on CO_2 emissions in sub-Saharan Africa.
d) Analyse the effect of financial development on CO_2 emissions in sub-Saharan Africa.
e) Evaluate the different patterns of CO_2 emissions in sub-Saharan African countries using the different colonial histories.

1.5 Significance of the study

Unlike Al-Mulali and Che (2012) who investigated the impact of energy consumption and CO_2 emissions on GDP growth and financial development in SSA, this study considers the impact of economic and financial development on the level of CO_2 emissions in SSA. Whenever CO_2 emissions are discussed what tops the list are fossil fuels and indeed it is the major source of human-induced CO_2 emissions (Goodland and Anhang 2009). Studies (Grunewald and Martinez-Zarzoso 2009; Tamazian *et al.* 2009; He and Richard 2010) consider industry activity to investigate the link between CO_2 emissions and economic development on the premise that fossil fuels led to the start of the industrial revolution in the 18th century. This makes the agricultural activity to be under-researched by studies in this area.

Activities like soil tillage and conversion of land not previously used for cultivation of crops release organic carbon into the atmosphere as CO_2 emissions (Doll and Baranski 2011). This is severe in East Africa, Namibia, Botswana, and Mauritania (WDR 1992). The application of agricultural lime (aglime) to soils to increase their level of alkalinity also leads to CO_2 emissions (West and McBride 2005). The increase in livestock production due to globally growing human population has led to tens of billions more livestock exhaling more CO_2 than pre-industrial era (Goodland and Anhang 2009). As more livestock are kept for consumption, forests are simultaneously cleared to grow feeds, more pastures get degraded through grazing the livestock, and the earth's forest carbon sink potential declines sharply. This makes the CO_2 exhaled by livestock to be no more natural than that of an auto tailpipe (Ibid.).

Considering the process of structural change in an economy,[5] SSA still has a high level of dependence on agriculture and yet the region is the most affected by the negative impact of climate change (UNCTAD 2012). For example, the negative impact of the combination of drought with civil strife in the year 2000 that left 20 million people with food shortage in the Greater Horn of Africa and reduced Kenya's hydroelectric power output (ECA 2007). With a low share of industrial activity, SSA is highly dependent on fossil fuels, metallic and non-

[5] The process of structural change states that there is a deterioration of environmental quality as countries experience a fall in the share of agriculture and a rise in the share of industry during the early stages of development (Panayotou 2003).

metallic minerals as the driver of its economic growth.[6] For example, crude oil accounts for more than 75% of exports in Angola, Chad, Equatorial Guinea, Gabon, Nigeria, and Sudan (UNCTAD 2012). Thus, this research is the first to examine the contributions of SSA's high agricultural activity and low industrial activity to CO_2 emissions under economic development.

With the benefits to provide economic opportunities and potentials that allow low-carbon development, SSA policymakers expressed their determination to move the region towards a green economy[7] at the African Ministerial Conference on Environment (AMCEN) in 2012 (Kim 2015). These economic opportunities are expected to bring about green investments which promote green growth and green jobs which are employment intensive (UN DESA, UNEP and UNCTAD 2013). While the low-carbon development strategies and policies are being planned and implemented at the continental, regional and national level, it is essential to examine, before the fact, the evidence of the effects of not only economic growth (income) but also employment generated in SSA on CO_2 emissions.

To measure the degree of later development in an economy, Taguchi (2012) used the ratio of GDP per capita of an economy relative to the maximum GDP per capita among the sample economies for every year. Since this study is using both economic and financial variables, it considers not only the degree of later economic development but also the degree of later financial development. This is measured as the ratio of financial deepening of an economy relative to the maximum financial deepening among the sample economies for every year. This clarifies whether the optimistic view of the financial sector as a provider of financial services to environmental-friendly projects that would reduce CO_2 emissions in SSA countries exist as the sector develops into the future.

Referring to the colonial economy, SSA countries were treated as settlements for resource extraction by colonial masters and this influenced their respective economic systems (Asuelime and Simura 2016). Although emerging markets like China and India are becoming involved with SSA countries under new trade agreements, their trading partners –even after independence- still largely remain their colonial masters (Nhamo 2009a). As mentioned earlier, this foreign

[6] The use of the term industry encompasses the mining of fossil fuels and all other minerals, manufacturing, construction, and gas sub-sectors (WDI 2014).

[7] United Nations Environmental Programme (UNEP) defined green economy as "the results in improved human well-being and social equity, while significantly reducing environmental risks and ecological scarcities" (GIZ 2013:9).

incursion may probably have an effect on the level of exploration and exploitation of carbon-related resources (like fossil fuel, metallic and non-metallic minerals) in SSA. Hence, this study finds the difference in the level of CO_2 emissions based on the groups of colonies, i.e. Anglophone, Francophone and Lusitanian nations, in SSA.

The motivation for this study builds from the awareness generated by the United Nations' World Commission on Environment and Development (WCED) (1987) that brought to fore gaps in terms of addressing the sustainable development agenda. This awareness was further emphasised by the United Nations Conference on Environment and Development (UNSD) which produced a number of international environment treaties including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, UNEP's Atlas on Africa (2008), UNEP's Global Green New Deal (GGND) in 2009, United Nations' Millennium Development Goals (MDGs) of 2000 to 2015, the United Nations' led 2030 agenda (that embeds the 17 Sustainable Development Goals –SDGs), and the 2016 new global climate deal that came out of Paris during the Conference of the Parties (COP) 21 in December 2015.

Finally, the findings of this study would serve as a useful platform for policymakers by pointing to what non-limiting factors of CO_2 emissions should be considered as area(s) of interest for each income group of SSA in the further integration of their respective climate change and green economy strategies and policies into their development plans.

1.6 Scope of the study

This study evaluates the relationship CO_2 emission has with economic and financial development. The economic development variables considered for this study are gross domestic product (GDP) per capita, the share of agriculture as a percentage of GDP, trade as a percentage of GDP, inflation rate, rate of employment generated and the degree of later economic development. The financial development variables include domestic credit to private sector to GDP ratio, foreign direct investments to GDP ratio, foreign exchange rate and the degree of later financial development. Total primary energy consumption per capita is considered as the variable that indicates energy consumption which is a source of CO_2 emissions.

The structural change theory maintains that a declining share of agriculture implies a rising share of industry (Todaro and Smith 2003). However, these two sectors have been found by the United

Nations Conferences on Trade and Development (UNCTAD) (2012) to be sectors that not only use resources intensively but are critical to mitigating the environmental impact of resource use. Hence, to cautiously examine the objectives of this study, industry share as a percentage of GDP is considered as a control variable to create nested models.[8] Other control variables are population density and urban population as a percentage of total population. All the mentioned variables (except total primary energy consumption per capita and employment generation rate) are sourced from the World Bank's World Development Indicators (WDI). Total primary energy consumption per capita is sourced from the Energy Information Administration (EIA) of the United States Department of Energy while data on employment is sourced from the World Bank's Africa Development Indicators (ADI).

This research uses unbalanced panel data for the period of 1989 – 2012 (24 years) for a sample of 45 countries out of the 48 SSA countries recognised by the World Bank. The remaining three countries are left out because they have more than 50% data unavailability. To correct for heteroscedasticity and contemporaneous correlation in this study a Feasible Generalised Least Square (FGLS) is estimated as advised by Halkos (2011) and Al-Sayed and Sek (2013). A Generalised Method of Moments (GMM), as discussed by Grunewald and Martinez-Zarzoso (2009), Tamazian and Rao (2010) and Taguchi (2012), is estimated so as to take care of likely endogeneity and nonlinearity in the study. The sample countries are divided into four clusters of income levels (as recognised by the World Bank as at July 2015): low (24 countries), lower-middle (13 countries), upper-middle (six countries) and high-income level (two countries). To ensure consistent estimation, the panel analyses for these clusters are estimated with Panel-Corrected Standard Error (PCSE) regression in place of FGLS and Instrumental Variable (IV) regression in place of GMM. The justification for applying these estimation methods are discoursed in chapter four.

1.7 Organisation of the study

The structure of this study is as follows:

The first chapter of this study covers the background to the study, statement of the problem, research questions, objectives of the study, significance of the study, and scope of the study.

[8] Nested model is when a model is a special case of another model (Gujarati 2014).

The background and contextual profiling on economics and governance of climate change are the subject matter in chapter two. The chapter highlights international efforts and instruments in place to reduce CO_2 emissions, the green economy, and climate and carbon financing.

The third chapter reviews the literature. This consists of the adopted theoretical base, conceptual issues and empirical review.

Chapter four is on research methodology which comprises of the research design, hypotheses, data description, model specification, estimation procedures and methods of data analysis.

The fifth chapter discourses the interpretation of estimated results while the sixth but the last chapter presents the discussion of findings, conclusions, policy recommendations, limitation of the study and suggestions for further research.

CHAPTER TWO: BACKGROUND AND CONTEXTUAL PROFILING – ECONOMICS AND GOVERNANCE OF CLIMATE CHANGE

2.0 Introduction

Climate change negatively affects people in every country of the world although those in developing countries have a greater exposure to the risks than developed countries due to their high vulnerability (UN Global Compact *et al.* 2011). As demonstrated in the introduction chapter, drought, water shortages and less predictable weather patterns, are some of the negative impacts of climate change and these are particularly high along the East Africa and Guinea Coast. Such extreme weather events are known root causes of hunger and malnutrition experienced by these regions (Schaeffer *et al.* 2014). The rising sea levels and frequent heavy precipitation events make residents in low-lying deltas of Asia and Africa vulnerable to more frequent and damaging floods. The Kashmir Monsoon flood in India and Pakistan, in September 2014, remains on the history books (UN Global Compact *et al.* 2011). Climate change alters the spatial distribution of some infectious diseases, like malaria, dengue fever and water-borne diseases in SSA countries, particularly Ethiopia, Eritrea, Kenya, Rwanda and Nigeria (UN Global Compact *et al.* 2011).

As a result, climate change mitigation has become a global public good which has no strong economic and political mechanisms that can ensure any efficient solution to the negative impacts of climate change (Cunha-e-Sá 2008).[9] As observed in the literature: International organisations and individual governments worldwide, in cooperation with the private and public sector, have been implementing various measures and policies to limit GHG emissions via transition away from carbon-intensive economies. A number of these measures and policies are presented in this chapter to inform our understanding of the causes of climate change and how they could be mitigated.

Thus, this chapter will start by highlighting the findings of the Intergovernmental Panel on Climate Change (IPCC) and Sir Nicholas Stern. The third section focuses on climate change

[9] Global public good is a good or a benefit that provides utility by reducing risk and promotes the well-being of everybody in the world (Deneulin and Townsend 2006). Global public bad is a risk that allows disutility and leads to ill-being of everybody in the world. While the accumulation of carbon in the atmosphere resulting in global warming and causing the negative impacts of climate change is a global public bad, the abatement of carbon emissions so as to reduce the climatic risk associated with global warming is a global public good (Morrissey et al. 2002).

economic instruments that encourage low carbon emissions. The fourth part deliberates on international climate change agreements. The green economy and SSA's efforts on climate change and transition to a greener economy are then addressed to identify the attempts made by the region of study to reduce its emissions. Section seven and eight document matters pertaining to carbon and climate financing of green investments in SSA, while, the last section is the chapter's conclusion.

2.1 Intergovernmental Panel on Climate Change Assessment Report

After the Brundtland commission of 1987, the IPCC was formed to collate and assess evidence on climate change in 1988 (Nhamo 2009a). The conclusion of the IPCC's First Assessment Report that the global temperature has been rising and would continue to rise played a major role in the foundation of the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC 2015). Since its First Assessment Report, published in 1990, understanding how the climate is changing has been made through improvements of datasets and analyses on broader geographical coverage (IPCC 2007). Hence, the focus of this discussion is on the two most recent IPCC assessment reports (the Fourth and Fifth Assessment Reports –AR4 and AR5).

By 2007, in the AR4, the IPCC concluded that it is more than 90% likely that humanity's GHG emissions (since 1750) are responsible for modern day accelerated climate change (Nhamo 2009a). The IPCC went further to affirm, in its AR5 (issued in 2014), that the evidence for human influence on climate change has increased since the AR4. In this report, the IPCC resolved that the warming of the climate system is univocal (IPCC 2015). Both the AR4 and AR5 have projected that human-caused warming would continue for centuries even if GHG emissions are made stable and stopped while continued GHG emissions will cause further global warming (IPCC 2015).

With the global warming goal of keeping the global temperature increase below 2°C on pre-industrial levels (Galarraga *et al*. 2011), the AR5 reports that the world's cumulative CO_2 emissions from all anthropogenic sources (since 1870) need to remain below 2900 $GtCO_2$ (gigatons of carbon dioxide). As at 2011, about two third of this had already been emitted (IPCC 2014). The average growth rate in world total CO_2 emissions rose from 1.93% during 1982-1991 to 3.04% during 2002-2011. The world average CO_2 emissions per person also rose from 4.2 tCO_2 in 1991 to 5.0 tCO_2 in 2011 (www.globalcarbonatlas.org).

Using a larger number of scenarios with additional factors than the AR4, the AR5 discloses that emissions scenarios leading to CO_2-equivalent concentrations in the atmosphere in 2100 of about 450 ppm (parts-per-million) or lower are likely to maintain the global warming objective of below 2°C over the 21st century relative to pre-industrial levels (IPCC 2014). Meanwhile, the CO_2-equivalent concentration in 2011 is estimated to be 430 ppm already. With this concentration level, and to avoid an overshoot in concentration levels in the future, substantial reductions in emissions are required (Ibid.). Advocates to societies to respond to climate change by adapting to its impacts and reducing GHG emissions (mitigation is the emphasis of this work) and enhancing carbon sinks had since been made in the AR4 (IPCC 2007). The AR4 noted that there is a wide variety of policies and instruments available to governments to create incentives for mitigation actions (IPCC 2007).

Thus, ongoing mitigation efforts have increased since the AR4. These include mechanisms that set a carbon price which is cap and trade systems (for example, the European Union Emissions Trading System) and carbon taxes (for example, Australian carbon tax) (The Climate Group 2013). Some countries have tax-based policies, technology and other policies aimed at reducing emissions (for example, low tax or sales tax holiday on the purchase of energy saving bulbs) (IPCC 2015). Many countries have fuel taxes (although not designed for emissions mitigation purpose) which are akin to carbon taxes. An increasing number of countries are removing or reducing fuels subsidies and subsidies for GHG-related activities in various sectors (IPCC 2014). Sector-specific policies have also been widely used like Investment in the transport sector (for example Bogotá, Colombia, bus rapid transit (UNEP 2011)).

There has also been a considerable increase in regional, national and sub-national low-carbon development plans and strategies since the AR4 (for example, Kenya’s National Climate Change Response Strategy (Dewar 2012)). However, the AR5 report emphasises that without additional mitigation efforts beyond those in place already, global warming by the end of the 21st century will lead to a very high risk of severe, widespread and irreversible impacts globally (IPCC 2014). It also noted that delays in the required additional mitigation efforts could increase the economic costs to hold climate change risks at a given level in the long run (IPCC 2015).

Like other reports, the AR5 maintains that anthropogenic GHG emissions are mainly driven by population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy (IPCC 2015). The report further indicates that the agriculture sector is the third contributor to GHG emissions in the world following energy production and use and industry (these are part of the research's variables of interest) (Ibid.).

Although the impact of climate change is perceived all over the world, the risks are unevenly distributed among regions (IPCC 2015) and Africa could be the hardest hit (Nhamo 2011c). This is established based on the continents low adaptation capacity and projected climate change impacts (over the 21st century) (IPCC 2007). An instance of such projected impacts, made by the IPCC, states that, by 2020, yields from rain-fed agriculture could be reduced by up to 50% in Africa which could be the root of hunger and malnutrition in SSA (IPCC 2007).

Just as projections from the Third Assessment Report (TAR) climate models are consistent with those of AR4, projections in AR4 and AR5 are consistent (IPCC 2015). Although some scientists dispute the argument of global warming caused by anthropogenic processes (for example, Douglas and Christy 2009; Gray 2008; Veizer 2005), there is a unanimous agreement on the existence of climate change. Due to accumulated evidence, the number of disputing scientists is becoming thin (Stern 2006). Thus, there is a 97% consensus among scholars on human-caused climate change (Maibach *et al.* 2014). Going further, the economic policies and instruments noted by the AR4 to be available to governments and the Stern Review on the economics of climate change, among others, are discussed.

2.2 Stern Review

Carbon emission is the greatest market failure ever witnessed in human history because firms failed to bear the full cost of their production since the inception of the industrial revolution (Andrew 2008). They instead externalise the remaining cost through emissions into the atmosphere, thereby, passing the cost to the society at large as global warming (Stern 2006). The negative externality of the accumulated carbon emissions in the atmosphere has made the firms better off by making profits and the society's welfare worse off due to the negative impacts of climate change (Andrew 2008). Since the anthropogenic climate change spans generations

(Sussman *et al*. 2014), it was imperative to consider the economic costs of climate change impacts and the costs and benefits of reducing GHG emissions that cause it (Stern 2007).

At the request of the ex-British Chancellor of the Exchequer Gordon Brown, Sir Nicholas Stern led the re-examination of the economic costs of climate change. The outcome of this is named the Stern Review. The request was made to aid the understanding of the challenges of climate change and how they can be resolved (Nordhaus 2007). The Review found that ignoring climate change will eventually be welfare damaging and it will be difficult to reverse the damage. This finding led to the suggestion of taking an immediate action to reduce GHG emissions which will help to reduce the risks of climate change (Stern 2007). This suggestion is consistent with that of the IPCC.

The assumption of a near-zero time discount rate (i.e. the paternalistic view) in the Review is the most debated issue because it is not consistent with today's marketplace real interest rates and savings rates (Nordhaus (2007). Thus, other analysts, like Hope (2006), Nordhaus (2007) and Mityakov and Rűhl (2009) who used time discount rates consistent with market interest rates and savings rates, found lower levels of GHG emissions reduction and social costs of carbon than what the Review obtained. In Stern's defence, Weitzman (2007) comments that economists are aware that the biggest uncertainty in the economics of climate change is the uncertainty of what interest rate to use for discounting. Stern (2009), also, supported the adoption of the paternalistic view by stating that it was used to avoid discrimination by date of birth as a higher time discount rate means that generation born later counts for less.

Neumayer (2007), on the other hand, feels that instead of debating on discounting the important issue for debate on the Review should be 'to what extent does climate change inflict irreversible damage to natural capital'. The Review failed to identify this issue instead it assumes that damage is substitutable by expressing climate change impacts as a percentage of GDP. Neumayer (2007) asserts that this should not be so as many effects of climate change cannot be adequately valued monetarily.

Not to focus only on disputes, the Review has been given praises for its contributions. Nordhaus (2007) commended the Review for linking climate change policies to economic and environmental objectives. Like the IPCC, the Review, as well, suggested that the right policy frameworks like creating a carbon price, via taxes, trading or regulation, and promoting the development and deployment of new technologies especially on energy efficiency should be in place (Stern 2007). According to Weitzman (2007), this 'inconvenient truth' was ignored in Al Gore's (2006) book and movie on global warming. The climate change policies are discussed in the following section.

The Review's main policy conclusion is that mitigation today is superior to adaptation tomorrow (Mityakov and Rűhl 2009). Effective mitigation actions require attention under the three areas that drive GHG emissions the most in developing countries (energy use, agriculture and deforestation) (Stern 2006). To top it up, the Review identified that capital markets, banks and other financial institutions should play an important role in raising and allocating funds needed for low-carbon investments (Stern 2007). Finding out the role played so far in the context of SSA is one of the objectives of this study.

2.3 Climate change economic instruments

After the standard welfare analysis showed that all generations would benefit from immediate mitigation actions[10] (Rezai *et al.* 2009), a debate was raised on the urgent actions needed to reduce carbon emissions (Andrew 2008). This led to the question of whether developing countries should follow the 'grow now, clean up later' logic that characterised the development path of rich countries (Van Alstine and Neumayer 2010). Looking at it from the angle of theory (hashed out in the next chapter), it is assumed that poor people care less about the environment. They, instead, give priority to consumption (Hallegatte *et al.* 2011). As their basic needs are met, their incomes start to rise, the proportion of tax revenues paid to government also rises (Everett *et al.* 2010), as such people start to place a higher weight on environmental quality (Hallegatte *et al.* 2011). This makes the government spend more on environmental protection and clean-up (Everett *et al.* 2010).

In response to the raised question, the 'grow now, cleanup later' argument is weak for a number of reasons. To mention a few, it may be economical to reduce pollution at early stages of

[10] The welfare analysis identified that the implementation of mitigation actions and institutions to enforce the true cost of production by firms represents a Pareto improvement. Therefore, the current generation invests in mitigation actions so that future generations enjoy higher output and consumption combined with a lower carbon concentration in the atmosphere (Rezai *et al.* 2009).

development than incur higher cleanup costs at later stages because some infrastructures are long lived and it may be difficult to change their form later on (World Bank 2012). Second, the logic ignores the role of environmental irreversibility, for example, when forests are destroyed for agriculture in Kenya, it is possible to restore the forests by replanting but it is not possible to restore their biodiversity potential (Hallegatte *et al.* 2011). This also affects the climate because emitted CO_2 remains in the atmosphere for a long time (World Bank 2012). Thus, delayed action to clean up later could be dangerous (Everett *et al.* 2010).

To resolve the weaknesses of the said logic, developing countries are advised to grow cleaner i.e. they should endeavour to pursue growth by minimising pollution (World Bank 2012). To strengthen clean growth (also referred to as green growth), Lecocq *et al.* (1998) advise policymakers to apply specific policies that support low-carbon development so that mitigation actions may be achieved at lower costs in the long run (Hallegatte *et al.* 2011). These policies are economic instruments that are consistent with those suggested as climate change policies (also referred to as greenhouse gas policies) in the IPCC's report and the Stern Review. The climate change economic instruments could be divided into non-market and market-based instruments (Fisher *et al.* 1995) and some of them are concisely presented in the forthcoming subsections.

In theory, an economy with a perfectly functioning market would need only market-based instruments to address a negative externality like the accumulation of carbon emissions in the atmosphere. This is because the application of both non-market-based and market-based instruments could diminish economic efficiency and increase administrative costs (Gupta *et al.* 2007). That is, in a perfectly competitive marketplace, the market-based instruments have theoretical advantages like static cost effectiveness i.e. emissions abatement can be realised at the lowest cost to the society and dynamic efficiency like low-carbon technologies (Stavins 1998). However, the market-based instruments are handicapped by barriers (both international and domestic) in practice (Holland 2009). These are market failures (e.g. unequal access to information about the availability of carbon credits) and negative distributional effects (like low-income households being more affected with market-based instruments because they are unable to afford the substitution option of a gas stove for kerosene stove). This provides the rationale that makes a mix of non-market-based and market-based instruments desirable as non-market-based instruments help to reduce market imperfections (for example, by making information publicly available) to ensure distributional equity (Stavins 1997).

2.3.1 Non-market-based instruments

Non-market-based instruments also referred to as conventional regulatory instruments are a set of standards used to regulate the activities of firms and individuals so as to, directly and indirectly, reduce their emissions (Fisher *et al.* 1995). These standards are applied in areas like energy efficiency, fuel use by motor vehicles and pesticides used for agriculture. Standards may be mandatory and set as targets or voluntary, i.e. not binding (Grubb 1991; Fisher *et al.* 1995).

The mandatory regulatory standards can loosely be categorised as either technology-based or performance-based. Certain equipment procedures and combustion processes are necessary to effect technology-based standards and put carbon emissions under check, for example, installing catalytic converters[11] in automobiles (Fisher *et al.* 1995). Performance-based standards, on the other hand, are more flexible. They specify allowable levels of pollutant emissions and polluting activities while permitting the entities to choose the way in which they will achieve these levels. Giving firms in the European Union maximum allowable levels of CO_2 emissions from combustion is a reference for performance-based standards. The United States Climate Change Action Plan of 1993 is an instance of a Voluntary standard initiative aimed at increasing energy efficiency (Fisher *et al*. 1995).

Even though regulatory standards are inclined to be less efficient than market-based instruments, they can be cost effective and there are circumstances where they are perfect for the occasion, for example when the government wants hard-and-fast compliance for cleaner growth (Everett *et al*. 2010).

2.3.2 Market-based instruments

Market-based instruments are carbon-related fiscal instruments imposed on emitters as cost incentives to control emissions (Bräuninger *et al*. 2011). These incentives motivate firms to devise clean and cleaner production techniques that would reduce carbon emissions to meet emission targets. Market-based instruments are cheaper than regulatory instruments on account of their flexibility and efficiency in delivering results (European Commission 2005).

[11] A catalytic converter is "a device used to reduce exhaust pollutant gases from an internal combustion engine" (Kalam et al 2009:468).

An array of market-based tools that are and may be used by governments of SSA countries to promote clean growth and transit to be a green economy (a concept discussed later on in this chapter) are enumerated in the following section.

2.3.2.1 Carbon prices, carbon tax and trading scheme

The role of carbon prices can be fulfilled in two ways. Firstly, this can be by shifting production activities towards low-carbon and energy-efficient technologies (Carraro and Favero 2009) (for example, the substitution of fuel energy with solar energy systems by households and firms in Kenya). Secondly, the substitution of high-carbon input factors with less-carbon-intensive input factors (for example, the substitution of coal with natural gas in Turkey) (Ibid.). A carbon price can be introduced by a trading scheme, imposing taxes on carbon emissions or implicit pricing via regulations and standards (Hepburn and Stern 2008). Although the trading scheme and carbon taxes differ in design, in theory, both are to achieve a similar level of efficiency by reaching a targeted abatement level at a minimum cost (Kasterine and Vanzetti 2010).

In a trading scheme, governments set a cap on the total volume of emissions and allocate it as allowances which can be traded while carbon prices are determined by market forces (Benz and Trück 2006). As a result, firms that would be penalised if they exceed their allowances (cost on emissions) will buy from firms that have not exhausted their allowances (value on reductions) (Carraro and Favero 2009). Due to the pressing requirement of globally reducing emissions, carbon price by market forces is necessary but not sufficient (Hepburn and Stern 2008). This is where (domestic and international) regulations and standards step in. If a lenient cap is set in a trading scheme, carbon prices are low while stringent caps mean higher prices (Carraro and Favero 2009).

When a government decides to use the carbon tax to determine the cost of externality generated (i.e. carbon price), it does not fix the volume of emissions (Barker *et al*. 2007). If the emission levels are still too high, the carbon tax is increased while the level of emissions permitted for a length of time is reduced under the trading scheme (Kasterine and Vanzetti 2010). Contrary to the carbon tax, the trading scheme is attributed to be an ideal instrument of choice because it has price volatility which makes it less politically dramatic to adjustment. The trading scheme is also internationally selected due to its role in guaranteeing efficiency and collaboration to achieve emissions reduction target (Hepburn and Stern 2008). However, in the presence of expensive transaction cost, market imperfections (like collapsing carbon credit prices) and uncertainty, the trading scheme is undesirable for domestic mitigation efforts in developing countries (Stavins 1997).

Consequently, the carbon tax can be politically difficult (like trade union strike) to enforce and adjust upwards even if it is effectively designed (Barker *et al*. 2007). It, however, yields adequate annual revenues for governments which can be used to leverage private finance for clean technology investments in developing countries (IMF 2008). The carbon tax also gives greater price stability and greater flexibility in response to changes in economic activity (Kasterine and Vanzetti 2010). For these reasons, expected welfare losses are minimised under carbon tax than under the trading system (Goulder and Pizer 2006). Finland introduced the world's first carbon tax in 1990 and since then, fifteen countries have globally adopted it (OECD 2013). In SSA, Zimbabwe had since 2001introduced carbon tax on all vehicles (Nhamo and Inyang 2011). South Africa has made moves to introduce the carbon tax by 2016 (Kim 2015), so also are Ethiopia (IMF 2016) and Mauritius (Dalmazzone 2015). Before moving on with other market-based instruments, justice would not be done to the carbon price and trading schemes without succinctly talking about how the carbon market reduces emissions internationally.

2.3.2.2 Carbon market

Emissions reduction is a new commodity tracked and traded only in carbon (UNFCCC 2010a). To encourage countries and the private sector to meet their emission targets, three market-based mechanisms, also called regulatory markets, are created: the Clean Development Mechanism (CDM), the International Emissions Trading (IET) and the Joint Implementation. These mechanisms emerge out of the Kyoto Protocol of 1997 that came into force in 2005 (Barker *et al*. 2007). Participants of a carbon market include the private sector (companies with binding or voluntary emission commitments, emission-reduction project developers, banks and other financial institutions, investment firms, technology developers, and law and accounting firms) and the public sector (multilateral development banks like World Bank, government agencies, United Nations agencies and non-governmental organisations (NGOs)) (UNFCCC 2010a).

Unlike the cap-and-trade system which allocates allowances under the IET, carbon credits are created under the baseline-and-credit system of the CDM and Joint Implementation (UNFCCC 2007, Article 6, 12 and 17 of the Kyoto Protocol). Carbon credits from developing countries are called Certified Emissions Reductions (CER) and Emission Reduction Units (ERU) is from developed countries. The CDM is where CERs are awarded and approved to emission-reduction projects hosted in developing countries (Carraro and Favero 2009). The CERs may be used to either achieve regulatory platforms in developing countries or traded on the international carbon market to developed country polluters as carbon offset (for example, a German utility buying carbon credits from the Ethiopian wind farm) (Purvis *et al.* 2013). Both options lead to benefits for investors: in the former case, investors in developing countries are able to avoid fines and penalties; in the latter, investors in developing countries are able to enjoy direct monetary gain (Elgar *et al*. 2009).

The Joint Implementation is where ERUs are awarded to projects hosted in developed countries, particularly those from the East European block. For example, a French utility may invest in a Joint Implementation project to earn carbon credits from a Romanian wind farm (Carraro and Favero 2009). The key issue in both the CDM and the Joint Implementation mechanism is that there should be additionality (Bakker 2006) whereby the CERs and ERUs are each equivalent to one ton of CO_2 (UNFCCC 2007, Article 6 and 12 of the Kyoto Protocol). When a CER and/or an ERU is sold or bought in the IET, such carbon credit is known as Assigned Amount Units (AAU). The IET spurred the well-recognised carbon markets like the European Union Emissions Trading Scheme (EU ETS) and the Regional Greenhouse Gas Initiative (RGGI) which are implemented as a cap-and-trade system (UNFCCC 2007, Article 17 of the Kyoto Protocol). The EU ETS is the largest emissions market in the world, so far, which makes the European carbon price the global benchmark price because different carbon prices exist in different carbon markets (Carraro and Favero 2009).[12] Since SSA is concentrated with developing countries and it

[12] The EU ETS is faced with collapsing carbon prices (http://carbon-pulse.com). The carbon price was €20 at the start of 2008 but steadily dropped to an annual average of €6 in 2014 and around €5 in 2017 (www.thomsonreuters.com). The drop in prices is as a result of many factors few of which include the global financial crisis (2008/2009) which reduced economic output and so emissions; the generous allocation of emissions permits to companies due to overestimation of Europe's emissions (Purvis *et al.* 2013); surplus AAU emerging from Eastern European Countries (Lütken 2016); and the abundance of cheap international credit offsets from the CDM (The Climate Group 2013). However, the EU ETS remains the largest carbon market in volume and value (Thomson Reuters 2016).

cannot engage the Joint Implementation (Nhamo 2011a), how the region has benefitted from the CDM is an interest that is discussed later in this chapter.

2.3.2.3 Other market-based instruments

Subsidies: although subsidies have been criticised as an inefficient policy instrument that leads to rent seeking, it may still be used to induce proactive investments for climate change mitigation (Porter 1990). For example, Value Added Tax (VAT) exemption granted to companies to support research and development on technology innovation that would reduce CO_2 emissions is an action that favours climate change mitigation (Bräuninger *et al*. 2011). A negation like the removal of fossil fuel subsidy is also proactive while the continuous issue of fossil fuel subsidy forestalls climate change mitigation (ADR 2012). Therefore, fossil fuel subsidy reform is starting to become popular in SSA with success stories from Ghana and Senegal (GSI 2010).

Energy tax: as highlighted in the introductory chapter, energy generation from fossil fuels remains a high source of carbon emissions. To this end, an energy tax may be imposed on the physical unit consumption of power. Normally, the tax aims at reducing energy use, either by enhancing efficiency or by decreasing the energy consumed (Bräuninger *et al*. 2011). For example, an energy tax could lead to an increase in the demand for more efficient air conditioning systems which would make such technology cheaper, more attractive and ultimately serve as a GHG reduction measure (Bräuninger *et al*. 2011). The energy tax is similar to the carbon tax as it reduces the use of fossil fuels to generate power. It, however, has a trivial effect on emissions because it exploits only one (power sector) of the four main (others are household, transportation and industrial) channels of CO_2 emissions reductions opportunities that are exploited under carbon tax (IMF 2011).

Feebate: this is an alternative to the carbon tax (IMF 2011). A feebate for the power sector, for example, would impose a tax (fee) per kilowatt per hour on relatively dirty generators. Relatively, clean generators would receive a subsidy (rebate) per kilowatt per hour (Parry and Krupnick 2011). This instrument is cost effective because emitters with clean technology would receive rewards (in form of tax reduction or subsidy) either for switching to low-carbon fuels or improving plant efficiency or both (IMF 2011).

Land use tax: this is a tax payment made either for land ownership or use (Bräuninger *et al*. 2011). Land use affects deforestation. Thus, the amount of unsealed area is an important determinant of resilience to climate change. Tax on land use for purposes of carbon sink and ecosystem preservation are expected to be low, otherwise, they are expected to be high (Bräuninger *et al*. 2011).

Payment for Ecosystem Services (PES): Wunder (2005) states that PES "is a voluntary transaction where a well-defined environmental service is being bought by at least one buyer from at least one provider of the service" (Bräuninger *et al*. 2011:67). As long as the benefits from changing the ecosystem instead of conserving it are larger, a payment is needed. For example, the PES is used to conserve and manage forests in the Eastern Arc Mountains, Kenya (Bräuninger *et al*. 2011) and expand farmland to 85% by 2020 in Rwanda (Dyszynski 2011).

Habitat banking: this aims at conserving ecosystem services of land and biodiversity. The concept adheres to the polluter-pays principle because the economic agent reducing ecosystem services on one site has to pay for the damage by financing habitat projects on another site or the same site (Bräuninger *et al*. 2011). For example, in South Africa, mining companies are required to set aside funds to cover all closure costs at the end of its economic life and replace the mine sites with fish pond projects or mushroom plantation (UNECA 2012a).

Since a single instrument cannot effectively address the several market failures[13] that could likely surface, the combination of the above instruments (non-market and market) are required to make up an economy's climate change policy (Everett *et al*. 2010). How well the climate change policy is designed and implemented determines the magnitude of an economy's carbon emissions reductions (Fisher *et al*. 1995). Thus, policymakers (at national and regional levels) must take caution when adopting and designing climate change policy (Stern 2007). This is by making sure that the chosen instruments are those that would establish incentives to reduce emissions across different sectors (effectiveness), cost little to implement (efficient), and would not be regressive and not disrupt the level of market competition (equity) (Stern 2008). Going forward, international actions on climate change and efforts on transitioning to a green economy are points of discourse.

[13] The market failure like what was experienced under the EU ETS where countries like the United Kingdom and Germany exerted their market power to extract better deals for firms within their borders (Andrew 2008).

2.4 International climate agreements

According to Dutt (2009), international law can be divided into hard and soft law. The hard law is a formally binding international treaty while the soft law is a non-binding agreement which is advisory and not enforcing (Grunewald and Martínez-Zarzoso 2009). An international treaty becomes ratified by a two-third majority of the parties to a convention (UNCITRAL 2015). For the purpose of this work, a summary of climate change binding and non-binding agreements, outlined in Table 2.1, are briefly elaborated in the subsections.

Table 2.1: Climate change agreements

Hard Law	*Soft Law*
• 1997: Kyoto Protocol • 2010: Cancun agreement • 2016: Paris agreement	• 1992: UNFCCC • 2007: Bali Road Map • 2009: Copenhagen Accord • 2011: Durban Platform

Source: Author (2016)

2.4.1 United Nations Framework Convention on Climate Change (UNFCCC)

After the report 'Our Common Future' by the Brundtland Commission (1987) brought to attention various global environmental issues, the largest gathering of state leaders in history was held in Rio de Janeiro, Brazil in 1992. This gathering is the United Nations Conference on Environment and Development and it is popularly referred to as the Earth Summit (UNSD 2013). The Earth Summit produced a number of international environment treaties and conventions; among them is the UNFCCC (Barker *et al*. 2007).[14]

The UNFCCC became the first formal international agreement to acknowledge and address human-driven climate change (Lattanzio 2014). Its ultimate objective is to stabilise the concentrations of GHGs in the atmosphere at a level that would prevent dangerous anthropogenic interference, allow ecosystems' adaption, ensure that food production is not threatened and enable sustainable development (United Nations 1992: Article 2).

To achieve its objective, all Parties to the convention are expected to take precautionary measures to anticipate, prevent and minimise the causes of climate change and mitigate its adverse effects for the benefit of the present and future generations (United Nations 1992: Article

[14] Other international environment treaties and conventions are the Convention on Biological Diversity, the Principles for the Sustainable Management of Forests, the Rio Declaration on Environment and Development, and the Agenda 21 (Barker et al 2007).

3). All Parties are expected to formulate, implement and update their national and regional programmes to contain measures of climate change adaptation and mitigation (United Nations 1992, Article 4). To further the understanding of the causes, effects, timing, economics and social consequences of climate change, all parties should promote and cooperate in scientific, technical, socio-economic and other research and development related to the climate system (Ibid.). This is a reason why this study is topical, since this kind of research is lacking in the case of SSA.

The UNFCCC is to obligate developed countries, referred to as Annexe II Parties (see Appendix Table A.I), to promote, facilitate and finance the transfer of and access to eco-friendly technologies and knowhow to developing countries (United Nations 1992, Article 4). Alongside, it should emphasise that the climate investment needs of developing countries, particularly the vulnerable Parties (SSA countries inclusive), should be given full consideration (United Nations 1992, Article 3). To effectively implement the convention, a Conference of the Parties (COP) was established as the supreme body of the UNFCCC (United Nations 1992, Article 7)

The convention has been criticised for only obliging and not committing countries to reduce their emissions. Regardless of this, it paved way for the introduction of the Kyoto Protocol (a binding agreement) and ensured that the environment would no longer be treated separately from development (NRG4SD 2011). Another issue raised is the North-South divide[15].

To start with, the convention expects financial commitments and adoption of national policies and climate change mitigation from developed countries ('North') while it expects no financial but voluntary responsive commitments from developing countries ('South') (Mejía 2010). This implies that the UNFCCC applies the principle of common but differentiated responsibilities to the two groups (Mahendra 2015). Another factor that led to the divide is the difference in scientific knowledge and data collection. Inadequacies of data and scientific knowledge (to provide convincing evidence) in developing countries contribute to the relative invisibility of Southern issues while favouring Northern biasness on the global climate agenda. Thus, there is an inadequate participation of the South during deliberations on global environmental governance (Karlsson 2002).

[15] The North-South divide is a term extensively used for making accounts of the negotiation dynamics in the international arena (Mejía 2010).

However, the North-South divide is beginning to show blurry signs under the UNFCCC. This is due to the Southern fragmentation into different coalitions (Mejía 2010). The South (used to and still) participates under the umbrella of the Group of 77 (G-77) countries, a group that contains 134 developing countries. Now, there are groups of developing countries like Brazil, South Africa, India and China (BASIC), the Association of Small Island States (AOSIS) and the least developed countries (LDCs) group which consist mostly of SSA countries (Nhamo 2011a). These groups are starting to unite based on their interests, taking different positions and negotiating independently from the G-77 (Mejía 2010). For instance, the LDC and the AOSIS, during the Bali COP, argued that large emitting developing countries like China and India should be made to reduce their emissions (Nhamo 2011a). This fragmentation has brought about a South-South divide which furthers into the uneven distribution of CDM projects among all developing countries with the least profited being the poorest region (SSA) (Mahendra 2015). This matter is discussed later in this chapter.

2.4.2 Kyoto Protocol

The Kyoto Protocol is an international agreement that was adopted at the third Session of the COP to the UNFCCC in 1997 in Kyoto, Japan. The Protocol came into force in February 2005 after it was ratified by at least 55 countries which account for at least 55% of total GHG emissions (Barker *et al*. 2007). It sets binding targets for 37 industrialised countries known as Annexe I countries (Table A.I). Other countries are those from developing regions known as non-Annexe I countries and they do not have emissions reduction obligations. The implementation of the Protocol is called the 'Marrakesh Accords' (NRG4SD 2011). The first commitment period started in 2008 and ended in 2012 and Annexe I countries were required to collectively reduce their GHG emissions (on average) by 5.2% based on their 1990 levels (Nhamo 2009b). Thus, while the convention encouraged industrialised countries to stabilise GHG emissions, the Protocol commits them to stabilise GHG emissions. In a study conducted by Grunewald and Martinez-Zarzoso (2011), they found that countries with emissions commitments from the Protocol emit less CO_2 than similar countries that did not ratify the Protocol.

As Canada withdrew its ratification of the Kyoto Protocol in 2012, the 'Doha Amendment to the Kyoto Protocol' was adopted in the same year. This adoption stressed a new commitment for Annexe I countries to the Kyoto Protocol for the period 2013 to 2020 (United Nations 2014). This second commitment period will enter into force on the 90th day after at least 144 of the 192 parties to the Kyoto Protocol have submitted their instruments of acceptance with the United Nations. So far, 71 countries (including 18 SSA countries) have ratified the Doha Amendment, as at October 2016 (from the UNFCCC website unfccc.int).

2.4.3 Bali Road Map

Despite so many counteractions at the conference, the thirteenth COP of the UNFCCC, which took place in 2007, in Bali, Indonesia, gave birth to the Bali Road Map (Hunter 2010). This year, also, marked the Nobel Peace Prize awarded to the Intergovernmental Panel on Climate Change (IPCC) and Al Gore (Watanabe *et al*. 2008). After the Fourth Assessment Report (AR4) of the IPCC established that there is the need for deep cuts in global emissions (UNFCCC 2008), all the parties to the UNFCCC agreed to launch a comprehensive and long-term cooperative action on emission reductions (Hunter 2010). This led to changes like the shift from the top-down approach of the UNFCCC and the Kyoto Protocol to the pledge and review approach which is an *ex-post* assessment rather than an *ex-ante* assessment of countries' emissions reduction commitments (Ngwadla *et al*. 2015).

The Bali Road Map to the COP15 contains a timetable with a 2009 deadline to negotiate further emissions reduction commitments and the Bali Action Plan. The Bali Action Plan contains the framework for negotiating a binding post-Kyoto agreement (Watanabe *et al*. 2008). The premise of the Bali Action Plan is different from that of the UNFCCC which requires ratification and not compliance and the Kyoto Protocol which requires both ratification and compliance. The Bali Action Plan provides for neither ratification nor compliance. It simply requires parties reaching an agreed outcome on the post-Kyoto Protocol by the fifteenth session (Ngwadla *et al*. 2015).

Since the COP13, the issue of technology development and transfer gained an extraordinary importance instead of being on the sidelines as before (Santarius *et al*. 2009). The significant development of the Bali Action Plan was that developing countries' Nationally Appropriate Mitigation Actions (NAMA) would be supported and enabled by technology, financing and capacity-building from industrialised countries (Mejía 2010). This is to take place under a Measurable, Reportable and Verifiable (MRV) procedure to ensure transparency (Santarius *et al*. 2009). The Bali Action Plan made reference to take further action to reduce emissions from deforestation and forest degradation (REDD -which is discussed later) in developing countries to ensure forest management and resource availability (Nhamo 2010).

The lessons learnt from the Bali Road Map are that unilateral actions in developing countries on climate change mitigation is not adequate, effective and fair to keep the world safe (Ngwadla *et al*. 2015). After 16 years of forming the UNFCCC, the Parties finally agreed to negotiate based on the understanding that all major emitters (like China and India) will take on mitigation activities. Thence, Bali extinguished the industrialised countries' (like the United States) excuse for not taking further commitments (Watanabe *et al*. 2008). The Bali Action Plan set forth priorities for the Copenhagen negotiators and all of the elements are reflected, to some extent, in the Copenhagen Accord (Hunter 2010).

2.4.4 Copenhagen Accord

Based on the Bali Road Map, the COP15 in Copenhagen, Denmark, in 2009 was expected to take care of two issues. It was to produce a legally binding treaty to reduce global emissions in the post-2012 era, i.e. a post-Kyoto Protocol (Mckibbin *et al*. 2010) and set the course to limit the rise in global temperatures to a maximum of $2^{o}C$ (Nhamo 2009a). Instead, it produced the Copenhagen Accord, a document that represents more of a new start to deal with the climate change problem (Spak 2010).

Unlike the Kyoto Protocol in which emissions reductions commitments were negotiated internationally, Annexe I countries only submitted their emissions target for 2020, using whatever base year they wish, under the Copenhagen Accord. The Accord also invited non-Annexe I countries to submit their NAMA (Hunter 2010). The different base years used by the Parties make it difficult to compare their likely emissions reductions and economic efforts required to achieve their commitments. The emissions target refers, only, to a single year's emissions (2020) whereas the Kyoto Protocol capped emissions over a-five-year period (2008-2012) (Mckibbin *et al*. 2010). In addition to these critiques, the pledged targets made by the Parties -especially the United States and China- were lower than what was recommended by the IPCC (Levin and Bradley 2010). The major setback is that the pledges are not even binding (Hunter 2010) because five countries, which represent less than one percent of global emissions, refused to endorse the Accord. Once again politics trumped science (McKibben 2010) and this setback may be due to the ongoing 2008-2009 global financial crisis (Angus 2010). Whatever the case, Mehra (2010) blames the United Nations' process for this outcome (Spak 2010).

As it is, we should not lose sight that the main objective of the convention is to take action to reduce carbon concentrations in the atmosphere and not to have a binding agreement (Hunter 2010). Thus, the Accord is still important because it includes emissions targets for BASIC and extends emission reductions post the 2012 Kyoto deadline (Spak 2010). In addition, developing countries agreed for the first time to provide national reports of their GHG inventories every two years. Although South Africa's pledged emissions target at Copenhagen was seen as a conflict of interest with the African Group (Nhamo 2011c), pledges made by BASIC represent the first step to bridging the North-South divide (Whalley and Walsh 2009).

In accordance with the provisions of the UNFCCC to support actions on mitigation, including finance for REDD, adaptation, technology development and transfer and capacity-building in developing countries, the Accord produced two important financial commitments (UNFCCC 2010b). Developed countries pledged $30 billion in new and additional sources for the period 2010-2012 and committed to providing up to $100 billion per year by 2020. The $30 billion is commonly called 'fast-start finance' (FSF) which are channelled more through bilateral than multilateral channels with a higher allocation to mitigation (including REDD) than adaptation (Brown *et al*. 2011). Also, a Copenhagen Green Climate Fund was proposed for creation (Nhamo 2011a). If these pledged finances are realised, global emissions will be reduced further and the most vulnerable countries will be better equipped (Houser 2010).

Hence, at best, Copenhagen made a few positive steps forward and deferred other issues (like enforceable emissions reduction commitment and stopping deforestation) to COP16 and beyond (Brown 2011). In fact, African countries felt that Copenhagen gave them an unjust deal (Nhamo 2011a).

2.4.5 Cancun agreement

The Cancun Agreement made at the sixteenth session of the COP to the UNFCCC in Cancun, Mexico, in 2010 imported the essential elements of the Copenhagen Accord (The Climate Institute 2010). In addition, it officially, for the first time, held to keep the global temperature increase under the 2ºC threshold and consider 1.5ºC when necessary (Galarraga *et al*. 2011). Thus, the COP16 marks the first time pollution commitments from the United States, China and all other major economies are captured in a formal UNFCCC agreement since its launch in 1992 (The Climate Institute 2010).

The Agreement formalised the $30 billion and the $100 billion pledges made in Copenhagen by developed countries and proposed that the Green Climate Fund (GCF) be established to channel the $100 billion (UNEP 2010b). The GCF is to function as a source of climate finance that provides a balanced allocation of funds between mitigation and adaptation actions (UNEP 2011a) and the World Bank was assigned as its interim trustee (Pew Centre on Global Climate Change 2010). The Agreement achieved a partial success on REDD, created a centralised registry responsible for compiling all NAMA proposals and there was a consensus on the issue of MRV (UNEP 2010b).

The COP16 was a contrast to the disappointment experienced in COP15 (Pew Centre on Global Climate Change 2010). Unlike the Copenhagen Accord which is a memorandum of understanding among the Parties, the Cancun Agreement is a detailed contract among the Parties (The Climate Institute 2010). The major accomplishment in Cancun was that the United Nations negotiation process can still produce tangible results as it did in Marrakesh, Morocco (Pew Centre on Global Climate Change 2010). Also, this marks the first time emission commitments from the United States, China and all other major economies are captured in a formal UNFCCC agreement since 1992 (The Climate Institute 2010). This has put the world back on the track of renewing international efforts to combat climate change (UNEP 2010a).

After deliberation, it was concluded that even though the Agreement saved the UNFCCC process, it has yet achieved little towards tackling climate change itself (UNEP 2010b). The reason for this is that negotiations for the second Kyoto Protocol phase remain open because Australia, Canada, Japan and Russia refuse to participate if the United States does not participate (Galarraga *et al*. 2011). This may be because these economies were more concerned about short-term priorities like unemployment, growth and budget cuts that arose from the recently experienced global financial crisis (Angus 2010). However, each year spent waiting for the second binding target is making the achievement of the UNFCCC's objective more difficult. For example, the CO_2 atmospheric concentration was approximately 350 parts per million (ppm) when climate change negotiations began in 1990, by the year of the Cancun meeting, the concentration had risen to 390 ppm (Brown 2011).

2.4.6 Durban platform

A decision known as the Durban Platform was reached at the seventeenth COP to the UNFCCC in Durban, South Africa, in 2011. The Platform was an opening to assess the 20 years' experience under the UNFCCC (Bodansky 2012) and so it launched a new process to develop a second protocol which would be applicable to all Parties to the UNFCCC (Kameyama *et al*. 2014). The negotiations, under the new process, are scheduled to conclude in 2015 and the outcome should be implemented from 2020 (Bodansky 2012).

The Durban Platform indicated that the work plan for the negotiations should address mitigation, adaptation, finance, technology, capacity building, and transparency, among other things (Bodansky 2012). The world's leading agricultural organisations (for example, Food, Agriculture and Natural Resources Policy Analysis Network (FANRPAN)) called on the COP17 climate negotiators to include agriculture in the work plan using the slogan 'no agriculture, no deal' (FANRPAN 2011). FANRPAN agitated that Africa's agricultural potential should be unlocked side by side building the continent's climate resilience (Ibid.).

The 'no agriculture, no deal' campaign enjoyed some progress in Durban as it was agreed to consider agriculture under the negotiations rather than sideline it as before (COMESA 2012). This is a small victory[16] because the sector is responsible for 14% of global emissions and (as explained in the previous chapter) is one of the activities that result to deforestation (The Climate Group 2011). Having this issue on the global climate agenda is germane to SSA, a region in which agriculture is a pillar to its economies and it is the home to the second most significant tropical forest (Congo Basin Forest) in the world after the Amazon (Nhamo 2011b).

In an effort to blur the North-South divide, the Durban Platform is applauded for the clause 'the outcome of the negotiations is applicable to all parties' (Ewing 2012). That is, developed countries do not have any more excuse not to participate in future UNFCCC agreements since developing countries would be participating (Stern 2011) and the (2008-2009) global financial crisis has ended. However, the Platform is accused of allowing developed countries to stall their responsibilities and showcase their lack of political will by postponing decision making and implementation stage to later years (Ewing 2012).

[16] This small victory was achieved thanks to the support of the Tripartite (Common Market for Eastern and Southern Africa-COMESA, East African Community-EAC and Southern Africa Development Community-SADC) Africa Bio-Carbon and Climate Change Initiatives (COMESA 2012).

Also at the seventeenth session, the Governing Instrument for the GCF was approved and since European donors and Korea have been its main sources of funding, so far, Korea was approved as the host country of the GCF in 2013 (UNECA 2014a). At the twentieth session of the COP in Lima, Peru, in 2014, the total pledges of contributions made for the GCF is $10.14billion, a long way from the $100billion (GCF 2014).

Going to the COP21 in Paris, France; Africa's position centres on issues and actions that will play along protecting SSA's ecosystems and enhancing the performance of the region's agriculture sector to be greener (Munang and Mgendi 2015).

2.4.7 Paris Agreement

The twenty-first COP to the UNFCCC that took place in Paris, France, in 2015 achieved the deadline set at the COP17 in Durban in 2011 (NRDC 2015). This is because the Paris Agreement is the new international legally-binding climate change framework that covers almost all of the world's emissions (Climate Focus 2015). This is a historical landmark in the global fight against climate change. Thus, the world is moving away from the action by a few to the action by all (European Commission 2016).

The COP21 yielded not only the Paris Agreement but also a decision. While the Agreement demonstrates the cooperative action to replace the Kyoto Protocol post-2020, the Decision is to guide the pre-2020 action and set out the implementation details for the Paris Agreement before it is being enforced (Climate Focus 2015). The Agreement establishes a global warming goal of well below 2°C on pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels (UNFCCC 2015a). This goal goes beyond what had been agreed in Copenhagen and confirmed in Cancun (Climate Focus 2015).

The Paris Agreement is being damned for putting emphasis on processes (and not on formulating emissions targets) and voluntary mitigation contributions called the Nationally Determined Contributions (NDCs) (Climate Focus 2015). However, unlike the Kyoto Protocol, it seeks to ensure that countries progressively formulate more ambitious climate targets that are consistent with the new goal (Ibid.). This would be done by making a revision of NDCs every 5-year to ensure progression beyond the last NDCs (UNFCCC 2015a). The Agreement emphasises that its implementation will be in accordance with the principle of common but differentiated responsibilities and respective capabilities because of different national circumstances. That is, developed countries should adopt economy-wide absolute emission reduction targets while developing countries should aim for this over time (UNFCCC 2015a). The bottom-up flexibility (i.e. the NDC) in the Agreement is expected to allow countries to match their contributions to their circumstances (C2ES 2015). Also, international cooperation between developed and developing countries by proposing joint NDCs is encouraged by the Agreement, unlike other existing climate treaties. Thus, the Paris Agreement is commented for being important, but only a step in the direction of an effective policy response (Climate Focus 2015).

In order to phase out greenhouse gases (GHG) as soon as possible (Oberthür *et al*. 2015), latest by the second half of this century (Climate Focus 2015), the Paris Agreement introduced stocktaking. This exercise will, also, take place every five years to ensure that the Agreement is on track and is being executed (UNFCCC 2015a). The first stocktaking is scheduled for 2023 before which (as noted in the Decision) an initial stock to measure progress towards the long-term emissions goals would be taken in 2018 (Ibid.).

The Agreement supports the mechanism that allows private and public entities to support mitigation projects that generate transferable GHG emissions (UNFCCC 2015a). However, such projects will need to have a net positive mitigation effect (emission reductions) which may not necessarily be used to offset emissions generated elsewhere (Climate Focus 2015). Thus, the Paris Agreement makes it crystal clear to governments, the private sector and the public that moving in the direction of a low-carbon economy is now to become not only desirable but unavoidable (Oberthür *et al*. 2015). This means that resource use has to shift away from fossil fuels to clean resources (European Commission 2016).

Shockingly, the Paris Agreement does not provide any framework for addressing emissions from agriculture. It only notes that low GHG development should be continued in a manner that does not threaten food production (Climate Focus 2015). This is due to higher concerns for food insecurity as carbon finance ends up in the pockets of project developers and private companies in developing countries (Bond *et al.* 2012) and not the lack of political will on the part developed countries. Also, the Agreement does not provide a time-bound commitment on climate finance and its disbursement. Proactively, the COP21 Decision highlights the need for enhanced finance (Climate Focus 2015). It states that the existing mobilisation of $100 billion per year by 2020 will continue to 2025 by which the Parties to the Paris Agreement shall set a new collective quantified goal from a floor of $100 billion per year (UNFCCC 2015a). Aside from climate finance, the Decision also calls for the ratification and implementation of the second phase of the Kyoto Protocol prior and up to 2020, respectively (Climate Focus 2015).

In resolve, the fact that the Paris Agreement does not contain binding emissions targets and financial obligations were to ensure that the Agreement is an executive-ratified treaty and not a congressional-ratified treaty to the United States (Baker and McKenzie 2015). This refrain has guaranteed not only the ratification of the United States but also those of Australia, Canada, Japan, Russia and any other country that may refuse to participate if the United States does not participate. The Paris Agreement was ratified before the deadline of April 2017 in October 2016 by 97 Parties to the Convention and it entered into force in November 2016 (unfccc.int). Hopefully, agriculture would not be sidelined in subsequent COP to the UNFCCC, as agreed under the Durban Platform.

2.5 The Green Economy

In the middle of the global financial crisis that peaked in 2008, the United Nations Environment Programme (UNEP) called for a Global Green New Deal (GGND) (Barbier 2009). This Deal, released in 2009, encouraged governments to support economic transformation to a greener economy as the way forward to mitigating and adapting to climate change. In a green economy, growth in income and employment are driven by public and private investments should be to reduce carbon emissions, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services (GIZ 2013).

The package of public investments and complementary policy and pricing reforms, as recommended by the GGND, required in the pathway to transition to a green economy rather than business as usual (BAU) (UNEP 2011), *inter alia*, are enumerated. Greener agriculture by adopting eco-friendly farming practices that would make GHG emissions net neutrality and possibly be a carbon sink and reduce deforestation and increase reforestation is needed (Ibid.). Another investment is to substitute fossil fuels energy generation (and reduce energy poverty) with renewable energy (UN DESA *et al*. 2013). So also is greening transport by investing in rail and water transport, bus rapid transit system (BRT) and non-motorised transport (UNEP 2011). As such, the investment path to the green economy is environmental, economic and developmental in scope (UN Global Compact *et al*. 2011) for both developed and developing countries (UN DESA *et al*. 2013).

Complementary investments in human capital like education, awareness, training and skill enhancement programmes are also needed to prepare the workforce for a green economy transition (UNEP 2015a). The rational use of subsidies, corrective taxes and other market-based instruments (as mentioned earlier) stimulate clean investments that form part of the complementary policy and pricing reforms in the pathway of the transition to a green economy (UNEP 2011).

Since 2008, a growing number of countries (SSA countries inclusive) have actively and continuously pursued the green economy pathway (UNEP 2015a). Thus, enabling a smooth transition to a green economy will also require South-South cooperation. Put differently, developing countries with experiences and successes in achieving a green economy could provide valuable ideas, expertise and technology to other developing countries to address their similar concerns (UNEP 2011). Multilateral Environmental Agreements (MEAs) are needed to facilitate a smooth and speedy transition to a green economy (GIZ 2013), thus, a vital reason to hasten the post-Kyoto framework (UNEP 2011). SSA's regional efforts on the green economy and climate change mitigation are discussed later.

Although there is no complete estimate of funds needed to green the global economy, the amounts involved are substantial (UNEP 2011). Thus, the GGND called on governments to allocate a significant share of stimulus funding to the identified green sectors (UN DESA 2012). Also, financial institutions and investment sectors are expected to be in a position to provide the finance needed by the public and private sectors for a green economy transition. For example, financial institutions, such as pension funds and insurance companies, around the world are becoming more aware of the reduced risks involved in building up green portfolios. Likewise, commercial and retail banks are designing green financial products (UNEP 2011).

After jumpstarting a green economy transition, the green funding mechanisms (like GCF), climate funds and carbon funds (discussed later) are needed in addition to public financing and borrowing from the financial sector for a smooth transition. Therefore, without implementing the aforementioned package of investments and policies and access to finance, the pathway towards a green economy remains rough (UNEP 2011). In realisation of this, greater efforts called for the

2012 Rio+20 Conference which focused on promoting the green economy as a catalyst to accelerate progress on sustainable development (UN DESA 2013). ‘The future we want’, the outcome document of the Rio+20, encourages each developed nation to develop its own green economy strategies, with support from the United Nations, for developing countries (United Nations 2012). Thus, there was the establishment of the Global Green Growth Institute (GGGI) to support developing countries in their transition towards a green economy (Kabaya 2012). Below are two popular green economy programmes that have been offering assistance in identifying and seizing opportunities that ensure the transition towards a green economy.

2.5.1 REDD+ in a Green Economy

Reducing Emissions from Deforestation and forest Degradation plus (REDD+), a United Nations programme, is an effort to create a financial value for the CO_2 stored in forests (Nhamo 2011b). Although REDD was first discussed in 2005 at the eleventh Conference of Parties (COP) to the UNFCCC, in 2007 at the COP13 to the UNFCCC, REDD became REDD+. In addition to reducing emissions, REDD+ is to serve as a comprehensive approach that would conserve and enhance forest carbon stocks and sustain management of forests (Global Symposium Report 2013). Following up on the decision made during the COP15, the COP16 incorporated REDD+ under the Kyoto Protocol mechanism (Boyle *et al*. 2011) which qualifies REDD+ for carbon trading credits on the carbon market (Nhamo 2014a). Being pro-poor and pro-jobs has linked the REDD+ to the green economy (Global Symposium Report 2013). According to the United Kingdom Department of Energy and Climate Change (2010), no doubt, the goal of limiting the rise in global temperatures to 2^oC will be much harder without REDD+ (Nhamo 2011b). Thus, REDD+ acts as a catalyst for transition into the green economy in countries[17] that are already striving towards the goal of a ‘low carbon, resource efficient and socially inclusive economy’ (Global Symposium Report 2013).

Despite the green growth advantages the REDD+ has to offer, some researchers (Sikor *et al*. 2010; Corbera and Schroeder 2010) argue that REDD+ projects could adversely impact and also get affected by the rights of indigenous people (Aggarwal 2012). Theoretically, the REDD+ is meant to be an opportunity to recognise local community rights and provide security of tenure (Sunderlin *et al*. 2009). However, empirically, it is contested that the REDD+ might recentralise

[17] Some SSA countries that have taken bold steps towards “REDD+ in a green economy” are Burkina Faso, Ghana, Ethiopia, Kenya, Madagascar, Republic of Congo, Tanzania, and Zambia (Global Symposium Report 2013).

the forest governance in the hands of the government because recognising the security of land tenure is critical for the implementation of its projects (Phelps *et al*. 2010). This makes local communities to contend with their lack of access to land and forest resources once REDD+ projects take off and fight to resolve what compensation would accrue to them, especially when land tenure rights are unclear (Eilenberg 2015).

Also, the REDD+ is faced with a lack of commitment from governments of developing countries (Mahanty and McDermott, 2013) which causes the delay in the completion of REDD+ projects process. They stop at either developing a national REDD+ strategy or at the implementation of policies phase and lose out on the performance-based payments phase (Korhonen-Kurki *et al*. 2014). To be effective at reducing and avoiding delays in climate change mitigation, the REDD+ must be proactive in addressing these contestations (Sunderlin *et al*. 2013). Moreover, to realise the REDD+ full potential, there is the need for an ambitious and legally binding post-Kyoto Protocol deal which is yet to surface (Nhamo 2011b).

Against all the contestations, reports from SSA countries like the Burkina Faso, Democratic Republic of Congo (DRC) and Ghana show significant progress in REDD+ projects execution (Nhamo 2011b; Global Symposium Report 2013). Meanwhile, Cameroon, for example, has made little progress in spite of its early participation in REDD+ (Brockhaus and Gregorio 2014). On the part of governments, REDD+ has been accused of uneven distribution of funds (especially in SSA) (Nhamo 2011b). This contestation has been identified to be due to donors request for countries that would yield high carbon emissions reduction, hence high carbon credits, or countries with an already capacity to handle REDD+ projects. SSA governments are, thence, implored to play their part by establishing the Measurable, Reputable and Verifiable (MRV) system (as instructed by the UNFCCC COP) and resolve other issues like land tenure rights, corruption and political stability (Nhamo 2011b). This call on SSA governments is common to that made under the sustainable development goals (SDGs) of the 2030 Agenda introduced in 2016 to pursue environmental and social goals (Lima et al 2017). The SDG 13 and 15 which relates to climate change mitigation and forest conservation, respectively, are related to the environmental goals of REDD+ to reduce carbon emissions from the forest sector which creates core synergy. However, while the SDGs do not indicate hierarchy between the two set of goals, REDD+ places environmental goals above social goals. This may place a conflict in the implementation process of both REDD+ and SDGs (Ibid.).

2.5.2 Green Growth Strategy

To resolve global climate change problems, Green Growth Strategy (GGS) was launched by the Organisation for Economic Co-operation and Development (OECD) in June 2009. The GGS was endorsed by OECD ministers in 2011 (OECD 2012). It is worth noting that green growth is an integral part of a green economy transition (Nhamo 2013). The focus of GGS is to attend to challenges that are common among OECD, emerging and developing countries (OECD 2012). The strategy is meant to help emerging and developing economies leapfrog by factoring their environmental issues into their infrastructure investment decisions and further develop agriculture and other natural resources in a way that would improve livelihoods, create jobs, and reduce poverty.[18] To attain these objectives, the OECD is working with the World Bank, UNEP and the GGGI through the Green Growth Knowledge Platform (GGKP) facilitating knowledge exchange, highlighting existing research gaps and providing policy guidance that is most needed (Ibid.).

2.6 SSA's efforts on climate change and transition into a green economy

The concept of a green economy has gained currency because of its proposed proactive response to address and prevent the climate, food and economic crises that the world has been facing in recent years (UN DESA *et al*. 2013). Definitely, the continent of Africa is not left out. Africa's acceptance of the green economy dates back to 2009 when the third African Ministerial Conference on Finance for Development, in Kigali, Rwanda, called for the creation of an enabling environment that embraces low-carbon development and supports the green economy transition (Nhamo and Nhamo 2014).

A roadmap for the green economy in Africa was adopted during the first Pan-African Biodiversity Conference in Libreville, Gabon, in 2010 (Nhamo and Nhamo 2014). During the 14th session of the African Ministerial Conference on Environment (AMCEN) in 2012, in Arusha, Tanzania, African leaders' determination to move towards a more inclusive and greener economy was portrayed (Kim 2015). A step was taken further in Arusha to make the decision on Africa's Post Rio+20 Strategy for Sustainable Development and establish mechanisms that

[18] These SSA countries are already enjoying assistance from GGS: Ethiopia, Kenya, Rwanda and South Africa (OECD 2012).

would provide coordinated support to member states on their transition to the green economy (UNEP 2015b). These mechanisms, among others, are the African Green Economy Partnership (AGEP), the promotion of regional and international cooperation, and the transfer of resource-efficient and green technologies (Kim 2015). The AGEP, for instance, is an effort that is supported by the UNEP through the Partnership for Action on Green Economy (PAGE). Burkina Faso, Ghana, Mauritius and Senegal are the first set of SSA countries to enjoy this partnership (UNEP 2015b).

In its crusade for the green economy, the African Development Bank (AfDB) defines the importance of green growth in an African context. Green growth is "pursuing inclusive economic growth through policies, programmes and projects that invest in sustainable infrastructure, better manage natural resources, build resilience to natural disasters, and enhance food security" (GIZ 2013:9). Given the natural disasters that have affected the continent in the recent past, the Bank asserts that adaptation to and mitigation of climate change is not an option but an imperative (AfDB 2014b). Examples of the natural disasters that occurred in SSA recently are the torrential rain that flooded Malawi in January 2015 and the wildfire that burned in South Africa in March of the same year (from the Guardian website www.theguardian.com). The Bank claims that, since many African countries are heavily dependent on natural resource exploitation, green growth could aid sound resource management in Africa to avoid overexploitation and leapfrog to greener infrastructural investments (AfDB 2012).

Over the years, the AfDB has developed policy frameworks that should now form pathways to transition to the green economy in its member countries. The Climate Risk Management and Adaptation Strategy (CRMA), the Climate Change Action Plan (CCAP) and the Energy Sector Policy are some examples of the AfDB policy frameworks (AfDB 2012). The AfDB's Agricultural Sector Strategy has also sought to integrate green growth approaches by additionally focusing on forestry, land and water management, and climate change mitigation and adaptation (Ibid.).

The Bank has been helping in the development of carbon as an asset by enhancing carbon stocks through sustainable forest management. This it does through mechanisms such as the Congo Basin Forest Fund (CBFF) and the implementation of REDD+ projects (AfDB 2012). The AfDB identifies that building partnerships and enhancing communication are crucial to a successful implementation of the green growth framework. Thus, the AfDB has and will continue to partner with the United Nations Economic Commission for Africa (UNECA), the African Union Commission (AUC) and Regional Economic Communities (RECs) (AfDB 2012). For instance, the AfDB, UNECA and AUC are the partners for the Climate for Development in Africa (ClimDev-Africa) initiative which was launched in 2010. They jointly organise the Conference on Climate Change and Development in Africa (CCDA) that commenced since 2011 (UNECA *et al*. 2013).

Expressing the success of the AfDB, UNECA and AUC partnership, the most recently concluded CCDA-IV took place in Marrakech, Morocco, in 2014 with the Conference theme 'Africa can feed Africa now, translating climate knowledge into action' (UNECA 2014b). The CCDA-IV presses for public-private partnership co-investment in affordable energy sources in African countries. It advocates for a window for accessing finance for agriculture under the United Nations Framework Convention on Climate Change (UNFCCC) and practitioners to have access to the financial sector. It also reiterates that African countries should be encouraged to integrate inclusive green economy strategies into their development framework and progress made should be tracked (UNECA 2014b).

In its Ten-Year Strategy 2013-2022, the AfDB makes it a focal point to provide support for African countries' climate change challenge and transition toward being green economies (AfDB 2014a). In the process of implementing the Ten-Year Strategy, the Bank is to help develop local capital markets to embrace green portfolios, inhibit the continent's high level of unemployment and boost agricultural productivity and food security (AfDB 2013a). To ensure due achievement, the Bank has been working with several of its member countries (like Cape Verde, Kenya, Mauritius, Mozambique and Sierra Leone) on mainstreaming green growth into their national development plans, developing the green economy roadmaps and action plans (AfDB 2014c). The green growth related and climate funding instruments at the AfDB, inter alia, are the CBFF, the Sustainable Energy Fund for Africa (SEFA), the Africa Renewable Energy Fund (AREF), the Global Environment Facility (GEF) and the ClimDev-Africa Special Fund (CDSF).

The AUC, also, has a global strategy called the Agenda 2063. The Agenda is to optimise the usage of Africa's resources with a target of addressing climate change and preserving the environment (UNIDO 2015). Identifying with the opportunities presented by international carbon abatement and climate change mitigation, there is the need for reliable and affordable energy supply in both rural and urban areas of SSA (UN-ENERGY/Africa 2007). For this purpose, the AUC and the New Partnership for Africa's Development (NEPAD), in collaboration with Regional Economic Communities (RECs) (like the Economic Community of Central African States (ECCAS), the Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC)), regional power pools, and African Energy Commission (AFREC), initiated a number of programmes aimed at developing renewable energy (AUC 2011). An example of such is the 2020 hydroelectricity initiative to upgrade major hydroelectric sites in Africa i.e. the Congo Basin, the Nile Basin, the Zambezi Basin, and the Fouta Djallon (AUC 2011). The most recent renewable energy programme is the African Renewable Energy Initiative (AREI) that was announced by African nations at the Conference of the Parties (COP) to the UNFCCC in Paris in 2015. AREI has the goal to build at least 10 gigawatts (GW) of new and additional renewable energy generation capacity by 2020 and 300 GW by 2030 (Climate Council 2015). These programmes would give SSA some protection from the fossil-fuel price increase and reductions in carbon emissions from the combustion of fossil fuels (UN-ENERGY/Africa 2007).

The pathway to transition to a green economy is explored not only at the continental level in Africa. Investments in green growth and policy design and implementation by regional and national governments of SSA is also critical (Elgar *et al*. 2009). The green economy and climate change strategies exist in RECs of the sub-Saharan region (i.e. the Common Market for Eastern and Southern Africa (COMESA), East African Communities (EAC), Economic Community of West African States (ECOWAS) and Intergovernmental Authority on Development (IGAD)), but it is inadequate in the Southern African Development Community (SADC) (Nhamo 2014b) and the Economic Community of Central African States (ECCAS) (Wouapi *et al*. 2014). Member states of the RECs are listed in Appendix Table A.II.

The COMESA started its Climate Change Programme since 2008. However, in the spirit of a tripartite in 2009, it invited its neighbouring RECs to commence the COMESA-EAC-SADC Tripartite Climate Change Adaptation and Mitigation programme and Climate Change Initiative (COMESA 2012). The Tripartite programme is a five-year plan that started in 2010 while the Tripartite initiative was launched in 2011 (COMESA *et al*. 2011). The EAC, in 2011, launched its own separate climate change master plan for a period of 2011-2031 (Nhamo 2014b).

Compared with other RECs in the Tripartite, the SADC's Green Growth Strategy and Action Plan have a late development. This is because the SADC, initially, treated the green economy transition strategy with scepticism due to the witnessed failure of the 1980s World Bank and International Monetary Fund (IMF) structural adjustment programmes (Nhamo and Nhamo 2014). The late development of climate change action plan in the ECCAS may be ascribed to the weak unity within the community (Meyer 2015). The SADC's Green Growth Strategy and Action Plan are currently being drafted, since 2013 (UNEP 2015b), while the ECCAS' climate change unit is to take the form of a department (Wouapi *et al*. 2014).

Although it does not have a climate change programme, the ECOWAS has initiatives developed in line with the principles of a green economy (UNECA 2013). There is the Global Alliance for Resilience Initiative (AGIR) (also supported by the West African Economic and Monetary Union (WAEMU)) and the Regional Agricultural Investment Program (PRIA) which were launched in 2012 and 2010 respectively (UNECA 2014c). So also is the initiative for energy efficiency, i.e. the ECOWAS Regional Centre for Renewable Energy and Energy Efficiency (ECREEE), which became operational in 2010, and the ECOWAS Initiative for safe, affordable and sustainable cooking by 2030 (UNECA 2013). Even though the West African Common Industrial Policy (WACIP), adopted in 2010, does not have a clear strategy for greening the industry sector, its analysis in the UNEP's report (2015b) seems to show that the policy moves along the pathway to transition to a green economy.

The IGAD Climate Prediction and Applications Centre (ICPAC) provides climate information, prediction products and services for early warning and related applications so as to reduce climate change (UNECA 2012b). The itemised SSA RECs' strategies are to guide their respective member states to achieve two objectives. To prepare and implement collective measures to address climate change (UNECA 2012b) and to ensure environmental sustainability and sustainable development in agriculture, agroforestry and renewable and efficient energy use (UNECA 2013).

In pursuance of the pathway to transit to a green economy, some SSA countries have made progress planning and implementing low-carbon development and climate resilience actions, policies and strategies (Nhamo 2014b).[19] These strategies and policies started emerging from the beginning of 2010 with Kenya's National Climate Change Response Strategy (Dewar 2012). Namibia also introduced its National Policy on Climate Change in the same year (Nhamo 2014b).

In 2011, South Africa signed the Green Economy Accord (Economic Development Department of South Africa 2011) and National Climate Change Response Strategy White Paper (Nhamo 2014b). During the same year, Ethiopia and Rwanda launched Climate Resilient Green Economy Strategy (GGBP 2014) and Green Growth National Strategy (GoR 2011) respectively. Malawi and Tanzania introduced their National Climate Change Policy and Strategy, respectively, in 2012 (Nhamo 2014b). While Mozambique's Green Economy Roadmap became operational in 2013 (GGBP 2014), Ghana found its National Climate Change Policy Framework in 2014 (Asante *et al*. 2015). Swaziland is notable for its 2014 National Climate Change Strategy and Action Plan and 2015 National Climate Change Policy (GoS 2014).[20]

The above-mentioned green growth and climate change strategies are written up to achieve objective(s) for a long term period. For example, Kenya's strategy has the objective to transform into a newly industrialising, middle-income country with a high quality of life to all its citizens in a clean and secured environment by 2030 (Mwenda and Khainga 2013). The strategies are to, among other things, introduce and ensure an increase in the usage of carbon efficient agricultural practices; protect and re-establish forests; and leapfrog to modern and energy efficient technologies in transport, construction and industry (Dewar 2012). They also intend to generate employment which is expected to be more than their corresponding BAU scenarios. For instance, Burkina Faso expects its green economy scenario to generate 160 million more jobs than its BAU scenarios of 27.6 to 27.7 million jobs by 2050 (Kim 2015). For large scale international support for finance and building the required institutional and technical capacity, it is noticed that the strategies adopted the concept of 'Measurement, Reporting and Verification' (MRV) which emerged during the Bali Roadmap (discussed in the previous section).

[19] Hitherto, sixteen SSA countries (Burkina Faso, Ethiopia, Ghana, Kenya, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Senegal, Sierra Leone, South Africa, Swaziland, Tanzania, Uganda and Zambia) have or are in the process of developing climate change and/or green economy strategies or action plans.

[20] It is worth noting that SSA countries like Uganda and Zambia have drafted National Climate change Policy and National Climate Change Response Strategy, respectively, (Nhamo 2014). Burkina Faso and Mauritius are still developing their Green Economy Strategy and Action Plan (UNEP 2015b)

Alternatively, some countries (like Cape Verde, Central African Republic, Gabon, Mali and Nigeria) do not have a separate strategy and action plan. They, simply, integrated the green economy and climate resilience into their national plans, as suggested by the fourth Intergovernmental Panel on Climate Change (IPCC) report (see UNEP 2011; Dewar 2012; CAR 2015). Also, thus far, countries like Seychelles, Somalia, South Sudan and Sudan are yet to integrate climate change into their development plans (AfDB 2014). One may justify for Somalia and South Sudan due to the long period of conflict, continuing insecurity and inadequate access to social and financial services. Seychelles and Sudan may not be excused for not having green growth and climate change policies in place (Ibid.). These countries, nonetheless, have a lot of lessons to learn from early starters of low-carbon resilient development agenda (like Ethiopia, Kenya, Rwanda and South Africa) (Fisher 2013).

In spite of all that has been said, more work needs to be done especially in the area of finance. Although there are a number of multilateral and bilateral sources to fund green growth (discussed in subsequent sections), budgetary support at the national level is vital (Nhamo 2013). Even in SSA, domestic public funds provide the seed capital to finance green investments (GGBP 2014). This is because, at the early stage of a project cycle, banks and other financial institutions in SSA find it difficult to invest because they are not familiar with how to evaluate the risk associated with green projects (World Bank 2010). This is why some SSA countries set up a fund to give grants and loans in support of green projects. An example of such funds is South Africa's Green Fund that was established in 2011 (GGBP 2014) while an example in terms of budgetary support is that of Ethiopia's national budgetary resources for climate change actions which have been around $440 million per year (Eshetu *et al*. 2014).

Some case examples are drawn on afterwards to illustrate some operational and executed projects in countries that are already working on transitioning to a green economy. To start with is one of the low-hanging fruits in terms of transitioning to a green economy, avoiding gas flaring (UNEP 2011b) when crude oil is extracted from the earth (UNECA 2012a). In 2010, gas flaring resulted in about 360 million tonnes of CO_2 emitted into the atmosphere across the world. In SSA, efforts to reduce gas flaring stand out by bottling the gas which may be used for both commercial and domestic purposes as liquefied natural gas (LNG) to generate energy. Angola, Equatorial Guinea and Nigeria have these projects undertaken under the CDM. In fact, Angola's LNG is one of the world's largest gas flaring reduction projects (UNECA 2012a).

The Social and Environmental Entrepreneurship In Developing countries (SEED) Awards is an annual awards scheme designed to find the most promising, innovative and locally start-up social and environmental enterprises in developing countries (UNECA 2012a). The SEED initiative was founded by the UNEP, the United Nations Development Programme (UNDP) and the International Union for Conservation of Nature (IUCN) at the 2002 World Summit on Sustainable Development in Johannesburg, South Africa (Creech *et al*. 2012). SSA countries, like Ghana, Kenya, Malawi, Rwanda and South Africa, have received awards for small and micro entrepreneurs success stories that manufacture and distribute carbon efficient and green technologies (UNECA 2012a) (see Appendix Table A.III for details of the awards).

Scaling up renewable energy production, Côte d'Ivoire has the third largest hydropower plants system in West Africa after Nigeria and Ghana and it has undergone system extension and construction (AfDB 2013b). Kenya is the world leader in the number of solar power systems installed per capita (AlliedCrowds 2015). In Ethiopia, a geothermal plant and six wind projects are used to generate over 1000 kilowatts (Babatunde 2014). Windmills are, also, used to generate and supply electricity for villages in Gambia (Sehjpal *et al*. 2013). All these renewable energy venues speak to the school of thought that focuses on development with reduced carbon emissions.

Still, in the spirit of scaling up renewable energy, Ghana's Parliament in 2011 passed the Renewable Energy Act to provide the legal and regulatory framework necessary for expanding its renewable energy sector (Ghana Ministry of Foreign Affairs 2013). The Act established a Renewable Energy Fund to provide the financial resources needed for the sector's expansion (UNEP 2015b). Kenya, South Africa and Uganda opened up their power generation sector to Independent Power Producers (IPPs) to increase both their amount of electricity generated and the share of renewable energy in their national energy mix (UNEP 2014). To advance the use of renewable energy, Botswana, Kenya and Mauritius apply feed-in tariffs to encourage greater private sector investment in renewable energy technologies. The feed-in tariffs obligate power distributors to buy, on a priority basis, all renewable energy source generated electricity at pre-determined fixed tariffs (Sehjpal *et al*. 2013; UNEP 2014). To achieve the same objective more efficiently, South Africa, on the other hand, has taken a step forward from feed-in tariffs to bidding approach (Nhamo 2013).

Besides Ethiopia, Malawi, South Africa and Uganda, energy efficient cooking stoves are also being produced and distributed in Ghana and Rwanda (OECD 2012). This is to reduce the use of firewood which may lead to depleted soil and forest and then reduce their carbon sink potential (WDR 1992).

In the spirit of aligning price signals to support green growth, South Africa is the most respected amongst SSA countries. For illustration, in 2009, the South African Finance Minister announced the introduction of a levy on incandescent light bulbs manufactured and imported. This policy's ability to reduce carbon in the use of electricity inspired other countries such as Botswana to adopt similar regulation (UNEP 2011). In this regard, South Africa also amasses billions of rand in revenue from fuel levy and emissions tax on new passenger motor vehicles (GGBP 2014).

Due to the success rate of Bogotá's, Colombia, bus rapid transit (BRT) system by contributing a 14% drop in emissions per passenger, BRT has been replicated in Lagos, Nigeria, and Johannesburg, South Africa. South Africa is, also, known for its world class metro rail (UNEP 2011). Still, on reducing carbon emissions from transportation, (according to IEA 2014) Malawi, Ethiopia and Kenya are already mixing ethanol with transport fuel. In fact, Ethiopia's National Biofuel Policy, for instance, does not only promote blending ethanol with gasoline for transportation it promotes it for cooking too. Since South Africa is currently the only SSA country with a stable vehicle manufacturing industry, the region has little control over the design of vehicles. As such, the use of plug-in hybrid electric vehicles (PHEVs or PEVs) is a mere expectation of reducing emissions in the region. However, the option of regulating the efficiency and age of incoming used vehicles is adopted by Angola, Botswana, Kenya and Nigeria (Hogarth *et al*. 2015).

Rwanda is not the only country where biogas is promoted and marketed to reduce carbon emissions, Biogas Construction Enterprises (BCE) is the platform authorised in Uganda to install biogas plants between 2009 and 2014 (Sehjpal *et al*. 2013).

CDM projects implemented in SSA play out well as part of the green economy transition measures. In spite of the fact that these projects have been implemented mainly in South Africa, other countries where CDM projects are sitting include Angola, Equatorial Guinea, Kenya, Nigeria, Rwanda, Senegal, Tanzania, Uganda and Zambia (UNFCCC 2013). Noteworthy is the South African Kuyasa CDM pilot project which retrofitted over 2,300 low-cost homes in the district of Khayelitsha in Cape Town with solar water heaters, solar panels, ceiling insulation, and other energy efficient lighting (Goldman 2010).

In February 2014, the Wildlife Conservation Society announced that the Government of Madagascar approved its first forest carbon credits sales to Microsoft, the Carbon Neutral Company and Zoo Zurich (GGBP 2014). The carbon credit sales mark the first sale of government-owned REDD+ credits in Africa. Intrinsically, this links deforestation to economic development, particularly in the agriculture sector (Ibid.). In Kenya, tax incentives for growing trees have been introduced alongside reforms to restrict harvesting and marketing of tree products (GGBP 2014). The Payment for Ecosystem Services (PES) is used not only in Kenya but in Tanzania to reduce CO_2 emissions from deforestation and forest degradation by supporting Community Carbon Cooperative development (GGBP 2014).

To curtail the volume of carbon emitted under agricultural practices, the reduction in the use of chemical pesticides while increasing the use of bio-pesticides are applied in Burkina Faso, Mali, Senegal, South Africa and Uganda (UNECA 2012a). Organic farming is becoming a trend due to its export markets where consumers are now expecting greener agricultural produce that have lower carbon footprints. In SSA, member states of the East African Community (EAC) are becoming leaders in organic farming (Ibid.). For training and skill enhancement, the Tamboura Farming Business in Bamako, Mali, is a green agriculture model school where young entrepreneurs may learn the art of modern agriculture (UNECA 2013). Also, Farmers' cooperatives in Mali and Burkina Faso are making a judicious use of unproductive lands by growing the Jatropha plant, which can be used for the production of biofuel (GGBP 2014).

The green economy transition discussion will not be complete without reflecting on fossil fuel subsidy (FFS). FFS is a subsidy given by governments to consumers. It allows consumers to pay less than the market price of fossil fuel products (like coal, petrol, diesel, kerosene, etc.) while producers receive the market price (Bárány and Grigonytė 2015). However, FFS tends to benefit high-income earners relative to the poor and it poses a high burden on government budgets in SSA. Also, it has a negative environmental, social and economic impact like supporting CO_2 emissions because as consumers pay less the quantity of fossil fuels used increases (ADR 2012). Removal of fossil fuel subsidies would thus free substantial resources that could be used to encourage green economic activities. Ghana and Senegal are success stories of eliminating FFS in SSA (GSI 2010) and so also is Nigeria where the process of eliminating the fuel subsidy was completed in January 2016 (reported by the Vanguard news website www.vanguardngr.com).

Companies respond to climate change by building climate goods and services to aid the transition to the green economy. These are enumerated in succeeding paragraphs.

The Johannesburg Stock Exchange (JSE) is the first stock exchange in SSA to develop a Socially Responsible Investment (SRI) Index and the Carbon Disclosure Project (CDP) (Nhamo and Swart 2012). These disclosure indicators, among others, are to make consumers and investors be aware of the environmental impacts companies make and their efforts to support South Africa's transition to a green economy (UNECA 2012a). Hopefully, this will yield adequate incentives, in terms of a rise in market capitalisation, for South African firms to want to reduce their carbon emissions.

Rehabilitated mines are being used for carbon capture and sequestration in South Africa. The country's mining companies are required to set aside funds during the life of their mining operation to cover all closure costs at the end of its economic life. For example, De Beers' Kimberly project uses underground mine tunnels to grow mushrooms (UNECA 2012a).

Kenya's Mumias Sugar Company Limited contributes to reducing carbon emissions via its cogeneration plant which produces power through the burning of bagasse, a waste product from sugarcane (UNEP 2014). Another company is Eskom, a South African power utility championing a strategy that focuses on using lower-carbon-emitting technologies to generate power and electricity (UN Global Compact *et al*. 2011).

Apparently, South Africa and Kenya are at the forefront of the green economy transition while other countries like Ethiopia, Mauritius and Rwanda have also taken it seriously (Nhamo 2013). A lot of work needs to be done for the transition to be completed by 2050 (a time constraint projected by the IPCC's climate change model) (Huq 2011). Hence, other countries need to double up and take note of valuable learning points from the countries at the forefront. Moving further, this chapter will not be complete without touching on carbon finance and climate funds which are in the following sections.

2.7 Carbon financing in SSA

Carbon finance is a set of international and national schemes aimed at reducing the economic burden of militating against climate change. It complements and leverages other financial resources to unlock low-carbon investments in host countries (Elgar *et al*. 2009). Of all the international carbon markets, the second largest carbon market (i.e. the Clean Development Mechanism (CDM)) is the most suitable for SSA countries (Nhamo 2011a). Other carbon finance mechanisms were created for developing countries by the World Bank through its carbon finance unit. The unit started with a single carbon fund called the Prototype Carbon Fund (PCF) in 1999. Presently, the Bank manages a robust suite of 15 carbon funds (World Bank 2013). To mention a few, the World Bank's carbon finance mechanisms include the BioCarbon Fund (BioCF), the Carbon Fund for Europe (CFE), the Carbon Initiative for Development (Ci-Dev), the Community Development Carbon Fund (CDCF), and the Spanish Carbon Fund (SCF). How these carbon finance mechanisms have, so far, aided climate change mitigation in SSA is explored in this section.

SSA makes little use of national carbon finance mechanisms to fund low-carbon projects (especially its renewable energy sector). For example, Ethiopia (IMF 2016), Mauritius (Dalmazzone 2015) and South Africa (World Bank 2014) are the few SSA countries that have plans to commence a carbon tax and Zimbabwe had since 2001introduced carbon tax on all vehicles (Nhamo and Inyang 2011). Although the CDM is the most widely used carbon finance mechanism in SSA, only 2.9% of all CDM projects are located in Africa, as at 2013, and the majority of these projects are in South Africa (World Bank 2013). Much of the CDM projects are apportioned to China, India and Brazil, majorly, because CER buyers (i.e. investors in the carbon markets) prefer CDM projects with high volume of emissions reductions. Meanwhile, most SSA countries are agro-based economies with small scale projects which yield a low volume of carbon credits (Nyambura and Nhamo 2014). Even with this, only a third of the CDM registered projects realise the carbon finance they put in for (Lütken 2016).

Like every market, international carbon markets are faced with the risk of failure while adapting with changes in economic and political factors (Cormier and Bellassen, 2012). Specifically, the CDM has its share of reasons for failure. The CDM's slow approval process is a reason that debars its objectives of access to carbon finance and reduction of emissions by increasing the transaction cost of projects which prevents affordability for SSA countries (Purvis *et al.* 2013).

There is also the issue of conflict of interest whereby some members of the CDM governing body are simultaneously climate-treaty negotiators and representatives of their respective countries (Bond *et al.* 2012). The major share of the demand for CDM's Certified Emissions Reductions (CERs) comes from the European Union Emissions Trading System (EU ETS) (Ibid.). Since the EU ETS has a drop in its demand for credits (from 2013) (Thomson Reuters 2016), the CDM is not left out of the experience of collapsing credit prices (Shishlov and Bellassen 2012). Dropping from around €14 at the end of 2008 (Purvis *et al.* 2013), credit price was around €4 at the end of 2012 (Bond *et al.* 2012) and further dropped to €0.65 at the end of 2015 (Thomson Reuters 2016). Undoubtedly, the CDM has helped SSA countries to discover their carbon emissions abatement potential by enabling them to adopt more ambitious climate policies. However, it requires procedural and policy reforms for SSA to benefit more from its carbon finance in coming years (Lütken 2016).

The increasing prominence of forests has, however, stimulated SSA's demand for carbon finance from the suite of World Bank managed carbon funds; for example, 2009 signed Ibi Bateke agroforestry project in the Democratic Republic of Congo to be completed by 2018 (World Bank 2015). SSA enjoys approximately 31% of asset support projects from BioCF Tranche 1 as at 2010 (World Bank 2010). Meanwhile, other carbon funds are not forthcoming, for example, Africa was apportioned just 2% of the PCF and SCF and 6% of the CFE as at 2010 (World Bank 2010). The percentage of all the World Bank's carbon finance portfolio apportioned to Africa was 13% as at 2013 (World Bank 2013) and 14% as at 2014 (World Bank 2014). Thus, Africa is still struggling to access financial resources for low-carbon investments (UNCCD 2013). Hopefully, may be SSA would receive a larger and fairer share of carbon finance through the World Bank's Ci-Dev Carbon Fund (World Bank 2013).

The reason why the use of carbon finance mechanisms is relatively limited in SSA is more than just the low volume of emissions reductions (Agarwal 2013) excuse given earlier. Other reasons can be broken down into two: (a) capacity barriers (i.e. lack of human capital and weak institutional coordination) and (b) financial barriers (i.e. high start-up costs, insufficient domestic funding and high perceived risk) (Elgar *et al*. 2009).

Using energy projects for illustration, renewable energy projects (such as cogeneration technology and high-temperature boilers) are skill-intensive to operate. Although these projects exist in a small number, SSA does not have the adequate skilled personnel to operate and maintain the projects (Hogarth *et al*. 2015). For example, a domestic company called Rural Energy and Environmental Systems (REES) in Ghana and Scoraig Wind Electric, a British company, co-developed a wind power project after which Scoraig had to launch a training programme for local enterprises' technicians on the design, construction, manufacture and installation of the wind turbines using locally sourced materials. The result of this was the manufacture of the first local wind turbine in Ghana by the trainees of the programme (Elgar *et al*. 2009).

The region is also in need of more skills to tap into carbon financing options. This is why universities and governments need to step up by delivering skills-based courses, seminars and vocational programs on not only climate change adaptation and mitigation projects but also on carbon finance (Elgar *et al*. 2009). An example is the Uganda Carbon Bureau which has since 2006 been training the public, private and financial sectors on how to scale up their participation in the carbon market (OECD 2013). The AfDB's seminars on raising awareness of its staff, project owners and government agencies on the potential of carbon finance are other examples (AfDB 2013c).

Low-carbon projects carry massive start-up costs. For example, renewable energy equipment like wave energy converter (WEC) and tidal power are expensive to execute. However, there is evidence that the cost of solar and wind energy equipment has been going down and there are indicators that scaling up is on its way (Hogarth *et al*. 2015). Still, small-scale projects that are often required in the poorest and most vulnerable population communities have very high transaction costs that drive investors away (Agarwal 2013). This challenge is further compounded by the poor investment climate in many SSA countries and weak capacity of government institutions to manage finance (Nakhooda *et al*. 2011). In favour of SSA countries, considerable efforts are being made to promote a more business-friendly environment that attracts Foreign Direct Investments (FDI) into the region (Agarwal 2013).

Since carbon financing is essentially paid after delivery of the emission reductions, developers need to commit significant costs at the beginning of a project without expecting returns for some time (Nakhooda *et al*. 2011). Thus, they have to find other sources of funding through the financial sector if and when the need for additional funds arises. This is why it has been observed that countries with higher domestic credit to private sector (% GDP) enjoy a higher number of CDM projects (Agarwal 2013). Some SSA countries with this trend are South Africa and Kenya (Ibid.). Even so, whether a country's financial sector is well developed or not, developers still face barriers like lack of collateral requirements and detrimental financial institutions' policies and regulations that hinder access to funds (Bondinuba 2012). After surmounting all challenges and delivering emission reductions, carbon finance provides only a portion of the required funding for the projects to the developers. These make financing large infrastructure projects not easy to obtain in SSA (Elgar *et al*. 2009).

To overcome these financial impediments and give incentives to investors, feed-in-tariffs, legislated in some SSA countries, are set to cover the cost of generation plus a reasonable profit margin (UNEP 2014). Cessation of fuel subsidies, like Ghana in 2005, is considered to be another way to overcome financial barriers (ADR 2012). Such funds can be diverted into developing low-carbon projects. One option is to relax import duties on low-carbon technologies. Another option is to mitigate the risk concern of private investors through insurance. This way, private investors can be motivated to invest. For example, the Multilateral Investment Guarantee Agency (MIGA) is a member of the World Bank Group that provides guarantees which protect cross-border investment and associated risks in developing countries (Elgar *et al*. 2009).

In remedy, efforts are made by SSA RECs to help direct investment to small-scale low-carbon projects. For example, the ECOWAS established a fund to purchase carbon credits upfront in its member states to provide start-up capital for domestic small and medium-sized enterprises and the Central African States Development Bank (BDEAC) developed similar instruments to facilitate access to funds for CDM project developers in its member states (Nakhooda *et al*. 2011). Nevertheless, a large and sustained contribution from public sector financing in cohort with funding from the financial sector is needed to finance low-carbon investments in SSA (Schaeffer *et al.* 2014).

2.8 Climate financing in SSA

Funding available under the UNFCCC and the Kyoto Protocol are the most important sources of international financing for climate investments (Ackerman 2009). Other sources of multilateral climate mitigation funding are the World Bank's Climate Investment Fund (CIF) and Forest Investment Program (FIP); the Congo Basin Forest Fund (CBFF); the Global Environment Facility (GEF); the Green Climate Fund (GCF); the Millennium Development Goals (MDG) Achievement Fund; the United Nations Reducing Emissions from Deforestation and forest Degradation (UN-REDD) programme; and the European Union's Global Climate Change Alliance (GCCA) and Global Energy Efficiency and Renewable Energy Fund (www.climatefundsupdate.org). There are also bilateral initiatives sponsored by Germany, Japan, Norway and the United Kingdom. Of these, Japan's 'Cool Earth Partnership' (later called Hatoyama Initiative, now referred to as Japan's Fast-Start Finance) is the largest bilateral funding initiative (Nakhooda *et al*. 2013b). Also, the World Bank's CIF has the largest value of approved projects among all multilateral and bilateral climate funds for mitigation (ICF International 2014). The attempt of climate finance in mitigating climate change in SSA is briefly discussed in this section.

The GEF has been the longest standing source of finance for climate change mitigation in SSA. The largest approved project of the GEF is the African Rift Geothermal Development Facility for six African countries (Ethiopia, Eritrea, Djibouti, Kenya, Uganda, and Tanzania) (Nakhooda *et al*. 2011). For instance, the Menengal geothermal project was launched in 2012, in Kenya. This project is designed to produce electricity for 500,000 households and displace two million tonnes of CO_2 per annum in Kenya (AfDB 2012).

Just like carbon finance mechanisms, SSA's access to climate funds are limited (UNECA 2014a). In fact, SSA's low-income countries appear to be the most neglected by these sources while attending to the region's middle-income countries. For illustration, Uganda and Chad combined received less than US$0.5million in climate funds over three years (2008-2011) (Nakhooda *et al*. 2011) while Somalia and Swaziland are far behind on receiving climate funds at all (Nakhooda *et al*. 2013a). In similarity to carbon finance, a large share of the 25% of climate funds approved (since 2003) to SSA is directed to South Africa and much of the finance has supported the Eskom renewable energy program (Nakhooda *et al*. 2013a).

Thus, due to SSA's large infrastructure deficit, there is still a pressing need to mobilise resources for climate change mitigation in SSA (UNECA 2014a). To resolve this challenge, the development of an African Climate Change fund, managed by an African institution, is touted as a way to meet Africa's specific needs (UNECA 2014a). The African Development Bank (AfDB), then, approved the creation of the Africa Climate Change Fund (ACCF) in 2014 (Gulati 2014).

The ACCF is a bilateral thematic trust fund to support African countries on their climate change resilient and low-carbon development activities (AfDB 2014a). With the establishment of the GCF since 2011, the ACCF represents a critical opportunity for the Bank to mobilise and implement more climate finance for Africa. To further ensure this, the AfDB is planning to set up an Africa Green Facility which makes the ACCF the first step in the right direction of reducing the climate mitigation infrastructural deficit in the continent. Also, the ACCF is meant to be a key financing instrument for implementing the AfDB's 2013-2022 ten-year strategy (AfDB 2014b).

Since International climate financing mechanisms cannot handle it all, more creative and innovative ways of generating climate finance from both domestic and external sources may be developed by SSA countries (UNECA 2014a). The case of Rwanda's Fund for Environment and Climate Change (FONERWA), instituted in 2012, is an example of this circumstance (Sida's Helpdesk for Environment and Climate Change 2013). FONERWA is, currently, the largest demand-based climate fund channel in Africa (CDKN 2013).

Thus, other SSA countries may learn from the experiences of South Africa's Green Fund and Rwanda's FONERWA on the mix of mechanisms and processes they employ to drive climate finance to their direction for climate mitigation purposes.

2.9 Conclusion

In this chapter, it has been asserted that even though SSA countries minimally contribute to carbon emissions, they are the most vulnerable to the impacts of climate change (AfDB 2014b). Understanding that their carbon emissions will likely increase under BAU growth patterns (OECD 2012), some SSA governments are beginning to implement a mix of climate change measures and policies that promote green and low-carbon development. To reduce carbon emissions now and in the future so as to avoid ruinous climate change and safeguard its environmental capital, SSA governments lagging behind need to overlook sentiments and board the ship (with a window of 30 years) of making green investments right away before it sails (by 2050) (Dercon 2014).

Although the delay in climate change mitigation measures, in SSA, is partly because Africa is apportioned a small portion of international carbon and climate finance instruments, especially the CDM (World Bank 2013). It is crucial for SSA countries to start (for those that have not) and continue (for those that have been) to allocate part of their budget to climate change mitigation actions. These budgetary allocations are importantly needed in infrastructure, agriculture and energy sectors (UNECA 2014a) and they are expected to reduce as the national financial sector gets involved (GGBP 2014). As such, SSA's national financial sectors are expected to work on providing, increasing and improving on green financial products and services made available (GGBP 2014). Aside funding, increasing institutional capacity, environmental and sectoral policies to link the environment and climate change with national development, and research and consultation on policy design are other areas that need attention by the governments of SSA (Nhamo 2014b).

CHAPTER THREE: LITERATURE REVIEW

3.0 Introduction

It has been ironed out in the previous chapter that SSA as a region, its regional economic communities and some of its national governments are already implementing a mix of climate change measures and policies that promote green and low-carbon development. However, to identify whether development in SSA has truly been reducing carbon emissions (or otherwise), there is need to review the theory on the link between environmental quality and development in the next section of this chapter. Section two and three describe the conceptual issues and theoretical model, respectively. In order to answer some of the raised issues (like the Stern's (2004) suggestion) in the introduction chapter, the fourth and fifth sections review the empirical evidence of studies on the CO_2-development relationship and their summary. The contribution of this research to the literature is presented in section six.

3.1 Theoretical Framework

Concerns about the impacts of economic activities on the environment can be traced back to the 19th century when Reverend Thomas Malthus condemned poor relief programmes (Raymond 2004). He argued that poor relief programmes are detrimental to the environment and a threat to man's ability to feed future generations. Since then, the debate about the relationship between environmental quality and development has been divided between Malthus' 'limit to grow' hypothesis and those that reason that economic growth is the key to environmental and human prosperity (Raymond 2004).

In the process of identifying factors that determine the degree of environmental impact during different stages of the development process, the IPAT equation was devised by Ehrlich and Holdren (1970) and Commoner (1972). The IPAT equation, which is represented by Equation 3.1, is expected to measure an economy's path towards sustainability. The environmental impact, represented by *I*, depends upon the levels of population (*P*), affluence (*A*) and technology (*T*). A growing population is implied to lead to higher pressure on the environment, a higher level of affluence would end up in a rising generation of wastes and pollution, and a level of technology can either reduce the degree of environmental impact or expand it (UNCTAD 2011).

$$I = P \times A \times T \qquad . \qquad . \qquad . \quad (3.1)$$

The IPAT equation has been altered in various ways. Grunewald and Martinez-Zarzoso (2009) cited that the main deficiency of the IPAT equation is that it cannot explain the non-proportional effects of the variables on the right-hand side of Equation 3.1 because it is an accounting equation. To correct this, Dietz and Rosa (1997) reformulated this equation into a stochastic equation (a more elaborate approach to IPAT) called Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT).

$$I_i = \alpha P_i^{\beta} A_i^{\gamma} T_i^{\delta} \varepsilon_i \qquad . \qquad . \qquad . \quad (3.2)$$

The term I is the environmental impact for country i, α is the constant term, P is the population of country i with coefficient β, A is affluence in country i with coefficient γ, T is technology in country i with coefficient δ and ε is the error term. In Equation 3.2, Dietz and Rosa (1997) stopped at T by making it an error term and not to determine the influence of technology on environmental impact. York, Rosa and Dietz (2003) expanded STIRPAT by adding ε as the error term and allowing T to measure the influence of technology (Grunewald and Martinez-Zarzoso 2009).

Some researchers pose that the fundamental indicator to resolve environmental problems is the affluence factor. They argue that as economies grow and per capita income rises, environmental degradation increases but after a certain level of income, i.e. a certain level of affluence is reached, environmental quality improves. This relationship between economic growth and the environment is called the Environmental Kuznets Curve (EKC) hypothesis (UNCTAD 2012). The EKC theme was popularised by the World Bank's World Development Report (WDR) 1992, without using the terminology EKC. The report argued that greater economic activity inevitably hurts the environment based on static assumptions about technology, tastes and environmental investments (Stern *et al*. 1996). The first use of the term, EKC, can be traced to a paper by Panayotou (1993) written for the World Employment Programme Research Working Paper Series. The first use of the term in an academic journal was by Selden and Song (1994) (Agras and Chapman 1999).

The EKC hypothesis suggests environmental degradation as a function of income. This is said not to be a stable relationship because it depends on the level of income as there exists one relationship for poor and another for rich countries. On the aggregate, this would give an inverted U-like curve. The inverted U relationship between environmental degradation and economic growth came to be known as the EKC, by analogy a relationship which has been postulated by Kuznets (1955) (Panayotou, 2003).[21]

The shape of the EKC can be explained in line with the process of structural change in economic development. In the early stages of development i.e. moving from being a pre-industrial economy to industrial economy (see Figure 3.1), there is a deterioration of environmental quality as the share of agriculture falls and the share of industry rises. This would happen as a consequence of increasing physical capital intensive activities over human capital intensive which in turn would make production, income per capita and consumption grow gradually. As the society achieves a higher level of income, the share of industry starts to decline and that of services increases i.e. moving from being an industrial economy to post-industrial, resulting in an expected improvement in environmental quality. This means that at the turning point (which is under industrial economies) in Figure 3.1, environmental indicators would start to display improvements (UNCTAD 2012).

In Figure 3.1, at the initial level of development, both the quantity and the intensity of environmental degradation are limited to the impacts of subsistence economic activity i.e. agriculture. As agriculture and resource extraction intensifies, industrialisation starts to take off; thus both resource depletion and waste generation accelerate. This is shown in Figure 3.1 as the upward slope of the curve. At later levels of development, structural change occurs towards information-based industries and services, more efficient technologies and demand for environmental quality arise. This results in the curve turning and afterwards a steady decline of environmental degradation (Moomaw and Unruh 1997; Panayotou 2003). This explains the downward slope of the curve in Figure 3.1.

[21] The original Kuznets curve was formulated by Simon Kuznets (1955) and it deals with the relationship between income inequality and income per capita i.e. in the early stages of economic growth the distribution of income worsens while it improves at later stages (UNCTAD 2012; Agras and Chapman 1999).

Figure 3.1: The shape of the EKC

Notes: The horizontal axis is income per capita.
Source: Panayotou (2003:46)

The EKC's behaviour is an income effect resulting from the environment being a luxury good. Early in the process of economic development, individuals are unwilling to trade consumption for investment in environmental protection and so environmental quality declines. Once individuals reach a given level of consumption (or income), they begin to demand increasing investments in an improved environment. Consequently, after the turning point, environmental indicators begin to demonstrate decreases in pollution and degradation (Moomaw and Unruh 1997; Galeotti 2003).

Another explanation for the shape of EKC is based on growth. As economies get richer, people incline to become educated and have less number of offspring which leads to lower growth rates of population. This reduced growth in population means less pressure is placed on natural resources and hence less environmental degradation. The shape of the EKC can also be attributed to the explanation that developing countries (especially the poorest) do not have the medium and capital to adopt clean technologies, and so in the early stages of development, environmental quality tends to be low. However, as countries get richer and adopt clean technologies, environmental quality improves (UNCTAD 2012).

$$E = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \varepsilon \qquad . \qquad . \qquad . \qquad (3.3)$$

The traditional model for the EKC which is presented in Figure 3.1 is expressed in Equation 3.3. Where E is an environmental indicator, Y is the income per capita, Y^2 is the squared income per capita, β_0, β_1, β_2 are coefficients and ε is the error term. Equation 3.3 is expected to convey a long-run relationship between environmental quality and economic growth (Dinda 2004).

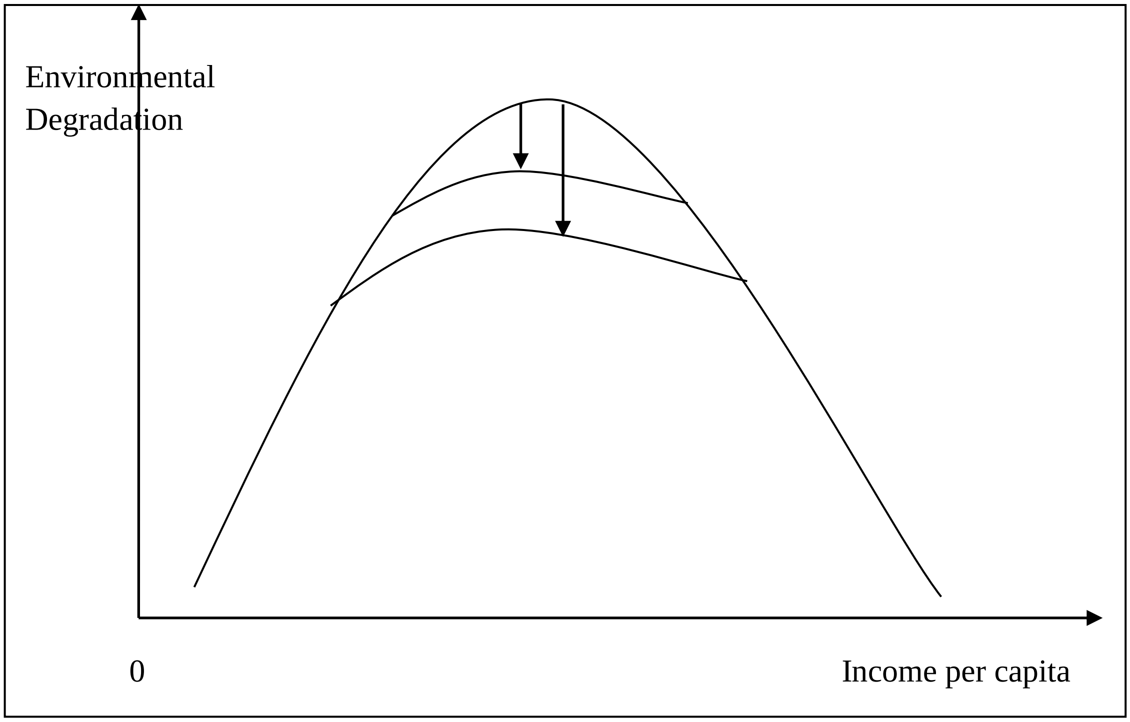
Economic growth can be linked to environmental quality through three different mechanisms: the scale effect, the composition effect and the technical effect. The scale effect has a negative impact on the environment because as increasing output requires more input, more natural resources are used up in production processes. This implies more waste and emissions which contribute to environmental degradation (Grossman and Krueger 1995).

The composition effect has a positive impact on the environment. That is, as income grows, the structure of the economy is expected to shift from primary activities which are pollution-intensive and environmentally damaging to tertiary activities which are environment-friendly. The technical effect is also expected to have a positive impact on environmental quality. That is, the replacement of obsolete and 'dirty' technologies with new and cleaner technologies will reduce emissions (Stagl 1999).

The three effects put together would make economic growth have a negative overall effect on environmental quality at the initial stage of development because the scale effect would be higher than the other two effects. This would result to the positive slope of the curve in Figure 3.1.

The negative effects are eventually compensated for by the positive impacts of the composition and technical effects that would prevail at the latter stages of development. This results in the negative slope of the curve in Figure 3.1. In a nutshell, an EKC relationship results if the composition and technical effects become larger than scale effects as economies grow (Clement and Meunie 2008).

Figure 3.2: Flatter EKC



Source: UNCTAD (2012:22)

It has been propounded that it is possible for developing countries to avoid the resource-intensive and polluting development trajectory of their industrialised counterparts. They might ‘leapfrog’ or ‘tunnel through’ the EKC by speeding up their development processes by avoiding inferior and less efficient industrial stages and moving directly to more advanced industrial stages. This will make their EKC turning point flatter (see Figure 3.2). However, the ability to tunnel through the EKC depends upon the occurrence of an effective technology transfer between the rich and poor countries and the ability of the developing countries to adapt and apply these technologies (UNCTAD 2012).

The EKC is the most popular model applied to explore the impact of economic growth on environmental degradation. However, like Grunewald and Martinez-Zarzoso (2009 and 2011), the STIRPAT equation and EKC are adopted for this study. The application of these two models will allow this research to explore not only the impact of economic growth on CO_2 emissions but also the impact of other indicators of economic development and financial development on CO_2 emissions.

3.2 Conceptual issues

Of all the explanations put forth to explain the EKC, the one often cited is (see Beckerman 1992; Baldwin 1995; Moomaw and Unruh 1997) that a cleaner CO_2 environment is a luxury good (also called superior good). That is, a cleaner CO_2 environment is a commodity with an income elasticity that is greater than one, as income grows environmental concern rises more than proportionally.

In a political system that is responsive to the preferences of its people, environmental protection rises more than proportionally with economic growth if the demand for a cleaner CO_2 environmental is a superior good. There is some evidence suggesting that, in general, the political systems in rich countries are more responsive than in poor countries because rich countries are likely to have the advanced social, legal and fiscal infrastructures that are essential for enforcing environmental regulations and promoting 'green awareness' (Rueschemeyer *et al*. 1991; Baldwin 1995; Barro 1996; Neumayer 1998).

Earlier studies (for example, Grossman and Krueger 1991; Shafik and Bandopadhyay 1992; Panayotou 1993) reached a conclusion that the connection between some environmental indicators and income per capita could be described as an inverted U curve, i.e. the EKC (Raghbendra and Whalley 2001; He and Richard 2010). However, it has gradually been acknowledged that "there is no one-fit-for-all growth-pollution relationship" (He 2009:31). The relation between economic growth and environmental damage seems more complex than portrayed by the EKC (Raghbendra and Whalley 2001). The complexity in this conceptualisation has been expressed in two folds; (i) the shape of the EKC and (ii) other explanatory variables considered.

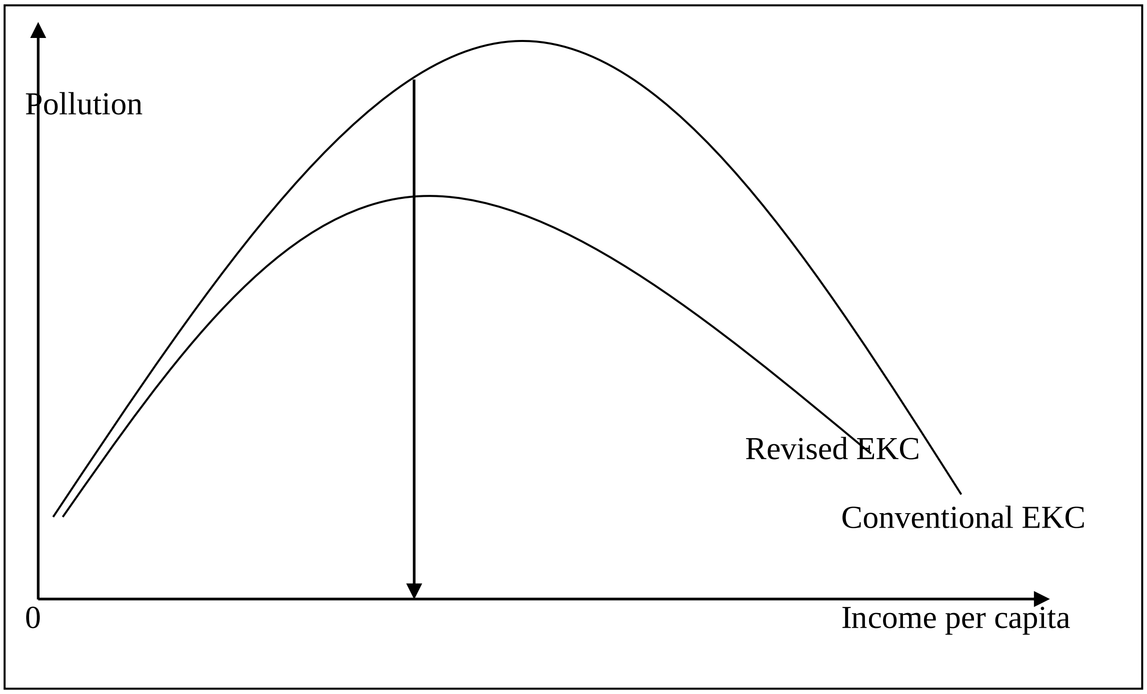
3.2.1 The shape of the EKC

Numerous critics have challenged the conventional EKC (as shown in Figure 3.1), both as a representation of what actually happens in the development process and as a policy prescription. In developing countries, some policymakers have interpreted the EKC as conveying a message about priorities: 'grow first then clean up later'. That is, in the first stage of industrialisation people are more interested in jobs and income than clean air and water (Dasgupta *et al*. 2002). However, the supposition that the rich care more about the environment than the poor (Martinez-Alier 1995) is systematically evidentially far from conclusive (Kriström and Riera 1996). This implies that policymakers might be able to prevent environmental degradation at any stage of development (Neumayer 1998).

It is quite plausible for developing countries (for example, Argentina, China) to have improvements in environmental quality by frequently penalising dangerous polluters, even when formal regulation is weak or absent, because of growing global and public concern and research knowledge about environmental quality. Thence, countries may be able to experience an EKC that is lower and flatter than what the conventional EKC suggests. That is, they may be able to develop from low-income per capita with little degradation in environmental quality and at some point experience improvements in both income and environmental quality (Dasgupta *et al*. 2002). Due to this argument, further research on the EKC has suggested that its shape is not likely to be fixed.

Thus, there are different versions of the EKC which are the conventional EKC, generalised EKC and revised EKC (which is expected to be flatter). New evidence suggests that the EKC model is misleading because it mistakenly assumes that strong environmental governance is not available in developing countries. The new results suggest that the curve is actually flat and shifts to the left, as growth generates less pollution in the early stages of industrialisation and pollution begins to fall at lower income levels (Dasgupta *et al*. 2004). This is depicted in Figure 3.3 where the conventional EKC is still rising at the point where the revised EKC is at the maximum and pollution falls at a lower income level on the revised EKC compared with the conventional EKC. The flatter EKC proposed by UNCTAD (2012) (explained in the previous section) and the revised EKC (as argued by Dasgupta *et al*. (2004)) have been found by studies like Piaggio and Padilla (2012) and Al-Sayed and Sek (2013).

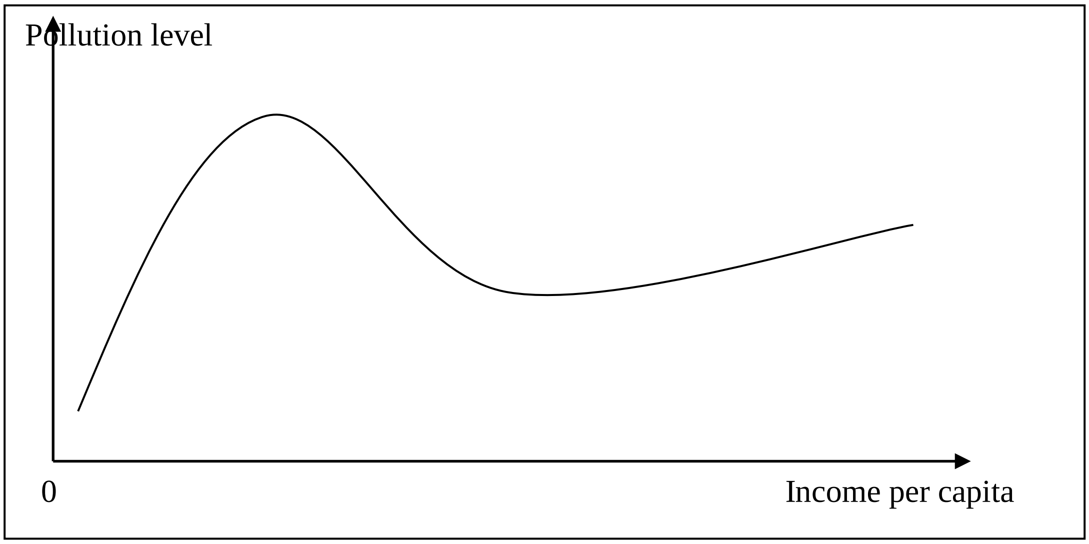
Figure 3.3: Revised and Conventional EKC



Source: Dasgupta *et al*. (2002:148)

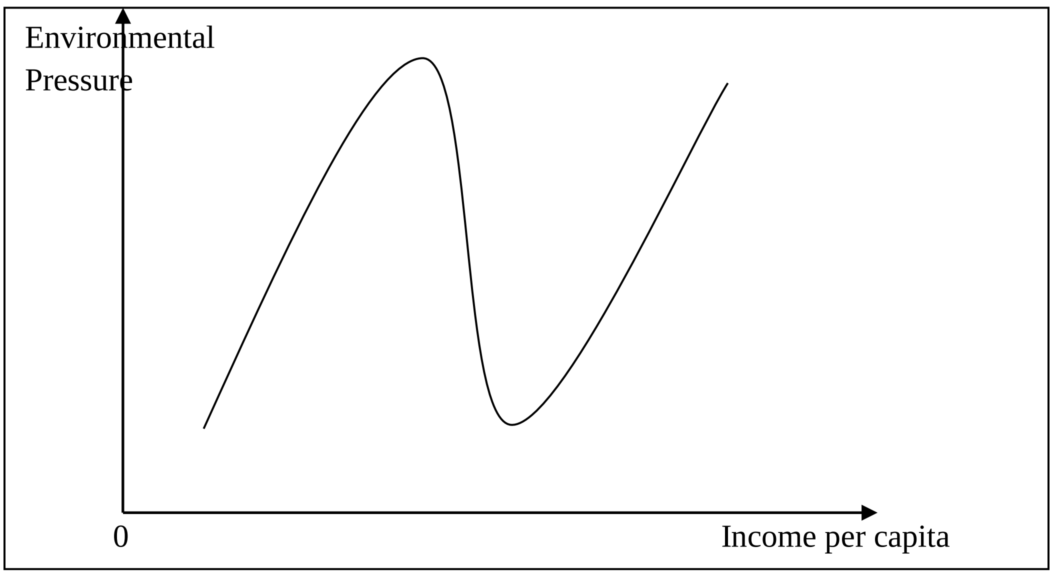
Some scholars (for example, De Bruyn *et al*. 1998) believe that the EKC does not hold in the long run. So the inverted U-shape would be only an initial stage of the relationship between economic growth and environmental pressure. Above a certain income level, there would be a new turning point that would become the trajectory ascendant again, leading to an N-shaped curve. This means that environmental degradation would come back at high growth levels (Carvalho and Almeida 2010). This version of EKC is termed the generalised EKC by Moomaw and Unruh (1997). This version, as presented by Moomaw and Unruh (1997) and Carvalho and Almeida (2010), is shown in Figure 3.4 and Figure 3.5, respectively. The turning point can be said, for the purpose of the generalised EKC, to be the point after which emissions start to fall or rise as income rises.

Figure 3.4: Generalised EKC



Source: Moomaw and Unruh (1997:3)

Figure 3.5: N-shaped curve



Source: Carvalho and Almeida (2010:4)

From the economic point of view, since CO_2 is invisible and has no smell, it was not considered as a waste. Even so, modern science has proved that it is a waste produced in many human activities. CO_2 global emissions from human activities have accelerated in recent years, increasing annually by an average of 1.1% during the 1990s to 3.8% since 2002 to 2011 (Granados and Carpintero 2009; PBL and JRC 2014). Unlike pollutants such as sulphur dioxide and suspended particulate matter which has a local dimension; CO_2 is a pollutant of global dimension. Consequently, the social costs accruing from global warming accumulate over time and across countries.[22] As such, from a theoretical viewpoint, the EKC hypothesis is said to be less likely for CO_2 emissions and more likely for sulphur dioxide and suspended particulate matter or else have high turning points (Carvalho and Almeida 2010; Granados and Carpintero 2009). That is, the free rider problem is more troublesome with CO_2 than sulphur dioxide and suspended particulate matter (Galeotti 2003).

In support of the theory that the EKC is less likely for CO_2, a positive linear relationship between CO_2 and GDP per capita has been maintained by some studies (for example, Shafik 1994; De Bruyn *et al*. 1998) while another emerging consensus holds that the curve might be N-shaped (cubic) (for example, Holtz-Eakin and Selden 1995; Moomaw and Unruh 1997) rather than an inverted U. Either a linear or cubic relationship does not allow for an optimistic interpretation that income is beneficial for the environment (Friedl and Getzner 2002).

Contrary to the theoretical viewpoint that the EKC is less likely for CO_2, so many studies found the EKC for CO_2 (for example, Sengupta 1996; Galeotti *et al*. 2001; Pauli 2003). Schmalensee *et al*. (1998) posit the existence of an EKC for CO_2 during the second half of the 20th century (1950-1990) and predicted the existence of such a curve further into the future period 1990-2050 (Granados and Carpintero 2009). This contradiction also exists for local dimension pollutants as Panayotou (1997) found the EKC for sulphur dioxide and suspended particulate matter but Selden and Song (1994) found an N-shaped curve. This demonstrates that the EKC holding for local dimension pollutants and not for global dimension pollutant is not guaranteed. Therefore, whether economic growth will be beneficial or harmful to the environment, in the long run, remains an empirical issue.

3.2.2 Additional explanatory variables

Although there appear to be some cases, historically, where improvements in environmental quality coincided with higher incomes, one cannot rely on economic growth to cure environmental ills. Economic growth on its own is not a viable prescription for the solution of environmental problems (Neumayer 1998). Andreoni and Levinson (2001) and Jaegar (1999) argue that the characteristics of cleanup technology are keys to the EKC (Raghbendra and

[22] Global warming is the changes in the surface air temperature, referred to as the global temperature, brought about by the enhanced greenhouse effect, which is induced by the emission of GHGs into the air (GEO4 2007).

Whalley 2001). As a result, in the literature, economic debates have arisen on the best variables to model the EKC for policy purpose on cutting emissions (for example, Agras and Chapman 1999; Panayotou *et al*. 2000; Neumayer 2004).

The STIRPAT equation contributes to this debate by supporting the argument that economic growth is not the only viable prescription for the solution of environmental problems. Dietz and Rosa (1997) analysed the driving forces of CO_2 emissions to be mainly human activities divided into three anthropogenic forces (population, affluence (measured as income), and technology (measured by industrial activity)) (Grunewald and Martinez-Zarzoso 2009).

So many economic variables have been used so far in the literature (see Appendix Table A.IV to A.VII). The frontier of the debate is the concept of financial sector development. The most popular reason for the introduction of financial development is that the financial sector provides developing countries with the opportunity to use new technologies that are clean and environment-friendly (Birdsall and Wheeler 1993; Frankel and Rose 2002; Tamazian *et al*. 2009). Yet, in the end, most studies concluded that, of all the explanatory variables tested, income has the most significant effect on CO_2 emissions (Agras and Chapman 1999).

3.3 Theoretical model

The theoretical model to explain the EKC was developed by Andreoni and Levinson (2001). Andreoni and Levinson (2001) explained the EKC from a consumer point of view and assume increasing returns to pollution abatement.

For the purpose of simplicity, we assume that an economy has only one person. This way our solution may be interpreted as Pareto efficient.[23] Suppose the single agent gets utility (U) from the consumption of one private commodity, denoted as C, and from a bad commodity called pollution, P. Preferences, in this respect, can be written as the utility of an agent is a general function of the agent's consumption and pollution:

$$U = U(C, P) \quad . \quad . \quad . \quad (3.4)$$

[23] An allocation is Pareto efficient when an action makes some individuals better off and no individual worse off (Koutsoyiannis 1979).

Obtaining partial differentiation of C and P from Equation 3.4, where $U_C > 0$ [or $\left(\frac{\delta U}{\delta C}\right) > 0$] and $U_P < 0$ [or $\left(\frac{\delta U}{\delta P}\right) < 0$], and utility is quasiconcave in C and –P.

Suppose further that pollution is a by-product of consumption and that our consumer has a means by which he can alleviate pollution by spending resources (represented by E) either to clean it up or, equivalently, to prevent it from happening at all. Pollution is then a positive function of consumption and a negative function of environmental effort (i.e. E):

$$P = P(C, E) \quad . \quad . \quad . \qquad (3.5)$$

Where $P_C > 0$ and $P_E < 0$

Suppose a limited income (Y) is spent on C and E. if we normalise C and E to be 1, our resource constraint is simply:

$$Y = C + E \quad . \quad . \quad . \qquad (3.6)$$

So we can have a new utility function that is linear and additive in C and P:

$$U = C - zP \quad . \quad . \quad . \qquad (3.7)$$

Where z is the constant marginal disutility of pollution and $z > 0$

Pollution can be re-stated as:

$$P = C - C^{\alpha}E^{\beta} \quad . \quad . \quad . \qquad (3.8)$$

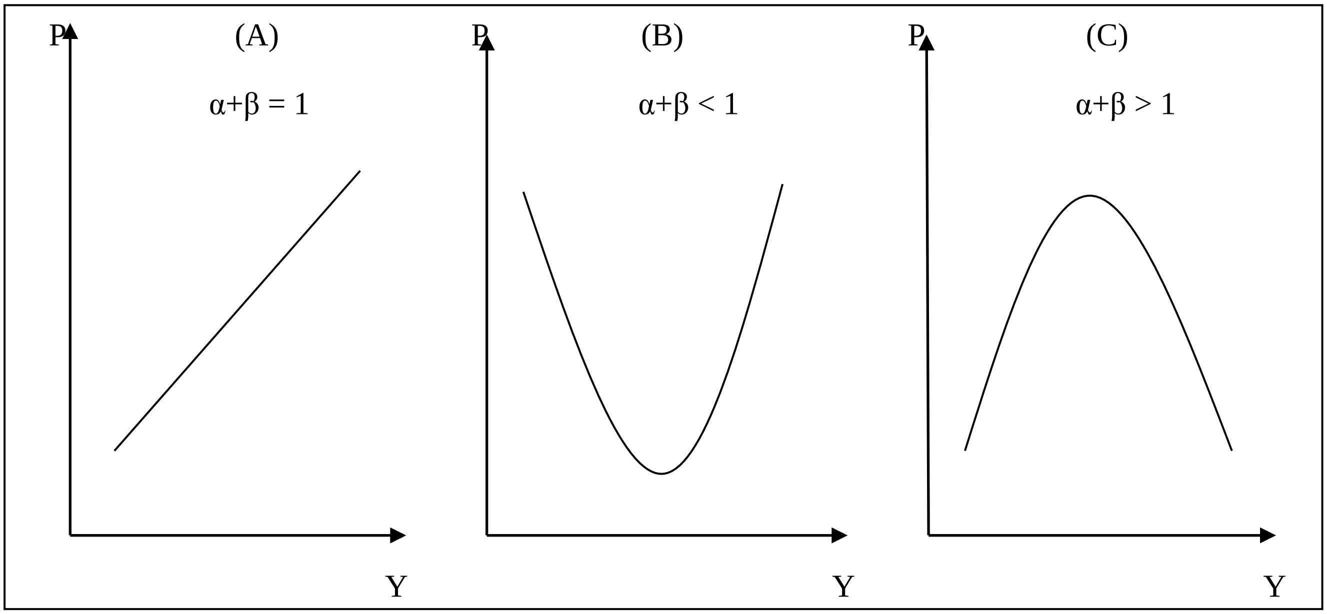
The first term (in Equation 3.8), C, is gross pollution before abatement and it is directly proportional to consumption. The second term, $C^{\alpha} E^{\beta}$, represents abatement. Equation 3.8 indicates that consumption causes pollution one-for-one but resources spent on environmental effort abate pollution with a standard concave production function.

If z = 1 in Equation 3.7, consumption and environmental effort have standard Cobb-Douglas solutions. The consumer can maximise utility by choosing optimal consumption and environmental effort according to the objective function (i.e. substituting Equation 3.8 into 3.7 to obtain the objective function, subject to the constraint in Equation 3.6):

$$U = C^{\alpha}E^{\beta} \; subject \; to \; Y = C + E \quad . \quad . \quad . \qquad (3.9)$$

The parameters α and β are assumed to be less than one. If $\alpha+\beta > 1$, pollution abatement technology exhibits increasing returns to scale. If $\alpha+\beta < 1$, pollution abatement exhibits decreasing returns to scale. If α+β = 1, effort spent on abating pollution has constant returns to scale. Figure 3.6 depicts these optimal pollution-income paths.

Figure 3.6: Optimal pollution-income paths



Source: Andreoni and Levinson (2001:273)

Solving for optimal consumption and environmental efforts in Equation 3.9:

$$C = \left(\frac{\alpha}{\alpha + \beta}\right)Y, \qquad E = \left(\frac{\beta}{\alpha + \beta}\right)Y \quad . \quad . \quad . \qquad (3.10)$$

Substituting the optimal consumption and environmental efforts in Equation 3.10 into Equation 3.8

$$P = \left(\frac{\alpha}{\alpha+\beta}\right)Y - \left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta}Y^{\alpha+\beta} \quad . \quad . \quad . \qquad (3.11)$$

To see the effect of income on environmental degradation, we take the first and second derivative of Equation 3.11 with respect to Y:

$$\frac{\partial P}{\partial Y} = \left(\frac{\alpha}{\alpha+\beta}\right) - (\alpha + \beta)[\left(\frac{\alpha}{\alpha+\beta}\right)^{\alpha}\left(\frac{\beta}{\alpha+\beta}\right)^{\beta}Y^{\alpha+\beta-1} \quad . \quad . \quad . \qquad (3.12)$$

$$\frac{\partial^2 P}{\partial Y^2} = -(\alpha + \beta - 1)(\alpha + \beta)[\left(\frac{\alpha}{\alpha + \beta}\right)^{\alpha}\left(\frac{\beta}{\alpha + \beta}\right)^{\beta}Y^{\alpha+\beta-2} \quad . \quad . \qquad (3.13)$$

Equation 3.12 is the first derivative and Equation 3.13 is the second derivative.

According to optimisation, in a maximisation function, the second derivative should be less than zero. As such, from Equation 3.9, the objective is that the consumer is maximising utility thus $\partial^2P/\partial Y^2 < 0$. This is shown in Equation 3.13. Given this fact, plus the EKC is concave (i.e. inverse U-shape) as shown in Figure 3.6(C), z cannot equal to one, thus, $\alpha+\beta > 1$. This means that emission abatement exhibits increasing returns to scale.

Introducing additional explanatory variables, if we obtain the natural log of the STIRPAT equation (Equation 3.2):

$$lnI = \alpha_0 + \beta lnP_i + \gamma lnA_i + \delta lnT_i + \mu_i \quad . \quad . \quad . \quad (3.14)$$

Where $\alpha_0 = ln\alpha$ and $\mu_i = ln\varepsilon_i$. The STIRPAT equation leads to a log-linear model (see Dietz and Rosa 1997). This model is one of the relationships that are explored in this research.

Instead of linear modelling, many studies model the EKC by analysing the relationship between some measure of environmental degradation, E, and real per capita income, Y, with a vector of other explanatory variables, Z (for example, population density, trade, investment, etc.) (Agras and Chapman 1999). Such model is expressed as:

$$E = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_k Z + \varepsilon \quad . \quad . \quad . \quad (3.15)$$

If the natural log of Equation 3.15 is obtained and it is brought together with Equation 3.14, we can summarise them as:

$$lnE = \beta_0 + \beta_1 lnY + \beta_2 lnY^2 + \beta_k lnZ + \varepsilon \quad . \quad . \quad . \quad (3.16)$$

Where $lnE = lnI$, $lnA_i = lnY$, and lnP_i and $lnT_i = lnZ$. Equation 3.16 becomes a log-quadratic model (Agras and Chapman 1999).

The version of EKC presented by Moomaw and Unruh (1997) and Carvalho and Almeida (2010) can be presented as:

$$E = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 Y^3 + \varepsilon \quad . \quad . \quad . \quad (3.17)$$

If other variables are added to Equation 3.17 (see Onafowora and Owoye 2013):

$$E = \beta_0 + \beta_1 Y + \beta_2 Y^2 + \beta_3 Y^3 + \beta_k Z + \varepsilon \quad . \quad . \quad . \quad (3.18)$$

If the natural log of Equation 3.18 is obtained and it is brought together with Equation 3.14, we obtain the log-cubic model in Equation 3.19.

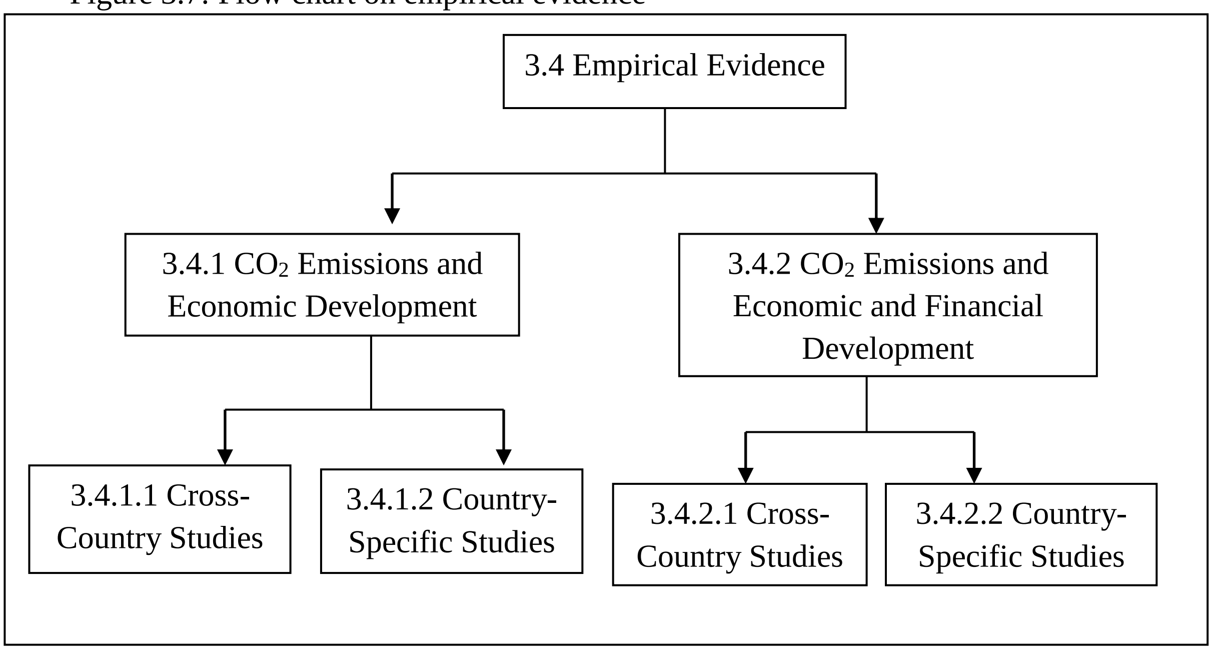
$$lnE = \beta_0 + \beta_1 lnY + \beta_2 lnY^2 + \beta_3 lnY^3 + \beta_k lnZ + \varepsilon \quad . \quad . \quad . \quad (3.19)$$

The thread that runs through all these is that this study estimates the log-linear (Equation 3.14), log-quadratic (Equation 3.16) and log-cubic (Equation 3.19) relationship between per capita emissions of CO_2 and per capita income while considering other variables that possess the characteristics of cleanup or increase in emissions. The log-linear, log-quadratic and log-cubic models are used because the possibility of obtaining either linear, inverted U or N-shaped curve cannot be ruled out. This is confirmed by the findings of empirical studies dissertated in the next section.

3.4 Empirical evidence

In the conduct of the review of empirical studies on the CO_2-development relationship, the grouping of the reviewed studies is charted in Figure 3.7. The first group contains studies that used economic development indicators as explanatory variables and the second group contains studies that used both economic and financial development indicators as explanatory variables.

Figure 3.7: Flow chart on empirical evidence



Source: Author (2016)

3.4.1 Carbon dioxide emissions and economic development

3.4.1.1 Cross-country studies

Panayotou, Peterson and Sachs (2000) test the hypothesis that structural change drives environmental transition and the robustness of the EKC using a long period of 1870-1994. The study used data on GDP per capita, population density, capital stock, and export volumes as developed by Maddison (1995). These data are for 17 Organisation for Economic Cooperation and Development (OECD) countries including the United Kingdom, the United States and Japan. Meanwhile, data on CO_2 emissions are from the Carbon Dioxide Information Analysis Centre (CDIAC) in the Oak Ridge National Laboratory (ORNL) of the United States Department of Energy. The paper is commended for applying the Feasible Generalised Least Squares (FGLS) technique in order to correct for the serial correlation detected under the Ordinary Least Squares (OLS) technique.

Panayotou *et al*. (2000) found the EKC relationship (i.e. an inverted U) for their panel data set. The study found that capital stock has a changing role. In the early stages of development, capital stock results in rising emissions, its contribution to emissions rises as the country industrialises, but falls and becomes negative in the post-industrial stage. They found that trade, generally, increases emissions but it tends to reduce emissions at high levels of income. These findings empirically back the definition of EKC in line with the stages of development experienced by the selected sample countries. Panayotou *et al*. (2000), also, found that the effects of increasing population density are less important than income effects, although it leads to increasing CO_2 emissions. This confirms Agras and Chapman (1999) that income has the most significant impact on environmental quality.

The roles of geographical factors as determinants of cross-country differences in per capita CO_2 emissions were investigated by Neumayer (2004). This is done by considering the effect of GDP per capita, cold and hot climates, transportation requirements and the availability of renewable energy sources on CO_2 emissions. The panel data for the study covers the period 1960–1999 for 163 countries and the Generalised Estimating Equations (GEE) estimator used for the analysis is an extension of the Generalised Linear Model (GLM) approach. Sources of CO_2 emissions and per capita GDP are the CDIAC in the ORNL of the United States Department of Energy and the Penn World Table. Other variables are from the climate data of the World Resource Institute (WRI), the Centre for International Earth Science Information Network (CIESIN) and the World

Bank, respectively. Neumayer (2004) found an inverted U relationship, just like Panayotou *et al*. (2000). From the perspective of geographical factors, the study found its hot climate variable (maximum temperature) to be statistically insignificant. Two cold climate variables are used and while one (minimum temperature) reduces CO_2 emissions the other (frost days) increases it. The two proxies for transportation requirements (total land area impacted by humans and the total length of road networks) are positively related to CO_2 emissions. Neumayer (2004) found an empirical support for clean growth as he detected that renewable energy as a percentage of energy consumption reduces CO_2 emissions.

With the goal of proposing an alternative method of estimating the EKC, Navin (2005) estimates the empirical models with parametric (Ordinary Least Squares -OLS and Generalised Least Squares -GLS) and nonparametric (Nadarya-Watson kernel estimator) estimation methods. CO_2 emissions, GDP per capita and population density are from the World Bank's World Development Indicator (WDI). The WDI publishes CO_2 data that originates from the CDIAC in the ORNL of the United States Department of Energy. The collected data is on a panel of 103 countries for the period 1975-1996. The nonparametric approach found that the absence of the EKC may not be robust for CO_2. This is because the nonparametric estimation captures a decline in CO_2 emissions when income is high. This finding supports that of Panayotou *et al*. (2000) and Neumayer (2004). The parametric estimation's results exhibit an N-shaped curve for CO_2 emissions-income relationship. This finding supports Moomaw and Unruh's (1997) generalised EKC. The study found that population density has a positive relationship with CO_2 emissions while income growth has a negative relationship with CO_2 emissions. Navin's (2005) finding on the relationship between CO_2 emissions and population density corroborates that of Panayotou *et al*. (2000).

Between 1995 and 2003, the Central and Eastern European countries significantly reduced their CO_2 emissions. Whether this reduction is just a fortuitous result of a major economic transformation or a result of more stringent environmental policy is the question Zugravu, Millock and Duchene (2008) answered through a simultaneous equation model of the demand (emissions) and supply (environmental stringency i.e. institutional quality and consumer preference for environmental quality) of pollution. Industrial CO_2 emissions data are from the International Energy Agency (IEA). Data on nine manufacturing sectors calculated in terms of their weight to total manufacturing production are from the United Nations Industrial

Development Organisation's (UNIDO) database while GDP, net per capita income and trade openness are from the World Bank's WDI. The study employed an unbalanced panel data containing 60 countries. Although the study did not test for the EKC, its modelling was made to follow the theory of demand and supply. Thus, choosing the Two Stage Least Squares (TSLS) as the paper's estimation method is ideal. The results obtained by Zugravu *et al*. (2008) indicate that output growth and trade openness increase CO_2 emissions. The positive relationship that trade openness has with CO_2 emissions partly corroborates the finding of Panayotou *et al*. (2000). With tests of robustness, the study found that democracy increases the stringency of environmental policy while trade openness reduces it. This confirms the 'race to the bottom' phenomenon and the importance of institutional factors in explaining and predicting emissions reduction.[24]

Similar to Navin (2005), Azomahou, Goedhuys and Nguyen-Van (2009) apply both parametric and nonparametric functions to the panel data of 107 countries over a period of 1961-2004. Although their results are not supportive of the EKC, Azomahou *et al*. (2009) obtained data on primary energy use per capita, foreign direct investment (FDI), investment net inflows, population density and trade openness from the World Bank's WDI database. Year dummies and regional dummies for East Asia and Pacific, Europe and Central Asia (used as reference), Latin America and the Caribbean, Middle East and North Africa, North America, South Asia and sub-Saharan Africa were used. The study also applied dummies to control for technological change and macroeconomic effects. Using gain statistic to test the significance of the non-linearity in their econometric specification, Azomahou *et al*. (2009) reject the parametric function (linear model) in favour of the nonparametric by using the Generalised Additive Model (GAM). They found that income significantly increases CO_2 emissions at low-income levels and insignificantly reduces CO_2 emissions at high-income levels. Based on this, they deduce that higher income countries are likely to achieve the delinking of CO_2 emissions from income. They found that CO_2 emissions monotonically increase with energy use.[25] However, the study did not explain its

[24] The expression 'race to the bottom' was presented by Dasgupta et al (2002). It is used to argue that international trade and investment put pressure on environmental standards (i.e. reduces it) and thus lead to environmental degradation (Zugravu et al 2008).

[25] Delinking is a term introduced by the World Bank in 1992 (Stagl 1999). It is when economic growth is not linked to pollution due to environmentally non-damaging practices (WDR 1992).

findings on the relationship CO_2 emissions has with FDI, investment net inflows, population density and trade openness.

Grunewald and Martinez-Zarzoso (2009) analyse the driving factors of CO_2 so as to test the EKC theory in the context of climate regulations (using the Kyoto Protocol and the Clean Development Mechanism (CDM)) using a static and dynamic panel model. Data on Kyoto Protocol ratification and CO_2 emissions are from the United Nations Framework Convention on Climate Change (UNFCCC) and data on the number of implemented CDM projects by host country come from the United Nations Environment Programme (UNEP). Data on other variables are from the World Bank's WDI and they cover unbalanced panel of 123 countries from 1975 till 2004. The study's empirical model is analysed with OLS and TSLS estimator. Their results indicate that the Kyoto obligations have a reducing effect on CO_2 emissions in developed and developing countries. This is consistent with the findings of Carvalho and Almeida (2010). However, Grunewald and Martinez-Zarzoso (2009) could not find an emission-reducing effect from the CDM variable. They also could not confirm the EKC for CO_2 among all the countries put together but it was confirmed for high-income countries. This depicts rising GDP as the main driving force behind rising emissions. Grunewald and Martinez-Zarzoso (2009) found that higher manufacturing output in GDP leads to higher CO_2 emissions.

Poudel, Paudel and Bhattarai (2009), also, utilise a semi-parametric and a parametric quadratic panel model to estimate EKC for CO_2 and per capita income in 15 Latin American countries by using forestry acreage, illiteracy rate and population density as additional explanatory variables. The World Bank database is the data source for all the variables, for a 21-year period (1980–2000), except forestry acreage which is from a number of sources listed in the appendix of the paper and no source is mentioned for illiteracy rate. In likeness to Azomahou *et al*. (2009), Poudel *et al*. (2009) reject the parametric quadratic relationship in favour of the semi-parametric estimate after conducting specification tests. They used one-way error component semi-parametric panel data model and Robinson's kernel estimation method. In terms of the CO_2-income relationship, results show an N-shaped curve for the region. All other variables are statistically insignificant. This supports Agras and Chapman's (1999) position that, of all explanatory variables tested, income has the most significant effect on CO_2 emissions.

Carvalho and Almeida (2010) probe the global EKC hypothesis by considering the role of the Kyoto Protocol as a global policy to reduce CO_2 over the period 2000-2004. Applying a fixed effect model and spatial dependence, the study estimated its models using OLS and FGLS. Their sources of data on CO_2 emissions and energy consumption are the United Nations Statistics Division (UNSD) which compiles information from the CDIAC and the Energy Information Administration (EIA) of the United States Department of Energy. Data on GDP per capita, Kyoto Protocol ratification, trade intensity and population density are from the World Bank, the IEA, the International Monetary Fund (IMF) and the Food and Agriculture Organisation (FAO), respectively. Carvalho and Almeida's (2010) econometric results suggest the existence of an N-shaped EKC (this corroborates Navin (2005)) and the potential importance of international agreements (using Kyoto protocol) for reducing CO_2 emissions. The study found that trade intensity and population density have a negative relationship while energy consumption has a positive relationship with CO_2 emissions. These findings contradict that of Panayotou *et al*. (2000) and Navin (2005). Unlike all the other reviewed studies, this study is not consistent in indicating the number of countries used. 167 countries are mentioned in the abstract and the body of the paper while 187 countries are mentioned and listed in the appendix. Thus, there is no uniformity in data reporting.

Choi, Heshmati and Cho (2010) investigate the existence of the EKC for CO_2 emissions and its causal relationships with economic growth and trade openness by using time series data (1971-2006) for 3 countries (China -an emerging market, Korea -a newly industrialised country, and Japan -a developed country). The paper uses OLS. After establishing the relationship between CO_2 emissions, GDP and openness, the study uses Vector Auto Regression (VAR), Johansen cointegration test and Vector Error Correction Model (VECM) to test and obtain the short-run and long-run relationship among the determinants and CO_2 emissions. Data on CO_2 emissions are sourced from the Carbon Dioxide Information Analysis Centre (CDIAC) in the Oak Ridge National Laboratory (ORNL) of the United States Department of Energy. The source of Real GDP per capita and trade openness is the Penn World Table, contribution to renewable energies is sourced from the OECD database and fossil consumption per capita is drawn from the BP statistical review of world energy. Choi *et al*. (2010) found that environmental consequences do not have uniform results across the countries i.e. there is heterogeneity among countries' and variables' impacts. For EKC: China shows an N-shaped curve while Japan has an inverted N-shape curve and Korea has a U-shaped curve. Choi *et al*. (2010) found that the quality of the environment may worsen as China becomes more open to international trade, the relationship between CO_2 emissions and trade openness is not statistically significant for Japan and CO_2 emissions are likely to decrease as Korea becomes more open to international trade.

Unlike Grunewald and Martinez-Zarzoso (2009), Grunewald and Martinez-Zarzoso (2011) assess the impact of global climatic regulation on CO_2 emissions by estimating a dynamic panel data model using Generalised Method of Moments (GMM) for a cross-section of 213 countries over the period 1960 to 2009. Their model is based on the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) and EKC approach while putting into consideration the endogeneity of the policy variable (i.e. CO_2 emissions). For data on CO_2 emissions, they refer to the CDIAC in the ORNL of the U.S. Department of Energy while data on population and share of manufacturing industry in GDP are from the World Bank's World Development Indicators (WDI). Meanwhile, data on the Kyoto Protocol ratification are from the UNFCCC and data on CDM projects are from the UNEP. Grunewald and Martinez-Zarzoso (2011) found that the Kyoto protocol has a potential reducing effect on CO_2 emissions. Their long run elasticity estimate indicates that countries with emission commitments from the Kyoto Protocol emit less CO_2 than similar countries that did not ratify the Protocol. They also found that an inverted U relationship exists among some high-income countries while there is no evidence for future declining emissions with rising income in middle and low-income countries. In spite of the difference in the number of countries, period and techniques of estimation used in both studies, these results are consistent with Grunewald and Martinez-Zarzoso (2009).

Jeßberger (2011) shows the atmospheric impact of the rising number of Multilateral Environmental Agreements (MEAs) on the forecasts of CO_2 emissions up to 2050 by using the findings of the inverted U-shaped EKC and applying a spline model. He made use of the UNEP clusterisation of MEAs, per capita values of GDP and CO_2 emissions for the period 1960 to 2006 for 160 countries from the World Bank's WDI. Jeßberger's (2011) results indicate that the number of atmosphere-related MEAs generates goodwill among global cooperation efforts towards reducing CO_2 emissions to stop climate change. In spite of the fact that Grunewald and Martinez-Zarzoso (2009, 2011) and Carvalho and Almeida (2010) and Jeßberger (2011) use different estimation methods and different proxies to represent international climate agreements (i.e. Kyoto Protocol and MEA), they all found that international climate agreements have the potential to reduce CO_2 emissions.

By implementing bootstrap panel unit root tests, cointegration techniques and panel Error Correction Models (ECM), Arouri, Youssef, M'henni and Rault (2012) investigate the relationship between CO_2 emissions, energy consumption and real GDP for 12 Middle East and North African Countries (MENA) over the period 1981–2005. These data are from the World Bank's WDI. Their results show that long-run energy consumption increases CO_2 emissions and real GDP exhibits a quadratic relationship with CO_2 emissions for the region as a whole. At country-level, their results show that the EKC is not verified for the studied countries except for Jordan. Arouri *et al*. (2012) corroborates Carvalho and Almeida (2010) and Azomahou *et al*. (2009) by obtaining a positive relationship between CO_2 emissions and energy consumption while they contradict either of them (i.e. Carvalho and Almeida 2010 and Azomahou *et al*. 2009) by finding an EKC, although they all used different methods of estimation.

Pandelis (2012) looks into the strength of empirical evidence in favour of the existence of the EKC for CO_2 emissions using two different model approaches in the literature: the reduced-form approach and the theory-based approach. An unbalanced panel data set of 35 countries over four periods: 1971-75, 1976-1980, 1981-85, and 1986-90 are used. CO_2 emissions per capita are from the CDIAC at the ORNL of the U.S. Department of Energy. GDP per capita and control variables, like relative income, alternative measure of income, trade openness, physical capital stock per worker, investment, average years of total schooling over the prior five years, the Gini coefficient, the gross general government debt expressed as a percentage of GDP and population growth are sourced from the Penn World Table. To incorporate potential endogeneity of the EKC model specification, the study employs TSLS. Pandelis (2012) found strong support for the EKC using both approaches, the income measures are the most robust variables affecting CO_2 emissions. This supports Agras and Chapman's (1999) position. There is little evidence in favour of political economy proxies (i.e. average years of total schooling over the prior five years and executives constraints), international trade (i.e. trade openness and investment) and other regressors (i.e. government debt as a percentage of GDP, population growth rates and tropical climate). Gini coefficient, however, like income, remained significant in explaining CO_2 emissions. The study's strong support for EKC affirms the results of Jeßberger (2011) and Arouri *et al*. (2012) even with the different estimation techniques, vector of variables and period of study which they all used. However, the robust checks made in the study indicate an N-shaped relationship between CO_2 emissions and income which comply with the conclusion of Moomaw and Unruh (1997), Carvalho and Almeida (2010) and Poudel *et al*. (2009).

To examine whether the 'race to the bottom' and revised EKC scenarios are applicable in Asia on CO_2 and SO_2 emissions, Taguchi (2012) applies the GMM estimation using panel data of 19 economies for the period 1950-2009. Data estimated by Stern (2005) are used for SO_2 emissions and data estimated by Boden, Marland and Andres (2011) are used for CO_2 emissions. The Boden, Marland and Andres' (2011) CO_2 estimated data are published by the CDIAC of the ORNL in the U.S. Department of Energy. Taguchi (2012) considers the degree of development of an economy as an additional variable to GDP per capita. The study measured the degree of economic development as the ratio of GDP per capita of an economy relative to the maximum GDP per capita among the sample economies, for every year, which is the GDP per capita of Japan. His findings indicate that SO_2 emissions comply with the expected an inverted U-shape while CO_2 emissions increase with per capita income. The revised EKC scenario was verified for SO_2 emissions but the 'race to the bottom' scenario was neither present for SO_2 nor CO_2 emissions. The outcome supports the literature's argument that the EKC is more likely to be applicable to local pollutants (SO_2) than to global pollutants (CO_2). The study is also supportive of Grunewald and Martinez-Zarzoso (2009, 2011) who could not confirm the EKC for CO_2 among all the countries put together but contradicts Tamazian and Rao (2010) and Gholami and Shafiee (2013) even though they all used the GMM estimation method but a different vector of additional variables. However, the study should have applied another dynamic panel estimator and not the GMM because the number of its panel group (19 countries) is small while the period is high (60 years). Thus, the GMM results may yield unreliable standard errors (Roodman 2009).

Analysing the EKC for the Organisation of the Petroleum Exporting Countries (OPEC), Gholami and Shafiee (2013) employs a dynamic panel model using the GMM estimation. Data on all variables in the study, for the period 1977-2004, are obtained from the World Bank's WDI. According to their results, the income-emission relationship for OPEC countries is N-shaped. This is consistent with the findings of Moomaw and Unruh (1997), Granados and Carpintero (2009), Carvalho and Almeida (2010), Poudel *et al*. (2009), and Pandelis (2012). All the factors used in the study (GDP per capita, the share of manufactured goods value added to GDP, trade openness and energy intensity) are found to be significantly responsible for emitted CO_2. However, openness and energy intensity are found to be the main macro determinants.

Onafowora and Owoye (2013) used the Autoregressive Distributed Lag (ARDL) Bounds testing approach to cointegration based on the Unrestricted Error Correction Model (UECM) to analyse the long-run relationships CO_2 emissions per capita have with GDP per capita, energy consumption, population density and trade openness for 8 countries. Their empirical analysis covers the period 1970-2010. CO_2 emissions are collected from CDIAC at the ORNL of the United States Department of Energy and other data are taken from the World Bank's WDI. Their results indicate that income and energy consumption are the main factors increasing CO_2 emission in all the 8 countries while the results for trade openness and population density are mixed. The study provides evidence for the two sides of literature that believe that CO_2-GDP relationship should be formulated as a quadratic and cubic model. They found EKC for only two countries (Japan and Korea) while other countries follow the N-shape. Onafowora and Owoye's (2013) findings for Japan and Korea contradict those of Choi *et al*. (2010) who found an inverted N-shape for Japan and U-shaped curve for Korea but the two studies corroborate on their findings for China, notwithstanding both studies used nonstationary estimators. Energy consumption has an increased effect on CO_2 emissions in all the sampled countries. Trade openness has an increasing effect on CO_2 emissions in Mexico, Nigeria and South Africa and a decreasing effect in Brazil, China and Japan. Population density has a statistically significant increasing effect on CO_2 emissions in Brazil, China, Egypt, Japan and Mexico but statistically insignificant for Nigeria, South Africa and South Korea.

To obtain information on carbon emissions elasticities of income and population, Liddle (2015) applies an unbalanced dataset for 26 OECD countries and 54 non-OECD countries for the period 1971 to 2011. Like Grunewald and Martinez-Zarzoso (2009; 2011), the study used the STIRPAT and EKC for modelling while using the Common Correlated Effects Mean Group (CMG) and Augmented Mean Group (AMG) estimation methods. All the variables are drawn from the International Energy Agency (IEA). The study found the income elasticity for the OECD countries to be significantly less than one and so also is the income elasticity for non-OECD countries but those of the non-OECD is significantly larger than that of the OECD countries. Liddle (2015) found that an inverted U relationship is likely for income and carbon emissions divided by GDP but not likely for income and carbon emissions per capita. The study discovered that the carbon emissions elasticity of population is not robust, thus, it concludes that researchers may use the population variable as a measure to capture other influences or missing variables by research design. Similar to Liddle (2015), this research also achieves the objective of carbon emissions elasticities of income for SSA and applied population (density) as a control variable.

With the intention of examining the long and short run and causal relationship between CO_2 emissions and GDP, renewable energy consumption, non-renewable energy consumption, urbanisation, trade openness and energy prices, Al-Mulali and Ozturk (2016) conducted a study on 27 advanced economies. Data for these variables are sourced from the Euromonitor International statistics, except for renewable and non-renewable energy consumption which are retrieved from the World Bank's World Development Indicators (WDI). Panel nonstationary techniques like the Fully Modified Ordinary Least Squares (FMOLS) and Vector Error Correction Model Granger causality were used to examine the selected economies for the period 1990–2012. The study found that all the variables are cointegrated. The results reveal that GDP, non-renewable energy consumption and urbanisation increase CO_2 emissions while renewable energy consumption, trade openness and energy prices reduce it. Al-Mulali and Ozturk (2016) support Pandelis (2012), Jeßberger (2011) and Arouri *et al*. (2012) by empirically confirming the EKC hypothesis. The study's finding on the relationship between trade openness and CO_2 emissions for developed countries agrees with Onafowora and Owoye (2013). Al-Mulali and Ozturk (2016) also back the findings of Neumayer (2004) who obtained an empiric support for clean growth using renewable energy as a percentage of energy consumption.

Like Neumayer (2004) and Al-Mulali and Ozturk (2016), Bilgili, Koçak and Bulut (2016) explore the potential impact of renewable energy consumption on environmental quality while investigating the validity of the EKC hypothesis. They employ a dataset of 17 OECD countries over the period 1977–2010 and the panel FMOLS and panel Dynamic Ordinary Least Squares (DOLS) as estimation techniques. The study only mentions that its data are from the World Bank database, it did not cite which of the World Bank's database it is. Bilgili *et al*.'s (2016) findings support the findings of both Neumayer (2004) and Al-Mulali and Ozturk (2016), in spite of their differences in the number of sample countries. That is, the study found an inverted U-shape between income and CO_2 and renewable energy consumption yields a decreasing impact on CO_2 emissions.

Baek (2016) estimates the effects of foreign direct investment (FDI) inflows, income and energy consumption on CO_2 emissions using the panel data of five Association of South East Asian Nations (ASEAN) countries over 1981–2010. Data for GDP, energy consumption and CO_2 emissions are from the WDI while that of FDI net inflow is collected from the United Nations Conferences on Trade and Development (UNCTAD). The overall results, based on PMG estimator, shows that FDI has a detrimental effect on CO_2 emissions thereby supporting the pollution haven hypothesis. This opposes Tamazian *et al*. (2009), Tamazian and Rao (2010) and Asghari (2013). However, when the study splits its data into two income groups, FDI at low-income level increases CO_2 and at high-income level reduces it. The study also found that income and energy consumption have an adverse effect on CO_2 emissions. Baek (2016) found the existence of a U-shaped relationship for low-income countries, i.e. after a certain level of income, CO_2 emissions increases as income increases. This is consistent with Choi *et al*. (2010) who found the same shape but for Korea. Like Al-Mulali and Ozturk (2016), Baek (2016) found the EKC between income per capita and CO_2 emissions for high-income countries.

A recent study on the relationship GDP and CO_2 emissions for 17 transitional economies by Mitić, Ivanović and Zdravković (2017) for the period 1997-2014 was conducted using DOLS and FMOLS. The study found a long run cointegration relationship and a monotonically increasing relationship between the two variables. Although Mitić *et al.* (2017) did not consider additional variables and did not test for the EKC; the study's finding is consistent with Azomahou *et al.* (2009) and Taguchi (2012). Unlike Mitić *et al.* (2017), Casey and Galor (2017) applied the STIRPAT framework and used total population, age structure, urban population as a percentage of total population and trade openness in addition to GDP per capita. Using a sample of 147 countries and a period of 1950-2010, Casey and Galor (2017) found that all the variables (except trade openness) significantly increase CO_2 emissions. Casey and Galor (2017) support Liddle (2015) that decrease in population could potentially reduce emissions and raise GDP per capita. The tabular summary of the studies reviewed above is displayed in Table A.IV (Appendix), as we move on to country-specific studies on CO_2 emissions and economic development.

3.4.1.2 Country-specific studies

In an attempt to provide more robust inferences for the EKC hypothesis for Canada, He and Richard (2010) use semi-parametric and flexible nonlinear parametric modelling methods for the period 1948-2004. Per capita CO_2 emissions data are from the World Resources Institute (WRI). All other data series (that is GDP, the price of crude oil, industrial production in GDP, the share of oil exports in total exports, the share of oil imports in total imports, exports to the U.S. and imports from the U.S.) are from the Statistics Canada. Gaussian kernel estimator and Partially Linear Model (PLM) are used as estimation methods. They found evidence that the relationship between CO_2 emissions per capita and GDP per capita is monotonically increasing. This is similar to the findings of Azomahou *et al*. (2009). They found industrial production in GDP, the share of oil exports in total exports and exports to the U.S. to be statistically insignificant. The price of crude oil has a negative relationship with CO_2 emissions while the share of oil imports in total imports and imports from the U.S. have a positive relationship with CO_2 emissions.

Boopen and Vinesh (2010) analyse the relationship between CO_2 emissions and GDP for Mauritius for the period 1975-2009. The sources of these two variables are the CDIAC of the ORNL at the U.S. Department of Energy and the World Bank's WDI. Other variables in the study, like investment divided by GDP, trade openness, secondary school enrolment ratio, regulation variable, population level and the number of vehicles on the road are also sourced from the WDI. The study applies Ordinary Least Squares (OLS) and Vector Auto Regression (VAR) for its analysis. Their results suggest that an inverted U-shape was not obtained. Investment divided by GDP, population level and vehicles on the road have a positive relationship with CO_2 emissions while secondary enrolment ratio and regulation variable have a negative relationship with CO_2 emissions. Unlike Poudel *et al*. (2009) and Pandelis (2012) who found no significant relationship between CO_2 emissions and literacy, Boopen and Vinesh (2010) found a significant negative relationship between CO_2 emissions and secondary enrolment ratio. This means that higher literacy (school enrolment) leads to lower CO_2 emissions in Mauritius.

Asghari (2012) investigates the role of different sources of growth in CO_2 emissions of Iran for the period 1980-2011. These sources are GDP, FDI and trade openness which are all obtained from the World Bank's WDI, including CO_2 emissions. She estimates a system of simultaneous equations, using TSLS, in which CO_2 emissions and per capita GDP are endogenously determined. The study found a U relationship between CO_2 emissions and income in Iran. The study concluded that in the early stages, FDI and trade openness cause CO_2 emissions to decrease until a turning point beyond which higher income leads to higher CO_2 emissions. These findings are consistent with those of Andreoni and Duriavig (2008) who also found a U-shaped curve between CO_2 and income for Italy.

Using fractional cointegration analysis, Alege and Ogundipe (2013) inquire into the relationship between CO_2 emissions and income in Nigeria over the period 1970-2011 by controlling for the role of FDI, institutional quality, trade openness and population density. Data employed in the paper are sourced from the World Bank database. Their results suggest that the series are not fractionally cointegrated. Since the realisation of EKC requires a long-run relationship between CO_2 emissions and GDP per capita, they concluded that there exists no evidence of the EKC in Nigeria. The study found a positive linear relationship between CO_2 emissions and income. This finding on Nigeria concurs with that of Ajide and Oyinlola (2010) and Onafowora and Owoye (2013), despite their use of different estimation methods. The study's results show that FDI and trade openness have a positive relationship with CO_2 emissions; weak institutions increase the extent of environmental degradation; and larger population density enhances consciousness for a cleaner environment. Alege and Ogundipe's (2013) findings on the relationship between CO_2 emissions and trade openness are consistent with that of Onafowora and Owoye (2013). However, Alege and Ogundipe (2013) and Ajide and Oyinlola (2010) contradict on FDI as Ajide and Oyinlola (2010) found that higher FDI causes a decrease in CO_2 emissions in Nigeria. This contradiction may be due to the different study periods used in the studies.

With a panel of 28 provinces, Li, Wang and Zhao (2016) study the impacts of income, energy consumption, trade openness and urbanisation on CO_2 emissions for China for the period 1996-2012. Data sources are China Statistical Yearbook, China Compendium of Statistics and China Energy Statistical Yearbook. Estimating with the system Generalised Method of Moments (GMM) and Autoregressive Distributed Lag (ARDL) model, their results uphold the EKC hypothesis for China. Li *et al*. (2016) negate Choi *et al*. (2010) and Onafowora and Owoye (2013) who found an N-shaped relationship between income and CO_2 emissions for China. This discrepancy may, also, be due to the difference in study periods. The results show that energy consumption contributes to environmental deterioration in China, both in the short and long run. Trade and urbanisation appear to increase CO_2 emissions, in the long run. This suggests that, unlike energy consumption, it takes time for trade openness and urbanisation to manifest their adverse impacts on environmental quality in China. Onafowora and Owoye (2013) also disagrees with Li *et al*. (2016) on the relationship trade openness has with CO_2 emissions in China which they found to be negative.

Balaguer and Cantavella (2016) perform a structural analysis on the EKC while using real oil prices as an indicator of variations in fuel energy consumption for Spain for the period 1874–2011. The estimates of the relationships between CO_2 emissions and economic growth and international oil prices are made with the ARDL estimator. The authors sourced data on CO_2 emissions from the Carbon Dioxide Information Analysis Centre (CDIAC) of the United States Department of Energy, GDP from the Maddison Historical Statistics and crude oil prices are gathered from the Statistical Review of World Energy of the British Petroleum company. Balaguer and Cantavella (2016) found support for the EKC hypothesis for Spain in both short and long run. Although both studies applied the same estimation method, Balaguer and Cantavella (2016) supports Li *et al*. (2016) by finding the existence of EKC. Their empirical results prove that changes in real oil prices are relevant in explaining the Spanish CO_2 emissions in a long run perspective with an inverse relationship. This is consistent with the findings of Al-Mulali and Ozturk (2016), although they used energy prices and not oil prices.

Studies on CO_2 emissions, economic and financial development are discussed in the following subsection while the summary on the aforesaid country-specific studies for CO_2 emissions and economic development are tabulated in Table A.V.

3.4.2 Carbon dioxide emissions, economic and financial development

3.4.2.1 Cross-country studies

Tamazian, Pinẽiro and Vadlamannati (2009) investigate the linkage between economic development, financial development and CO_2 emissions with a panel data over the period 1992–2004 for BRIC economies (Brazil, Russia, India and China). Data on CO_2 emissions, the share of industrial output in GDP, financial openness, energy and oil consumption are obtained from the World Bank's WDI. Data on research and development (R&D) expenditure as a percentage of GDP are from the OECD; financial liberalisation are from Gupta and Yuan (2008); stock traded in market divided by GDP and the ratio of deposit money bank assets to GDP are from Beck *et al*. (2000) updated data version of 2007. FDI inflow stock is from the UNCTAD, capita account convertibility index is from Chinn and Ito (2008), and the share of total energy imports divided by GDP is from the UNSD.

The results of Tamazian *et al*. (2009) show that increase in FDI inflow is associated with lower levels of per capita CO_2 emissions. Same is the case with financial liberalisation, capital account convertibility and financial openness. The results support the EKC theory that pollution levels increase as the countries develop but begin to decrease as rising income pass beyond a threshold or turning point. Tamazian *et al*. (2009) also analyse the nexus between economic growth, finance and environmental degradation while excluding the control variables. Results from this suggest that excluding energy-related variables does not significantly alter the results for BRIC countries.

Considering the importance of institutional quality, Tamazian and Rao (2010) conducted a similar study by using Generalised Least Squares (GLS) and Generalised Method of Moments (GMM) estimation method to control for endogeneity. Their panel study considers 24 transition economies from the Former Soviet Union (FSU) and Central and Eastern Europe (CEE) for a period of 1993-2004. Variables considered are GDP per capita, inflation rate, FDI, price liberalisation, FOREX and trade liberalisation, trade openness, financial liberalisation, institutional efficiency, energy consumption and energy imports. Sources of data on these variables are the World Bank's WDI, IMF's World Economic Outlook (WEO) and Chinn and Ito (2008). Tamazian and Rao's (2010) results support the EKC hypothesis while establishing the importance of both institutional quality and financial development for environmental performance. They found that financial liberalisation may be harmful to environmental quality if it is not accomplished in a strong institutional framework. On the contrary, they found that higher levels of FDI help to achieve lower CO_2 emission per capita. The effect of trade openness increases CO_2 emission, but this increase is reduced when trade openness interacted with institutional quality. With this finding, it can be noted that Tamazian and Rao (2010), like Zugravu *et al*. (2008), confirms the 'race to bottom' expression by Dasgupta *et al*. (2002).

Although Tamazian *et al*. (2009) did not candidly state their adopted estimation technique, results of this study are similar to those of Tamazian and Rao (2010). This is not farfetched as both studies use similar model specification and procedure of estimation but their variables differ a bit. While Tamazian and Rao (2010) did not consider the stock market value added, industry share, R&D expenditure and financial openness, Tamazian *et al*. (2009) did not consider institutional quality, inflation, price liberalisation, FOREX and trade liberalisation, and trade openness.

When Asghari (2013) examined the effect of economic and financial development on CO_2 emissions in four euro-Mediterranean countries for the period 1980-2011, she applied simultaneous equations. CO_2 emissions per capita and financial development are endogenously determined in these equations. Explanatory variables considered for the study are GDP per capita, trade openness, FDI to gross fixed capital stock and openness by FDI. Her panel data are from the World Bank's WDI. The results indicate that financial development and GDP per capita squared increase environmental quality. Thus, there is an existence of the EKC and financial development plays a determinant role in CO_2 emissions reductions. Ashgari (2013) also obtained similar results to those of Tamazian *et al*. (2009) and Tamazian and Rao (2010), though she used a different estimation procedure and a reduced number of variables.

Al-Mulali, Chong, Low and Mohammed (2015) utilise ecological footprint as an indicator of environmental degradation to investigate the EKC while applying energy consumption, urbanisation, trade openness and financial development (proxy by domestic credit to private sector). Carbon emissions are included in the calculation of ecological footprint which is why this study is reviewed in this research, i.e. the variable ecological footprint may be referred to as the total environmental degradation. Al-Mulali *et al*. (2015) examined 93 countries which are categorised into 16 low-income countries (LIC), 26 lower-middle-income countries (LMIC), 26 upper-middle-income countries (UMIC) and 31 high-income countries (HIC) for the period 1980-2008.

The data source for energy consumption is the United States Energy Information Administration (EIA), the data source for ecological footprint is the Global Footprint Network while the data source for all the other variables is the World Bank's WDI. The fixed effects and GMM estimation results show an inverted U-shaped relationship between ecological footprint and GDP growth in UMIC and HIC but not in LIC and LMIC. The authors observed that energy consumption increases environmental damage in all the income groups. Urbanisation and trade openness increase the ecological footprint while financial development reduces the ecological footprint of LMIC, UMIC and HIC. Meanwhile, they found that urbanisation, trade openness and financial development have no significant effect on the ecological footprint of LIC because these variables compared with other income groups are low in LIC. All the findings (on UMIC and HIC) support those of Tamazian *et al*. (2009), Tamazian and Rao (2010) and Asghari (2013).

Salahuddin, Gow and Ozturk (2015) examine the effects of economic growth, electricity consumption and financial development on CO_2 emissions for the Gulf Cooperation Council (GCC) countries for the period 1980-2012. The Dynamic Ordinary Least Squares (DOLS), Fully Modified Ordinary Least Squares (FMOLS) and Dynamic Fixed Effect Model (DFE) are the econometric methods applied in the study. Per capita real GDP and domestic credit to the private sector as a share of GDP are used to proxy economic growth and financial development. Data are from the WDI. Salahuddin *et al*. (2015) found that electricity consumption and economic growth have a positive relationship with CO_2 emissions while a negative relationship was found between CO_2 emissions and financial development. That is, electricity consumption and economic growth stimulate CO_2 emissions while financial development reduces it. Unlike other studies in this subsection, Salahuddin *et al*. (2015) did not test the hypothesis of the EKC but their findings that financial development reduces CO_2 emissions is supportive of Tamazian *et al*. (2009), Tamazian and Rao (2010), Asghari (2013) and Al-Mulali *et al*. (2015).

Moving on to country-specific studies on CO_2 emissions and economic and financial development, a tabular summary of the studies reviewed in this subsection are presented in the Appendix (Table A.VI).

3.4.2.2 Country-specific studies

Ajide and Oyinlola (2010) examine the relationship between CO_2 emissions per capita and these variables -GDP, the share of manufacturing in GDP, FDI, traded value of stock market to the GDP and energy consumption- for the period 1980-2008 for Nigeria. Data are sourced from the World Bank Database. Their results present evidence that CO_2 emissions are not driven by income growth, it is rather influenced by financial development. The results show a non-existence of the EKC in Nigeria. They found that FDI decreases CO_2 emissions per capita while traded value of stock market to GDP increases CO_2 emissions per capita. Energy consumption and the share of manufacturing in GDP are not significant in the study. The study does not mention the estimation technique applied. However, it lends support to Tamazian *et al*. (2009) and Tamazian and Rao (2010) that increase in FDI inflow is associated with lower levels of CO_2 emissions but contradicts Tamazian *et al*. (2009) by finding that stock market to GDP has a positive (instead of negative) impact on CO_2 emissions. Unlike Ajide and Oyinlola (2010) who did not disclose the estimation method used, subsequent studies are more reliable because they applied cointegration estimation methods.

Shahbaz, Tiwari and Nasir (2011a) found out the effects of financial development, economic growth, coal consumption, trade openness and urbanisation on CO_2 emissions over the period of 1965-2008 for South Africa. The Autoregressive Distributed Lag (ARDL) bounds testing approach to cointegration and Error Correction Model (ECM) are the estimation methods used. Per capita access to domestic credit of private sector is used to proxy financial development while the urban population as a share of total population proxy urbanisation. Data are collected from the World Bank's World Development Indicator (WDI). Their findings show that a rise in economic growth increases CO_2 emissions while financial development lowers it. Shahbaz *et al*. (2011a) obtained empirical evidence that confirms that coal consumption significantly contributes to environmental deterioration; trade openness improves environmental quality by lowering the growth of energy pollutants; and like coal consumption, urban population increases CO_2 emissions. Unlike Ajide and Oyinlola (2010) and Boopen and Vinesh (2010) who found non-existence of the EKC for Nigeria and Mauritius, Shahbaz, Tiwari and Nasir (2011a) found that the EKC exists for South Africa.

Shahbaz, Islam and Butt (2011b) look at the relationship among CO_2 emissions, financial development, economic growth, energy consumption, and population growth in Pakistan for the period 1974-2009. This study is similar to Shahbaz (2013) using the same estimation technique (ARDL bounds testing approach to cointegration and ECM) and the same case study (Pakistan). The difference in them lies in the variables used. While Shahbaz (2013) generated and used the index of financial instability, Shahbaz *et al*. (2011b) used real market capitalisation as an indicator for financial development. All the data are from the World Bank's WDI. Shahbaz *et al*. (2011b) found that the main contributors to CO_2 emissions in Pakistan are economic growth, population growth and energy consumption. The results also lend support to the existence of the EKC and financial development reduces emissions in Pakistan. These findings corroborate those of Shahbaz (2013), in spite of the difference in the period of study.

Zhang (2011) used cointegration test, Granger causality test, Vector Error Correction Model (VECM) and variance decomposition to explore the influence of financial development on CO_2 emissions in China for a sample period 1980-2009. Data on CO_2 emission is from the BP statistical review of World Energy; GDP and FDI net inflows as a percentage of GDP are from the World Bank's WDI and Global Development Finance (GDF), respectively. The ratio of loans in financial intermediation to GDP, ratio of stock market capitalisation to GDP and ratio of stock market turnover to GDP are from the Wind Database. The ratio of the sum of loans to township enterprises, enterprises with foreign fund, and private enterprises and self-employed individuals to GDP are obtained from the China Statistical year book of the People's Bank of China. Zhang's (2011) results indicate that China's financial development acts as an important driver for increase in CO_2 emissions, especially its financial intermediation scale, while FDI has the least influence on CO_2 emissions. Zhang's (2011) findings that financial development increases CO_2 emissions contradict those of Shahbaz, Islam and Butt (2011b) and Shahbaz, Tiwari and Nasir (2011a) who found that financial development reduces CO_2 emissions. This may be due to the different estimation methods they used.

Shahbaz, Adnan and Tiwari (2012a) probe the linkages among economic growth, energy consumption, financial development, trade openness and CO_2 emissions using quarterly data over the period of 1975-2011 in the case of Indonesia. The study used the ARDL bounds testing approach to cointegration, Ordinary Least Squares (OLS), ECM and VECM Granger causality as its estimation technique. All the utilised data are collected from the World Bank's WDI. Per capita domestic credit to private sector is the proxy for financial development and real GDP per capita is the proxy for economic growth. The empirical findings indicate that economic growth and energy consumption increases CO_2 emissions while financial development and trade openness compact it i.e. improve environmental quality. These findings are consistent with those of Shahbaz, Islam and Butt (2011b) and Shahbaz, Tiwari and Nasir (2011a) for Pakistan and South Africa, respectively. Like Shahbaz, Islam and Butt (2011b) and Shahbaz, Tiwari and Nasir (2011a), Shahbaz, Adnan and Tiwari (2012a) also found that the EKC exists for Indonesia.

Shahbaz (2012) analyse the relationship among economic growth, energy intensity, financial development (proxy by real domestic credit to private sector per capita) and CO_2 emissions over the period of 1971-2009 in the case of Portugal. This study employs the ARDL bounds testing approach, VECM Granger causality approach and Innovative Accounting Approach (IAA). All the analysed data are collected from the World Bank's WDI. His results confirm that economic growth (i.e. GDP per capita) and energy intensity increase CO_2 emissions while financial development condenses it. An inverted U (i.e. EKC) is confirmed between economic growth and CO_2 emissions. These results are consistent with those of Shahbaz, Adnan and Tiwari (2012a) and Shahbaz, Islam and Butt (2011b) for Indonesia and Pakistan, respectively.

Whether financial development reduces CO_2 emissions in the case of Malaysia was the question Shahbaz, Solarin and Mahmood (2012b) answered. They applied ARDL for the bounds testing approach to cointegration and VECM Granger causality on GDP per capita, energy consumption per capita, FDI, domestic credit to private sector per capita and trade openness for the period 1971-2008. Data are obtained from the World Bank's WDI. Their results validate that domestic credit to private sector per capita reduces CO_2 emissions while economic growth, energy consumption and FDI retard environmental quality (this contradicts Ajide and Oyinlola (2010) and Tamazian and Rao (2010) who found that FDI reduces CO_2 emissions). Shahbaz, Solarin and Mahmood (2012b) also found that an increase in trade openness reduces emissions which support Shahbaz, Tiwari and Nasir (2011a) and Shahbaz, Adnan and Tiwari (2012a).

Boutabba (2013) conducted a similar study as above for India for the period 1970-2008. This study employs the ARDL bounds testing procedure cointegration and VECM. The data on per capita CO_2 emissions, per capita real GDP, per capita energy use, financial development (proxy by the domestic credit to private sector as a share of GDP) and trade openness originate from the WDI. The study's results confirm the existence of EKC in India (this supports the finding of Piaggio and Padilla (2012) on India). The findings, also, reveal that financial development increases per capita CO_2 emissions. This suggests that financial development increases environmental degradation. This also affirms the findings of Zhang (2011), although these studies used similar estimation method.

Shahbaz (2013) explores the relationship between financial instability and CO_2 emissions within a multivariate framework for the period 1972-2009 in the case of Pakistan. The study used the ARDL bounds testing approach to cointegration and ECM as its method of estimation. Data on CO_2 emissions per capita, real GDP per capita, energy consumption per capita and trade openness are collected from the World Bank's WDI while an index for financial instability is generated by the author following Loayza and Ranciere (2006). The study found that the effect of financial instability is positive on CO_2 emissions. This implies that a rise in financial instability is harmful while financial stability is beneficial for the environment in Pakistan. It also found that the EKC exists; a dominant role is played by energy consumption to CO_2 emissions; and trade openness is inversely linked with CO_2 emissions. All these findings are consistent with Shahbaz, Tiwari and Nasir (2011a), even though the studies used the same estimation methods but different case studies (i.e. South Africa).

Considering structural breaks and regime-switching in United Arab Emirates (UAE), Charfeddine and Khediri (2016) investigate the relationship between CO_2 emissions, electricity consumption, economic growth, financial development (proxy by domestic credit to private sector as a percentage of GDP), trade openness and urbanisation (proxy by urban population as a percentage of total population) for the period spanning from 1975 to 2011. All the variables are collected from the WDI. Applying the Gregory and Hansen and Hatemi-J cointegration tests with structural break procedure and VECM, Charfeddine and Khediri (2016) confirm the existence of EKC and found that financial development increases CO_2 emissions in the case of UAE. These findings support Zhang (2011) and Boutabba (2013). They found that electricity consumption, urbanisation and trade openness contribute to environmental quality. Thus, unlike Salahuddin *et al*. (2015) who found that electricity consumption stimulates CO_2 emissions in GCC countries (among which is the UAE), Charfeddine and Khediri (2016) found that electricity consumption declines CO_2 emissions.

The study conducted on Pakistan by Javid and Sharif (2016) for the period 1972-2013 is on the effects of financial development (proxy by domestic credit to private sector as a percentage of GDP), per capita real income, per capita energy consumption and openness on per capita CO_2 emissions. All the variables are sourced from the World Bank's WDI and the ARDL approach to cointegration is applied to estimate the study's model. Javid and Sharif (2016) confirm the existence of EKC in Pakistan. They found that financial development occurs at the expense of environmental quality and per capita energy consumption also has a positive relationship with CO_2 emissions. On the existence of EKC, Javid and Sharif (2016) affirm Shahbaz, Islam and Butt (2011b) and Shahbaz (2013). They, however, contradict Shahbaz, Islam and Butt (2011b) and Shahbaz (2013) and support Zhang (2011), Boutabba (2013) and Charfeddine and Khediri (2016) on their findings on the effect of financial development on CO_2 emissions. Unlike Shahbaz (2013), Javid and Sharif (2016) found that the openness variable has no significant influence on emissions in Pakistan.

A more recent study by Ozatac, Gokmenoglu and Taspinar (2017) investigates the EKC for Turkey with energy consumption, trade openness, urbanisation and financial development as additional variables for the period 1960-2013. Like Shahbaz *et al.* (2011b) and Shahbaz (2013), the study also applied the ARDL approach and it confirms the EKC for Turkey and that financial development reduces CO_2 emissions. The study suggests that urban population awareness should be raised for urbanisation to contribute to a cleaner CO_2 environment in Turkey. Table A.VII (in the Appendix) presents a summary of the studies reviewed in this section.

3.4.3 Panel study on sub-Saharan Africa

Unlike all the studies reviewed in the above subsections which investigate the impact of economic and financial development on CO_2 emissions, Al-Mulali and Che (2012) investigate the impact of energy consumption and CO_2 emissions on economic growth and financial development in thirty SSA countries for the period 1980-2008. Data on GDP per capita (the indicator for economic growth) and domestic investment are obtained from the IMF's World Economic Outlook (WEO) and broad money and domestic credit to private sector (the indicators of financial development) are sourced from the World Bank's WDI. Data on total primary energy consumption and CO_2 emissions are obtained from the Energy Information Administration (EIA) of the United States Department of Energy. Al-Mulali and Che (2012) used panel cointegration and panel Granger causality as its estimation methods. Their results show that energy consumption plays an important role by increasing both economic growth and financial development, resulting in high pollution. This result is consistent with Zhang (2011) but opposes Shahbaz, Adnan and Tiwari (2012a) and Shahbaz (2012). A summary of this study is exhibited in the Appendix (Table A.VIII).

3.5 Summary and conclusion

The review of the literature reveals that a panel study on the impact of CO_2 emissions on economic growth and financial development in SSA has been conducted (see Al-Mulali and Che 2012). However, a panel study on the impact of economic and financial development on CO_2 emission has not been conducted using SSA as a case study.

Of all the 50 studies reviewed for this research, only six studies did not apply the Environmental Kuznets Curve (EKC) theory. The six studies are Zugravu *et al*. (2008), Zhang (2011), Al-Mulali and Che (2012), Salahuddin *et al*. (2015), Casey and Galor (2017) and Mitić *et al.* (2017). Contrary to the view that the EKC hypothesis is less likely for CO_2 emissions, 27 studies out of the 44 EKC tested-studies found the inverted U-shape of the EKC (see the second column of Table A.IX). Four studies found the N-shape relationship between CO_2 emissions and income and six studies found the monotonic relationship (see the third column and first column of Table A.IX, respectively).

There are some studies that found the EKC (i.e. inverted U-shape) and also the N-shape because they made use of time series analysis or parametric and nonparametric methods of estimation or different samples classified based on income level. For example, Onafowora and Owoye (2013) found the EKC for two countries and the N-shape for six others. Instead of the popular linear, inverted U and N-shapes, some studies found a U-shape[26] and an inverted N-shape[27]as the relationship between CO_2 emissions and income. Examples of such studies are: Asghari (2012) and Baek (2016) found a U-shape and Choi *et al*. (2010) found an inverted N-shape. Meanwhile, Ajide and Oyinlola (2010) found an insignificant relationship between CO_2 emissions and income.

This summary of CO_2 emissions-income relationships supports the debate of He (2009) that there is no one-fit-for-all growth-pollution relationship even when using the same estimation method. For example, Tamazian and Rao (2010), Taguchi (2012) and Gholami and Shafiee (2013) used GMM and they found inverted U, linear and N-shapes, respectively, although they used a different sample of countries as case studies.

The inverted U-shape and U-shape generate a turning point, the N-shape and inverted N-shape generate two turning points, and the linear or monotonic relationship generates no turning point. Although not all the studies reviewed estimated a turning point(s), Table A.X depicts turning points from the studies that found the EKC, U, N and inverted N-shape. The turning points found in this literature partially support Stern's (2004) suggestion that including more low-income countries in a study might yield a higher turning point. Grunewald and Martinez-Zarzoso (2011) and Skaza and Blais (2013), for example, found $209,452 for 213 countries using GMM and $59,309 for 190 countries using OLS, respectively, supports Stern (2004). However, Al-Sayed and Sek (2013) found $8,673 for 20 developing countries and $67,846 for 20 developed countries using OLS and GLS. This does not support Stern's (2004) proposition.

[26] The U-shape means that initially, CO_2 emissions decrease as income rises, reaches a turning point and CO_2 emissions start to rise as income rises.
[27] Inverted N-shape means that initially, CO_2 emissions deceases as income rises, reaches a turning point and CO_2 emissions start to rise as income rises till it reaches another turning point where CO_2 emissions decrease again as income rises.

In terms of financial development, 12 studies out of the 16 studies reviewed in this respect found that financial development reduces CO_2 emissions (For example, Tamazian and Rao 2010; Shahbaz 2013; Al-Mulali *et al*. 2015). The remaining four studies found that financial development stimulates CO_2 emissions (For example, Ajide and Oyinlola 2010; Javid and Sharif 2016).

3.6 Contribution to the Body of Literature

There is a gap in the literature on the usage of SSA's panel data to investigate the impact of economic and financial development on CO_2 emissions, thus, the initiation of this study. It is observed that panel studies neglect agriculture as a factor in determining CO_2 emissions because they assume every developing economy is undergoing industrial transformation (for example, Grunewald and Martinez-Zarzoso 2011; Tamazian *et al*. 2009; Zugravu *et al*. 2008). However, there is still a high dependence on agriculture and low dependence on industrial development in SSA and yet the region is the most affected by climate change impact (UNCTAD 2012). This study contributes by investigating whether agriculture is reducing or adding to CO_2 emissions in SSA.

This study does not intend to disregard industrial development because SSA countries are known to, also, be dependent on the exploitation of natural resources (like fossil fuels, metallic and non-metallic minerals) as drivers of their economic growth (UNCTAD 2012). That is, the exploitation of natural resources is classified as activities under the industrial sector (CBN 2009). Unlike other studies, the study considers the industry as a control variable to investigate the effect of industrial transformation on CO_2 emissions in SSA (having the structural change theory in mind).

Major macroeconomic variables (like GDP, inflation rate and literacy rate) have been considered in the literature (for example, Boopen and Vinesh (2010) and Tamazian and Rao (2010)) but not employment generation rate. Under the argument for the green economy, both public and private investment in low-carbon projects will lead to growth in income and employment (GIZ 2013). For this reason, considering the relationship of employment generated with CO_2 emissions (before the fact) for the region that is embracing the transition into a green economy is worthwhile.

Taguchi (2012) considered the degree of later economic development as an additional variable. This study also considers the degree of later economic development and contributes by considering the degree of later financial development as there is no study in the literature that has considered this variable. This variable serves as a further clarification between the optimistic view of the financial sector as a provider of financial services to environmental-friendly projects and the pessimistic view of the financial sector as a provider of financial services to carbon-intensive projects.

According to Nhamo (2009a:125), "Africa's Principal international trading partners continue to be its former slave masters". Probably SSA countries' foreign incursion may have an effect on the way carbon-related resources are being exploited and managed, thus, leading to high or controlled CO_2 emissions. The difference in the level of CO_2 emissions based on the groups of colonies in each sample is another contribution investigated in this study.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.0 Introduction

It has been established in the previous chapters that even though sub-Saharan African (SSA) countries minimally contribute to carbon emissions, they are the most vulnerable to the impacts of climate change (AfDB 2014b). Studies reviewed in chapter three have proven that there is a link between CO_2 emissions and economic and financial development. In realisation of this, some SSA countries (for example, Ethiopia, Kenya, Rwanda, South Africa) are already making green investments and implementing a mix of climate change measures and policies. These they do so that their economic activities may reduce and not increase carbon emissions now and in the future. However, others (like, Cameroon, Nigeria, Seychelles, Sudan) are still majorly applying their business as usual (BAU) carbon-intensive technologies and materials.

The purpose of this chapter is to specify and explain the empirical models which will be used to investigate the questions raised in the introduction chapter. These questions are: does the Environmental Kuznets Curve (EKC) model relation shape exist in SSA; if so, what is the income elasticity of demand for a cleaner CO_2 environment and the turning point; what is the effect of economic and financial development on CO_2 emissions in SSA; and with different colonial histories, do SSA countries have different patterns regarding CO_2 emissions?

Thus, the methodology adopted for this study is discussed in seven sections. The first section is on research design, the second section is on the hypotheses of the study and models are specified in the third section. A priori expectation and data are described in the fourth section and section five explains the methods of data analysis chosen for this research. The last two sections describe the study's estimation procedure and the conclusion of this chapter.

4.1 Research Design

This study is meant to examine and analyse the impact of (selected indicators of) economic and financial development on carbon dioxide (CO_2) emissions for the period 1989 to 2012 (24 years) for a panel of 45 SSA countries. Empirical models are developed to adequately investigate the objectives of this study. The study employs two econometric techniques of analysis to the sample of countries, i.e. the Feasible Generalised Least Squares (FGLS) and Generalised Method of Moments (GMM). The sampled countries are divided into a-four-cluster of low (twenty-four countries), lower-middle (thirteen countries), upper-middle (six countries) and high-income level (two countries). The panel analyses on the clusters are estimated with the Panel-Corrected Standard Errors (PCSE) and Instrumental Variable (IV) regression.

FGLS and PCSE are chosen so as to correct for likely heteroscedasticity and contemporaneous correlation that could make the coefficients in the panel models to be biased. GMM and IV are used so as to take care of likely endogeneity and nonlinearity in the models. The nature of the data for this study is secondary from the World Bank's database (called the World Development Indicator (WDI) and Africa Development Indicators (ADI)) and the United States Energy Information Administration (EIA). The econometric software package for the analysis is the Stata 14.

4.2 Hypotheses

The hypotheses for this research are as guided by the theoretical framework and empirical literature discoursed in the previous chapter and the research questions presented in the first chapter. To start with, some scholars (for example, Grossman and Krueger 1991; Beckerman 1992) have posited that the fundamental indicator to resolve environmental problems (such as carbon emissions) is the affluence factor. That is, experiencing an increase in income. They argue that as an economy grows and income increases, environmental degradation increases. After a certain level of income (or affluence) is reached, environmental quality improves. This relationship is called the Environmental Kuznets Curve (EKC) hypothesis (UNCTAD 2012).

Some scholars (like Moomaw and Unruh 1997; Carvalho and Almeida 2010), however, believe that the EKC does not hold for CO_2 emissions. They say that the EKC's inverted U-shape would only exist at an initial stage of the relationship between economic growth and environmental degradation. At another higher income level, there would be another turning point leading to an N-shaped curve. However, the EKC may hold for CO_2 emissions in SSA due to the tendency of relative decrease in CO_2 emitted per unit of primary energy consumed in the region (i.e. decarbonisation) (see: Roberts and Grimes 1997; Schmalensee *et al.* 1998). The average growth rate of decarbonisation in SSA increased from 0.33% during 1993 and 2002 to 0.53% during 2003 and 2012 (WDI 2014). This is an increase of 0.20% points, i.e. 60.6% percentage increase, in the average growth rate of decarbonisation. Thus, to answer the question "does the Environmental Kuznets Curve (EKC) model relation shape exist in SSA", these hypotheses are formulated:

H_{01}: income (Y) does not have a significant relationship with carbon dioxide (CO_2) emissions.

H_{02}: the EKC does not exist which indicate that the relationship between Y and CO_2 is not graphically represented by an inverted U-shape.

H_{03}: the N-shape does not exist which means that a higher Y does not have a different effect on CO_2.

The second research question (what is the income elasticity of demand for a cleaner CO_2 environment and the turning point in SSA?) is answered by applying the results of hypotheses H_{01} to H_{03} to some calculations (which are discussed in section 4.4).

Critics of the EKC (like Neumayer 1998; Dasgupta *et al*. 2002) have called on policymakers to avoid the interpretation of the EKC which is to 'grow first and clean up later'. They suppose that policymakers may improve environmental quality by frequently penalising dangerous polluters. Thence, countries may be able to experience an EKC that is lower and flatter (called the revised EKC) than the conventional EKC. This supposition is tested with the next hypothesis.

H_{04}: the revised EKC does not exist i.e. the degree of economic development does not have a significant positive relationship with CO_2 emissions.

The literature recognises that even though income may have a relationship with carbon emissions, it is on its own not the only indicator that may contribute to and/or resolve environmental problems. Hence, different vectors of economic and financial development variables have been applied in the literature (see, Grunewald and Martinez-Zarzoso 2011; Tamazian *et al*. 2009). With agriculture as a percentage of GDP, employment generation rate and the degree of financial development as a contribution to the literature, these hypotheses are formulated to answer "what is the effect of economic and financial development on CO_2 emissions in SSA".

H_{05}: economic development variables do not have a significant relationship with CO_2 emissions.

H_{06}: financial development variables do not have a significant relationship with CO_2 emissions.

The vector of economic and financial development variables selected is presented in the following section and defined in section 4.4.

According to Nhamo (2009a:125), “Africa’s Principal international trading partners continue to be its former slave masters”. Based on Nhamo’s findings, it is inferred that SSA countries’ foreign incursion may have an effect on the way carbon-related resources are being exploited and managed. Hence, there may be a difference in the level of CO_2 emitted amongst the Anglophone, Francophone and Lusitanian countries of SSA. The last hypothesis is to answer the last research question “do sub-Saharan African countries with different colonial histories have different patterns regarding CO_2 emissions”.

H_{07}: there is no significant difference in the level of CO_2 emissions amongst Anglophone, Francophone and Lusitanian countries.

Having these formulated hypotheses in mind, the empirical models for this research are specified in the immediate section.

4.3 Model Specification

The study’s empirical model is based on the theoretical models in the previous chapter. The models are re-stated in these three equations:

$$lnE = \beta_0 + \beta_2 lnY + \beta_k lnZ + \varepsilon \qquad . \qquad . \qquad . \qquad (4.1)$$

$$lnE = \beta_0 + \beta_2 lnY + \beta_3 lnY^2 + \beta_k lnZ + \varepsilon \qquad . \qquad . \qquad . \qquad (4.2)$$

$$lnE = \beta_0 + \beta_2 lnY + \beta_3 lnY^2 + \beta_4 lnY^3 + \beta_k lnZ + \varepsilon \qquad . \qquad . \qquad . \qquad (4.3)$$

Where *lnE* is the logarithm of environmental degradation, β_0 is the constant while β_2, β_3 β_4 and β_k are coefficients of respective explanatory variables, *lnY* is the logarithm of income, lnY^2 is the logarithm of squared income, lnY^3 is the logarithm of cubed income, *lnZ* is the vector of other variables and ε is the error term. Equation 4.1, 4.2 and 4.3 are log-linear, log-quadratic and log-cubic models adduced with the possibility of obtaining either linear, inverted U or N-shape relation (see Shafik and Bandyopadhyay 1992).

For this study, carbon dioxide (CO_2) emission per capita is the proxy for environmental degradation. GDP per capita (Y) serves as the proxy for income whereby the coefficients of *lnY*, lnY^2 and lnY^3 test the first three hypotheses. *lnZ* is the vector of the selected economic and financial development variables, control and dummy variables. The coefficient of lnZ answers the hypotheses H_{04}-H_{07} and the vector of variables are detailed in a general form model in Equation 4.4.

$$lnCO_{2it} = f(lnY, lnY^2, lnY^3, lnA, lnT, ln\pi, lnEgr, lnEc, lnDe, lnD, lnFDI, lnO, lnDf, D_1, D_2, lnI, lnP, lnUp) \quad . \quad . \quad . \quad (4.4)$$

Since GDP per capita is not the only variable that defines economic development, other economic development variables in Equation 4.4 are the share of agriculture as a percentage of GDP (*lnA*), trade as a percentage of GDP (*lnT*), inflation rate (*ln*π), employment generation rate (*lnEgr*), and total primary energy consumption per capita (*lnEc*). These are to test H_{05} while the degree of later economic development (*lnDe*) tests H_{04}. The financial development variables are the domestic credit to private sector to GDP ratio (*lnD*), foreign direct investments to GDP ratio (*lnFDI*), foreign exchange rate (*lnO*) and the degree of later financial development (*lnDf*). They test the sixth hypothesis. The dummy variables D_1 and D_2 are for French and Portuguese-speaking countries which test the seventh hypothesis. The control variables are the share of industry in GDP (*lnI*), population density (*lnP*) and urban population as a percentage of total population (*lnUp*). They are used as robustness checks to examine the behaviour of the estimated results of the hypotheses tested. This is based on the template that environmental pressures have been noted to intensify in developing countries not only because of structural change from agricultural activities to industrial activities but also because of growing population and increasing urbanisation (UNCTAD 2012).

Adopting the theoretical model in Equation 4.1 for log-linear panel models, a nested panel model is specified without the control variables in Equation 4.5.

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.5)$$

The acronyms in Equation 4.5 (and subsequently) are as defined above, *i* indexes country, *t* is for time and ε_{it} is the error term that may be autocorrelated over time or contemporaneously correlated across countries.

Based on the structural change theory that a declining share of agriculture (*lnA*) implies a rising share of industry (*lnI*) in GDP (Todaro and Smith 2003), the effects of structural transformation, growing population (*lnP*) and increasing urbanisation (*lnUp*) on CO_2 emissions are applied as robustness checks by specifying the following four log-linear models. Equation 4.6 introduces the control variables except for *lnI*; Equation 4.7 includes *lnI* and excludes *lnA*, ln*P* and *lnUp*; Equation 4.8 includes *lnI*, *lnP* and *lnUp* and excludes *lnA*; and all the vector of variables are modelled in Equation 4.9.

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.6)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.7)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.8)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.9)$$

As such, Equations 4.5 to 4.8 are nested in Equation 4.9. The above five log-linear panel models are specified because some scholars argue that carbon dioxide emission has a linear function with income (see Bertinelli and Strobl 2005; Azomahou *et al.* 2009; Taguchi 2012). However, the economic theory that is profoundly adopted for this type of study is the Environmental Kuznets Curve (EKC) which portrays a quadratic model with income and squared income. Therefore, the log-quadratic model in Equation 4.2 is specified in a similar fashion like those under log-linear.

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.10)$$

The effects of structural transformation, growing population (*lnP*) and increasing urbanisation (*lnUp*) on CO_2 emissions are applied as robustness checks by specifying the following four log-quadratic models. Equation 4.11 introduces the control variables except for the share of industry (*lnI*); Equation 4.12 includes *lnI* and excludes the share of agriculture (*lnA*), ln*P* and *lnUp*; Equation 4.13 includes *lnI*, *lnP* and *lnUp* and excludes *lnA*; and Equation 4.14 contains all the vector of variables. Thus, Equation 4.10, 4.11, 4.12 and 4.13 are nested in Equation 4.14.

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.11)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.12)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.13)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.14)$$

Some authors also claim that the EKC does not hold in its classical form leading to an N-shaped relationship between carbon dioxide emissions and income (see Moomaw and Unruh 1997; Carvalho and Almeida 2010; Gholami and Shafiee 2013). Thus, Equation 4.3, which is a log-cubic function, is used to model as above. This yields five log-cubic models (presented below) of which Equations 4.15, 4.16, 4.17 and 4.18 are nested in Equation 4.19.

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_4 lnY_{it}^3 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.15)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_4 lnY_{it}^3 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.16)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_4 lnY_{it}^3 + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.17)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_4 lnY_{it}^3 + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.18)$$

$$lnCO_{2it} = \beta_0 + \beta_2 lnY_{it} + \beta_3 lnY_{it}^2 + \beta_4 lnY_{it}^3 + \beta_5 lnA_{it} + \beta_6 lnT_{it} + \beta_7 ln\pi_{it} + \beta_8 lnEgr_{it} + \beta_9 lnEc_{it} + \beta_{10} lnDe_{it} + \beta_{11} lnD_{it} + \beta_{12} lnFDI_{it} + \beta_{13} lnO_{it} + \beta_{14} lnDf_{it} + \beta_{15} D_{1it} + \beta_{16} D_{2it} + \beta_{17} lnI_{it} + \beta_{18} lnP_{it} + \beta_{19} lnUp_{it} + \varepsilon_{it} \quad . \quad . \quad . \quad (4.19)$$

The formulation of the static models in Equation 4.5 to 4.19 is informed by Shafik and Bandyopadhay (1992) who formulated the log-linear, log-quadratic and log-cubic models. On the premise that CO_2 is the most concentrated greenhouse gas in the air and it can persist for over 100 years once emitted (Cunha-e-Sá 2008), the study would also introduce a period lagged logarithm of CO_2 emissions ($lnCO_{2it-1}$) into the models in Equation 4.5 to 4.19. This makes dynamic panel models which would test if past CO_2 emissions have an effect on today's CO_2 emissions and put into consideration likely endogeneity of the selected variables (see Tamazian and Rao 2010; Grunewald and Martinez-Zarzoso 2011; Li *et al*. 2015). In other words, like Tamazian and Rao (2010), the study estimates both the static (on the assumption of exogeneity) and dynamic (to correct for endogeneity) version of the specified models and cointegration test is conducted to identify spurious relationship (see Stern 2004).

All the variables (except the dummy variable for French-speaking countries (*D_1)* and Dummy variable for Portuguese-speaking countries (*D_2)*) in all the panel models are logarithmic. This is not only to allow the coefficients to be interpreted in terms of elasticity. It is also applied to reduce any likely problem of heteroscedasticity which is notorious in panel models (see Stern 2004). As suggested by Mazzanti *et al*. (2006), the multivariate investigations would add robustness to the expected results.

4.4 Data Description and A Priori Expectations

The study variables are selected based on data availability and appropriateness for most SSA countries so as to avoid having a highly scanty unbalanced panel data.

CO_2 emission per capita is the explained variable. It is used as a proxy for carbon emissions. It includes CO_2 that is produced during the consumption of solid, liquid and gas fuels and gas flaring. They are measured in metric tonnes. Out of all greenhouse gases, *CO_2* is the most concentrated in the atmosphere. Its data situation is the most prominent of any pollutant as relatively more time series are available for many developing countries (Roberts and Grimes 1997; Al-Sayed and Sek 2013). As such it is a good proxy. Other variables mentioned below are the explanatory variable.

These variables are used as indicators for Economic development-

GDP per capita serves as a proxy for income. It is measured as gross domestic product (GDP) divided by population. It is in constant 2005 U.S. dollars, this makes it real GDP per capita. According to theory, Income represents scale effect, i.e. the effect of an increase in economic activity on emissions. GDP per capita squared takes in factors like output composition and environmental awareness that are varying in the economy as GDP per capita increases (de Bruyn 1997). In another word, GDP per capita squared shows what happens to CO_2 emissions as income increases while cubed GDP per capita depicts what further happens to CO_2 emissions as income experiences further increase.

All the models in the previous section are specified because there is no one-fit-for-all growth-pollution relationship (He 2009). The best fit model(s) would produce one of these seven results as the relationship between CO_2 and income per capita (Y): monotonically falling or increasing, inverse U-shape i.e. the EKC, U-shape, N-shape, inverted N-shape or no relationship.

For the linear relationship: CO_2 would be monotonically increasing as Y rises if $\beta_2>0$ and it would be monotonically decreasing as Y rises if $\beta_2<0$. If the model(s) with the best fit is linear, the income elasticity of demand for a cleaner CO_2 environment ($\in$) would be β_2.

For the quadratic relationship: the EKC would exist if $\beta_2>0$ and $\beta_3<0$ (inverse U-shape) i.e. CO_2 increases as Y rises until it gets to a (turning) point where CO_2 starts to reduce as Y continues to rise. A U-shape relationship would exist between CO_2 and Y if $\beta_2<0$ and $\beta_3>0$ i.e. CO_2 reduces as Y rises until it gets to a (turning) point where CO_2 starts to increase as Y continues to rise. Irrespective of the type of quadratic relationship, the turning point is calculated as

$$e^{-\beta_2/2\beta_3} \quad . \quad . \quad . \quad (4.20)$$

Where e is exponential. If the model(s) with the best fit is quadratic, $\in$ (elasticity) would be calculated with the formula in Equation 4.21.

$$\in = \beta_2 + 2\beta_3 lnY \quad . \quad . \quad . \quad (4.21)$$

For the cubic relationship: if $\beta_2>0$, $\beta_3<0$, $\beta_4>0$, the N-shape would exist i.e. CO_2 increases as Y rises until it gets to a (turning) point where CO_2 starts to reduce as Y continues to rise and as Y rises further CO_2 increases again. If the coefficients are reversed in their signs $\beta_2<0$, $\beta_3>0$, $\beta_4<0$, the inverted N-shape would exist i.e. CO_2 reduces as Y rises until it gets to a (turning) point where CO_2 starts to increase as Y continues to rise and as Y rises further CO_2 reduces again. Irrespective of the type of cubic relationship, the turning point is calculated as

$$e^{\frac{-\beta_3 \pm \sqrt{\beta_3^2 - 3\beta_2\beta_4}}{3\beta_4}} \quad . \quad . \quad . \quad (4.22)$$

If the model(s) with the best fit is cubic, $\in$ would be calculated with the formula in Equation 4.23.

$$\in = \beta_2 + 2\beta_3 lnY + 3\beta_4 lnY^2 \quad . \quad . \quad . \quad (4.23)$$

Where increasing income yields a cleaner CO_2 environment, the income elasticity of demand ($\in$) is greater than one which means that a cleaner CO_2 environment is a luxury good (also called superior good). If it is less than one but greater than zero, a cleaner CO_2 environment is a necessary commodity while a cleaner CO_2 environment is an inferior commodity if income elasticity of demand is less than zero. If $\beta_2=\beta_3=\beta_4=0$, there would be no relationship between CO_2 and Y (see Shafik and Bandyopadhay 1992; Onafowora and Owoye 2013). All the studies in this area used income as an explanatory variable. Most of these studies found an inverted U-shape (the EKC) as the CO_2-income relationship (see the previous chapter).

The direction of other explanatory variables with CO_2 emissions would be determined from the results of the study's analysis.

Agriculture share as a percentage of GDP is the proxy for the agriculture sector and it is the value added of agriculture divided by GDP. The value added of agriculture includes the value from forestry, hunting, fishing, crops and livestock production. The primary sectors (crop and livestock production, fisheries, forestry and mining) are highly resource-intensive (like land and forest depletion) which end up into the release of carbon dioxide. Also, conventional agriculture which is the use of petrochemical fertilisers and pesticides contributes to emissions but organic farming has adaptation potential that supports the reduction in emissions (UNDESA *et al*. 2013). Agriculture as a share of GDP (A) would be reducing CO_2 if the coefficient $\beta_5<0$ but it would be increasing CO_2 if $\beta_5>0$. That is, agricultural practices could reduce or indulge CO_2. This would be a contribution to the literature of panel studies in this area.

Trade as a percentage of GDP is the sum of exports and imports of goods and services divided by GDP. It is also called openness to trade. Under free trade, the Heckscher-Ohlin trade theory suggests that developing countries would specialise in the production of commodities that are labour and natural resources abundant for exportation. This specialisation is usually pollution-intensive. Developing countries also serve as dumping ground for outdated technology through importation from developed countries (Begun and Eicher 2008). All these would most likely stimulate an increase in emissions of carbon into the atmosphere, referred to as 'pollution haven effect' (Cole 2004). As such, the study expects $\beta_6>0$. However, Trade as a percentage of GDP (T) could have a negative relationship with CO_2 ($\beta_6<0$) if developing countries have a comparative advantage in cleaner industries. Another explanation for this is that increased openness may lead to increased competition, which could cause more investment in efficient and cleaner technologies that meet climate change mitigation actions (Shafik and Bandyopadhyay 1992). Table 4.2 contains a list of studies that used trade openness. The first three and last three studies all found a positive relationship between trade openness and CO_2 for developing countries while Onafowora and Owoye (2013) found a negative relationship for developed economies. However, Shahbaz *et al*. (2011a), Shahbaz *et al*. (2012a), Shahbaz *et al*. (2012b) and Charfeddine and Khediri (2016) found a negative relationship for South Africa, Indonesia, Malaysia and UAE which are not developed countries. Thus, the pollution haven effect does not apply to all developing countries.

Table 4.1: Studies that used Trade Openness

Studies	Outcome
Zugravu *et al*. (2008)	+ for 60 emerging and developed nations
Tamazian and Rao (2010)	+ for transitional economies
Boopen and Vinesh (2010)	+ Mauritius
Shahbaz, Tiwari & Nasir (2011a)	– South Africa
Shahbaz, Adnan & Tiwari (2012a)	– Indonesia
Shahbaz, Solarin & Mahmood (2012b)	– Malaysia
Charfeddine & Khediri (2016)	– United Arab Emirates (UAE)
Alege and Ogundipe (2013)	+ Nigeria
Gholami and Shafiee (2013)	+ for OPEC countries
Onafowora and Owoye (2013)	+ for developing countries – for developed countries

+ denotes that trade increases CO_2; – denotes that trade decreases CO_2

Source: Author (2016)

The *inflation rate* is measured as the annual growth rate of GDP implicit deflator. It depicts the annual rate of price change in an economy. According to Hoffmann (2011), if developing countries attract carbon-intensive commodities, as inflation rate rises, the carbon-intensive commodities are consumed while substitute clean commodities are either not affordable or not available to buy. This may result in higher emissions. Due to this, the study expects $\beta_7>0$ but if substitute clean commodities are available and affordable as inflation rate rises then $\beta_7<0$ is obtainable. Tamazian and Rao (2010) found that inflation rate has a negative relationship with CO_2 but the coefficient is asymptotically equal to zero which practically eliminates its effect.

Employment generation rate is the percentage increase in the number of persons employed (Bassi and Lombardi 2013). The United Nations Environmental Programme (UNEP 2011) stipulates that the transition to a green economy is seen as when investments drive green growth and green jobs that support carbon emissions reduction. Although the region collectively expressed its determination in 2012 at the African Ministerial Conference on Environment, some SSA countries (like Ethiopia, Kenya, Malawi, Rwanda, South Africa and Tanzania) have since 2008 made progress planning and implementing low-carbon development strategies (Nhamo 2014b). For policy evaluation reasons, it is prudent to explore whether the rate of employment generated *(Egr)* in SSA support a cleaner CO_2 environment on the premise that the creation of green jobs promotes employment generation (Deschenes 2013). Empirically close to this, Boopen and Vinesh (2010) found a significant negative relationship between school enrolment ratio and CO_2 emissions for Mauritius (an SSA-country). Just as education helps to reduce emissions through climate change awareness programmes, the more the green jobs generated the more it promotes employment generation, and the more aware and sensitised employed people are about reducing their carbon footprint. Hence, the study expects the coefficient of employment generated $\beta_8<0$. This is also a contribution to the literature of panel studies in this area.

Total primary energy consumption per capita describes the amount of energy used by each person in a country per year. In another word, it is the ratio of energy consumption and population (Arouri *et al*. 2012). This variable includes the consumption of fossil fuels (such as coal and crude oil outputs –like petrol and natural gas), nuclear, renewable electricity and net electricity imports. The inclusion of energy consumption in studies on carbon emissions is not a new indicant in the literature (see Carvalho and Almeida 2010; Tamazian and Rao 2010; Arouri *et al*. 2012; Shahbaz, Adnan and Tiwari 2012a; Shahbaz 2013). In fact, whenever CO_2 emissions are discussed what tops the list is the consumption of fossil fuels for energy and indeed it is the major source of human-induced CO_2 emissions (Goodland and Anhang 2009). This is arguable because energy consumption has been found to stimulate economic activity and resultantly lead to increase in CO_2 emissions (Shahbaz, Solarin and Mahmood 2012b). This takes place, especially, in most developing countries where cheap fuels (like coal) are used to meet energy needs (Duflo *et al*. 2008). With respect to this, studies in the literature have found that energy consumption *(Ec)* increases CO_2 emissions. Thus, disregarding the role of energy consumption in our modelling may cause a specification bias (Balaguer and Cantavella 2016). The study a priori expects a rise in energy consumption increases CO_2 emissions (i.e. $\beta_9>0$). Finding an increasing impact of energy consumption on CO_2 emissions will be in line with the popular view that energy consumption is the main source of CO_2 emissions (Onafowora and Owoye 2013). If this research does not find a positive relationship between energy consumption and CO_2 emissions then more and more renewable energy sources may have been substituted for fossil fuels (Neumayer 2004).

The *degree of economic development* is measured as the ratio of GDP per capita of an economy relative to the maximum GDP per capita among the sampled economies for every year. This variable interprets the later degree of development in an economy. The optimistic critique of EKC suggests that the level of the curve drops and shifts to the left as growth generates less pollution in the early stages of industrialisation and pollution begins falling at lower income levels (Dasgupta *et al*. 2004). This scenario is known as the revised EKC (see the previous chapter). The Degree of economic development (*De*) was used by Taguchi (2012) to identify the existence of revised EKC scenario. If $\beta_{10}>0$ then there is a linkage between the later development of an economy with lower CO_2 emissions but if $\beta_{10}<0$ then it means that the revised EKC does not exist. Taguchi (2012) found a negative relationship between the degree of economic development and CO_2, i.e. he did not find the revised EKC for his sampled 19 countries.

The most popular reason for the introduction of financial development to the link between CO_2 emissions and development is that the financial sector has the ability to render superior financial services to eco-friendly programs that would reduce CO_2 emissions in developing countries (Tamazian *et al.* 2009). However, there is an alternate opinion that since developing countries attract material-intensive commodities (Hoffmann 2011), the financial sector would mostly provide financial assistance for the production and consumption of carbon-related commodities (World Bank 2000). This would increase the volume of emissions even with good environmental policies (Jensen 1996). Accordingly, evidence has been found to support that financial development reduces CO_2 emissions in some case studies while it contributes to emissions in other case studies (even when the same financial development indicator(s), estimation method and procedure are used). Thus, if financial development indicators (except the degree of financial development) reduces CO_2, the study expects the coefficients of domestic credit to private sector to GDP *(D), FDI* to GDP ratio, and official exchange rate (*O)* to be less than zero i.e. β_{11}, β_{12} and $\beta_{13}<0$, respectively. If financial development influences CO_2, then β_{11}, β_{12} and $\beta_{13}>0$ is expected.

Domestic credit to private sector to GDP ratio is the finance provided to the private sector by financial institutions divided by GDP. It represents the role of financial intermediaries in channelling funds to participants in private markets (Boutabba 2013). Table 4.3 depicts studies that used domestic credit to private sector to GDP ratio as a proxy for financial development. Even though they used similar estimation method and procedure for different case studies, all the studies, except Boutabba (2013), Charfeddine and Khediri (2016) and Javid and Sharif (2016), found that domestic credit to private sector to GDP ratio helps to achieve lower CO_2 emissions. Boutabba (2013), Charfeddine and Khediri (2016) and Javid and Sharif (2016) found that it increases CO_2 which implies that maybe the domestic credit provided to the private sector are not applied to low-carbon investments in India, UAE and Pakistan. The contradiction between Shahbaz (2012) and Javid and Sharif (2016) on Pakistan may be due to the difference in their study periods.

Table 4.2: Studies that used Domestic credit to private sector to GDP ratio (*D*)

Studies	Outcome
Shahbaz, Tiwari & Nasir (2011a)	– South Africa
Shahbaz, Adnan & Tiwari (2012a)	– Indonesia
Shahbaz (2012)	– Pakistan
Shahbaz, Solarin & Mahmood (2012b)	– Malaysia
Boutabba (2013)	+ India
Charfeddine & Khediri (2016)	+ UAE
Javid & Sharif (2016)	+ Pakistan

+ denotes that *D* increases CO_2; – denotes that *D* decreases CO_2
Source: Author (2016)

Foreign direct investments (FDI) to GDP ratio is defined as the net inflows of investment in an economy divided by GDP. This variable measures the contribution of foreign funds in an economy to reduce or influence CO_2. This variable is a *de facto* measure of financial openness (Quinn *et al*. 2011). Table 4.4 shows studies that used FDI. The first three studies found that increasing FDI leads to decrease in CO_2 emissions. This finding supports the premise that FDI (or multinational plants) in developing countries are more likely to act as a conditional factor that motivates the procurement and use of energy efficient and cleaner technologies. On the contrary, the last two studies found that increasing FDI leads to increase in CO_2. The similarity in results may be due to the similar estimation method applied by Shahbaz *et al*. (2012b) and Alege and Ogundipe (2013).

Table 4.3: Studies that used FDI

Studies	Outcome
Tamazian *et al*. (2009)	– for BRIC countries
Tamazian and Rao (2010)	– for transitional economies
Ajide & Oyinlola (2010)	– Nigeria
Shahbaz, Solarin & Mahmood (2012b)	+ Malaysia
Alege and Ogundipe (2013)	+ Nigeria

+ denotes that *FDI* increases CO_2; – denotes that *FDI* decreases CO_2
Source: Author (2016)

Meanwhile, for example, the difference in results obtained by Ajide and Oyinlola (2010) and Alege and Ogundipe (2013) may be due to the difference in estimation methods, the period of study, the vector of additional variables and/or models specified.

Official exchange rate is the proxy for the foreign exchange rate. It is the exchange rate determined in the international exchange market i.e. the foreign exchange (FOREX) market. It is measured as a local currency relative to the U.S. dollar. The FOREX market is the largest financial market in the world, measured by its daily turnover (Barker 2007). No study has considered the price of a nation's currency in terms of another currency in the literature. This is because studies (for example, Tamazian *et al*. 2009; Ajide and Oyinlola 2010; Zhang 2011) have focused on other financial market indicators (for example, stock market capitalisation to GDP and stock market turnover to GDP). Although this research would have followed in this direction, data for such and similar indicators for most SSA countries are inadequate. Due to data adequacy, the choice of the official exchange rate *(O)* is backed by the literature in which Tamazian and Rao (2010) used an interactive measure of FOREX and trade liberalisation. Their results indicate that the interactive measure has a positive but statistically insignificant effect on CO_2 emissions. Using these indicators (in quantitative and not qualitative manner i.e. trade openness and official exchange rate) separately, the research may obtain significant results. If exchange rate depreciation supports the importation of energy-efficient technologies and cleaner commodities while promoting exports, the official exchange rate may limit CO_2 emissions. Meanwhile, if exchange rate depreciation supports the importation of energy-inefficient technologies and carbon-oriented commodities while promoting exports, official exchange rate may stimulate an increase in emissions.

The *degree of financial development* is measured as the ratio of financial deepening of an economy relative to the maximum financial deepening among the sampled economies for every year. Financial deepening is measured as the ratio of money supply to GDP. The degree of financial development (*Df*) is used to know if there is a linkage between later development in a financial sector with lower CO_2 emissions. If $\beta_{14}>0$ then there is a linkage between later development in a financial sector with lower CO_2 emissions but if $\beta_{14}<0$ then it means that later development in a financial sector would lead to higher CO_2 emissions.

The type of foreign incursion experienced by each SSA country before their respective independence is the genesis of the heterogeneity in the way carbon-related resources are exploited and managed in the region. Decades after their independence, SSA countries' trading partners still largely remain their colonial masters (Nhamo 2009a). This study makes use of *dummies* to represent official languages so as to estimate if there is any difference in the level of CO_2 emissions among the countries i.e. resource management. The use of dummies in this study area is not new: Azomahou *et al*. (2009) used dummies to represent regions but they did not give any report on their effects. Tamazian *et al*. (2009) used a dummy variable for financial liberalisation and they found that financial liberalisation leads to a decline in CO_2 emissions. In this study, English-speaking SSA countries serve as the benchmark and so it would be taken as the constant β_0, D_1 represents the dummy variable for French-speaking SSA countries with the coefficient β_{15} and D_2 represents the dummy variable for Portuguese-speaking SSA countries with the coefficient β_{16}. If β_{15} and $\beta_{16}=0$ then there is no difference in the level of CO_2 emitted by French and Portuguese-speaking countries compared with the base (i.e. English-speaking SSA countries). If β_{15} and $\beta_{16}>0$, it means that there is a higher level of CO_2 emissions among the French and Portuguese-speaking countries than the English-speaking countries. If β_{15} and $\beta_{16}<0$, it means that there is a lower level of CO_2 emissions among the French and Portuguese-speaking countries in comparison to the English-speaking countries.

Based on structural change, in the early stages of development, as agriculture and resource extraction intensifies, industrialisation starts to take off; thus both resource depletion and waste generation accelerate which leads to environmental pressure. The *Share of industry in GDP* is value added in mining, manufacturing, construction, electricity, water and gas divided by GDP. The Share of industry in GDP is expected to have a positive relationship with CO_2 emissions i.e. $\beta_{17}>0$. If $\beta_{17}<0$, then an increase in the share of industry in GDP decreases CO_2 emissions, i.e. there is sustainable industrial transformation which yields green growth.

Table 4.4: Studies that used share of industry in GDP (*I)*

Studies	Outcome
Egli (2001)	Not significant for Germany
He and Richard (2009)	+ Canada
Tamazian *et al*. (2009)	+ for BRIC countries

+ denotes that *I* increases CO_2
Source: Author (2016)

The assumption that industrial production is more polluting than agricultural production is based on the argument of early stages of development in structural change (He and Richard 2009). Hence, this variable would inform on whether the industry sector is more polluting than the agriculture sector. To do this, the share of industry in GDP and the share of agriculture in GDP are alternately controlled for in the panel models. Increasing income accompanied by the structural change from agriculture to industry provides a reason why an N-shaped curve may be obtained for CO_2 emissions in sun-samples of SSA countries (Carvalho and Almeida 2010). Table 4.5 shows studies that used the share of industry in GDP. The last two studies on the table found that increasing share of industry in GDP leads to increase in CO_2 emissions.

Environmental pressures have been noted to intensify not only because of structural transformation and rising affluence but also because of growing population and increasing urbanisation (UNCTAD 2012). This is the reason why this research controlled for these variables -population density and urban population as a percentage of total population.

Selden and Song (1994) argued that higher *population density* may lead to a decline in per capita pollution emissions because the benefit of abatement increases as more people are affected by pollution. That is high population density results into greater social conscience about environmental problems. Meanwhile, Panayotou *et al.* (2000) observed that, as an economy transforms agricultural-based to industrial-based, higher population density may lower transportation and electrification costs but increases emissions level. Population density *(P)* is the proxy for emissions caused by increasing population and it is measured as the mid-year population divided by land area in square kilometres. Thus, the coefficient (β_{18}) of population density is expected to have a negative effect on CO_2 emissions, i.e. an increase in *P* causes a reduction on CO_2 ($\beta_{18}<0$). However, if high population density leads to more CO_2 emissions, then $\beta_{18}>0$ could be the case. That is, increasing population density places pressure on natural resources (like coal), causing more CO_2 emissions (Panayotou 1997). In Table 4.6, Carvalho and Almeida (2010) found that increasing population density leads to lower CO_2 emissions while Onafowora and Owoye (2013) found that increasing population density makes CO_2 emissions higher. This difference may be because Carvalho and Almeida (2010) conducted a panel study while Onafowora and Owoye (2013) conducted a cross-sectional time series study.

Table 4.5: Studies that used population density (*P*)

Studies	Outcome
Carvalho and Almeida (2010)	– For developed and developing nations
Poudel, Paudel & Bhattarai (2009)	Not significant 15 Latin American nations
Onafowora and Owoye (2013)	+ For eight countries

+ denotes that *P* increases CO_2; – denotes that *P* decreases CO_2
Source: Author (2016)

As an economy transforms, more of its population leave the rural areas for urban centres in search for white collar jobs (Cole and Neumayer 2004). Africa is recognised as the fastest urbanising continent in the world (United Nations 2012). Studies have found that increasing urban population increases fossil fuel demand thereby generating more CO_2 emissions (see, Shahbaz, Tiwari and Nasir 2011a; Hossain and Hasanuzzaman 2012). As such, the study expects $\beta_{19}>0$ but if $\beta_{19}<0$ (as Charfeddine and Khediri (2016) found in the case of UAE) then increasing urban population generates less CO_2 emissions. That is, increase in urbanisation takes into account having a cleaner CO_2 environment. *Urban population as a percentage of total population* is the number of people living in urban areas divided by total population.

A period Lagged CO_2 *emission* ($lnCO_{2it-1}$) is considered as an additional explanatory variable by Tamazian and Rao (2010), Grunewald, Martinez-Zarzoso (2011) and Gholami and Shafiee (2013). They all found that previous period's CO_2 emissions significantly drive current period's

CO_2 emissions. If the coefficient of $lnCO_{2it-1}$ is β_1, the study expects $\beta_1>0$. A high positive and significant value of the coefficient means that there is stickiness in CO_2 emissions that need to be controlled on time because it influences following periods (Gholami and Shafiee 2013). Short and long run elasticities are obtainable from the dynamic panel models that would be specified. The short run elasticity would be obtained using the above-said formulas while the long-run elasticity would be obtained using:

$$\in = {\beta_k}/{(1-\beta_1)} \qquad . \qquad . \qquad . \qquad (4.24)$$

That is, the long run coefficients of the regressors would be obtained by dividing the short run coefficients with $(1-\beta_1)$. The essence of applying most of the study variables in per capita or percentage measure is to make room for differences in terms of the residuals among SSA countries. This is expected to reduce the problem of heteroscedasticity (Liddle 2015).

Data on all the above-mentioned variables are sourced for 45 countries out of the 48 SSA countries from the World Bank's database named the World Development Indicator (WDI) (2013 and 2015), except for total primary energy consumption per capita which is from the United States Energy Information Administration (EIA) (2015) and data on employment which is from the World Bank's Africa Development Indicators (ADI) (2013). These three countries (Sao Tome, Somalia and South Sudan) are not considered in this study because they have a more than 50% attrition rate in their data availability. The EIA and World Bank database are chosen as the sources of data for the variables not only because they have the data this study requires but also because they have been found as sources used by researchers in the literature. To mention a few, Carvalho and Almeida (2010) and Al-Mulali and Che (2012) sourced data from the EIA as did Grunewald and Martinez-Zarzoso (2011) and Onafowora and Owoye (2013) from the WDI.

The countries selected for this study are itemised in Table 4.7. The sample can be divided into four clusters of income levels as recognised by the World Bank as at July 2015: low (24 countries), lower-middle (13 countries), upper-middle (six countries) and high-income levels (two countries). Aside from making a panel analysis on all the 45 countries, analyses would be made using these clusters. Thus, a sub-sample-specific dimension is expected from the empirical findings of this panel study on the impact of income and other variables on per capita CO_2 emissions in SSA. That is, this study expects the explained variable (per capita CO_2 emissions) to respond differently to the above-outlined regressors under the total sample and each of the sub-samples.

Table 4.6: List of selected sample of SSA countries

Country	Low-income	Lower-middle	Upper-middle	High-income
Angola			✓	
Benin	✓			
Botswana			✓	
Burkina Faso	✓			
Burundi	✓			
Cameroon		✓		
Cape Verde		✓		
Central African Republic	✓			
Chad	✓			
Comoros	✓			
Congo Democratic Republic	✓			
Congo Republic		✓		
Cote d'Ivoire		✓		
Equatorial Guinea				✓
Eritrea	✓			
Ethiopia	✓			
Gabon			✓	
Gambia	✓			
Ghana		✓		
Guinea	✓			
Guinea Bissau	✓			
Kenya		✓		
Lesotho		✓		
Liberia	✓			
Madagascar	✓			
Malawi	✓			

Mali	✓			
Mauritania		✓		
Mauritius			✓	
Mozambique	✓			
Namibia			✓	
Niger	✓			
Nigeria		✓		
Rwanda	✓			
Senegal		✓		
Seychelles				✓
Sierra Leone	✓			
South Africa			✓	
Sudan		✓		
Swaziland		✓		
Tanzania	✓			
Togo	✓			
Uganda	✓			
Zambia		✓		
Zimbabwe	✓			
Total number in each level	24	13	6	2

Source: World Bank (2015)

The period of this study is 1989-2012. The reason for choosing this period is to examine how the explanatory variables influence changes in CO_2 emissions in SSA in the period after which the issue of climate change started developing i.e. a year after the creation of the Intergovernmental Panel on Climate Change (IPCC) in 1988 and before the Africa Development Bank's (AfDB) ten-year strategy 2013-2022 on climate change and transition to a green economy. As mentioned earlier, this study applies an unbalanced panel data. One of the reasons for this is to have a relatively recent study period. For instance, data for the above-mentioned explained variable is available only up to 2011. The other reason is to have a well representative number of SSA sample countries. For this, a balanced panel data is not feasible because about half of all SSA countries have data with missing observations for few years. Thus, using a balanced panel data for half (24) of the total 48 SSA countries as the sample is not a fair representation of the region of study like the research's chosen sample of an unbalanced panel data of 45 SSA countries. In support of this action, Baltagi (2005) remarked that, although a high attrition rate in a particular unbalanced data increases the degree of computational difficulty during estimation, a modest attrition rate generates relatively efficient results than extracting a sub-balanced panel from an unbalanced panel data. Aside from the general reason that data on some countries can be traced back longer than others, Baltagi's (2005) observation is the other ground on which the application of an unbalanced panel data is becoming popular in this area of study (see for example, Zugravu *et al*. 2008; Grunewald and Martinez-Zarzoso 2009; Pandelis 2012; Liddle 2015).

4.5 Method of Data Analysis

This is a panel study with the advantage of an increase in sample size which possesses the statistical advantage of consistent estimators but plagued with heteroscedasticity and autocorrelation. Dijkgraaf and Vollebergh (2005) found that the crucial assumption of homogeneity across countries when ordinary least squares are used in panel studies is problematic in estimating the EKC model. In the presence of this, the Feasible Generalised Least Squares (FGLS) should be used in order to obtain consistent coefficient estimates because it gives room for correcting for both heteroscedasticity and autocorrelation (Panayotou *et al*. 2000).

Since this study is using an unbalanced panel data, the FGLS (Groupwise heteroscedasticity and serial correlation) method is applied when the number of the cross-section (N) is greater than the number of the time period (T) but not when $N<T$ (Reed and Ye 2011). For $N \leq T$ (and the panel data is unbalanced), the regression with Panel-Corrected Standard Error (PCSE) is recommended because the standard error estimates from FGLS becomes anticonservative (which may be unreliable) when the number of the cross section is smaller or equal to the time period (Beck and Katz 1995). The PCSE also gives room for correcting for both heteroscedasticity and autocorrelation, referred to as Prais-Winsten regression (StataCorp 2015). Thus, FGLS (Groupwise heteroscedasticity and serial correlation) would be used to estimate the specified

panel models in Equation 4.5 to 4.19 for the total sample of 45 SSA countries while the sub-samples of 24 low-income countries; 13 lower-middle-income countries (MICs); six upper MICs and two high-income countries of the region would be estimated with PCSE (Prais-Winsten regression). FGLS has been used by Carvalho and Almeida (2010), Luzzati and Orsini (2010) and Tamazian and Rao (2010). However, the PCSE has not been used by any study in this area.

Halkos (2003) pointed out that the use of a static model could be justified only if it represents an equilibrium relationship. Since an equilibrium relationship between pollution and income may and may not exist in the observed data, a dynamic model approach has been included to provide statistically sound estimates. The dynamic panel model is estimated by inserting a lagged dependent variable as a regressor into Equation 4.5 to 4.19 for materialising a partial adjustment towards an equilibrium emissions level.

The econometric concern for specifying dynamic panel models is potential endogeneity. As suggested by many studies (see for example, Arrow *et al*. 1995; Stern *et al*. 1996; Stern 2004), estimating the panel models expressed in Equation 4.4 to 4.18 may suffer simultaneity bias as it is inappropriate to assume that unidirectional causality runs from regressors to carbon emissions. Tamazian and Rao (2010); Grunewald and Martinez-Zarzoso (2011); Taguchi (2012) and Han and Lee (2013) address this problem by using the Generalised Method of Moments (GMM) in estimating EKC dynamic panel models. The GMM is an approach used when facing heteroscedasticity of unknown form. It was introduced by Arellano and Bond (1991) with further development by Blundell and Bond (1998). GMM, as introduced by Arellano and Bond (1991), is referred to as difference GMM while that of Blundell and Bond (1998) is referred to as system GMM.

The difference GMM estimation starts by differencing all regressors as such the inconsistency arising from simultaneity bias, bias from the differenced lagged dependent variable and individual effects are removed. The differenced estimator has been used in EKC studies by Grunewald and Martinez-Zarzoso (2011); Taguchi (2012) and Han and Lee (2013). The first difference transformation that occurs under difference GMM does have a weakness: it magnifies gaps in unbalanced panels. For example, if some data on y_{it} (dependent variable) is missing then both Δy_{it} and Δy_{it-1} would be missing in the transformed data. The difference GMM estimator also suffers from a weak instrument problem when the dynamic panel autoregressive coefficient (ρ) approaches unity (Han and Phillips 2010).

Blundell and Bond (1998) demonstrate in separate simulations that if the dependent variable is close to a random walk i.e. non-stationary then difference GMM performs poorly. This is because past levels convey little information about future changes, so that untransformed lags are weak instruments for transformed variables. Thus, Blundell and Bond (1998) introduced the system GMM. The system GMM has been shown to be a better efficient estimator than the difference GMM (see for example, Soto 2009; Grunewald and Martinez-Zarzoso 2011). Instead of transforming the regressors to expunge fixed effects, the system GMM differences the instrumental variables to make them exogenous to fixed effects. “In a nutshell, where Arellano-Bond instruments differences (or orthogonal deviations) with levels, Blundell-Bond instruments levels with differences” (Roodman 2009:114). These authors (Tamazian and Rao 2010; Grunewald and Martinez-Zarzoso 2011; Li *et al*. 2015) have used the system GMM. Like them, this research would apply the system GMM to estimate for the forty-five sample countries but not the four sub-samples. This is because GMM can only be used when the number of the cross-section (*N*) is large and the number of the time period (*T*) is small. In the case of this study, the standard errors and the Arellano–Bond autocorrelation test may be unreliable if we apply GMM to the sub-samples because their *N* is small (Roodman 2009). Thus, the Instrumental Variable (IV) estimator is unbiased for this scenario of dynamic panel analysis (Hsiao and Zhang 2015). Table 4.8 presents a summary of the selected and discussed estimation methods.

Table 4.7: Summary of estimation methods

	Condition	Static Model	Dynamic Model
Sample of 45 SSA countries	$N > T$	FGLS	GMM
Sub-samples based on income levels	$N \leq T$	PCSE	IV

Source: Author (2016)

4.6 Estimation Procedure

To achieve the objectives of this study, the models in Section 4.3 are logged. Using logarithmic models is a common phenomenon in the EKC literature (see for example, Choi *et al*. 2010;

Grunewald and Martinez-Zarzoso 2011; Arouri *et al*. 2012; Onafowora and Owoye 2013). This is partly because it allows an elasticity interpretation of the estimated coefficients and partly because the model fit is empirically better. Then, a descriptive statistic analysis is made by obtaining measures of central tendency (mean and median), a measure of variability (standard deviation) and the measure of linear relationship (correlation matrix) of all the variables.

Panel unit root tests are estimated to know the stationarity properties of the series of the variables. As suggested by Halkos (2003), panel cointegration test is conducted on pollution and income so as to know if they have an equilibrium relationship. It is necessary for the EKC regressions to cointegrate because only then would there be a long-run relationship (Galeotti *et al*. 2006); if not, the estimates will be spurious. Applying methods that can handle unbalanced panel data, the panel unit root tests are conducted using Im-Pesaran-Shin (IPS) test as introduced by Im *et al*. (2003) and Fisher-type test (based on Augmented Dickey-Fuller (ADF)) as proposed by Maddala and Wu (1999) and Choi (2001). Meanwhile, the panel cointegration test is conducted using the Pedroni cointegration test by Pedroni (1999).

Taking heteroscedasticity into account during the estimation stage seems to significantly improve the goodness of fit of globally aggregated fitted emissions to actual emissions (Stern 2004). As such, to take into account heteroscedasticity and serial correlation, FGLS (and PCSE for sub-samples) specification is used on the static models.

As noted in the previous section, estimating the panel models expressed in Equation 4.4 to 4.18 may suffer from simultaneity bias. As such, the system GMM (and IV for sub-samples) is applied to Equation 4.19 to 4.33. The system GMM, unlike the difference GMM, would help to avoid the problem of weak instruments. To ensure the validity of the system GMM, these diagnostic tests are noted: the Sargan test of overidentifying restrictions to test the validity of instruments and the Arellano-Bond Serial Correlation test to test for autocorrelation.

Simultaneity bias becomes less serious in static models that exhibit cointegration (Stern 2004). As such, after going through with the procedure outlined above for both sample and sub-sample countries, cointegration test is conducted on the static models. This would confirm that the static models are reliable but if otherwise then a partial adjustment towards an equilibrium emissions level (i.e. dynamic models) alone are relied upon for inferences. This is conducted with the ADF test procedure as suggested by Engle and Granger (1987).

4.7 Conclusion

To study the relationship which economic and financial development have with CO_2 emissions in SSA, this chapter specifies log-linear, log-quadratic and log-cubic models based on theory and empiricism. These models are all nested with chosen control variables. All the selected study and control variables have been defined and the a priori expectations identified. The taken estimation methods include FGLS and PCSE for static models and GMM and IV for dynamic models. The application of these estimation methods to the models presented in this chapter yields the analyses that are discussed in the next chapter.

CHAPTER FIVE: INTERPRETATION OF ESTIMATED RESULTS

5.0 Introduction

This study has discussed that the sub-Saharan Africa (SSA) is the most affected by the negative impact of climate change even though it contributes the least to global carbon emissions. It is no more business as usual (BAU) in SSA as efforts are being made to ensure clean development. It is, however, not clear whether past efforts reflect some reduction in carbon emissions in the region. Furthermore, this research considers both economic and financial development indicators. The economic development indicators are real GDP per capita, agriculture as a share of GDP, trade openness, inflation rate, employment generation rate, energy consumption per capita and the degree of economic development. These economic development indicators serve as control variables (the share of industry in GDP, population density and urban population as a percentage of total population). The selected financial development indicators are the ratio of domestic credit to private sector to GDP, the ratio of net inflow of foreign direct investment to GDP, official exchange rate and the degree of financial development which is measured as the ratio of financial deepening of an economy relative to the maximum financial deepening among the sample economies for every year. To evaluate the difference in the level of CO_2 emitted amongst English, French and Portuguese-speaking countries in SSA, dummy variables are used to identify the French and Portuguese-speaking countries for comparison with the emissions level of the English-speaking countries (the benchmark level of emissions).

To achieve the research objective, the discoursed theoretical, conceptual and empirical frameworks (provided in chapter three) were used to specify the methodology (in chapter four). The specified methods were applied to obtain the estimation results presented and interpreted in this chapter. An unbalanced sample of 45 SSA countries and four sub-samples of 24 low-income countries, 13 lower-middle-income countries, six upper-middle-income countries and two high-income countries for the period 1989 to 2012 were used. The sample and sub-samples were analysed using static estimation methods (Feasible Generalised Least Square (FGLS) and Panel-Corrected Standard Errors (PCSE)) and dynamic estimation methods (Generalised Method of Moments (GMM) and Instrumental Variable (IV) regression), as suitable.

This chapter starts with descriptive statistics which present the measures of central tendency and variability and the correlation matrix. Section two discusses the results of the integration tests. As suggested by Halkos (2003), the panel cointegration tests on carbon dioxide (CO_2) emissions and income are presented, so as to know if they have an equilibrium relationship, in the third section. The results of the regression on static models and dynamic models are submitted in section four. The fifth section delivers the cointegration tests on the residuals from the estimated static models. The sixth section focuses on the income elasticity of demand for environmental quality and the turning point income per capita while the last section is the conclusion to this chapter.

5.1 Descriptive statistics

5.1.1 Summary statistics

As a prelude to the extensive analysis conducted for this research, this section summarises the measures of central tendency and variability for the study variables under the entire sample of SSA countries and the sub-samples based on income levels in Table 5.1.

On average, the real GDP per capita (*Y*) for the high-income countries (HIC) is larger and the low-income group (LIC) is lower than the entire sample and other income groups. This confirms that the sub-samples are appropriately divided into income levels. The maximum statistic of the real GDP per capita for the entire sample is the same maximum statistic for HIC (i.e. Equatorial Guinea in 2008) while the minimum statistic for the entire sample is the same for LIC (i.e. Liberia in 1995). The same trend is observed for CO_2 emissions per capita but the maximum value is from Equatorial Guinea in 2003 while the minimum value is from Chad in 1991. The degree of economic development (*De*) rises with income level. HIC and the upper-middle-income countries (UMIC) have a higher average degree of economic development which indicates that they are more developed in SSA than LIC and lower-middle-income countries (LMIC). As such, LIC and LMIC have a wide room of later economic development to catch up.

Based on the process of structural change in economic development, interestingly, the average share of agriculture in GDP (*A*) is lowest in UMIC and not HIC and (as expected) highest in LIC.

Table 5.1: Measures of central tendency and variability

	CO_2	*Y*	*A*	*T*	*Π*	*Egr*	*Ec*	*De*	*D*	*FDI*	*O*	*Df*	*I*	*P*	*Up*
The entire sample of SSA countries															
Mean	0.816	1466.9	28.10	76.15	59.818	2.958	12.99	12.66	18.21	4.197	6260226	27.92	26.25	77.16	34.35
Maximum	10.26	15912	93.98	531.7	26765.9	15.14	193	100	167.5	161.8	6.72E+09	100	94.43	618.7	86.37
Minimum	0.011	69.579	1.954	10.95	-31.566	-16.52	0.3	0.74	0.724	-82.89	1.27E-09	3.03	1.882	1.653	5.342
Std Dev	1.778	2464.7	16.32	50.93	854.08	2.021	26.27	20.66	21.49	10.66	2.05E+08	19.70	14.41	108.6	14.80
Obs	1013	1076	1069	1063	1075	880	1074	1076	1015	1064	1074	1019	1062	1080	1080
SSA Low-Income Countries (LIC)															
Mean	0.157	346.72	37.58	57.20	79.868	3.038	2.838	3.068	12.03	3.439	11774779	24.07	18.66	81.28	27.28
Maximum	1.589	722.04	93.98	321.6	26765.8	11.26	23	7.928	103.6	89.48	6.72E+09	100	47.13	438.5	58
Minimum	0.011	69.579	7.414	10.95	-27.048	-7.549	0.3	0.74	0.724	-82.89	1.27E-09	3.030	1.882	4.582	5.342
Std Dev	0.218	137.49	12.81	31.52	1142.3	1.586	3.363	1.332	8.678	10.20	2.81E+08	17.95	7.452	94.63	11.23
Obs	547	572	569	562	571	480	571	572	533	560	571	536	565	576	576
SSA Lower-Middle-Income Countries (LMIC)															
Mean	0.451	969.05	22.67	83.26	14.948	2.887	7.641	8.455	17.11	3.990	187.78	26.81	31.56	53.09	38.84
Maximum	1.447	2711.7	49.42	209.9	165.53	15.14	23	22.94	65.74	37.27	733.03	79.51	77.41	184.7	64.1
Minimum	0.089	374.59	3.383	11.09	-29.172	-14.92	1.3	3.511	1.616	-3.285	0.0045	6.444	10.36	1.910	13.43
Std Dev	0.272	570.06	11.12	42.04	24.501	2.387	4.181	4.871	10.66	5.769	227.91	14.12	12.81	39.85	12.63
Obs	283	312	312	310	312	260	312	312	298	312	311	298	312	312	312
SSA Upper-Middle-Income Countries (UMIC)															
Mean	2.885	4486.7	6.835	94.85	94.941	2.775	40.76	39.28	46.12	2.529	96.197	41.96	42.18	106.3	49.56
Maximum	9.889	8280.3	24.03	178.9	5399.5	11.79	120	91.12	167.5	40.17	733.03	100	72.72	618.7	86.37
Minimum	0.018	973.81	2.032	38.65	-17.786	-16.52	7.1	9.839	2.014	-8.589	2.99E-08	10.35	23.67	1.653	24.95
Std Dev	2.834	1871.6	3.571	27.48	516.69	2.745	30.73	17.37	44.07	5.234	189.42	24.55	13.59	212.7	16.56
Obs	137	144	144	143	144	120	143	144	136	144	144	137	144	144	144
SSA High-Income Countries (HIC)															
Mean	4.727	8991.5	13.61	196.4	7.5876	1.541	85.92	74.54	14.63	19.38	252.48	37.88	34.48	96.79	44.39
Maximum	10.26	15912	62.56	531.7	64.735	3.907	193	100	33.29	161.8	733.03	87.88	94.43	195.2	52.91
Minimum	0.085	374.12	1.954	52.78	-31.566	0	4.3	4.186	2.149	-4.955	4.7619	3.233	9.669	13.03	33.76
Std Dev	3.311	4819.6	19.35	111.3	18.371	1.609	58.51	36.66	10.35	27.94	265.55	29.72	27.76	78.62	6.325
Obs	46	48	44	48	48	40	48	48	48	48	48	48	41	48	48

Source: Author (2016)

Note: Std Dev represents standard deviation while Obs represents the number of observations. Where CO_2 is emissions per capita, *Y* is the real GDP per capita, *A* is the share of agriculture in GDP, *T* is trade openness, π is inflation rate, *Egr* is employment generation rate, *Ec* is energy consumption per capita, *De* is the degree of economic development, *D* is domestic credit to private sector to GDP, *FDI* is foreign direct investment to GDP, *O* is official exchange rate, *Df* is the degree of financial development, *I* is the share of industry in GDP, *P* is population density and *Up* is urban population as a percentage of total population.

However, the share of agriculture in GDP varies between 1.95% (Seychelles in 2012) from HIC and 93.98% (Liberia in 1996) from LIC. Accordingly, UMIC has the highest average share of industry in GDP (*I*), HIC has the maximum share (Equatorial Guinea in 2005) while the minimum (Liberia in 1996) lies with LIC. The total primary energy consumption per capita (*Ec*) has the same trend with income level, the degree of economic development and CO_2 emission per capita but the maximum statistic of 193 Btu per person (British thermal unit) is from Seychelles in 2006 while the minimum is 0.3 Btu per person from Chad in 2012. While HIC has the highest average employment generation rate (*Egr*), LMIC has the maximum employment generation rate (Lesotho in 2006).[28] The average inflation rate (π) in SSA is this high (59.8%) because of inflation rates from low and upper-middle-income countries. With the lowest observed average inflation rate, inflation appears to be better controlled in HIC than other income groups.[29]

Averagely, HIC is the most open to trade (*T*) in SSA, followed by UMIC, LMIC and LIC, respectively. HIC, also, enjoys more net inflow of foreign direct investment to GDP (*FDI*) than other income groups but LMIC is more open to FDI than LIC while UMIC benefits from FDI the least with an average of 2.53%.[30] The domestic credit to private sector to GDP (*D*) ranges between LIC (the Central Africa Republic in 1991) and UMIC (South Africa in 2007) with minimum and maximum values of 0.724% and 167.5%, respectively. Looking at the average degree of financial development (*Df*), the financial sectors of UMIC and HIC are more developed than LIC and LMIC which implies a gap for later development of financial sectors in LIC and LMIC. The very high mean and maximum statistics of the official exchange rate (*O*), under the entire sample and LIC, is due to the very sharp devaluation of the Zimbabwean dollar experienced in 2008. Also, LIC has a concentration of countries with more devalued and depreciating Official exchange rates. In SSA, UMIC has the highest average population density (*P*) and the highest percentage of its population living in cities (urban population as a percentage of total population (*Up*)).

[28] The negative minimum values of employment generation rate imply that there was a percentage decrease in the number of persons employed.
[29] The minimum values of inflation rate are negative because they are expressed as the annual growth rate of GDP implicit deflator.
[30] The negative minimum values of the net inflow of FDI to GDP indicate that divestment is more than the investment made by non-resident investors in the reporting economy.

Compared with other sub-samples, the data series for the share of agriculture in GDP for LIC is clustered around the mean due to its high mean statistic with a relatively low value of standard deviation. The share of industry in GDP for LMIC and UMIC also has less variability. HIC and UMIC are identified to have less dispersed series for employment generation rate and trade openness, respectively. While HIC has a clustered series for urban population as a percentage of GDP, it has a high variability for domestic credit to private sector as a percentage of GDP because of its high standard deviation compared with other sub-samples. All other data set for the study variables vary more around their mean.

Thus, the summary statistics presented in Table 5.1 shows the diversity that exists in the entire sample of 45 SSA countries by creating four sub-samples based on income levels. To detect the degree of association among the study variables, correlation matrices are presented in the next section.

5.1.2 Correlation matrix

This section discusses the results obtained after testing the strength of association between the study variables. The pairwise correlation results for the entire sample and income groups of SSA countries are presented in Tables 5.2 to 5.6. Comparing the correlation matrices, there is generally a weak and moderate correlation between the explanatory variables with a few exceptions in the entire sample and sub-samples except for the high-income countries (HIC) (Table 5.6). The high negative correlation observed under the entire sample (Table 5.2) between real GDP per capita (*Y*) and the share of agriculture in GDP (*A*) was also obtained under lower-middle (LMIC) (Table 5.4) and HIC. Meanwhile, this is weak and moderate for low (LIC) (Table 5.3) and upper-middle-income countries (UMIC) (Table 5.5). A high direct correlation is also observed between real GDP per capita and energy consumption per person (*Ec*) for the entire sample, UMIC and HIC but not for LIC and LMIC. This is the same for the high inverse association between the share of agriculture in GDP and energy consumption per capita. The entire sample and HIC present a high negative correlation between the share of agriculture in GDP and the degree of economic development (*De*) while LMIC and UMIC present a moderate negative correlation and LIC presents a low negative correlation. A high positive linear relationship between real GDP per capita and the degree of economic development is persistent in all the sample and sub-samples.

Table 5.2: Pairwise correlation matrix for the entire sample of SSA countries

	lnCO_2	*lnY*	*lnA*	*lnT*	*lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
lnCO_2	1.000														
lnY	0.868	1.000													
lnA	-0.801	-0.872	1.000												
lnT	0.539	0.522	-0.505	1.000											
lnπ	-0.068	-0.103	0.039	0.075	1.000										
lnEgr	-0.095	-0.087	0.087	-0.064	-0.043	1.000									
lnEc	0.940	0.861	-0.802	0.475	-0.030	-0.105	1.000								
lnDe	0.858	0.986	-0.849	0.493	-0.088	-0.092	0.852	1.000							
lnD	0.489	0.369	-0.393	0.199	-0.178	-0.080	0.454	0.350	1.000						
lnFDI	0.213	0.234	-0.212	0.431	-0.002	0.073	0.207	0.193	-0.033	1.000					
lnO	-0.253	-0.157	0.202	-0.070	-0.304	0.098	-0.292	-0.201	-0.130	-0.107	1.000				
lnDf	0.378	0.274	-0.335	0.143	0.001	-0.073	0.367	0.290	0.729	-0.002	-0.324	1.000			
lnI	0.524	0.562	-0.634	0.441	0.078	-0.093	0.517	0.558	0.097	0.178	-0.146	0.011	1.000		
lnP	-0.066	-0.164	0.126	-0.089	-0.017	-0.131	-0.087	-0.186	0.186	-0.141	0.103	0.222	-0.277	1.000	
lnUp	0.618	0.591	-0.469	0.390	-0.122	0.060	0.615	0.563	0.123	0.340	-0.051	0.099	0.318	-0.287	1.000

Note: Correlation results written in Agency FB are not statistically significant while correlation results written in Times New Roman are statistically significant.

Table 5.3: Pairwise Correlation Matrix for SSA low-income countries (LIC)

	lnCO_2	*lnY*	*lnA*	*lnT*	*Lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
lnCO_2	1.000														
lnY	0.473	1.000													
lnA	-0.420	-0.294	1.000												
lnT	0.395	0.255	-0.247	1.000											
lnπ	-0.185	-0.205	0.065	-0.036	1.000										
lnEgr	0.026	0.040	-0.034	0.089	-0.088	1.000									
lnEc	0.869	0.354	-0.433	0.344	-0.064	-0.053	1.000								
lnDe	0.432	0.905	-0.244	0.121	-0.167	-0.013	0.325	1.000							
lnD	0.351	0.084	-0.271	0.172	-0.230	0.088	0.258	0.024	1.000						
lnFDI	0.165	0.186	-0.114	0.428	0.009	0.145	0.133	0.048	-0.030	1.000					
lnO	-0.267	0.026	0.126	-0.028	-0.166	0.106	-0.304	-0.104	-0.088	-0.065	1.000				
lnDf	0.330	0.061	-0.227	0.142	0.020	0.006	0.267	0.090	0.676	0.032	-0.286	1.000			
lnI	0.146	0.173	-0.597	0.022	0.051	-0.132	0.240	0.165	0.035	-0.012	0.013	0.024	1.000		
lnP	0.162	-0.069	-0.042	-0.083	0.067	-0.037	0.165	-0.135	0.229	-0.190	0.094	0.124	-0.085	1.000	
lnUp	0.495	0.452	-0.113	0.465	-0.101	0.109	0.452	0.346	-0.125	0.388	-0.059	-0.011	-0.034	-0.291	1.000

Note: Correlation results written in Agency FB are not statistically significant while correlation results written in Times New Roman are statistically significant.

Table 5.4: Pairwise correlation matrix for SSA lower-middle-income countries (LMIC)

	lnCO₂	*lnY*	*lnA*	*lnT*	*lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
lnCO₂	1.000														
lnY	0.408	1.000													
lnA	-0.236	-0.753	1.000												
lnT	0.592	0.460	-0.617	1.000											
lnπ	-0.135	-0.368	0.274	-0.185	1.000										
lnEgr	-0.141	-0.108	0.117	-0.190	-0.006	1.000									
lnEc	0.469	0.366	-0.185	0.236	-0.013	0.033	1.000								
lnDe	0.366	0.927	-0.657	0.407	-0.317	-0.090	0.305	1.000							
lnD	0.420	0.205	-0.048	0.271	-0.302	-0.031	0.131	0.158	1.000						
lnFDI	0.086	0.232	-0.277	0.268	-0.009	-0.024	0.155	0.136	-0.084	1.000					
lnO	0.235	0.363	-0.238	0.142	-0.538	0.110	0.069	0.296	0.347	-0.045	1.000				
lnDf	0.240	0.037	-0.070	0.202	-0.099	0.034	-0.081	0.099	0.693	-0.113	-0.026	1.000			
lnI	0.279	0.411	-0.541	0.590	-0.034	-0.090	0.301	0.383	-0.187	0.350	0.105	-0.243	1.000		
lnP	0.031	0.044	-0.028	0.089	-0.077	-0.189	-0.287	-0.010	0.379	-0.037	-0.062	0.335	-0.149	1.000	
lnUp	0.033	0.248	-0.107	-0.101	-0.257	0.238	0.305	0.172	-0.131	0.172	0.412	-0.192	0.067	-0.266	1.000

Note: Correlation results written in Agency FB are not statistically significant while correlation results written in Times New Roman are statistically significant.

Table 5.5: Pairwise correlation matrix for SSA upper-middle-income countries (UMIC)

	lnCO₂	*lnY*	*lnA*	*lnT*	*lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
lnCO₂	1.000														
lnY	0.608	1.000													
lnA	-0.641	-0.550	1.000												
lnT	-0.603	-0.347	0.370	1.000											
lnπ	-0.274	-0.659	0.156	0.164	1.000										
lnEgr	-0.199	-0.146	0.051	-0.057	0.080	1.000									
lnEc	0.857	0.771	-0.614	-0.625	-0.441	-0.229	1.000								
lnDe	0.568	0.934	-0.421	-0.400	-0.608	-0.104	0.732	1.000							
lnD	0.581	0.336	-0.257	-0.494	-0.276	-0.243	0.747	0.274	1.000						
lnFDI	-0.320	-0.287	0.017	0.310	0.183	0.087	-0.354	-0.341	-0.267	1.000					
lnO	0.301	0.591	-0.255	0.087	-0.461	-0.091	0.354	0.487	-0.237	-0.178	1.000				
lnDf	0.391	0.089	-0.104	-0.131	-0.081	-0.223	0.469	0.115	0.779	-0.157	-0.459	1.000			
lnI	-0.258	-0.242	-0.017	0.212	0.299	0.232	-0.468	-0.246	-0.847	0.180	0.062	-0.740	1.000		
lnP	0.305	0.051	-0.036	0.133	-0.015	-0.368	0.325	0.027	0.460	-0.177	0.069	0.622	-0.361	1.000	
lnUp	0.556	0.824	-0.553	-0.361	-0.446	-0.024	0.607	0.761	-0.042	-0.242	0.590	-0.281	0.216	-0.042	1.000

Note: Correlation results written in Agency FB are not statistically significant while correlation results written in Times New Roman are statistically significant.

Table 5.6: Pairwise correlation matrix for SSA high-income countries (HIC)

	lnCO₂	*lnY*	*lnA*	*lnT*	*lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
lnCO₂	1.000														
lnY	0.897	1.000													
lnA	-0.918	-0.980	1.000												
lnT	-0.266	-0.373	0.437	1.000											
lnπ	0.163	0.192	-0.270	-0.091	1.000										
lnEgr	0.659	0.682	-0.858	0.026	0.062	1.000									
lnEc	0.853	0.875	-0.922	-0.546	0.210	0.413	1.000								
lnDe	0.873	0.990	-0.966	-0.449	0.168	0.713	0.872	1.000							
lnD	0.217	0.101	-0.244	-0.306	0.036	-0.576	0.415	0.109	1.000						
lnFDI	-0.221	-0.199	0.276	0.572	-0.109	-0.146	-0.295	-0.228	-0.179	1.000					
lnO	-0.383	-0.432	0.603	0.658	-0.080	0.598	-0.641	-0.490	-0.756	0.270	1.000				
lnDf	0.221	0.271	-0.400	-0.613	0.054	-0.775	0.549	-0.323	0.819	-0.254	-0.936	1.000			
lnI	0.029	0.083	0.059	0.445	-0.049	0.931	-0.305	0.082	-0.813	0.358	0.608	-0.740	1.000		
lnP	0.544	0.614	-0.749	-0.593	0.143	0.463	0.768	0.651	0.700	-0.211	-0.967	0.881	-0.499	1.000	
lnUp	0.524	0.613	-0.749	-0.520	0.149	0.364	0.742	0.643	0.650	-0.121	-0.939	0.843	-0.445	0.989	1.000

Source: Author (2016)

Note: Correlation results written in Agency FB are not statistically significant while correlation results written in Times New Roman are statistically significant.

While a moderate positive association was found between real GDP per capita and urban population as a percentage of total population (*Up*) for other income groups, a high positive association was obtained for UMIC. A high negative association was also obtained between domestic credit to private sector to GDP (*D*) and the share of industry in GDP (*I*) under UMIC and HIC but not under the entire sample, LIC and LMIC. Although a moderate positive linear relationship exists between domestic credit to private sector to GDP and the degree of financial development (*Df*) under LIC and LMIC, a strong positive linear relationship was observed for the entire sample and UMIC while a high positive linear relationship was found under HIC.

Unlike other income groups, HIC bears a high direct correlation between employment generation rate (*Egr*) and the share of industry in GDP and between population density (*P*) and urban population as a percentage of total population. HIC also portrays that the share of agriculture in GDP has a strong negative correlation with population density and urban population as a percentage of total population; meanwhile, they are weak under other income groups and the entire sample. This is also observed for the association official exchange rate has with population density and urban population as a percentage of total population.

The presented correlation matrices identify the degree of independent variation among the explanatory variables (and not the cause and effect relationship). Thus, the above-identified high correlation among the explanatory variables can be argued to be large enough to cause a multicollinearity problem. This problem is said to inflate the standard errors of an estimated regression result and make the *t* statistics not significant (Aczel 1999). However, just as a near zero correlation between two explanatory variables (for example, inflation rate (π) and the degree of financial development) does not mean independence, the spotted high correlation in Table 5.2-5.6 may be a sufficient condition but definitely not an essential condition for the existence of multicollinearity (Gujarati 2014). This study leans on this argument as it is permissible by the literature. For illustration, in spite of the high correlation between GDP per capita and energy consumption, scholars (like Tamazian and Rao 2010; Arouri *et al*. 2012; Onafowora and Owoye 2013; Al-Mulali *et al*. 2015; Javid and Sharif 2016) explore the effect of GDP per capita and energy consumption on CO_2 emissions in the literature by using the finding of Kraft and Kraft

(1978) on the link between economic growth and energy consumption as the basis of their study.[31]

Aside from the literature's permissibility, the large sample and relatively large sub-samples used for this study would help to reduce any anticipated collinearity (Baek 2016). Furthermore, conducting cointegration tests before (and after) the static regression results and applying dynamic estimation methods (to take care of case(s) of no cointegration and endogeneity) are meant to support the reliability of the findings.

5.2 Integration tests

Pre-empirical analysis, this study conducts unit root tests on all the study variables. This is to follow the standard inference procedure by identifying and categorising the stationary and non-stationary variables. For robustness, the study applies the two panel unit root test methods that handle unbalanced panel data i.e. the Fisher-type test (based on Augmented Dickey-Fuller (ADF)) as proposed by Maddala and Wu (1999) and Choi (2001) and Im-Pesaran-Shin (IPS) test as introduced by Im *et al*. (2003). Both tests are conducted by including time trend and panel means.

The IPS test relaxes the assumption that all panels share a common autoregressive parameter. In other words, the test ensures a fit to each panel separately and then averages the resulting unit root test statistics. The null hypothesis for the IPS test is that all panels contain unit roots and the alternative hypothesis is that some panels are stationary (Im *et al*. 2003).

The Fisher-type test presents its results after using the four methods proposed by Choi (2001). These are the inverse chi-square test (P), inverse normal test (Z), inverse logit test (L*) and the modification of the inverse chi-square test (i.e. modified P (Pm)). The null hypothesis of the Fisher-type test is that all panels contain unit roots while the alternative hypothesis is that at least one panel is stationary.

[31] The general opinion is that an increase in economic growth leads to an increase in energy consumption which is associated with an increase in carbon emissions (Kraft and Kraft 1978).

Table 5.7: Unit root tests results

	lnCO₂	*lnY*	*lnA*	*lnT*	*lnπ*	*lnEgr*	*lnEc*	*lnDe*	*lnD*	*lnFDI*	*lnO*	*lnDf*	*lnI*	*lnP*	*lnUp*
The entire Sample of SSA countries															
Fisher-ADF:															
P	236.01	185.91	159.69	156.34	529.61	266.903	225.81	351.17	594.02	498.67	477.55	972.39	149.99	242.20	715.89
Z	-4.371	-1.747	-4.344	-3.331	-16.97	-5.6224	-6.057	-12.82	-18.69	-14.73	-16.28	-26.23	-3.027	-1.870	-12.83
L*	-6.861	-3.591	-4.470	-3.729	-21.58	-7.835	-7.261	-14.2	-24.31	-19.85	-19.69	-40.03	-3.207	-5.019	-28.71
Pm	10.883	7.149	5.195	4.945	32.767	13.4853	10.122	19.467	37.567	30.460	28.887	65.769	4.471	11.345	46.651
IPS	-7.062	-21.11	-3.958	-3.116	-15.85	-5.2135	-5.658	-11.55	-17.10	-13.94	-13.43	-25.46	-2.798	-40.93	-20.77
Diagnosis	I(0)[1]	I(0)[5]/ I(1)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(0)[1]	I(0)[5]/[1]	I(0)[1]/ I(1)[1]
lags	0	0	0	0	0	0	0	0	0	0	0	0	0	0/1	0
SSA Low-Income Countries (LIC)															
Fisher-ADF:															
P	72.887	418.90	90.633	99.955	252.95	133.89	137.90	205.43	297.98	201.82	255.25	487.87	442.88	1054.2	138.25
Z	-1.359	-15.99	-3.366	-3.100	-11.69	-3.347	-5.136	-9.881	-12.91	-8.725	-11.77	-18.29	-17.22	-26.84	-4.892
L*	-1.702	-23.57	-3.578	-3.621	-14.16	-5.1413	-6.453	-11.39	-16.70	-10.77	-14.55	-27.54	-24.98	-60.29	-6.557
Pm	2.540	37.845	4.351	5.303	20.916	8.766	9.176	16.068	25.513	15.699	21.152	44.894	40.303	102.69	9.211
IPS	-1.323	-15.36	-3.076	-2.902	-10.79	-3.2483	-4.834	-8.965	-11.78	-8.078	-9.522	-17.94	-16.39	-38.21	-3.520
Diagnosis	I(0)[10]	I(1)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(1)[1]	I(0)[1]	I(0)[1]
lags	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
SSA Lower-Middle-Income Countries (LMIC)															
Fisher-ADF:															
P	49.113	233.63	36.259	280.18	194.59	83.513	36.066	96.164	180.30	222.39	144.62	326.27	63.179	136.58	166.04
Z	-1.493	-11.63	-1.433	-14.24	-10.34	-3.4376	-1.545	-6.768	-10.55	-10.73	-9.191	-15.42	-3.323	-4.940	-3.701
L*	-2.053	-17.91	-1.435	-21.57	-14.78	-4.7372	-1.459	-7.294	-13.82	-16.77	-11.07	-25.13	-3.755	-10.54	-11.30
Pm	3.205	28.794	1.423	35.248	23.379	7.9756	1.396	9.729	21.397	27.235	16.449	41.64	5.156	15.335	19.419
IPS	-1.455	-13.57	-1.332	-13.75	-9.937	-3.2511	-1.399	-6.064	-9.635	-10.56	-8.413	-14.95	-3.056	-23.43	-31.87
Diagnosis	I(0)[10]	I(1)[1]	I(0)[10]	I(1)[1]	I(0)[1]	I(0)[1]	I(0)[10]	I(1)[1]	I(1)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(0)[1]	I(0)[1]	I(1)[1]
lags	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table 5.7 – (Continued): Unit root tests results

	$lnCO_2$	lnY	lnA	lnT	lnπ	lnEgr	lnEc	lnDe	lnD	lnFDI	lnO	lnDf	lnI	lnP	lnUp
SSA Upper-Middle-Income Countries (UMIC)															
Fisher-ADF:															
P	111.44	79.584	27.466	111.99	51.374	49.495	40.814	33.074	59.879	53.586	55.897	125.58	19.696	55.901	139.22
Z	-7.124	-6.443	-2.566	-8.693	-5.149	-4.59	-2.815	-3.476	-4.076	-5.089	-5.48	-9.794	-1.576	-2.643	-8.534
L*	-12.61	-8.950	-2.588	-12.78	-5.816	-5.3912	-3.708	-3.567	-6.329	-6.039	-6.334	-14.35	-1.597	-4.801	-17.31
Pm	20.298	13.796	3.157	20.412	8.037	7.6537	5.882	4.302	9.773	8.489	8.960	23.184	1.571	8.961	25.969
IPS	-14.67	-6.083	-2.303	-8.305	-4.682	-4.1049	-2.678	-2.971	-3.793	-4.669	-4.971	-9.249	-1.432	-2.432	-4.891
Diagnosis	I(0)[1]	I(1)[1]	I(0)[1/5]	I(1)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(0)[10]	I(0)[1]	I(0)[1]
lags	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0
SSA High-Income Countries (HIC)															
Fisher-ADF:															
P	53.631	10.408	32.988	34.997	30.697	14.2413	64.263	12.628	28.073	20.869	21.797	32.668	25.548	66.208	94.064
Z	-6.489	-2.036	-4.606	-5.089	-4.682	-3.1529	-7.334	-2.430	-3.972	-3.491	-3.508	-4.812	-4.129	-7.464	-8.679
L*	-10.88	-2.046	-6.683	-7.100	-6.228	-4.1964	-13.04	-2.525	-5.655	-4.218	-4.395	-6.627	-5181	-13.43	-19.08
Pm	17.547	2.265	10.249	10.959	9.439	3.6208	21.306	3.051	8.511	5.964	6.292	10.136	7.619	21.994	31.843
IPS	-6.348	-1.789	-4.292	-4.778	-4.382	Insufficient Periods	-7.337	-2.150	-3.745	-3.203	-3.217	-4.507	-3.651	-7.495	-17.35
Diagnosis	I(1)[1]	I(1)[5]	I(1)[1]	I(1)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(1)[5]	I(1)[1]	I(0)[1]	I(1)[1]	I(1)[1]	I(1)[1]	I(1)[1]	I(0)[1]
lags	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: Author (2016)

Note: P represents inverse chi-square, Z represents inverse normal, L* represents inverse logit and Pm represents modified inverse chi-square of the Fisher-type test. IPS represents the Im-Pesaran-Shin test. [1] denotes the rejection of the null hypothesis of non-stationarity at 0.01 level of significance, [5] denotes the rejection of the null hypothesis of non-stationarity at 0.05 level of significance and [10] denotes the rejection of the null hypothesis of non-stationarity at 0.1 level of significance. I(0) means an integration at order zero and I(1) means an integration at order one. The sign / indicates a different diagnosis of which the Fisher-type test is written to the left and the IPS is written to the right.

Table 5.7 presents the unit root tests results obtained. Under the results for the entire sample, CO_2 emission per capita, share of agriculture in GDP (*A*), trade openness (*T*), inflation rate (π), employment generation rate (*Egr*), total primary energy consumption per capita (*Ec*), net inflow of foreign direct investment to GDP ratio (*FDI*), share of industry in GDP (*I*) and population density (*P*) integrate at level (i.e. I(0)) at one percent level of significance. This means that at least one panel or some of the panels are stationary for these variables.

The degree of economic development (*De*), ratio of domestic credit to private sector to GDP (*D*), official exchange rates (*O*) and the degree of financial development (*Df*) integrate at first difference (I(1)) at one percent level of significance under the entire sample. This signifies that all the panels for these variables contain unit roots and so they are non-stationary at level but are stationary at a higher order of integration. The Fisher-type test and the IPS test do not agree on the order of integration for real GDP per capita (*Y*) and urban population as a percentage of total population (*Up*). The Fisher-type test gives a diagnosis of stationarity for the two variables at level (I(0) at five and one percent level of significance respectively) while the IPS gives a diagnosis of integration to order one (I(1) at one percent level of significance) for the two variables.

The results for the sub-samples are consistent with the entire sample for real GDP per capita, inflation rate, the net inflow of foreign direct investment to GDP ratio, official exchange rates, the degree of financial development and urban population as a percentage of total population. Contrary to the entire sample, the share of industry in GDP integrates at first difference for LIC and HIC. The ratio of domestic credit to private sector to GDP and degree of economic development are stationary at level and first difference under UMIC. CO_2 emission per capita, the share of agriculture in GDP, employment generation rate, energy consumption per capita and population density, all integrate at first difference under HIC. Trade openness, also, integrates at order one under LMIC, UMIC and HIC.

To avoid spurious inferences, most of the variables are expected to be stationary at level (i.e. the mean and autocovariance of the variables do not change with time). However, this is not the case under HIC because it has the lowest number of variables (just three) that are stationary at level while the entire sample and UMIC have eleven variables stationary at level. The LICs and LMICs have nine and eight of their variables stationary at level, respectively. This is why the study would conduct panel cointegration tests before and after the estimation of the static models (as specified in chapter four). The results of the panel cointegration tests would determine whether the static regressions are reliable or not. If there is any non-cointegrating regression then the simultaneity bias becomes an issue which is taken care of by the estimated dynamic regressions.

5.3 Panel cointegration tests on carbon dioxide emissions and Income

Based on the suggestion of Halkos (2003) that when estimating the Environmental Kuznets Curve (EKC) a panel cointegration test should be conducted on pollution and income so as to know if they have an equilibrium relationship, this section displays the results of the Pedroni panel cointegration tests in Table 5.8.

Table 5.8: Pedroni panel cointegration tests results

	Panel v	Panel ρ	Panel PP	Panel ADF	Group ρ	Group PP	Group ADF
The entire sample of SSA countries							
Log-Linear	0.6141	-3.77[1]	-7.546[1]	-6.101[1]	-0.6172	-6.406[1]	-4.923[1]
Log-Quadratic	-0.6528	-1.242	-6.211[1]	-5.59[1]	1.384	-5.66[1]	-5.749[1]
Log-Cubic	-2.086	0.106	-7.461[1]	-6.935[1]	2.638	-7.598[1]	-8.126[1]
SSA Low-Income Countries (LIC)							
Log-Linear	0.8982	-1.458[10]	-3.854[1]	-3.679[1]	0.6373	-2.794[1]	-3.063[1]
Log-Quadratic	-0.2007	0.106	-3.345[1]	-3.162[1]	1.818	-2.761[1]	-2.683[1]
Log-Cubic	-0.8902	1.185	-3.403[1]	-3.097[1]	2.76	-3.281[1]	-3.721[1]
SSA Lower-Middle-Income Countries (LMIC)							
Log-Linear	-0.3314	-2.069[5]	-4.118[1]	-3.406[1]	-0.1436	-3.427[1]	-3.474[1]
Log-Quadratic	-0.6068	-0.711	-3.967[1]	-3.856[1]	1.024	-4.223[1]	-3.464[1]
Log-Cubic	-2.069	0.5511	-4.574[1]	-2.927[1]	2.009	-6.637[1]	-3.474[1]
SSA Upper-Middle-Income Countries (UMIC)							
Log-Linear	0.7602	-5.987[1]	-9.671[1]	-8.83[1]	-4.443[1]	-10.52[1]	-9.537[1]
Log-Quadratic	0.3274	-4.061[1]	-10.37[1]	-6.463[1]	-3.074[1]	-11.54[1]	-7.45[1]
Log-Cubic	-0.1803	-2.724[1]	-10.84[1]	-6.726[1]	-1.891[5]	-11.83[1]	-7.791[1]
SSA High-Income Countries (HIC)							
Log-Linear	-0.5285	0.2717	-0.0463	0.1186	0.8558	0.4033	0.5823
Log-Quadratic	-0.2895	-0.1782	-1.171	-1.126	0.4058	-0.8808	-0.8299
Log-Cubic	-0.7826	0.3535	-1.614[10]	-1.78[5]	0.9074	-1.401[10]	-1.586[10]

Source: Author (2016)

Note: [1] indicates the rejection of the null hypothesis of no cointegration at 0.01 level of significance (Panel v > 2.326 and other Panel and Group statistics < -2.326). [5] indicates the rejection of the null hypothesis of no cointegration at 0.05 level of significance (Panel v > 1.645 and other Panel and Group statistics < -1.645). [10] indicates the rejection of the null hypothesis of no cointegration at 0.1 level of significance (Panel v > 1.282 and other Panel and Group statistics < -1.282).

The panel cointegration tests are to determine whether a cointegrating relationship exists between CO_2 emissions per capita (the regressand) and real GDP per capita (the regressor) according to the EKC hypothesis using three functional forms i.e. log-linear, log-quadratic and log-cubic. The Pedroni cointegration test (as proposed by Pedroni (1999)) employs four within-dimension-based statistics (hereon referred to as panel statistics) and three between-dimension-based statistics (hereafter referred to as group mean statistics). These seven statistics test the null hypothesis of no cointegration and the alternate hypothesis of cointegration. The panel statistics assume that all the panels (also called cross sections) have an identical autoregressive term as such if the alternate hypothesis is accepted then CO_2 emissions per capita and real GDP per capita cointegrate for all the sample countries. The group mean statistics assume that the autoregressive term varies across the panels and the rejection of the null hypothesis implies that there is cointegration for at least one panel.

On the first row of Table 5.8, the four-panel statistics are the variance ratio statistic (Panel v), the Phillips and Perron rho statistic (Panel ρ), the Phillips and Perron *t* statistic (Panel PP) and the Augmented-Dickey-Fuller *t* statistic (Panel ADF). The three group mean statistics are the Phillips and Perron rho statistic (Group ρ), the Phillips and Perron *t* statistic (Group PP) and the Augmented-Dickey-Fuller *t* statistic (Group ADF). All these statistics are nonparametric except for Panel ADF and Group ADF which are parametric. All the statistics (except the variance ratio (Panel v)) have a standard normal distribution that diverges to negative infinity i.e. the left tail is their rejection region for the null hypothesis. Panel v has a standard normal distribution that diverges to positive infinity, that is to say, the right tail is applied as its null hypothesis rejection region (Pedroni 1999). All the tests are conducted with the time trend.

The interpretation of Table 5.8 is based on the insight suggested by Karaman-Örsal (2007) that the Phillips and Perron *t* statistic (Panel PP and Group PP) and the Augmented-Dickey-Fuller *t* statistic (Panel ADF and Group ADF) have the best performance amongst the seven statistics of the Pedroni panel cointegration test. As such, although Panel v and Group ρ suggest that the null hypothesis of no cointegration cannot be rejected for the log-linear relationship between CO_2 emissions per capita and real GDP per capita for the entire sample, there is overwhelming evidence of panel cointegration and cointegration for at least one panel under Panel ρ, Panel PP, Panel ADF, Group PP and Group ADF at one percent level of significance. Four out of the seven statistics reject the null hypothesis of no panel cointegration (Panel PP, Panel ADF, Group PP and Group ADF) at one percent level of significance for both log-quadratic and log-cubic relationship between CO_2 emissions per capita and real GDP per capita for the entire sample of SSA countries.

The alternate hypothesis of panel cointegration and at least one panel cointegrate is accepted under Panel PP, Panel ADF, Group PP and Group ADF at one percent level of significance for log-linear, log-quadratic and log-cubic for the LIC sub-sample. Other statistics reject the alternate hypothesis for LIC except for Panel ρ for log-linear which also accept the alternate hypothesis at ten percent level of significance. This interpretation is the same for LMIC, except Panel ρ for log-linear which accepts the alternate hypothesis at five percent level of significance.

Panel v portrays no evidence for panel cointegration for UMIC under the three likely relationships between CO_2 emissions per capita and real GDP per capita. All the other six statistics present strong evidence of panel cointegration and cointegration for at least one panel under log-linear, log-quadratic and log-cubic for UMIC. All the statistics do not reject the null hypothesis of no cointegrating log-linear and log-quadratic relationship for HIC but Panel PP, Panel ADF, Group PP and Group ADF for the log-cubic relationship have weak evidence that rejects the null hypothesis for the HIC.

Therefore, there is an equilibrium relationship between CO_2 emissions per capita and real GDP per capita for the entire sample, LIC, LMIC and UMIC sub-samples but no equilibrium relationship for HIC sub-sample. This suggests that the estimates of the static models (in the next section) for the entire sample, LIC, LMIC and UMIC are not spurious while those of the HIC may be spurious.

5.4 Regression results

5.4.1 Regression results from the entire sample of SSA countries

5.4.1.1 Static models

The Feasible Generalised Least Squares (FGLS) is used to estimate the static models for the entire sample of SSA countries. Results of these models are presented in Table 5.9. All the results are robust to heteroscedasticity and serial correlation, i.e. the variances of the estimation are allowed to differ from each panel and first order autoregressive serial correlation is allowed to be common for all panels. Although the estimates are generated based on no cross-sectional correlation because the panels do not have the same number of observations (i.e. the study is based on an unbalanced data set), according to Reed and Ye (2011), the performance of the estimator is still intact.

The first set of models in Table 5.9 (log-linear models) shows a statistically significant real GDP per capita (*lnY*) with a positive relationship with the explained variable (CO_2 emissions per capita). The results across the five specifications (Models 1A-5A) suggest that a percent increase in real GDP per capita increases CO_2 emissions per capita by a range of 0.361-0.578 percent annually in SSA, other variables held constant. When population density (*lnP*) and urban population as a percentage of total population (*lnUp*) were introduced under Model 2A, employment generation rate (*lnEgr*) and the degree of economic development (*lnDe*) became significant at 10 and five percent levels of significance, respectively, so also were *lnP* and *lnUp* at one percent level of significance. In the absence of the share of agriculture in GDP (*lnA*), the share of industry in GDP (*lnI*), *lnP* and *lnUp* were introduced under Model 4A, inflation rate ($ln\pi$), employment generation rate and the degree of economic development became statistically significant and so also were *lnP* and *lnUp*. Retaining all the control variables and agriculture as a percentage of GDP in Model 5A, employment generation rate, the degree of economic development, population density and urban population as a percentage of total population are still statistically significant. Thus, a dirtier CO_2 environment intensifies not only because of rising income but also because of growing population and increasing urbanisation (UNCTAD 2012).

Under all the models, the share of agriculture in GDP is significant at one percent with a negative relationship with CO_2 emissions per capita while the share of industry shows no evidence of a relationship with CO_2 emissions per capita. Hence, under the stages of structural change, it can be resolved that SSA is still largely dependent on agriculture with a low share of industrial development (UNCTAD 2012). With the assumption of structural transformation but population and urbanisation are the same in Model 6A and 8A, real GDP per capita (*lnY*) and real GDP per capita squared (lnY^2) (under log-quadratic models) are significant with the a priori sign of an inverted U-shape. This supports that the EKC holds for CO_2 emissions due to the relative decarbonisation witnessed in SSA during the study period (Schmalensee *et al.* 1998).

Table 5.9: Static regression results (as estimated with FGLS) for the entire sample

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 1A	Model 2A	Model 3A	Model 4A	Model 5A	Model 6A	Model 7A	Model 8A	Model 9A	Model 10A	Model 11A	Model 12A	Model 13A	Model 14A	Model 15A
β_0	-5.38^{1} [.429]	-5.86^{1} [.440]	-6.25^{1} [.378]	-7.05^{1} [.392]	-5.82^{1} [.470]	-8.13^{1} [.815]	-5.82^{1} [.887]	-7.94^{1} [.828]	-5.93^{1} [.898]	-5.69^{1} [.896]	-8.21^{10} [4.52]	-3.31 [4.88]	-7.38 [4.69]	-4.48 [5.01]	-3.45 [5.04]
Economic Development Indicators:															
lnY	.498^{1} [.074]	.361^{1} [.079]	.578^{1} [.073]	.456^{1} [.076]	.364^{1} [.079]	1.37^{1} [.232]	.344 [.270]	1.07^{1} [.230]	.098 [.269]	.326 [.275]	1.35 [2.05]	-.842 [2.23]	.766 [2.13]	-.611 [2.29]	-.734 [2.29]
lnY^2	----	----	----	----	----	-.067^{1} [.017]	.001 [.019]	-.037^{5} [.016]	.026 [.019]	.002 [.019]	-.051 [.309]	.189 [.335]	.020 [.322]	.141 [.345]	.173 [.347]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.001 [.015]	-.010 [.016]	-.003 [.016]	-.006 [.017]	-.009 [.017]
lnA	-.113^{1} [.030]	-.153^{1} [.032]	----	----	-.160^{1} [.034]	-.154^{1} [.032]	-.157^{1} [.034]	----	----	-.163^{1} [.036]	-.155^{1} [.032]	-.164^{1} [.034]	----	----	-.172^{1} [.037]
lnT	.114^{1} [.028]	.070^{5} [.029]	.116^{1} [.029]	.735^{5} [.030]	.070^{5} [.029]	.120^{1} [.028]	.069^{5} [.029]	.121^{1} [.029]	.066^{5} [.030]	.070^{5} [.030]	.115^{1} [.029]	.066^{5} [.029]	.117^{1} [.030]	.064^{5} [.031]	.065^{5} [.031]
$ln\pi$	.003 [.003]	.005 [.003]	.004 [.003]	.005^{10} [.003]	.005 [.003]	.004 [.003]	.005 [.003]	.004 [.003]	.006^{10} [.030]	.005 [.003]	.004 [.003]	.005 [.003]	.005 [.003]	.006^{10} [.003]	-.005 [.003]
lnEgr	-.008 [.009]	-.018^{10} [.009]	-.007 [.009]	-.018^{10} [.010]	-.018^{10} [.009]	-.011 [.009]	-.019^{5} [.009]	-.009 [.009]	-.018^{10} [.009]	-.019^{5} [.009]	-.012 [.009]	-.019^{5} [.010]	-.010 [.009]	-.019^{10} [.010]	-.020^{5} [.009]
lnEc	.392^{1} [.029]	.347^{1} [.030]	.394^{1} [.030]	.352^{1} [.030]	.343^{1} [.030]	.408^{1} [.030]	.345^{1} [.030]	.404^{1} [.030]	.344^{1} [.031]	.343^{1} [.031]	.408^{1} [.030]	.350^{1} [.031]	.410^{1} [.031]	.350^{1} [.032]	.351^{1} [.031]
lnDe	.044 [.066]	.153^{5} [.068]	.045 [.067]	.142^{5} [.067]	.155^{5} [.068]	.054 [.066]	.157^{5} [.068]	.050 [.068]	.149^{5} [.068]	.159^{5} [.068]	.052 [.066]	.150^{5} [.069]	.042 [.069]	.144^{5} [.069]	.153^{5} [.070]
Financial Development Indicators:															
lnD	.068^{1} [.023]	.079^{1} [.023]	.066^{1} [.023]	.078^{1} [.023]	.080^{1} [.024]	.072^{1} [.023]	.081^{1} [.023]	.069^{1} [.024]	.079^{1} [.023]	.083^{1} [.024]	.072^{1} [.023]	.083^{1} [.024]	.070^{1} [.024]	.085^{1} [.024]	.086^{1} [.024]
lnFDI	-.007^{5} [.003]	-.007^{5} [.003]	-.007^{5} [.003]	-.007^{5} [.003]	-.007^{5} [.003]	-.009^{1} [.003]	-.007^{5} [.003]	-.008^{1} [.003]	-.006^{5} [.003]	-.007^{5} [.003]	-.008^{5} [.003]	-.006^{5} [.003]	-.008^{5} [.003]	-.006^{10} [.003]	-.006^{10} [.003]
lnO	-.030^{1} [.008]	-.033^{1} [.008]	-.027^{1} [.007]	-.031^{1} [.008]	-.033^{1} [.008]	-.028^{1} [.008]	-.033^{1} [.008]	-.027^{1} [.008]	-.032^{1} [.008]	-.033^{1} [.008]	-.027^{1} [.008]	-.033^{1} [.008]	-.026^{1} [.008]	-.032^{1} [.008]	-.032^{1} [.008]
lnDf	.001 [.026]	-.009 [.027]	-.009 [.027]	.002 [.027]	-.004 [.027]	.005 [.026]	-.008 [.027]	.013 [.027]	.001 [.027]	-.003 [.027]	.002 [.026]	-.011 [.027]	.010 [.027]	- .000 [.027]	-.006 [.027]
Dummy Variables:															
D_1	-.152^{1} [.045]	-.123^{5} [.049]	-.160^{1} [.045]	-.150^{1} [.047]	-.121^{5} [.049]	-.155^{1} [.045]	-.127^{5} [.049]	-.167^{1} [.046]	-.147^{1} [.048]	-.123^{5} [.050]	-.166^{1} [.046]	-.127^{5} [.049]	-.175^{1} [.046]	-.145^{1} [.048]	-.121^{5} [.049]
D_2	-.198^{1}	-.315^{1}	-.199^{1}	-.316^{1}	-.319^{1}	-.240^{1}	-.327^{1}	-.227^{1}	-.321^{1}	-.331^{1}	-.245^{1}	-.326^{1}	-.233^{1}	-.319^{1}	-.329^{5}

	[.074]	[.080]	[.074]	[.078]	[.081]	[.075]	[.080]	[.075]	[.079]	[.081]	[.076]	[.081]	[.077]	[.081]	[.083]
Control Variables:															
lnI	----	----	-.016 [.034]	.040 [.034]	-.019 [.037]	----	----	-.012 [.035]	.037 [.034]	-.023 [.037]	----	----	-.016 [.035]	.041 [.036]	-.024 [.038]
lnP	----	.083[1] [.014]	----	.076[1] [.015]	.082[1] [.015]	----	.086[1] [.015]	----	.087[1] [.015]	.085[1] [.015]	----	.083[1] [.014]	----	.083[1] [.015]	.082[1] [.015]
lnUp	----	.370[1] [.051]	----	.357[1] [.048]	.368[1] [.052]	----	.379[1] [.053]	----	.382[1] [.051]	.375[1] [.054]	----	.375[1] [.054]	----	.380[1] [.053]	.370[1] [.055]
Obs	809	809	802	802	802	809	809	802	802	802	809	809	802	802	802

Source: Author (2016)

Note: Numbers in [ ] are heteroscedasticity and autocorrelation consistent standard errors. [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance. Obs represents the number of observations.

In the presence of growing population (*lnP*) and increasing urbanisation (*lnUp*) in Models 7A, 9A and 10A, *lnY* and lnY^2 are insignificant but the introduced variables, and employment generation rate (*lnEgr*) and the degree of economic development (*lnDe*) are statistically significant. This explains the reason why studies in the literature report different results for the CO_2-income relationship using the same estimation method and case study. Real GDP per capita (*lnY*), squared real GDP per capita (lnY^2) and cubed real GDP per capita (lnY^3) are also not significant under the log-cubic models which means that the log-cubic functional form is not a statistically good fit for the entire sample. Thus, on the premise that the creation of green jobs promotes employment generation (Deschenes 2013), the results reveal that employment generation supports a cleaner CO_2 environment in SSA. That is, the creation of green jobs may account for a relatively higher share of employment generated.

Across Table 5.9, the degree of financial development (*lnDf*)) has an insignificant relationship with the explained variable. Economic development indicators (Trade openness (*lnT*), total primary energy consumption per capita (*lnEc*) and the degree of economic development (*lnDe*)), financial development indicator (domestic credit to private sector to GDP (*lnD*)) and control variables (population density (*lnP*) and urban population as a percentage of total population (*lnUp*)) have an increased effect on CO_2 emissions per capita. For illustration, every percent increase in the ratio of domestic credit to private sector to GDP leads to an increase in the range of 0.066-0.086 percent in CO_2 emissions per capita in SSA, *ceteris paribus*.

Also, economic development indicator (the share of agriculture in GDP (*lnA*)) and financial development indicators (net inflow of foreign direct investment to GDP ratio (*lnFDI*) and official exchange rates (*lnO*)) have an inverse effect on the explained variable. For instance, a percent increase in the share of agriculture in GDP results in a reduction of between 0.113 and 0.172 percent in CO_2 emissions per capita in SSA, other variables remaining the same. The dummy variables for French-speaking SSA countries (D_1) and Portuguese-speaking SSA countries (D_2) also have negative signs which mean that the intercept values of French and Portuguese-speaking SSA countries are statistically different (lower) from the intercept value of English-speaking SSA countries (β_0) which is the benchmark.

Thus, Models 1A-5A, 6A and 8A would inform our inferences on the relationship between CO_2 emissions per capita real and GDP per capita (*lnY*) if they pass the cointegration tests (presented in section 5.5) to confirm that they are not nonsense regressions. The above static models are estimated on the assumption of strict exogeneity which is relaxed in the next sub-section.

5.4.1.2 Dynamic models

Controlling for endogeneity, Models 1A to 15A are re-estimated with system Generalised Method of Moments (GMM) which are delivered as Models 16A-30A in Table 5.10. The results presented are from the robust first step system GMM estimator. Not all statistically significant variables under the static models in Table 5.9 are significant in Table 5.10. For instance, two of the five log-quadratic models (Model 6A and 8A) in Table 5.9 have a significant inverted U relationship between CO_2 emissions per capita real and GDP per capita (*lnY*). To the contrary, none of the log-quadratic models (21A-25A) in Table 5.10 has a statistically significant relationship between real GDP per capita and CO_2 emissions per capita. This supports studies in the literature that report different empirical results for the same case study using different estimation methods.

Table 5.9 and 5.10 share some similarities though. One is that there is no significant log-cubic relationship between CO_2 emissions per capita real and GDP per capita (*lnY*). There is a monotonic increasing (i.e. linear) relationship between CO_2 emissions per capita real and GDP per capita (*lnY*) under the dynamic models 16A, 18A and 19A. The degree of financial development (*lnDf*) and the share of industry in GDP (*lnI*) (and other control variables) have no significant relationship with the explained variable across Table 5.10.

Also, across Table 5.10, the indicators of economic development (trade openness (*lnT*), total primary energy consumption per capita (*lnEc*) and the degree of economic development (*lnDe*)) and financial development (domestic credit to private sector to GDP (*lnD*)) have a positive relationship with CO_2 emissions per capita. The significant values of the coefficients for the degree of economic development indicate that the dynamic models support the static models that there is hope for SSA to experience revised EKC in the early stages of industrialisation (Dasgupta *et al*. 2004). The dummy variables for French-speaking SSA countries (D_1) and Portuguese-speaking SSA countries (D_2) have a significant negative sign.

Table 5.10: Dynamic regression results (as estimated with system GMM) for the entire sample

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 16A	Model 17A	Model 18A	Model 19A	Model 20A	Model 21A	Model 22A	Model 23A	Model 24A	Model 25A	Model 26A	Model 27A	Model 28A	Model 29A	Model 30A
β_0	-1.60[1] [.423]	-1.44[1] [.402]	-1.80[1] [.436]	-1.70[1] [.452]	-1.60[1] [.464]	-1.44[5] [.715]	-1.14 [.710]	-1.06 [.861]	-.874 [.851]	-.828 [.837]	-4.63 [2.45]	-.717 [2.49]	-3.07 [3.18]	-3.40 [2.94]	-3.52 [2.82]
$ln\ CO_{2t-1}$	.723[1] [.048]	.728[1] [.050]	.714[1] [.049]	.727[1] [.051]	.735[1] [.051]	.733[1] [.048]	.740[1] [.051]	.724[1] [.051]	.738[1] [.054]	.743[1] [.055]	.743[1] [.047]	.750[1] [.049]	.734[1] [.054]	.744[1] [.056]	.753[1] [.056]
Economic Development Indicators:															
lnY	.096[10] [.050]	.076 [.051]	.124[5] [.061]	.112[10] [.063]	.094 [.059]	.040 [.208]	.027 [.258]	-.087 [.288]	-.147 [.337]	-.198 [.331]	-.371 [1.01]	-.214 [1.06]	.806 [1.37]	.933 [1.23]	1.01 [1.18]
lnY^2	----	----	----	----	----	.004 [.016]	.007 [.018]	.014 [.023]	.018 [.025]	.021 [.025]	.066 [.139]	.037 [.144]	-.112 [.202]	-.137 [.180]	-.149 [.172]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.003 [.006]	-.002 [.006]	.006 [.010]	.007 [.009]	.008 [.008]
lnA	-.007 [.037]	-.023 [.033]	----	----	-.008 [.034]	.007 [.033]	-.015 [.030]	----	----	.006 [.032]	.002 [.032]	-.020 [.028]	----	----	.001 [.029]
lnT	.084[1] [.023]	.072[1] [.025]	.067[5] [.026]	.054[1] [.024]	.054[5] [.025]	.090[1] [.023]	.077[1] [.026]	.083[1] [.023]	.064[1] [.022]	.064[1] [.023]	.087[1] [.020]	.075[1] [.023]	.080[1] [.024]	.067[1] [.024]	.064[5] [.025]
$ln\pi$	-.006 [.006]	-.006 [.006]	-.006 [.005]	-.006 [.006]	-.006 [.007]	-.005 [.006]	-.006 [.006]	-.004 [.006]	-.006 [.006]	-.005 [.007]	-.005 [.006]	-.005 [.006]	-.005 [.006]	-.005 [.005]	-.005 [.006]
lnEgr	-.015 [.011]	-.007 [.014]	-.012 [.012]	-.002 [.015]	.005 [.015]	-.010 [.012]	-.005 [.014]	-.006 [.013]	-.001 [.015]	-.002 [.015]	-.008 [.013]	-.004 [.014]	-.006 [.013]	-.001 [.016]	-.003 [.015]
lnEc	.123[1] [.036]	.108[1] [.033]	.128[1] [.033]	.113[1] [.029]	.108[1] [.030]	.118[1] [.037]	.099[1] [.036]	.120[1] [.032]	.099[1] [.031]	.094[1] [.030]	.115[1] [.037]	.095[1] [.34]	.105[1] [.033]	.087[1] [.031]	.085 [.031]
lnDe	.095[5] [.047]	.099[5] [.054]	.083[5] [.040]	.078[10] [.045]	.082[10] [.045]	.092[5] [.045]	.104[10] [.061]	.082[5] [.039]	.088 [.052]	.091[10] [.051]	.084[10] [.044]	.104[10] [.058]	.080[5] [.039]	.098[10] [.053]	.095[10] [.052]
Financial Development Indicators:															
lnD	.032 [.020]	.025 [.016]	.031[10] [.019]	.024 [.016]	.024 [.016]	.029 [.019]	.022 [.019]	.027 [.019]	.022 [.018]	.023 [.019]	.029 [.019]	.024 [.017]	.031 [.020]	.029 [.019]	.029 [.019]
lnFDI	-.002 [.004]	.000 [.004]	-.003 [.004]	-.000 [.003]	-.000 [.004]	-.002 [.004]	-.000 [.004]	-.003 [.004]	-.001 [.004]	-.002 [.004]	-.002 [.004]	-.001 [.003]	-.002 [.004]	-.001 [.003]	-.001 [.004]
lnO	-.001 [.006]	-.003 [.006]	-.000 [.006]	-.001 [.006]	-.002 [.006]	.001 [.005]	-.001 [.006]	.002 [.006]	.000 [.006]	-.001 [.006]	-.000 [.005]	-.002 [.006]	.001 [.006]	-.002 [.006]	-.002 [.006]
lnDf	-.025 [.042]	.031 [.042]	-.021 [.040]	-.027 [.040]	-.030 [.040]	-.031 [.041]	-.033 [.041]	-.031 [.038]	-.029 [.038]	-.032 [.038]	-.035 [.041]	-.037 [.041]	-.034 [.039]	-.034 [.040]	-.035 [.039]

Table 5.10 – Continued: Dynamic regression results (as estimated with system GMM) for the entire sample

	Model 16A	Model 17A	Model 18A	Model 19A	Model 20A	Model 21A	Model 22A	Model 23A	Model 24A	Model 25A	Model 26A	Model 27A	Model 28A	Model 29A	Model 30A
Dummy Variables:															
D_1	-.075[10] [.042]	-.058 .036]	-.089[5] [.043]	-.067 [.037]	-.059 [.036]	-.088[10] [.047]	-.069[10] [.041]	-.095[5] [.047]	-.080[10] [.042]	-.076[10] [.040]	-.083[10] [.042]	-.063[10] [.038]	-.107[5] [.048]	-.087[5] [.043]	-.084[5] [.042]
D_2	-.058 [.055]	-.048 [.055]	-.061 [.054]	-.053 [.049]	-.057 [.047]	-.090[5] [.045]	-.068 [.047]	-.101[5] [.043]	-.060 [.044]	-.077[10] [.044]	-.108[5] [.044]	-.079[10] [.045]	-.120[5] [.047]	-.092[5] [.047]	-.096[5] [.046]
Control Variables:															
lnI	----	----	.018 [.048]	.030 [.047]	.033 [.050]	----	----	.014 [.043]	.028 [.045]	.042 [.051]	----	----	.023 [.437]	.038 [.047]	.043 [.051]
lnP	----	.024 [.020]	----	.020 [.019]	.024 [.019]	----	.027 [.021]	----	.024 [.021]	.030 [.021]	----	.031 [.022]	----	.033 [.022]	.032 [.021]
lnUp	----	.009 [.037]	----	-.006 [.039]	.008 [.039]	----	.018 [.051]	----	.014 [.056]	.043 [.054]	----	.027 [.046]	----	.029 [.049]	.032 [.049]
Obs	808	808	801	801	801	808	808	801	801	801	808	808	801	801	801
Arrelano-Bond autocorrelation Tests															
order 1	-2.42 (.015)	-2.46 (.014)	-2.41 (.016)	-2.44 (.015)	-2.44 [.015]	-2.44 (.015)	-2.49 (.013)	-2.46 (.014)	-2.51 (.012)	-2.51 (.012)	-2.42 (.016)	-2.47 (.014)	-2.48 (.013)	-2.52 (.012)	-2.51 (.012)
order 2	.960 (.337)	.977 (.328)	.965 (.334)	.977 (.329)	.980 [.330]	.961 (.337)	.979 (.327)	.975 (.329)	.986 (.324)	.989 (.323)	.959 (.338)	.979 (.327)	.977 (.329)	.989 (.323)	.992 (.321)
Sargan test of overidentifying restrictions from the non-robust estimation															
Chi^2	1016.2 (.105)	1062.9 (.092)	1003.3 (.126)	1034.8 (.185)	1048.4 (.221)	1063.8 (.039)	1089.9 (.069)	1042.8 (.068)	1063.5 (.136)	1083.3 (.135)	1085.4 (.039)	1100.1 (.099)	1074.7 (.039)	1084.7 (.129)	1094.3 (.178)

Source: Author (2016)

Note: [ ] indicate robust standard errors and ( ) indicate the probability value for respective diagnostics. [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance. Obs represents the number of observations.

The coefficients of the estimated models in Table 5.10 are short-run effects. The statistically significant coefficient of the lagged explained variable ($lnCO_{2t-1}$) confirms that there is a long-run relationship between CO_2 emissions per capita and the regressors and current CO_2 emissions are driven by previously emitted CO_2. The long-run effects are obtained by dividing a statistically significant coefficient with one minus a statistically significant lagged explained variable (1-$lnCO_{2t-1}$) within the same model. Using Model 16A for illustration, the short-run effects of *lnY, lnT, lnEc, lnDe and* D_1 are 0.096, 0.084, 0.123, 0.095 and -0.075 while the long-run effects (after dividing by (1-0.723)) are 0.346, 0.303, 0.444, 0.343 and -0.271. This implies that the long-run effects of these variables on CO_2 emissions per capita are larger than their respective short-run effects, except for D_1 which has a smaller coefficient in the long run than the short run. This deduces that the effects of (these variables, for illustration) trade openness (*lnT*) on CO_2 emissions per capita are larger in the long run than the short run, i.e. 0.303 > 0.084, *ceteris paribus*. The negative sign for D_1 means that there is a higher limiting effect on CO_2 emissions in the long run than the short run in Francophone countries.

Table 5.10 further presents the Arellano-Bond autocorrelation tests for each model. This test was carried out after the robust estimation with a null hypothesis of no autocorrelation and the alternate hypothesis of autocorrelation. The null hypothesis of no first-order autocorrelation (order 1) is not rejected at one percent significance level but rejected at five percent significance level, throughout the table. However, we fail to reject the null hypothesis of no second-order autocorrelation (order 2) at all levels of significance. This proves that the error terms of the estimates of Models 16A to 30A are serially uncorrelated, i.e. the models are specified correctly.

The Sargan tests are obtained after performing the non-robust estimation of the models. The Sargan tests are to affirm the null hypothesis that overidentifying restrictions are valid or the alternative hypothesis that overidentifying restrictions are invalid. Few of the models reject the null hypothesis at five percent significant level (Models 21A, 26A and 28A) and some reject the null hypothesis at ten percent level of significance (Models 17A, 22A, 23A and 27A). Other models (including Models 16A, 18A and 19A) fail to reject the null hypothesis which confirms that the appropriate instrumental variables selection is made.

5.4.2 Regression results from the sub-sample of low-income countries

Unlike the entire sample, FGLS and system GMM are not used to specify the static and dynamic models of all the sub-samples. This is because FGLS and system GMM are intentional for a large number of cross-sections (i.e. countries) and small number of time periods. Thus, to avoid bias, regression with Panel-Corrected Standard Error (PCSE) and Instrumental Variable (IV) regression are used to specify the static and dynamic models from this sub-section forward.

5.4.2.1 Static models

For consistency, the regression for PCSE was estimated controlling for heteroscedasticity and serial correlation. This estimation procedure is called the heteroscedastic PCSE or the Prais-Winsten regression. The estimated results for the static models are presented in Table 5.11. The results show a significant linear and N-shape (cubic) relationship between CO_2 emissions per capita and real GDP per capita (*lnY*). The linear relationship exists with and without the introduction of population density (*lnP*) and urban population as a percentage of total population (*lnUp*) while the cubic relationship is significant only when *lnP* and *lnUp* are brought in. That is, models without *lnP* and *lnUp* express emissions per capita as a function of rising affluence and structural transformation while models with *lnP* and *lnUp* express emissions per capita as a function of rising affluence, structural transformation, growing population and increasing urbanisation. For this income group, Models 1B to 5B, 12B, 14B and 15B are identified.

Obtaining the N-shape relationship for LIC is contrary to the inverted U-shape obtained for the entire sample. The existence of the N-shape may be explained as an outcome of the efforts of low-income countries to increase their share of industrial development while ignoring the constraint of energy generation and consumption by fossil fuels which lead to a dirtier CO_2 environment (Carvalho and Almeida 2010).

Like the entire sample, the degree of financial development (*lnDf*) and the share of industry in GDP (*lnI*) have an insignificant relationship with the explained variable across Table 5.11. Some economic development variables (trade openness (*lnT*), total primary energy consumption per capita (*lnEc*)), financial development variable (domestic credit to private sector to GDP (*lnD*)) and control variables (population density (*lnP*) and urban population as a percentage of total population (*lnUp*)) have a positive relationship with CO_2 emissions per capita for the sample of LIC in SSA. For illustration, a percent increase in energy consumption per capita in LIC leads to an increase between 0.401-0.556 percent in emissions per capita, other variables being constant.

Table 5.11: Static regression results (as estimated with PCSE) for LIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 1B	Model 2B	Model 3B	Model 4B	Model 5B	Model 6B	Model 7B	Model 8B	Model 9B	Model 10B	Model 11B	Model 12B	Model 13B	Model 14B	Model 15B
β_0	-6.01^{1} [.716]	-6.24^{1} [.669]	-6.42^{1} [.688]	-6.80^{1} [.640]	-6.18^{1} [.708]	1.18 [4.00]	-.709 [4.03]	-.365 [4.00]	-2.14 [3.99]	-3.83 [4.09]	-45.9 [41.7]	-75.4^{10} [41.8]	-56.5 [43.3]	-90.3^{5} [43.1]	-84.6^{10} [43.1]
Economic Development Indicators:															
lnY	.611^{1} [128]	.312^{5} [.133]	.613^{1} [.130]	.315^{5} [.134]	.316^{5} [.134]	-1.91 [1.38]	-1.59 [1.37]	-1.52 [1.40]	-1.29 [1.38]	-1.67 [1.39]	23.1 [22.2]	38.2^{10} [22.2]	28.4 [23.05]	45.7^{5} [22.9]	43.2^{10} [22.9]
lnY^2	----	----	----	----	----	.220^{10} [.122]	.166 [.122]	.187 [.124]	.141 [.123]	.173 [.124]	-4.20 [3.92]	-6.86^{10} [3.92]	-5.10 [4.08]	-8.17^{5} [4.06]	-7.76^{10} [4.05]
lnY^3	----	----	----	----	----	----	----	----	----	----	.259 [.230]	.412^{10} [.230]	.310 [.240]	.488^{5} [.239]	.465^{10} [.238]
lnA	-.101^{10} [.056]	-.109^{5} [.054]	----	----	-.122^{5} [.057]	-.112^{5} [.056]	-.119^{5} [.055]	----	----	-.134^{1} [.057]	-.111^{10} [.057]	-.117^{5} [.054]	----	----	-.126^{5} [.057]
lnT	.082^{10} [.044]	.047 [.042]	.085^{10} [.045]	.042 [.043]	.044 [.042]	.075^{10} [.045]	.038 [.042]	.079^{10} [.045]	.035 [.043]	.036 [.043]	.073 [.045]	.035 [.041]	.077^{10} [.045]	.029 [.043]	.030 [.042]
lnπ	-.004 [.005]	-.004 [.005]	-.003 [.006]	-.003 [.005]	-.003 [.005]	.005 [.006]	-.004 [.005]	-.004 [.005]	-.003 [.005]	-.004 [.005]	-.005 [.006]	-.004 [.005]	-.004 [.006]	-.003 [.005]	-.004 [.005]
lnEgr	.002 [.018]	-.013 [.020]	.003 [.020]	-.011 [.021]	-.011 [.021]	.004 [.018]	-.012 [.020]	.005 [.020]	-.010 [.021]	-.010 [.021]	.003 [.018]	-.014 [.019]	.004 [.019]	-.012 [.021]	-.012 [.020]
lnEc	.520^{1} [.051]	.401^{1} [.047]	.529^{1} [.051]	.413^{1} [.047]	.405^{1} [.047]	.543^{1} [.051]	.424^{1} [.046]	.556^{1} [.050]	.436^{1} [.047]	.433^{1} [.047]	.541^{1} [.050]	.409^{1} [.046]	.554^{1} [.050]	.423^{1} [.046]	.420^{1} [.046]
lnDe	-.051 [.109]	.114 [.106]	-.029 [.110]	.135 [.107]	.122 [.107]	-.053 [.109]	.113 [.107]	-.032 [.111]	.134 [.108]	.121 [.107]	-.049 [.109]	.122 [.105]	-.028 [.110]	.145 [.107]	.131 [.106]
Financial Development Indicators:															
lnD	.070^{5} [.033]	.097^{1} [.034]	.084^{5} [.034]	.114^{1} [.035]	.109^{1} [.034]	.056^{10} [.034]	.091^{1} [.034]	.071^{5} [.035]	.109^{1} [.035]	.103^{1} [.035]	.057^{10} [.034]	.093^{1} [.034]	.072^{10} [.035]	.113^{1} [.035]	.106^{1} [.035]
lnFDI	-.002 [.004]	-.003 [.004]	-.001 [.005]	-.003 [.005]	-.003 [.005]	.000 [.005]	-.001 [.005]	.001 [.005]	-.001 [.005]	-.001 [.005]	.000 [.005]	-.002 [.005]	.000 [.005]	-.002 [.005]	-.002 [.005]
lnO	-.018^{10} [.009]	-.027^{5} [.011]	-.021^{5} [.010]	-.031^{1} [.011]	-.029^{1} [.011]	-.013 [.009]	-.022^{5} [.010]	-.017^{10} [.009]	-.026^{5} [.011]	-.024^{5} [.010]	-.012 [.009]	-.021^{10} [.011]	-.015^{10} [.009]	-.025^{5} [.011]	-.023^{5} [.011]
lnDf	.018 [.039]	.000 [.039]	.025 [.040]	.007 [.040]	.004 [.040]	.026 [.039]	.005 [.039]	.034 [.040]	.013 .039]	.011 [.039]	.031 [.039]	.011 [.039]	.040 [.040]	.021 [.040]	.019 [.040]
Dummy Variables:															
D_1	-.204^{1} [.060]	-.166^{1} [.063]	-.209^{1} [.061]	-.180^{1} [.064]	-.171^{1} [.064]	-.195^{1} [.057]	-.166^{1} [.060]	-.196^{1} [.059]	-.177^{1} [.062]	-.166^{1} [.060]	-.198^{1} [.058]	-.173^{1} [.063]	-.199^{1} [.059]	-.185^{1} [.063]	-.175^{1} [.062]
D_2	-.429^{1}	-.413^{1}	-.460^{1}	-.451^{1}	-.429^{1}	-.432^{1}	-.423^{1}	-.465^{1}	-.459^{1}	-.438^{1}	-.419^{1}	-.403^{1}	-.449^{1}	-.439^{1}	-.419^{1}

	[.117]	[.109]	[.117]	[.113]	[.112]	[.112]	[.104]	[.112]	[.105]	[.105]	[.113]	[.105]	[.111]	[.105]	[.105]
Control Variables:															
lnI	----	----	-.010 [.056]	.036 [.052]	-.012 [.054]	----	----	-.011 [.056]	.036 [.051]	-.018 [.054]	----	----	-.007 [.055]	.045 [.051]	-.006 [.053]
lnP	----	.126[1] [.028]	----	.124[1] [.028]	.121[1] [.029]	----	.113[1] [.028]	----	.112[1] [.028]	.107[1] [.029]	----	.115[1] [.029]	----	.113[1] [.029]	.108[1] [.029]
lnUp	----	.492[1] [.073]	----	.501[1] [.076]	.429[1] [.076]	----	.479[1] [.071]	----	.486[1] [.074]	.474[1] [.074]	----	.511[1] [.073]	----	.523[1] [.076]	.510[1] [.076]
R^2	.780	.799	.773	.793	.796	.787	.806	.779	.799	.803	.787	.804	.780	.799	.803
Obs	443	443	439	439	439	443	443	439	439	439	443	443	439	439	439

Source: Author (2016)

Note: Numbers in [ ] are heteroscedasticity and autocorrelation consistent standard errors. [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

Table 5.12: Dynamic regression results (as estimated with IV regression) for LIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 16B	Model 17B	Model 18B	Model 19B	Model 20B	Model 21B	Model 22B	Model 23B	Model 24B	Model 25B	Model 26B	Model 27B	Model 28B	Model 29B	Model 30B
β_0	.369 [.951]	.162 [1.13]	-.151 [.737]	-.310 [.800]	.104 [1.15]	3.06 [5.90]	4.83 [6.21]	2.36 [5.63]	4.20 [6.07]	5.04 [6.27]	29.4 [49.1]	6.69 [54.6]	15.9 [51.0]	-5.19 [56.1]	-5.33 [56.5]
$ln\ C0_{2t-1}$	.896[1] [.057]	.843[1] [.072]	.922[1] [.065]	.866[1] [.081]	.870[1] [.083]	.905[1] [.061]	.846[1] [.075]	.936[1] [.060]	.875[1] [.083]	.877[1] [.084]	.921[1] [.058]	.852[1] [.077]	.956[1] [.066]	.885[1] [.086]	.887[1] [.087]
Economic Development Indicators:															
lnY	-.094 [.142]	-.182 [.154]	-.088 [.141]	-.173 [.152]	-.184 [.155]	-.980 [1.98]	-1.80 [2.19]	-.968 [1.95]	-1.79 [2.18]	-1.92 [2.21]	-14.4 [26.4]	-2.29 [29.4]	-7.66 [27.5]	3.61 [30.1]	4.01 [30.3]
lnY^2	----	----	----	----	----	.078 [.171]	.141 [.190]	.077 [.169]	.142 [.189]	.151 [.192]	2.35 [4.70]	.144 [5.22]	1.18 [4.87]	-.886 [5.35]	-.969 [5.39]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.128 [.278]	.005 [.308]	-.059 [.287]	.064 [.315]	.069 [.318]
lnA	-.091 [.098]	-.082 [.106]	----	----	-.058 [.113]	-.121 [.102]	-.113 [.105]	----	----	-.075 [.116]	-.136 [.099]	-.120 [.110]	----	----	-.076 [.120]
lnT	.067[5] [.029]	.081[5] [.033]	.074[5] [.029]	.087[1] [.031]	.082[5] [.033]	.066[5] [.030]	.085[5] [.035]	.075[5] [.029]	.094[1] [.033]	.087[5] [.035]	.074[10] [.040]	.085[10] [.045]	.078[10] [.039]	.089[5] [.044]	.081[10] [.046]
$ln\pi$	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.007]	-.010 [.008]	-.010 [.008]	-.009 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.010 [.008]	-.011 [.008]
lnEgr	.129[5] [.129]	-.013 [.019]	.009 [.018]	-.005 [.022]	-.006 [.022]	.003 [.018]	-.011 [.021]	.014 [.020]	-.001 [.023]	-.003 [.023]	.004 [.018]	-.012 [.021]	.016 [.020]	-.001 [.024]	-.003 [.024]

lnEc	.129^{5} [.059]	.079 [.070]	.108^{10} [.064]	.062 [.071]	.067 [.072]	.129^{5} [.061]	.070 [.075]	.102 [.064]	.047 [.076]	.055 [.077]	.107^{10} [.059]	.052 [.072]	.083 [.062]	.032 [.072]	.040 [.074]
lnDe	.118 [.116]	.232^{10} [.140]	.109 [.116]	.221 [.140]	.220 [.143]	.102 [.119]	.224 [.146]	.092 [.119]	.211 [.147]	.213 [.148]	.082 [.116]	.224 [.154]	.074 [.118]	.214 [.154]	.217 [.156]
Financial Development Indicators:															
lnD	.049^{10} [.026]	.078^{10} [.033]	.054^{5} [.027]	.081^{5} [.033]	.079^{5} [.033]	.042 [.035]	.066^{10} [.039]	.048 [.033]	.070^{10} [.039]	.066^{5} [.039]	.023 [.029]	.054 [.039]	.034 [.028]	.065^{10} [.038]	.061 [.039]
lnFDI	-.006 [.007]	-.008 [.008]	-.006 [.008]	-.007 [.008]	-.008 [.008]	-.007 [.008]	-.009 [.008]	-.007 [.008]	-.008 [.008]	-.009 [.008]	-.008 [.008]	.052 [.072]	-.007 [.008]	-.008 [.008]	-.008 [.008]
lnO	.012 [.008]	.006 [.010]	.012 [.008]	.006 [.010]	.006 [.010]	.012 [.009]	.006 [.010]	.013 [.009]	.006 [.010]	.006 [.010]	.010 [.010]	.004 [.011]	.011 [.010]	.006 [.011]	.006 [.012]
lnDf	-.105^{10} [.059]	-.101^{10} [.057]	-.106^{10} [.057]	-.101^{10} [.055]	-.111^{10} [.059]	-.116^{5} [.057]	-.110^{10} [.057]	-.113^{5} [.056]	-.108^{10} [.055]	-.118 [.058]	-.106^{10} [.057]	-.105 [.058]	-.107^{10} [.056]	-.106^{10} [.057]	-.116^{10} [.059]
Dummy Variables:															
D_1	-.048^{5} [.024]	-.071^{5} [.029]	-.060^{5} [.025]	-.080^{1} [.031]	-.078^{5} [.031]	-.047^{5} [.025]	-.069^{5} [.031]	-.062^{5} [.025]	-.081^{5} [.032]	-.077^{5} [.033]	-.043^{10} [.024]	-.067^{5} [.032]	-.059^{5} [.025]	-.081^{5} [.033]	-.077^{5} [.034]
D_2	-.090^{10} [.047]	-.092^{5} [.046]	-.082^{10} [.049]	-.085^{10} [.048]	-.083^{10} [.048]	-.082^{10} [.050]	-.078 [.051]	-.073 [.052]	-.069 [.052]	-.067 [.053]	-.072 [.049]	-.064 [.052]	-.060 [.052]	-.054 [.053]	-.052 [.054]
Control Variables:															
lnI	----	----	.070 [.065]	.060 [.068]	.049 [.072]	----	----	.088 [.065]	.079 [.066]	.060 [.073]	----	----	.0100 [.065]	.089 [.069]	.071 [.076]
lnP	----	.021 [.036]	----	.021 [.035]	.015 [.037]	----	.031 [.042]	----	.032 [.041]	.026 [.042]	----	.038 [.042]	----	.036 [.041]	.029 [.043]
lnUp	----	.101 [.083]	----	.099 [.082]	.091 [.085]	----	.121 [.093]	----	.119 [.093]	.113 [.094]	----	.139 [.094]	----	.135 [.095]	,129 [.096]
R^2	.969	.971	.969	.971	.971	.968	.968	.968	.968	.968	.969	.966	.968	.966	.966
Obs	411	411	411	411	411	411	411	411	411	411	411	411	411	411	411
Sargan test of overidentifying restrictions															
Chi^2	10.03 (.349)	9.478 (.220)	9.474 (.283)	8.800 (.185)	9.460 (.149)	7.534 (.582)	6.996 (.429)	6.639 (.576)	6.032 (.419)	6.437 (.376)	7.673 (.567)	6.394 (.495)	7.161 (.519)	7.424 (.386)	5.941 (.429)

Source: Author (2016)

Note: Numbers in [ ] are standard errors and ( ) indicate the probability value for the Sargan test. ^{1} means 0.01 level of significance, ^{5} means 0.05 level of significance and ^{10} means 0.1 level of significance. Obs represents the number of observations.

These economic development variables (the share of agriculture in GDP (*lnA*)) and financial development variable (official exchange rates (*lnO*)) have a negative relationship with the explained variable in LIC. For example, one percent increase in official exchange rates (local currency to US dollar) results in a reduction between 0.015 and 0.031 percent in CO_2 emissions per capita, other variables remaining the same. Like the entire sample, this means that exchange rate depreciation supports the importation of energy-efficient technologies which results in emissions reduction. The effect of this reduction in emissions may, however, not make a mitigating impact due to the increasing effect of trade openness and domestic credit to private sector on CO_2 emissions in LIC.

The dummy variables for French-speaking SSA countries (D_1) and Portuguese-speaking SSA countries (D_2) are also significant. Other variables (i.e. the degree of economic development (*lnDe*), inflation rate ($ln\pi$), employment generation rate (*lnEgr*) and the net inflow of foreign direct investment to GDP ratio (*lnFDI*))) are not statistically significant. The dynamic framework for this income group is presented in the next sub-section.

5.4.2.2 Dynamic models

The results of LIC's dynamic models are obtained using the Instrumental Variable (IV) regression with the option of Two Stage Least Squares (TSLS) random effects estimator (proposed by Balestra and Varadharajan-Krishnakumar (1987)). This option was chosen because it computes and generates results for the unbalanced panel data of all the sub-samples during the course of the analysis. The results obtained are displayed as Table 5.12 above.

Unlike the entire sample where the dynamic specification supports the static estimation with a linear relationship between CO_2 emissions per capita and real GDP per capita, the dynamic estimation for LIC depicts that there is no significant relationship for CO_2 emissions per capita and real GDP per capita. This is not the only difference between the static and dynamic results for LIC. The share of agriculture in GDP, official exchange rates, population density and urban population as a percentage of total population are the other economic and financial development indicators and control variables that are also insignificant. The degree of financial development is otherwise found to be statistically significant with a negative sign. This result suggests that CO_2 emissions may continue to increase as financial development increases into the future in LIC. This supports the efforts of low-income countries to increase their share of industrial development which requires financial services for the production and consumption of carbon-related commodities at the expense of a dirtier CO_2 environment (World Bank 2000).

Consistent with LIC's static models, trade openness, total primary energy consumption per capita, domestic credit to private sector to GDP, French-speaking SSA countries and Portuguese-speaking SSA countries are statistically significant with the same sign. The lagged regressand ($lnCO_{2t-1}$) is significant which not only means that the previous level of CO_2 emitted per capita contributes to the current level of CO_2 emissions per capita but also implies that there is a long-run effect of statistically significant regressors on CO_2 emissions per capita. Other variables are not statistically significant.

The Sargan tests for overidentifying restrictions are obtained after performing the fixed effects estimation of the models. All the models fail to reject the null hypothesis at ten percent level of significance which confirms that the appropriate instrumental variables selection is made.

5.4.3 Regression results from the sub-sample of lower-middle-income countries

5.4.3.1 Static models

Results for static models on LMIC in SSA are displayed in Table 5.13. Models 1C, 3C and 4C indicate a significant linear relationship between CO_2 emissions per capita and real GDP per capita (*lnY*). Other models do not indicate a significant relationship between the two study variables. In contrast to the static regression results for the entire sample and LIC, only the indicators of economic development and one control variable (trade openness (*lnT*), inflation rate ($ln\pi$), total primary energy consumption per capita (*lnEc*) and population density (*lnP*)) are statistically significant with positive signs. That is, all the other regressors are not significant.

Interestingly, the inflation rate is significant throughout Table 5.13 but not in Table 5.9 and 5.11. This explains why some studies in the literature find a significant relationship between an explanatory variable and CO_2 emissions while other studies find no significant relationship using the same estimation method but a different sample of countries. A percent increase in inflation rate increases CO_2 emissions per capita by a range of 0.021-0.023 percent annually in LMIC, *ceteris paribus*. This is indicative that LMIC attracts carbon-intensive commodities (Hoffmann 2011) as inflation rate rises while the substitute clean commodities are either not available or not affordable to buy, thereby resulting in higher emissions. To know what the results would be like if the assumption of no endogeneity is relaxed, the dynamic version is investigated next.

Table 5.13: Static regression results (as estimated with PCSE) for LMIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 1C	Model 2C	Model 3C	Model 4C	Model 5C	Model 6C	Model 7C	Model 8C	Model 9C	Model 10C	Model 11C	Model 12C	Model 13C	Model 14C	Model 15C
β_0	-5.49[1]	-5.13[1]	-5.34[1]	-5.61[1]	-512[1]	-2.25	-5.80	-2.15	-5.78	-5.39	-80.1	-104.8	-77.2	-103.3	105.0
	[1.47]	[1.39]	[1.17]	[1.18]	[1.45]	[8.15	[8.32]	[8.85]	[8.85]	[8.79]	[100.7]	[99.9]	[102.5]	[101.4]	[99.8]
Economic Development Indicators:															
lnY	.418[10]	.354	.406[10]	.412[10]	.352	-.548	.535	-.538	.447	.420	33.4	43.7	32.2	42.9	43.5
	[.226]	[.245]	[.217]	[.227]	[.249]	[2.34]	[2.41]	[2.58]	[2.59]	[2.58]	[43.8]	[43.5]	[44.6]	[44.2]	[43.5]
lnY^2	----	----	----	----	----	.071	-.013	.068	-.002	-.005	-4.85	-6.26	-4.68	-6.16	-6.31
						[.171]	[.176]	[.188]	[.189]	[.189]	[6.34]	[6.29]	[6.46]	[6.39]	[6.29]
lnY^3	----	----	----	----	----	----	----	----	----	----	.237	.300	.228	.296	.303
											[.305]	[.303]	[.311]	[.307]	[.303]
lnA	.005	-.063	----	----	-.056	.014	-.059	----	----	-.053	.005	-.068	----	----	-.052
	[.099]	[.099]			[.103]	[.099]	[.099]			[.103]	[.099]	[.099]			[.103]
lnT	.230[1]	.171[5]	.186[5]	.144	.143	.241[1]	.176[5]	.199	.153[10]	.147	.238[1]	.176[5]	.203[5]	.159[10]	.162[10]
	[.083]	[.085]	[.091]	[.090]	[.090]	[.083]	[.085]	[.092]	[.091]	[.091]	[.088]	[.087]	[.095]	[.093]	[.093]
$ln\pi$	.023[5]	.022[5]	.022[5]	.022[5]	.021[5]	.023[5]	.022[5]	.022[5]	.023[5]	.021[5]	.022[5]	.021[5]	.022[5]	.022[5]	.021[5]
	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]	[.010]
lnEgr	-.023	-.019	-.022	-.017	-.018	-.025	-.019	-.023	-.017	-.018	-.022	-.018	-.021	-.015	-.017
	[.032]	[.028]	[.030]	[.027]	[.027]	[.033]	[.028]	[.031]	[.028]	[.028]	[.032]	[.027]	[.031]	[.027]	[.028]
lnEc	.234[5]	.297[1]	.263[5]	.309[1]	.304	.219[5]	.293[1]	.240[5]	.301[1]	.299[1]	.218[5]	.288[1]	.233[5]	.289[1]	.270[5]
	[.101]	[.105]	[.102]	[.106]	[.106]	[.101]	[.106]	[.103]	[.108]	[.107]	[.105]	[.109]	[.107]	[.111]	[.110]
lnDe	-.151	-.129	-.152	-.165	-.139	-.167	-.129	-.163	-.164	-.139	-.132	-.081	-.133	-.119	-.093
	[.201]	[.214]	[.207]	[.216]	[.217]	[.203]	[.216]	[.209]	[.218]	[.220]	[.208]	[.218]	[.212]	[.219]	[.220]
Financial Development Indicators:															
lnD	.087	.053	.079	.039	.052	.088	.054	.086	.042	.053	.073	.038	.072	.027	.040
	[.078]	[.079]	[.077]	[.078]	[.079]	[.078]	[.216]	[.077]	[.077]	[.079]	[.079]	[.081]	[.078]	[.079]	[.081]
lnFDI	-.011	-.009	-.011	-.011	-.010	-.011	-.009	-.011	-.011	-.010	-.011	-.010	-.011	-.011	-.011
	[.009]	[.008]	[.008]	[.008]	[.008]	[.009]	[.008]	[.009]	[.009]	[.008]	[.009]	[.008]	[.009]	[.008]	[.009]
lnO	.036	.011	.038	.009	.009	.039	.010	.039	.009	.008	.036	.006	.036	.004	.004
	[.025]	[.029]	[.026]	[.030]	[.029]	[.026]	[.031]	[.026]	[.031]	[.031]	[.028]	[.032]	[.028]	[.032]	[.032]
lnDf	.082	.055	.079	.062	.055	.083	.055	.081	.063	.056	.088	.062	.086	.070	.065
	[.089]	[.089]	[.088]	[.088]	[.089]	[.089]	[.089]	[.088]	[.089]	[.089]	[.089]	[.089]	[.089]	[.089]	[.089]
Dummy Variables:															
D_1	-.155	.078	-.158	.122	.107	-.148	.077	-.149	.119	.105	-.131	.093	-.131	.132	.115
	[.128]	[.194]	[.137]	[.203]	[.203]	[.127]	[.192]	[.133]	[.199]	[.201]	[.129]	[.198]	[.134]	[.202]	[.202]
D_2	-.197	-.195	-.163	-.085	-.137	-.206	-.197	-.177	-.094	-.139	-.199	-.216	-.172	-.117	-.172
	[.176]	[.247]	[.192]	[.248]	[.262]	[172]	[.249]	[184]	[.247]	[.262]	[.177]	[.251]	[.187]	[.246]	[.258]

Control Variables:															
lnI	----	----	.033 [.101]	.082 [.101]	.060 [.105]	----	----	.039 [.107]	.081 [.106]	.060 [.110]	----	----	.042 [.107]	.082 [.106]	.061 [.109]
lnP	----	.167^{1} [.052]	----	.167^{1} [.054]	.170^{1} [.053]	----	.167^{1} [.052]	----	.167^{1} [.054]	.169^{1} [.054]	----	.172^{1} [.054]	----	.171^{1} [.055]	.174^{1} [.054]
lnUp	----	-.020 [.233]	----	-.083 [.239]	-.051 [.246]	----	-.019 [.232]	----	-.078 [.235]	-.050 [.244]	----	.006 [.234]	----	-.049 [.234]	-.061 [.239]
R^2	.383	.387	.364	.374	.379	.389	.390	.374	.380	.382	.383	.383	.371	.377	.385
Obs	233	233	233	233	233	233	233	233	233	233	233	233	233	233	233

Source: Author (2016)

Note: Numbers in [ ] are heteroscedasticity and autocorrelation consistent standard errors. ^{1} means 0.01 level of significance, ^{5} means 0.05 level of significance and ^{10} means 0.1 level of significance. Obs represents the number of observations.

Table 5.14: Dynamic regression results (as estimated with IV regression) for LMIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 16C	Model 17C	Model 18C	Model 19C	Model 20C	Model 21C	Model 22C	Model 23C	Model 24C	Model 25C	Model 26C	Model 27C	Model 28C	Model 29C	Model 30C
β_0	-4.35^{1} [1.26]	-3.28^{1} [1.01]	-2.69^{1} [.792]	-2.35^{1} [.743]	-3.19^{1} [1.01]	-3.83 [3.93]	-4.72 [3.82]	-1.17 [3.19]	-2.96 [3.76]	-4.26 [3.82]	-8.70 [18.1]	-11.9 [24.1]	-12.5 [31.5]	-11.9 [27.6]	-10.6 [22.7]
ln $C0_{2t-1}$	.593^{1} [.108]	.678^{1} [.077]	.574^{1} [.110]	.676^{1} [.076]	.707^{1} [.073]	.630^{1} [.104]	.715^{1} [.075]	.648^{1} [.100]	.721^{1} [.073]	.747^{1} [.071]	.690^{1} [.089]	.709^{1} [.072]	.664^{1} [.096]	.705^{1} [.074]	.732^{1} [.071]
Economic Development Indicators:															
lnY	.359^{5} [.141]	.321^{5} [.132]	.183 [.112]	.199^{10} [.106]	.320^{5} [.133]	.281 [1.11]	.801 [1.08]	-.167 [1.15]	.442 [1.09]	.703 [1.09]	2.56 [7.83]	3.93 [10.4]	4.80 [13.7]	4.35 [12.0]	3.44 [9.82]
lnY^2	----	----	----	----	----	.004 [.081]	-.036 [.078]	.024 [.084]	-.019 [.079]	-.029 [.078]	-.328 [1.14]	-.492 [1.51]	-.696 [1.99]	-.588 [1.74]	-.430 [1.43]
lnY^3	----	----	----	----	----	----	----	----	----	----	.016 [.055]	.022 [.073]	.035 [.096]	.028 [.084]	.019 [.069]
lnA	.147^{5} [.062]	.097^{10} [.058]	----	----	.103^{10} [.059]	.135^{5} [.061]	.092 [.058]	----	----	.095 [.059]	.117^{5} [.058]	.094 [.058]	----	----	.098^{10} [.058]
lnT	.219^{1} [.075]	.169^{1} [.061]	.163^{5} [.066]	.113^{5} [.055]	.139^{5} [.060]	.199^{1} [.072]	.155^{5} [.060]	.132^{5} [.062]	.099^{10} [.054]	.125^{5} [.059]	.169^{5} [.067]	.161^{1} [.061]	.129^{5} [.063]	.107^{10} [.056]	.133^{5} [.061]
lnπ	.028^{5} [.012]	.030^{1} [.011]	.027^{5} [.012]	.029^{5} [.011]	.030^{1} [.011]	.027^{5} [.012]	.029^{1} [.011]	.026^{5} [.012]	.029^{5} [.011]	.029^{5} [.011]	.026^{5} [.011]	.029^{1} [.011]	.026^{5} [.012]	.029^{5} [.011]	.029^{5} [.011]
lnEgr	-.009 [.039]	.013 [.038]	-.026 [.041]	.003 [.038]	.012 [.038]	-.008 [.038]	.015 [.038]	-.022 [.039]	.004 [.038]	.014 [.038]	-.006 [.037]	.015 [.038]	-.020 [.039]	.004 [.038]	.014 [.038]
lnEc	.057	.071	.007	.031	.059	.059	.077	.018	.039	.066	.062	.074	.016	.033	.062

	[.057]	[.056]	[.064]	[.058]	[.058]	[.056]	[.056]	[.062]	[.058]	[.058]	[.055]	[.057]	[.064]	[.060]	[.059]
lnDe	-.143 [.107]	-.173 [.115]	-.046 [.104]	-.097 [.104]	-.191 [.116]	-.139 [.107]	-.163 [.115]	-.058 [.102]	-.094 [.105]	-.178 [.117]	-.128 [.105]	-.159 [.116]	-.053 [.102]	-.089 [.107]	-.178 [.117]
Financial Development Indicators:															
lnD	.015 [.052]	-.018 [.052]	$.102^{10}$ [.059]	.041 [.049]	-.014 [.052]	.010 [.051]	-.025 [.051]	.078 [.056]	.028 [.048]	-.023 [.052]	-.001 [.049]	-.026 [.052]	.071 [.054]	.031 [.048]	-.021 [.052]
lnFDI	-.011 [.012]	-.006 [.013]	-.009 [.014]	-.008 [.013]	-.008 [.013]	-.012 [.013]	-.008 [.013]	-.011 [.013]	-.009 [.013]	-.010 [.013]	-.013 [.012]	-.008 [.013]	-.011 [.013]	-.009 [.013]	-.009 [.013]
lnO	.017 [.013]	.007 [.013]	.005 [.014]	-.004 [.014]	.002 [.014]	.017 [.014]	.005 [.014]	.006 [.014]	-.004 [.014]	.001 [.014]	.015 [.013]	.005 [.014]	.005 [.013]	-.004 [.014]	.001 [.014]
lnDf	.073 [.063]	.032 [.060]	.018 [.060]	.002 [.058]	.034 [.059]	.069 [.062]	.031 [.060]	.018 [.058]	.003 [.057]	.033 [.059]	.064 [.060]	.033 [.060]	.020 [.058]	.005 [.058]	.035 [.060]
Dummy Variables:															
D_1	-.060 [.064]	.055 [.083]	-.034 [.067]	.071 [.091]	.092 [.091]	-.055 [.063]	.055 [.082]	-.027 [.065]	.067 [.090]	.086 [.091]	-.048 [.061]	.054 [.082]	-.024 [.065]	.068 [.090]	.088 [.091]
D_2	-.051 [.098]	.075 [.138]	-.084 [.104]	.027 [.141]	.145 [.147]	-.038 [.096]	.096 [.138]	-.052 [.099]	.049 [.139]	.157 [.147]	-.014 [.092]	.091 [.139]	-.044 [.097]	.038 [.141]	.152 [.148]
Control Variables:															
lnI	----	----	.027 [.071]	.047 [.069]	.068 [.069]	----	----	.024 [.069]	.038 [.069]	.057 [.070]	----	----	.024 [.069]	.042 [.069]	.061 [.070]
lnP	----	$.051^{5}$ [.024]	----	.064 [.024]	$.049^{5}$ [.023]	----	$.047^{5}$ [.023]	----	$.057^{5}$ [.024]	$.044^{10}$ [.023]	----	$.048^{5}$ [.023]	----	$.060^{5}$ [.024]	$.046^{10}$ [.023]
lnUp	----	-.097 [.093]	----	-.061 [.092]	-.129 [.098]	----	-.103 [.094]	----	-.065 [.092]	-.128 [.098]	----	-.099 [.094]	----	-.060 [.093]	-.127 [.099]
R^2	.841	.855	.832	.853	.857	.846	.857	.844	.856	.858	.852	.857	.846	.855	.858
Obs	219	219	219	219	219	219	219	219	219	219	219	219	219	219	219
Sargan test of overidentifying restrictions															
Chi^2	13.9 (.235)	21.5 (.064)	10.2 (.516)	16.4 (.229)	21.2 (.097)	15.8 (.201)	23.7 (.050)	12.3 (.423)	18.0 (.169)	23.7 (.070)	16.8 (.209)	24.9 (.051)	16.8 (.210)	23.7 (.069)	25.2 (.066)

Source: Author (2016)

Note: Numbers in [ ] are standard errors and ( ) indicate the probability value for the Sargan test. ^{1} means 0.01 level of significance, ^{5} means 0.05 level of significance and ^{10} means 0.1 level of significance. Obs represents the number of observations.

5.4.3.2 Dynamic models

Table 5.14 presents the dynamic version of the static models for LMIC and it shows that there is a long-run relationship between CO_2 emissions per capita and the regressors because the lagged dependent variable ($lnCO_{2t-1}$) is significant (at one percent). Although the proportion of the variation in CO_2 emissions per capita explained by all the regressors (R^2) is depicted as very low under the static models for LMIC (Table 5.13), the dynamic models give a higher goodness of fit. The dynamic models found a significant linear relationship (under Models 16C, 17C, 19C and 20C) between CO_2 emissions per capita and real GDP per capita.

Like the static models, economic development indicators and one control variable (trade openness (*lnT*), inflation rate ($ln\pi$) and population density (*lnP*)) are the only factors that are statistically significant with a positive sign. However, while the static models found that energy consumption per capita has a significant effect on CO_2 emissions per capita, the dynamic models did not, instead, it found that the share of agriculture in GDP (*lnA*) has a significant increasing effect on the explained variable. This serves to confirm that agriculture leads to higher levels of emissions in LMIC due to conventional agricultural practices and/or increase in livestock production for consumption of its growing population which affects forest carbon sink potentials (West and McBride 2005; Goodland and Anhang 2009).

Also, using Model 16C as illustration, the short-run effects of *lnY, lnA*, *lnT* and $ln\pi$ are 0.359, 0.147, 0.219 and 0.028 while the long-run effects (after dividing these coefficients with (1-0.593)) are 0.882, 0.361, 0.538 and 0.069, respectively. This connotes that the long-run effects of these significant explanatory variables are larger on CO_2 emissions per capita. The Sargan tests identify that most of the models (16C, 18C, 19C, 21C, 23C, 24C, 26C and 28C) fail to reject the null hypothesis of overidentifying restrictions are valid at ten percent level of significance while other models fail to reject the null hypothesis at five percent level of significance.

5.4.4 Regression results from the sub-sample of upper-middle-income countries

5.4.4.1 Static models

The results of the specified static models for UMIC, laid out in Table 5.15, show that real GDP per capita (*lnY*) has a significant linear effect on CO_2 emissions per capita under Model 3D while it has a significant N-shape effect on the explained variable under Models 11D, 12D, 14D and 15D. This finding is similar to that of the static models' results for LIC in Table 5.11. These economic development indicators (the share of agriculture in GDP (*lnA*), trade openness (*lnT*) and employment generation rate (*lnEgr*)), financial development indicators (domestic credit to private sector to GDP (*lnD*) and net inflow of foreign direct investment to GDP ratio (*lnFDI*)) and the dummy variable for French-speaking SSA countries (D_1) are significant with an inverse effect on CO_2 emissions per capita. Contrary to the entire sample and sub-samples of LIC and LMIC, trade openness has a decreasing and not an increasing effect on CO_2 emissions per capita. That is, CO_2 emissions per capita would decrease between 0.190 and 0.401 percent if trade openness increases by a percent in UMIC annually, other variables remaining the same. According to Shafik and Bandyopadhyay (1992), this accounts that upper-middle-income countries in SSA may have a comparative advantage in cleaner industries or increased openness to trade may have caused more investment in efficient and cleaner technologies that meet climate change mitigation actions (Shafik and Bandyopadhyay 1992).

With an increased effect on the explained variable, some economic development indicators (total primary energy consumption per capita (*lnEc*) and the degree of economic development (*lnDe*)), financial development indicator (the degree of financial development (*lnDf*)), dummy variable for Portuguese-speaking SSA countries (D_2) and the control variable share of industry in GDP (*lnI*) are statistically significant. The share of industry in GDP has no significant effect on CO_2 emissions per capita in LIC and LMIC but it has in UMIC (and HIC). This indicates that industrialisation is higher in UMIC (and HIC) than in LIC and LMIC of SSA and the industrial transformation has not been green growth sustainable.

Opposite to previous sub-samples, the degree of economic and financial development are statistically significant with the expected sign in UMIC. Also, UMIC is the first to have both the share of agriculture and industry in GDP statistically significant, although not in the same model, and while the share of agriculture in GDP is reducing CO_2 emissions per capita, the share of industry in GDP is contributing to it. The economic development indicator inflation rate ($ln\pi$) is not statistically significant across Table 5.15 but the financial development indicator domestic credit to private sector to GDP has a weak evidence for a decreased effect on CO_2 emissions. As such, unlike previous sub-samples, the domestic credit provided to the private sector in UMIC might have been applied to low-carbon investments that reduce CO_2 emissions (Tamazian 2009). With the highest average domestic credit to private sector to GDP, the affordability of cleaner technologies is expected of UMIC.

Table 5.15: Static regression results (as estimated with PCSE) for UMIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 1D	Model 2D	Model 3D	Model 4D	Model 5D	Model 6D	Model 7D	Model 8D	Model 9D	Model 10D	Model 11D	Model 12D	Model 13D	Model 14D	Model 15D
β_0	-2.48 [1.75]	-2.47 [1.87]	-5.97[1] [1.51]	-5.92[1] [1.54]	3.05 [1.89]	-9.19 [12.3]	-9.99 [11.8]	6.30 [13.7]	6.49 [13.9]	-2.47 [13.2]	-442.8[1] [157.5]	-488.9[1] [171.8]	-259.9 [165.1]	-349.1[10] [187.8]	-484.4[1] [170.3]
Economic Development Indicators:															
lnY	.059 [.229]	-.029 [.257]	.277[10] [.166]	.281 [.212]	-.026 [.253]	1.86 [2.97]	1.88 [2.95]	-2.77 [3.35]	-2.83 [3.45]	-.158 [3.34]	163.9[1] [59.0]	181.2[1] [64.4]	97.3 [61.9]	130.5[10] [70.4]	180.2[1] [63.8]
lnY^2	----	----	----	----	----	-.114 [.181]	-.120 [.178]	.185 [.200]	.189 [.205]	.005 [.201]	-20.27[1] [7.36]	-22.4[1] [8.03]	-12.3 [7.74]	-16.4[10] [8.77]	-22.4[1] [7.96]
lnY^3	----	----	----	----	----	----	----	----	----	----	.832[1] [.305]	.922[1] [.332]	.519 [.321]	.688[10] [.364]	.927[1] [.329]
lnA	-.223[5] [.091]	-.230[5] [.092]	----	----	-.226[5] [.089]	-.237[5] [.095]	-.259[1] [.095]	----	----	-.232 [.095]	-.343[1] [.087]	-.327[1] [.089]	----	----	-.306[1] [.088]
lnT	-.344[1] [.130]	-.304[10] [.163]	-.367[1] [.134]	-.376[5] [.165]	-.316[10] [.161]	-.318[5] [.135]	-.287[10] [.160]	.401[1] [.136]	-.395[5] [.164]	-.311[10] [.159]	-.198 [.127]	-.190 [.147]	-.359[1] [.135]	-.345[5] [.157]	-.206 [.146]
$ln\pi$	.009 [.015]	.010 [.015]	.012 [.014]	.011 [.015]	.004 [.016]	.009 [.016]	.009 [.016]	.009 [.015]	.009 [.015]	.005 [.016]	.015 [.016]	.016 [.016]	.013 [.015]	.014 [.015]	.011 [.016]
lnEgr	-.022[10] [.013]	-.025[10] [.014]	-.021 [.014]	-.021 [.014]	-.024[10] [.013]	-.024[10] [.013]	-.028[5] [.014]	-.018 [.014]	-.019 [.015]	-.026[10] [.014]	-.032[5] [.014]	-.031[5] [.014]	-.021 [.014]	-.019 [.014]	-.029[5] [.014]
lnEc	.948[1] [.099]	.971[1] [.139]	.970[1] [.105]	.962[1] [.140]	.981[1] [.136]	.974[1] [.096]	1.03[5] [.138]	.915[1] [.111]	.917[1] [.142]	.999[1] [.138]	1.13[1] [.098]	1.09[1] [.131]	.992[1] [.117]	.935[1] [.139]	1.05[1] [.132]
lnDe	.326 [.213]	.385[10] [.221]	.266 [.210]	.267 [.222]	.378[10] [.217]	.362[10] [.205]	.436[5] [.213]	.275 [.206]	.280 [.222]	.420 [.211]	.372[5] [.178]	.364[10] [.201]	.230 [.197]	.209 [.219]	.356[10] [.199]
Financial Development Indicators:															
lnD	-.124 [.079]	-.117 [.095]	-.079 [.101]	-.081 [.107]	-.063 [.103]	-.130[10] [.076]	-.139 [.092]	-.039 [.107]	-.038 [.112]	-.069 [.109]	-.160[5] [.069]	-.142[10] [.086]	-.048 [.104]	-.037 [.109]	-.076 [.103]
lnFDI	-.023[5] [.010]	-.023[5] [.010]	-.019[10] [.010]	-.019[10] [.010]	-.024[5] [.010]	-.021[5] [.010]	-.021[5] [.011]	-.022[5] [.011]	-.022[5] [.011]	-.023[5] [.011]	-.017[10] [.010]	-.016 [.010]	-.020[10] [.011]	-.019[10] [.011]	-.018[10] [.010]
lnO	-.013 [.034]	-.003 [.040]	-.031 [.034]	-.033 [.039]	-.003 [.039]	-.021 [.036]	-.007 [.041]	-.014 [.039]	-.013 [.046]	.002 [.042]	-.051[10] [.031]	-.062 [.041]	-.034 [.038]	-.056 [.050]	-.053 [.042]
lnDf	.168[5] [.078]	.197[5] [.098]	.167[5] [.078]	.160[10] [.096]	.216 [.096]	.175[5] [.078]	.214[5] [.095]	.166[5] [.077]	.170[10] [.095]	.225[5] [.094]	.208[1] [.070]	.187[5] [.091]	.179[5] [.075]	.139 [.095]	.197[5] [.090]
Dummy Variables:															
D_1	-.340 [.214]	-.360[10] [.208]	-.480[5] [.197]	-.482[5] [.205]	-.275 [.210]	-.246 [.271]	-.231 [.277]	-.615[5] [.245]	-.622[5] [.264]	-.282 [.279]	-.089 [.221]	-.138 [.248]	-.611[1] [.232]	-.636[5] [.252]	-.184 [.249]
D_2	.789[1]	.824[1]	.706[1]	.707[1]	.685[1]	.869[1]	.921[1]	.546[10]	.549[10]	.711[5]	.809[1]	.774[1]	.452	.428	.588[5]

	[.229]	[.227]	[.235]	[.242]	[.235]	[.250]	[.236]	[.313]	[.313]	[.281]	[.203]	[.209]	[.298]	[.302]	[.256]
Control Variables:															
lnI	----	----	$.397^{10}$ [.206]	$.388^{10}$ [.216]	$.351^{10}$ [.205]	----	----	$.495^{5}$ [.232]	$.494^{5}$ [.239]	.334 [.227]	----	----	$.564^{5}$ [.227]	$.494^{5}$ [.235]	.298 [.215]
lnP	----	-.015 [.027]	----	.003 [.028]	-.013 [.027]	----	-.017 [.026]	----	-.002 [.028]	-.017 [.026]	----	.009 [.027]	----	.019 [.030]	.008 [.027]
lnUp	----	.040 [.277]	----	.008 [.294]	-.201 [.286]	----	-.065 [.271]	----	.009 [.292]	-.214 [.276]	----	.152 [.243]	----	.253 [.280]	.021 [.247]
R^2	.883	.896	.886	.889	.902	.896	.915	.890	.890	.915	.934	.935	.902	.902	.936
Obs	116	116	116	116	116	116	116	116	116	116	116	116	116	116	116

Source: Author (2016)

Note: Numbers in [ ] are heteroscedasticity and autocorrelation consistent standard errors. ^{1} means 0.01 level of significance, ^{5} means 0.05 level of significance and ^{10} means 0.1 level of significance. Obs represents the number of observations.

Table 5.16: Dynamic regression results (as estimated with IV regression) for UMIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 16D	Model 17D	Model 18D	Model 19D	Model 20D	Model 21D	Model 22D	Model 23D	Model 24D	Model 25D	Model 26D	Model 27D	Model 28D	Model 29D	Model 30D
β_0	-.502 [1.29]	-.466 [1.52]	-2.04^{10} [1.12]	-1.89 [1.15]	-1.03 [1.49]	-6.29 [7.31]	-9.10 [7.84]	-1.49 [9.81]	-2.50 [9.86]	-6.11 [9.99]	-2.83 [12.0]	-3.18 [7.39]	-1.44 [7.92]	.000 [.000]	.000 [.000]
$ln\ C0_{2t-1}$	$.545^{1}$ [.101	$.541^{1}$ [.113]	$.586^{1}$ [.101]	$.588^{1}$ [.103]	$.545^{1}$ [.112]	$.527^{1}$ [.101]	$.505^{1}$ [.111]	$.585^{1}$ [.102]	$.582^{1}$ [.103]	$.519^{1}$ [.112]	$.537^{1}$ [.101]	$.500^{1}$ [.112]	$.583^{1}$ [.102]	$.577^{1}$ [.102]	$.515^{1}$ [.110]
Economic Development Indicators:															
lnY	-.015 [.196]	.068 [.280]	.104 [.139]	.196 [.181]	-.001 [.287]	1.37 [1.73]	2.27 [1.95]	-.036 [2.49]	.380 [2.53]	1.36 [2.57]	.512 [4.33]	.270 [2.52]	.162 [2.66]	-.303 [1.13]	-.475 [.971]
lnY^2	----	----	----	----	----	-.090 [.108]	-.141 [.122]	.007 [.151]	-.011 [.152]	-.087 [.159]	-.018 [.544]	.097 [.334]	-.028 [.368]	.056 [.277]	.096 [.232]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.001 [.023]	-.009 [.016]	.002 [.019]	-.002 [.017]	-.006 [.014]
lnA	-.091 [.092]	-.075 [.114]	----	----	-.102 [.117]	-.133 [.089]	-.144 [.116]	----	----	-.149 [.115]	-.101 [.090]	-.145 [.116]	----	----	-.149 [.113]
lnT	$-.262^{10}$ [.154]	$-.324^{10}$ [.195]	$-.275^{10}$ [147]	$-.345^{5}$ [.171]	-.254 [.197]	-.190 [.158]	-.280 [.187]	-.266 [.146]	$-.355^{5}$ [.169]	-.239 [.187]	$-.286^{10}$ [.156]	$-.325^{10}$ [.186]	$-.331^{5}$ [.146]	$-.403^{5}$ [.167]	-.286 [.185]
$ln\pi$	.009 [.023]	.013 [.023]	$.033^{10}$ [.019]	$.034^{10}$ [.018]	.025 [.021]	.007 [.023]	.013 [.022]	.026 [.020]	.028 [.019]	.021 [.019]	.006 [.023]	.006 [.021]	.028 [.020]	.024 [.019]	.015 [.019]
lnEgr	-.031 [.020]	-.031 [.020]	-.029 [.020]	-.028 [.021]	-.030 [.020]	-.032 [.020]	$-.035^{10}$ [.020]	-.029 [.020]	-.029 [.021]	-.033 [.020]	$-.034^{10}$ [.020]	$-.036^{10}$ [.020]	-.032 [.021]	-.029 [.021]	-.033 [.020]
lnEc	$.410^{1}$	$.438^{5}$	$.345^{5}$	$.358^{5}$	$.443^{5}$	$.458^{1}$	$.562^{1}$	$.355^{5}$	$.378^{5}$	$.521^{5}$	$.424^{1}$	$.560^{1}$	$.330^{5}$	$.373^{5}$	$.504^{5}$

	[.143]	[.196]	[.145]	[.176]	[.197]	[.145]	[.207]	[.166]	[.186]	[.212]	[.146]	[.208]	[.164]	[.182]	[.202]
lnDe	.198 [.148]	.172 [.181]	.187 [.142]	.153 [.157]	.240 [.182]	.239 [.149]	.223 [.178]	.183 [.143]	.143 [.156]	.262 [.178]	.195 [.151]	.202 [.179]	.167 [.144]	.124 [.156]	.246 [.178]
Financial Development Indicators:															
lnD	-.077 [.072]	-.108 [.083]	-.040 [.084]	-.058 [.088]	-.034 [.088]	-.071 [.072]	-.139 [.085]	-.040 [.109]	-.067 [.110]	-.070 [.107]	-.093 [.072]	-.153[10] [.084]	-.052 [.109]	-.074 [.103]	-.067 [.096]
lnFDI	-.014 [.015]	-.012 [.015]	-.004 [.013]	-.003 [.013]	-.010 [.015]	-.015 [.015]	-.010 [.015]	-.005 [.013]	-.002 [.013]	-.010 [.015]	-.013 [.015]	-.011 [.015]	-.005 [.014]	-.003 [.014]	-.012 [.015]
lnO	-.001 [.027]	.002 [.032]	-.002 [.027]	-.005 [.031]	.004 [.032]	-.011 [.028]	-.001 [.032]	-.003 [.028]	-.007 [.032]	.003 [.032]	-.000 [.028]	.001 [.032]	.005 [.028]	-.004 [.032]	.007 [.032]
lnDf	.119[10] [.068]	.130 [.089]	.116[10] [.068]	.116 [.084]	.150[5] [.091]	.118[10] [.067]	.166[10] [.090]	.116[10] [.069]	.118 [.084]	.170[10] [.091]	.137[5] [.068]	.171[10] [.091]	.133[10] [.069]	.125 [.083]	.176[10] [.090]
Dummy Variables:															
D_1	-.171 [.177]	-.178 [.182]	-.229 [.150]	-.171 [.164]	-.066 [.200]	-.052 [.202]	.001 [.227]	-.229 [.167]	-.163 [.180]	.025 [.228]	-.149 [.200]	-.014 [.229]	-.271 [.169]	-.181 [.178]	-.008 [.216]
D_2	.406[5] [.169]	.409[5] [.180]	.347[10] [.182]	.311 [.189]	.339[10] [.188]	.475[1] [.183]	.522[1] [.199]	.334 [.240]	.316 [.244]	.430[10] [.254]	.420[5] [.182]	.502[5] [.201]	.310 [.245]	.284 [.236]	.372 [.228]
Control Variables:															
lnI	----	----	.147 [.156]	.229 [.192]	.268 [.192]	----	----	.163 [.221]	.227 [.246]	.195 [.247]	----	----	.154 [.228]	.250 [.240]	.245 [.222]
lnP	----	.001 [.025]	----	.008 [.020]	-.006 [.026]	----	-.005 [.024]	----	.009 [.020]	-.009 [.024]	----	-.003 [.025]	----	.011 [.020]	-.007 [.024]
lnUp	----	-.111 [.211]	----	-.207 [.246]	-.294 [.259]	----	-.257 [.235]	----	-.223 [.246]	-.342 [.256]	----	-.280 [.238]	----	-.256 [.245]	-.377 [.255]
R^2	.972	.972	.971	.971	.972	.972	.973	.971	.971	.973	.972	.973	.971	.971	.973
Obs	109	109	109	109	109	109	109	109	109	109					
Sargan test of overidentifying restrictions															
Chi^2	18.1 (.114)	17.2 (.246)	18.1 (.201)	21.2 (.096)	20.5 (.084)	17.3 (.241)	20.1 (.169)	15.3 (.225)	19.4 (.150)	19.6 (.105)	24.9 (.052)	26.5 (.033)	26.7 (.045)	30.6 (.015)	26.6 (.032)

Source: Author (2016)

Note: Numbers in [ ] are standard errors and ( ) indicate the probability value for the Sargan test. [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance. Obs represents the number of observations.

5.4.4.2 Dynamic models

Table 5.16 presents the estimated results for UMIC after relaxing the assumption of no endogeneity. The dynamic models exhibit no relationship between CO_2 emissions per capita and real GDP per capita under log-linear, log-quadratic and log-cubic but they give evidence that there is a long-run relationship between the regressand and regressors. The same was found for the dynamic models for LIC. The dynamic models corroborate the static models in Table 5.15 by presenting the results that these economic development indicators (trade openness and employment generation rate) and financial development indicator (domestic credit to private sector to GDP) have a significant inverse effect on CO_2 emissions per capita while energy consumption per capita, degree of financial development and the dummy variable for Portuguese-speaking SSA countries have a significant direct effect on the regressand. Unlike the static models, the dynamic models find the inflation rate to be positively statistically significant while other regressors are statistically insignificant.

Model 27D and 30D reject the null hypothesis of overidentifying restrictions are valid under the Sargan tests. The selection of the appropriate instrumental variables are confirmed for Models 16D-18D and 21D-25D as they fail to reject the null hypothesis at ten percent level of significance while other models fail to reject the null hypothesis at five percent level of significance.

5.4.5 Regression results from the sub-sample of high-income countries

5.4.5.1 Static models

The static regression results for HIC in SSA are in Table 5.17. Like the entire sample, the log-quadratic models depict a statistically significant real GDP per capita (lnY) and squared real GDP per capita (lnY^2). However, the signs do not show an inverted U-shape relation, it shows a U-shape relation between CO_2 emissions per capita and real GDP per capita (Models 6E-10E). This result can be explained by the UNFCCC principle of common but differentiated responsibilities between developed and developing countries (Mahendra 2015). Although these are high-income countries, they have no financial but voluntary responsibilities towards climate change mitigation actions and the results reveal that they take for granted this little incentive to take unilateral actions to reduce CO_2 emissions (Carvalho and Almeida 2010).

Across Table 5.17, these economic development indicators (trade openness (*lnT*), employment generation rate (*lnEgr*) and total primary energy consumption per capita (*lnEc*)), financial development indicators (domestic credit to private sector to GDP (*lnD*) and net inflow of foreign direct investment to GDP ratio (*lnFDI*)) and population density (*lnP*) significantly increase CO_2 emissions per capita in HIC. For instance, a percent increase in FDI to GDP would cause the explained variable to increase by around 0.143 percent annually, *ceteris paribus*. In spite of having the highest average FDI to GDP, FDI in high-income countries does not act as a conditional factor that motivates the procurement and use of energy efficient and cleaner technologies. This corroborates that the countries may have been taking for granted their no financial but voluntary responsibilities to take unilateral actions on emissions reduction.

Since this sub-sample contains just two countries, the dummy variable for French-speaking SSA countries (D_1) was dropped when specifying the models (although Seychelles' official languages are French and English, it was identified as Anglophone in this study while Equatorial Guinea is a Portuguese-speaking country). The dummy variable for Portuguese-speaking SSA countries (D_2) has a significant negative sign throughout Table 5.17, except under Model 4E where it has a positive sign. This means that Seychelles emit more CO_2 than Equatorial Guinea.

Economic development indicators (the share of agriculture in GDP (*lnA*), inflation rate (*lnπ*) and the degree of economic development (*lnDe*)), financial development indicators (official exchange rates (*lnO*) and the degree of financial development (*lnDf*)) and control variables (the share of industry in GDP (*lnI*) and urban population as a percentage of total population (*Up*)) have a significant negative effect on CO_2 emissions per capita in HIC. This means that, for illustration, CO_2 emissions per capita enjoy a reduction in the range 0.722-1.17 percent when the share of industry in GDP increases by a percent in HIC, other variables held constant. This implies that industrial transformation in HIC could be supportive of green growth.

Trade openness (*lnT*), inflation rate (*lnπ*), employment generation rate (*lnEgr*), degree of economic development (*lnDe*), domestic credit to private sector to GDP (*lnD*), degree of financial development (*lnDf*) and the share of industry in GDP (*lnI*) have an opposite sign to those of the static results for UMIC. This would inform on which of the sub-sample(s) has been minimising CO_2 emissions while pursuing growth. However, the assumption of no endogeneity is relaxed in the next sub-section while another diagnostic test is made in the next section.

Table 5.17: Static regression results (as estimated with PCSE) for HIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 1E	Model 2E	Model 3E	Model 4E	Model 5E	Model 6E	Model 7E	Model 8E	Model 9E	Model 10E	Model 11E	Model 12E	Model 13E	Model 14E	Model 15E
β_0	10.3^{1} [4.37]	30.3 [28.3]	-1.97 [4.68]	69.4^{5} [31.2]	64.1^{5} [29.3]	40.2^{1} [6.50]	57.1^{5} [25.8]	37.3^{1} [5.88]	72.5^{1} [25.3]	72.6^{1} [25.7]	82.8^{10} [43.3]	95.1^{5} [47.9]	55.2 [45.0]	65.7 [48.4]	64.8 [49.1]
Economic Development Indicators:															
lnY	-.479 [.579]	-.112 [.738]	.911 [.870]	-.318 [.850]	.377 [.782]	-10.7^{1} [1.99]	-10.3^{1} [2.03]	-9.96^{1} [1.46]	-7.95^{1} [1.97]	-8.02^{1} [2.23]	-28.0 [17.6]	-26.7 [17.7]	-17.2 [18.2]	-4.75 [18.9]	-4.34 [19.5]
lnY^2	----	----	----	----	----	.632^{1} [.119]	.629^{1} [.119]	.605^{1} [.071]	.487^{1} [.118]	.492^{1} [.136]	2.92 [2.32]	2.79 [2.33]	1.54 [2.38]	.075 [2.44]	.015 [2.53]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.097 [.099]	-.092 [.099]	-.039 [.100]	.017 [.102]	.020 [.106]
lnA	-1.67^{1} [.335]	-1.75^{1} [.557]	----	----	-.959^{10} [.509]	.096 [.424]	-.003 [.560]	----	----	.031 [.531]	-.015 [.442]	-.111 [.568]	----	----	.050 [.556]
lnT	.270 [.188]	.383^{10} [.223]	.195 [.232]	.363 [.244]	.508^{5} [.237]	.506^{1} [.167]	.607^{1} [.214]	.508^{1} [.169]	.621^{1} [.209]	.618^{1} [.215]	.534^{1} [.164]	.613^{1} [.207]	.515^{1} [.168]	.622^{1} [.210]	.617^{1} [.215]
$ln\pi$	-.076^{5} [.029]	-.076^{5} [.029]	-.013 [.031]	-.061^{5} [.028]	-.073^{1} [.027]	-.023 [.024]	-.023 [.024]	-.034 [.021]	-.043^{10} [.023]	-.042^{10} [.024]	-.026 [.024]	-.026 [.024]	-.034 [.021]	-.043^{10} [.023]	-.042^{10} [.025]
lnEgr	8.06^{1} [1.43]	8.10^{1} [1.44]	6.79^{1} [1.54]	5.73^{1} [1.32]	5.95^{1} [1.31]	6.64^{1} [.997]	6.69^{1} [1.00]	6.19^{1} [.955]	5.96^{1} [.983]	5.95^{1} [.986]	6.31^{1} [1.03]	6.35^{1} [1.04]	6.11^{1} [.964]	5.99^{1} [.983]	5.98^{1} [.982]
lnEc	.355^{1} [.109]	.376^{1} [.114]	.314^{1} [.097]	.259^{1} [.096]	.267^{1} [.096]	.294^{1} [.069]	.313^{1} [.074]	.289^{1} [.062]	.282^{1} [.071]	.281^{1} [.071]	.269^{1} [.075]	.286^{1} [.080]	.281^{1} [.065]	.285^{1} [.073]	.285^{1} [.073]
lnDe	-1.12^{10} [.622]	-1.48^{5} [.745]	-.312 [1.07]	-.529 [.948]	-.670 [.871]	.911 [.662]	.577 [.782]	.727 [.763]	.259 [.804]	.281 [.820]	.546 [.776]	.268 [.852]	.600 [.884]	.306 [.875]	.340 [.917]
Financial Development Indicators:															
lnD	.288 [.234]	.227 [.243]	.455^{5} [.229]	-.038 [.241]	-.018 [.228]	.479^{1} [.170]	.429^{5} [.196]	.428^{1} [.158]	.201 [.206]	.203 [.207]	.421 [.183]	.379^{10} [.201]	.408^{5} [.166]	.203 [.207]	.206 [.208]
lnFDI	.081 [.075]	.077 [.075]	.143^{10} [.084]	.021 [.080]	.046 [.080]	.087 [.054]	.084 [.055]	.084 [.063]	.072 [.064]	.073 [.065]	.083 [.054]	.081 [.055]	.087 [.064]	.071 [.065]	.071 [.065]
lnO	-.742^{1} [.249]	-.575 [.360]	-1.22^{1} [.323]	-.453 [.338]	-.565^{10} [.328]	-.680^{1} [.202]	-.538^{10} [.292]	-.763^{1} [.217]	-.515 [.273]	-.516^{10} [.279]	-.615^{1} [.209]	-.495^{10} [.291]	-.734^{1} [.233]	-.523^{10} [.273]	-.523^{10} [.282]
lnDf	.032 [.281]	.171 [.363]	-.434 [.332]	-.298 [.299]	-.077 [.312]	-.613^{1} [.220]	-.480^{10} [.282]	-.526^{5} [.203]	-.412^{10} [.229]	-.425 [.268]	-.402 [.325]	-.290 [.359]	-.462 [.292]	-.439 [.295]	-.461 [.356]
Dummy Variable:															
D_2	-5.61^{1} [1.82]	-8.78 [6.26]	-1.29 [2.26]	14.1^{1} [4.87]	5.58 [6.43]	-5.73^{1} [1.23]	-8.72^{10} [5.24]	-4.38^{1} [1.44]	-1.26 [5.39]	-1.10 [6.00]	-5.18^{1} [1.34]	-7.96 [5.18]	-4.32^{1} [1.46]	-1.17 [5.42]	-.911 [6.15]
Control Variables:															

lnI	----	----	-1.17^{1} [.330]	$-.801^{1}$ [.277]	$-.722^{1}$ [.268]	----	----	-.112 [.231]	-.314 [.243]	-.316 [.246]	----	----	-.096 [.243]	-.329 [.262]	-.332 [.262]
lnP	----	-.594 [3.69]	----	12.9^{1} [2.26]	7.38^{5} [3.69]	----	-.678 [3.08]	----	3.82 [2.95]	3.92 [3.51]	----	-.690 [3.01]	----	3.94 [3.00]	4.11 [3.71]
lnUp	----	-5.06 [9.83]	----	-32.6^{1} [9.56]	-23.7^{5} [10.2]	----	-4.13 [8.68]	----	-15.7^{10} [8.99]	-15.8^{10} [9.43]	----	-3.46 [8.48]	----	-16.1^{10} [9.24]	-16.4 [9.94]
R^2	.971	.971	.908	.974	.978	.982	.983	.984	.985	.985	.982	.983	.984	.986	.985
Obs	37	37	34	34	34	37	37	34	34	34	37	37	34	34	34

Source: Author (2016)

Note: Numbers in [ ] are heteroscedasticity and autocorrelation consistent standard errors. [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance. Obs represents the number of observations.

Table 5.18: Dynamic regression results (as estimated with IV regression) for HIC SSA countries

	Log-Linear models					Log-Quadratic models					Log-Cubic models				
	Model 16E	Model 17E	Model 18E	Model 19E	Model 20E	Model 21E	Model 22E	Model 23E	Model 24E	Model 25E	Model 26E	Model 27E	Model 28E	Model 29E	Model 30E
β_0	6.92 [6.96]	20.4 [66.9]	6.46 [8.13]	93.9 [73.6]	117.4 [72.9]	40.2^{1} [12.1]	126.7^{5} [54.9]	42.6^{1} [10.8]	175.0^{1} [54.3]	175.5^{1} [56.2]	89.9 [77.5]	165.6^{10} [85.9]	52.7 [85.9]	152.4^{5} [74.6]	154.6^{5} [78.1]
ln $C0_{2t-1}$	.040 [.195]	-.001 [.205]	.269 [.178]	-.031 [.189]	-.096 [.188]	-.143 [.162]	-.222 [.157]	-.136 [.159]	$-.257^{10}$ [.140]	$-.258^{10}$ [.146]	-.174 [.168]	-.215 [.161]	-.145 [.167]	-.219 [.140]	-.222 [.146]
Economic Development Indicators:															
lnY	-.090 [1.07]	-.095 [1.58]	-.836 [1.43]	-.665 [1.47]	-.452 [1.43]	-10.8^{1} [3.57]	-12.0^{1} [3.32]	-11.3^{1} [2.84]	-10.9^{1} [2.70]	-10.8^{1} [3.11]	-30.7 [30.9]	-23.2 [30.4]	-15.2 [34.5]	7.75 [30.9]	7.17 [32.2]
lnY^2	----	----	----	----	----	$.651^{1}$ [.211]	$.804^{1}$ [209]	$.647^{1}$ [.161]	$.714^{1}$ [.173]	$.703^{1}$ [.199]	3.23 [4.02]	2.34 [3.93]	1.13 [4.47]	-1.63 [3.98]	-1.53 [4.15]
lnY^3	----	----	----	----	----	----	----	----	----	----	-.108 [.169]	-.066 [.166]	-.019 [.186]	.098 [.166]	.094 [.174]
lnA	-1.39^{5} [.629]	-.082 [.964]	----	----	-1.18 [.880]	-.098 [.644]	.308 [743]	----	----	-.092 [.716]	-.186 [.673]	.079 [.776]	----	----	-.165 [.718]
lnT	.286 [.421]	.121 [.433]	.322 [.488]	.235 [.402]	.396 [.405]	.435 [.329]	.387 [.315]	.515 [.338]	$.529^{10}$ [.284]	$.537^{10}$ [.300]	.473 [.339]	.424 [.323]	.496 [.343]	$.520^{10}$ [.283]	$.534^{10}$ [.300]
$ln\pi$	-.073 [.046]	$-.087^{10}$ [.048]	.013 [.049]	-.050 [.044]	-.065 [.044]	-.036 [.037]	-.046 [.036]	-.018 [.034]	-.036 [.030]	-.038 [.033]	-.038 [.038]	-.053 [.036]	-.019 [.034]	-.042 [.030]	-.045 [.033]
lnEgr	6.67^{1} [2.06]	6.71^{1} [2.30]	5.33^{5} [2.45]	5.84^{1} [2.11]	6.39^{1} [2.07]	6.33^{1} [1.59]	7.29^{1} [1.64]	5.77^{1} [1.67]	6.97^{1} [1.47]	6.99^{1} [1.53]	6.11^{1} [1.66]	7.52^{1} [1.71]	5.84^{1} [1.71]	7.65^{1} [1.49]	7.68^{1} [1.55]
lnEc	$.361^{5}$ [.175]	$.289^{10}$ [.175]	.299 [.202]	.205 [.166]	.214 [.160]	$.367^{1}$ [.135]	$.324^{5}$ [.125]	$.341^{5}$ [.138]	$.273^{5}$ [.114]	$.273^{5}$ [.118]	$.350^{5}$ [.140]	$.310^{5}$ [.129]	$.326^{5}$ [.141]	$.284^{5}$ [.114]	$.283^{5}$ [.118]

lnDe	-1.11 [1.12]	-1.38 [1.71]	1.19 [1.78]	-.048 [1.62]	-.419 [1.58]	.769 [1.06]	-.339 [1.24]	1.73 [1.22]	.192 [1.10]	.159 [1.17]	.458 [1.20]	-1.06 [1.27]	1.66 [1.48]	-.214 [1.15]	-.282 [1.23]
Financial Development Indicators:															
lnD	.212 [.614]	.105 [.715]	.358 [.703]	.372 [.678]	.636 [.682]	.700 [.501]	1.09^{10} [.569]	.749 [.491]	1.29^{5} [.519]	1.30^{5} [.538]	.665 [.514]	1.11^{10} [.587]	.784 [.499]	1.42^{1} [.539]	1.43^{5} [.560]
lnFDI	.040 [.141]	.050 [.149]	.126 [.159]	.053 [.138]	.036 [.134]	.054 [.109]	.024 [.106]	.073 [.109]	.018 [.095]	.017 [.098]	.056 [.111]	-.004 [.106]	.088 [.109]	-.029 [.094]	-.030 [.098]
lnO	$-.756^{10}$ [.441]	-.585 [.841]	$-.913^{5}$ [.533]	-.207 [.808]	-.094 [.782]	-.748 [.341]	.117 [.624]	$-.892^{5}$ [.363]	.334 [.569]	.333 [.588]	$-.701^{5}$ [.356]	.272 [.629]	$-.858^{5}$ [.403]	.539 [.567]	.534 [.589]
lnDf	-.053 [.441]	-.034 [.678]	-.677 [.539]	-.238 [.563]	.144 [.613]	$-.593^{5}$ [.384]	-.169 [.482]	$-.788^{5}$ [.369]	-.073 [.387]	.046 [.450]	-.399 [.503]	.129 [.548]	-.721 [.525]	-.031 [.431]	.021 [.502]
Dummy Variable:															
D_2	-4.08 [2.77]	7.84 [14.3]	-2.18 [3.72]	15.1 [10.0]	3.49 [12.9]	-4.20^{10} [2.14]	-6.41 [10.8]	-2.66 [2.52]	-6.83 [8.76]	-7.39 [10.0]	-3.71 [2.30]	-9.87 [10.8]	-2.71 [2.56]	-11.4 [8.76]	-12.4 [9.93]
Control Variables:															
lnI	----	----	-.912 [.554]	-1.07^{5} [.525]	-1.20^{5} [.515]	----	----	-.432 [.376]	$-.763^{5}$ [.353]	$-.776^{5}$ [.379]	----	----	-.391 [4.20]	$-.775^{10}$ [.411]	$-.793^{10}$ [.434]
lnP	----	7.86 [7.03]	----	14.3^{1} [4.55]	8.23 [6.31]	----	3.94 [5.09]	----	4.97 [3.84]	4.64 [4.72]	----	2.56 [5.16]	----	4.16 [3.80]	3.56 [4.72]
lnUp	----	13.4 [21.1]	----	-40.4^{10} [22.7]	-38.8^{10} [21.8]	----	-27.4^{10} [15.4]	----	-42.1^{1} [15.4]	-41.9^{1} [15.9]	----	-29.0^{10} [15.9]	----	-47.9^{1} [16.8]	-47.4^{1} [17.6]
R^2	.962	.965	.951	.970	.974	.979	.984	.978	.987	.987	.979	.984	.979	.988	.988
Obs	32	32	32	32	32	32	32	32	32	32	32	32	32	32	32
Sargan test of overidentifying restrictions from the fixed effect regression															
Chi^2	8.52 (.203)	5.26 (.384)	6.61 (.578)	2.60 (.857)	3.31 (.769)	8.35 (.138)	7.46 (.113)	6.82 (.448)	6.29 (.392)	10.1 (.121)	7.34 (.197)	6.58 (.159)	6.62 (.357)	6.93 (.327)	20.1 (.003)

Source: Author (2016)

Note: Numbers in [ ] are standard errors and and ( ) indicate the probability value for the Sargan test.. ^{1} means 0.01 level of significance, ^{5} means 0.05 level of significance and ^{10} means 0.1 level of significance. Obs represents the number of observations.

5.4.5.2 Dynamic models

After controlling for endogeneity, Table 5.18 does not show evidence that there is a long-run relationship between the regressand and regressors, except under Models 24E and 25E where the lagged dependent variable ($lnCO_{2t-1}$) is significant at ten percent. Using Model 25E for example, the short-run effects of *lnY*, lnY^2, *lnT*, *lnEgr*, *lnEc*, *lnD*, *lnI* and *lnUp* are -10.8, 0.703, 0.537, 6.99, 0.273, 1.30, -0.776 and -41.9 while the long-run effects (after dividing by (1+0.258)) become -8.58, 0.559, 0.427, 5.56, 0.217, 1.03, -0.617 and -33.3, respectively. This implies that the long-run effects of lnY^2 (i.e. higher income), *lnT*, *lnEgr*, *lnEc* and *lnD* on CO_2 emissions per capita are lower than their respective short-run effects while the long-run effects of *lnY*, *lnI* and *lnUp* are higher (because they are negative) than their respective short-run effects.

The log-quadratic models under the dynamic models affirm the U-shape relationship between CO_2 emissions per capita and real GDP per capita (Models 21E-25E) in HIC. Although the degree of economic development and the net inflow of foreign direct investment to GDP ratio are not significant throughout the table, the dummy variable for the Portuguese-speaking SSA country (D_2) has a significant negative sign under Model 21E alone. All the other regressors have the same significant effect on CO_2 emissions per capita as under the static models' regression results for HIC. The Sargan tests confirm the selection of the appropriate instrumental variables for all the models at ten percent level of significance, except for Model 30 which rejects the null hypothesis of overidentifying restrictions are valid at one percent level of significance.

5.5 Cointegration tests on the residuals of the estimated static models

Based on the argument of Halkos (2003) that a static model regression results on the relationship between CO_2 emissions per capita and real GDP per capita (i.e. the Environmental Kuznets Curve (EKC) hypothesis) may not be justified if the two variables do not cointegrate, the study conducted the Pedroni cointegration test in the second section of this chapter. Meanwhile, to avoid the omitted variables bias (a criticism raised by Stern (2004)), the study investigated not only the effect of real GDP per capita but also the effect of the above-mentioned regressors on CO_2 emissions per capita. Thus, to ensure robustness check on the reliability of the static models, the cointegration tests are extended to other variables.

However, the Pedroni cointegration test could not handle more than seven regressors at a time. As such, the Engle-Granger cointegration test (as proposed by Engle and Granger (1987)) was conducted by first obtaining the residuals of the models with significant log-linear, log-quadratic and/or log-cubic relationship between CO_2 emissions per capita and real GDP per capita (due to the EKC) under the static models of the entire sample and sub-samples. These residuals are then subjected to the integration test (i.e. the Augmented Dickey-Fuller (ADF)). The null hypothesis of this approach is that if CO_2 emissions per capita and all the regressors are not cointegrated, then their linear, quadratic and/or cubic combination will not be stationary, so therefore, the residuals will also have unit root at level.

Table 5.19: Unit root tests for residuals of static models for the entire sample

	Fisher-type (ADF)				Diagnosis	lags
	P	Z	L*	Pm		
Log-linear models:						
Model 1A	191.09	-3.48	-4.41	7.53	I(0)[1]	0
Model 2A	199.08	-4.11	-4.98	8.13	I(0)[1]	0
Model 3A	176.91	-2.53	-3.51	6.48	I(0)[1]	0
Model 4A	181.88	-2.89	-3.84	6.85	I(0)[1]	0
Model 5A	193.33	-3.83	-4.58	7.70	I(0)[1]	0
Log-quadratic model:						
Model 6A	190.75	-3.56	-4.41	7.51	I(0)[1]	0
Model 8A	173.63	-2.40	-3.29	6.23	I(0)[1]	0

Source: Author (2016)

Note: [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

The study considered the possibility of obtaining linear, inverted U, U, inverted N or N-shape relationship between CO_2 emissions per capita and real GDP per capita. As such, after obtaining the regression results of the static models for the entire sample (discussed in the previous section) Models 1A-5A showed a significant linear relationship while Models 6A and 8A evidenced an inverted U-shape. Table 5.19 presents the integration tests for the residuals of the respective models. All the residuals reject the null hypothesis of a unit root at one percent level of significance at order zero. Thus, since the residuals are stationary, CO_2 emissions per capita and all the regressors are cointegrated. This implies that the respective static models under the entire sample are not spurious regressions and inferences made from them are reliable.

Table 5.20: Unit root tests for residuals of static models for LIC SSA countries

	Fisher-type (ADF)				Diagnosis	lags
	P	Z	L*	Pm		
Log-linear models:						
Model 1B	117.49	-3.65	-4.65	7.09	I(0)[1]	0
Model 2B	107.81	-3.45	-4.04	6.10	I(0)[1]	0
Model 3B	99.05	-2.54	-3.11	5.21	I(0)[1]	0
Model 4B	94.62	-2.40	-2.80	4.76	I(0)[1]	0
Model 5B	106.39	-3.20	-3.73	5.96	I(0)[1]	0
Log-cubic model:						
Model 12B	89.86	-2.90	-3.04	4.27	I(0)[1]	0
Model 14B	76.98	-1.78	-1.89	2.96	I(0)[5]	0
Model 15B	86.26	-2.57	-2.65	3.90	I(0)[1]	0

Source: Author (2016)

Note: [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

For LIC, Models 1B-5B portrayed a significant linear relationship while Models 12B, 14B and 15B evidenced an N-shape. Table 5.20 presents the integration tests for the residuals of the identified models. All the residuals reject the null hypothesis of a unit root at one percent level of significance at order zero, except Model 14B which is at five percent significance level. Since the residuals are stationary, then CO_2 emissions per capita and all the regressors have a cointegrating relationship. This implies that the static models are reliable and not nonsense regressions.

Table 5.21: Unit root tests for residuals of static models for LMIC SSA countries

	Fisher-type				Diagnosis	lags
	P	Z	L*	Pm		
Log-linear models:						
Model 1C	46.78	-1.85	-1.97	2.88	I(0)[5]	0
Model 3C	48.20	-1.80	-2.01	3.08	I(0)[5]	0
Model 4C	49.35	-2.06	-2.32	3.24	I(0)[5]	0

Source: Author (2016)

Note: [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

Models 1C, 3C and 4C gave evidence for a significant linear relationship under LMIC. Table 5.21 shows that there is evidence for a long-run relationship between CO_2 emissions per capita and all the regressors under the models. This is because the residuals of the models reject the null hypothesis of a unit root at five percent level of significance at order zero. This means that the respective static models are not spurious regressions.

Table 5.22: Unit root tests for residuals of static models for UMIC SSA countries

	Fisher-type				Diagnosis	lags
	P	Z	L*	Pm		
Log-linear models:						
Model 3D	15.73	-0.31	-0.29	0.76	I(0)	0
Log-cubic models:						
Model 11D	29.52	-2.05	-2.15	3.58	I(0)[5]	0
Model 12D	27.77	-1.90	-1.95	3.22	I(0)[5]	0
Model 14D	13.32	-0.08	0.01	0.27	I(0)	0
Model 15D	22.14	-1.34	-1.25	2.07	I(0)	0

Source: Author (2016)
Note: [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

In the case of UMIC (Table 5.22), only two of the models with a significant relationship between CO_2 emissions per capita and real GDP per capita have a significant integration test on their residuals with an N-shape. That is, Models 11D and 12D indicate an equilibrium relationship (at five percent significance level) while Models 3D, 14D and 15D do not reject the null hypothesis of no cointegration between CO_2 emissions per capita and the regressors. Models 3D, 14D and 15D are spurious regressions while Models 11D and 12D are not spurious regressions.

Table 5.23 presents the results for HIC. Although Models 6E to 10E gave a significant U-shape relationship between CO_2 emissions per capita and real GDP per capita, the integration tests on the models fail to reject the null hypothesis of a unit root in the residuals. This means that there is no equilibrium relationship between CO_2 emissions per capita and the regressors for HIC which indicates that a partial adjustment towards an equilibrium emissions level is required for inferences on HIC so as avoid simultaneity bias.

Table 5.23: Unit root tests for residuals of static models for HIC SSA countries

	Fisher-type				Diagnosis	lags
	P	Z	L*	Pm		
Log-quadratic models:						
Model 6E	2.39	0.31	0.29	-0.57	I(0)	0
Model 7E	2.45	0.33	0.32	-0.55	I(0)	0
Model 8E	6.07	-0.63	-0.67	0.73	I(0)	0
Model 9E	6.06	-0.21	-0.24	0.73	I(0)	0
Model 10E	6.04	-0.20	-0.24	0.72	I(0)	0

Source: Author (2016)
Note: [1] means 0.01 level of significance, [5] means 0.05 level of significance and [10] means 0.1 level of significance.

Thus, simultaneity bias is severe for HIC because there is no equilibrium relationship (i.e. no cointegration) but less serious for the entire sample, LIC, LMIC and UMIC (Models 11D and

12D) because there is cointegration. After identifying the non-spurious static models, the derivation of the income elasticity of demand for environmental quality for each sub-sample and the entire sample and their turning point(s), where applicable, are discoursed in the next section.

5.6 Income elasticity of demand for environmental quality and turning point

The study has established the relationship between CO_2 emissions per capita and the explanatory variables using both static and dynamic models and conducted robust checks for the existence of equilibrium relationship for the static models. Based on the identified relationship between CO_2 emissions per capita and real GDP per capita for the entire sample and sub-samples, income elasticity of demand for environmental quality and turning point(s) (as applicable) where emissions start to fall or rise as income (real GDP per capita) rises are presented in this section.

Income elasticity of demand for environmental quality is obtained differently under different functional forms. For log-linear models, the income elasticity of demand for environmental quality (∈) is the coefficient of real GDP per capita (lnY). The ∈ for log-quadratic and log-cubic models were obtained using the formulas in Equations 5.1 and 5.2, respectively.

$$\in = \beta_2 + 2\beta_3 lnY \quad . \quad . \quad . \tag{5.1}$$

$$\in = \beta_2 + 2\beta_3 lnY + 3\beta_4 lnY^2 \quad . \quad . \quad . \tag{5.2}$$

Where β_2 is the coefficient of real GDP per capita (lnY), β_3 is the coefficient of squared real GDP per capita (lnY^2) and β_4 is the coefficient of cubed real GDP per capita (lnY^3). The income elasticity of demand for environmental quality (∈) for both log-quadratic and log-cubic models are evaluated with the log of the mean values of real GDP per capita (i.e. the log of the mean value for Y, as presented in Table 5.1) and the log of the respective squared mean values.

Turning points are obtainable under log-quadratic and log-cubic, but not log-linear, by applying Equations 5.3 and 5.4, respectively. Where, e is exponential and the definitions of other notations remain the same.

$$e^{-\beta_2/2\beta_3} \quad . \quad . \quad . \tag{5.3}$$

$$e^{\frac{-\beta_3 \pm \sqrt{\beta_3^2 - 3\beta_2\beta_4}}{3\beta_4}} \quad . \quad . \quad . \tag{5.4}$$

The static models identified a statistically significant linear and inverted U-shape relationship between CO_2 emissions per capita and real GDP per capita while the dynamic models identified only a linear relationship for the entire sample. Table 5.24 presents the income elasticity of demand for a cleaner CO_2 environment and turning point for the entire sample. The static log-linear models (Models 1A-5A) depict an income elasticity that is below one and positive (in the range of 0.361-0.578) with no turning point because a linear curve does not have a turning point. This means that CO_2 emissions per capita monotonically increase with income in SSA. That is, as real GDP per capita increases there would be a less than proportionate rise in CO_2 emissions per capita which is equivalent to less than a proportionate decline in the demand for a cleaner CO_2 environment in the entire sample of SSA countries. As the section goes, it is demonstrated that this supports the N-shape, linear and U-shape relationship found between CO_2 emissions per capita and real GDP per capita for LIC and UMIC, LMIC and HIC.

Table 5.24: Income elasticity and turning point for the entire sample

	Log-Linear					Log-Quadratic	
	Model 1A	Model 2A	Model 3A	Model 4A	Model 5A	Model 6A	Model 8A
Static models							
Income elasticity	0.498	0.361	0.578	0.456	0.364	0.393	0.530
Turning Point	Nil	Nil	Nil	Nil	Nil	27553.38	1903985
	Model 16A	Model 18A	Model 19A				
Dynamic models							
Short run:							
Income elasticity	0.096	0.124	0.112				
Turning Point	Nil	Nil	Nil				
Long run:							
Income elasticity	0.347	0.434	0.410				
Turning Point	Nil	Nil	Nil				

Source: Author (2016)

After applying Equations 5.1 and 5.3 to static log-quadratic models 6A and 8A, the income elasticity of demand for a cleaner CO_2 environment is less than one and so inelastic. That is a cleaner CO_2 environment may be referred to as a necessity and not a luxury in SSA. This supports the finding that there is the revised EKC for SSA under the degree of economic development (Section 5.4.1.1). The inverted U-shape depicts that CO_2 emissions increase more than proportionately at low incomes but would begin to decline slowly at higher income (see Model 6A and 8A under Table 5.9). The inverted U-shape under Model 6A generated the turning point of US$27,553.38 while Model 8A brought forth US$1,903,985 (presented on Table 5.24). This means that Model 6A informs that CO_2 emissions per capita may start to fall at the point where real GDP per capita is around US$27,553.38 in SSA while Model 8A suggests that CO_2 emissions per capita may start to fall at the threshold of about US$1,903,985.

SSA has been confirmed to be majorly agro-based with a low share of industry (Asuelime and Simura 2016) from the results interpreted in section 5.4. Whereby, agriculture significantly affects CO_2 emissions under all the income groups but industry significantly affects CO_2 emissions only under UMIC and HIC. However, SSA countries have no financial but voluntary responsibilities towards emissions reduction under UNFCCC which explains the N-shape, linear and U-shape relationship found for LIC and UMIC, LMIC and HIC. Neither the N-shape nor linear and U-shape relationship allows for an optimistic interpretation like the inverted U-shape that income is beneficial for the environment (Friedl and Getzner 2002).

Thus, it is unsurprising that the turning point under Model 6A (assumes SSA is agro-based) and Model 8A (assumes SSA may be undergoing industrial transformation) are out-of-sample of the minimum and maximum values of per capita GDP. This means that SSA experiencing the EKC may be a thing of the future. The revised EKC may take place at an estimated turning point of US$27,553.38 or below if SSA countries do away with taking their voluntary responsibilities for granted. Otherwise, it may not take place until an estimated turning of US$1,903,985. The out-of-sample turning point is not new in the literature. Neumayer (2004), Navin (2005) and Grunewald and Martinez-Zarzoso (2011) found an out-of-sample turning point for 163, 103 and 213 countries, respectively. Carvalho and Almeida (2010) even reported that more than 80% of the countries they analysed are yet far from entering the turning point because their income is very inferior to the turning point calculated.

The dynamic models for the entire sample give room for two sets of results (in Table 5.24), the short-run and long-run income elasticity of demand for environmental quality. The long-run income elasticity for log-linear models is calculated by using Equation 5.5. Where β_1 is the coefficient of the lagged CO_2 emissions per capita and β_2 is the coefficient of real GDP per capita (lnY). For log-quadratic and log-cubic income elasticity and turning point(s), the long run values are obtained by dividing each coefficient in Equation 5.1 to 5.4 with (1- β_1).

$$\epsilon = \beta_2 / (1 - \beta_1) \quad . \quad . \quad . \qquad (5.5)$$

The short-run income elasticity (in Table 5.24) is smaller than the long-run income elasticity. The long-run income elasticity is somewhat within the range of those estimated under the static models and less than one, i.e. CO_2 emissions per capita is monotonically increasing with income.

Table 5.25: Income elasticity and turning point for LIC

	Log-Linear					Log-Cubic		
	Model 1B	Model 2B	Model 3B	Model 4B	Model 5B	Model 12B	Model 14B	Model 15B
Static models								
Income elasticity	0.611	0.312	0.613	0.315	0.316	-27.58	-32.74	-31.25
Turning Point 1st	Nil	Nil	Nil	Nil	Nil	186.15	201.82	221.94
Turning Point 2nd	Nil	Nil	Nil	Nil	Nil	355.59	348.56	305.82

Source: Author (2016)

Although the dynamic models for LIC depict no statistically significant relationship between CO_2 emissions per capita and real GDP per capita, the static models gave a linear and N-shape relationship between the two study variables (Table 5.25). There is no turning point for Models 1B-5B while two turning points were computed for Models 12B, 14B and 15B. The first threshold (within the range of US$186.15-US$221.94) is the point where CO_2 emissions per capita reduced with higher real GDP per capita. However, this reduction in emissions in LIC is only temporary as the increase in real GDP per capita got to the second threshold point (in the range US$305.82-US$355.59) where CO_2 emissions per capita rose again.

The income elasticity of demand for a cleaner CO_2 environment under the log-linear models is positive and less than one. This implies that an increase in real GDP per capita leads to a less than proportionate increase in CO_2 emissions per capita in LIC. The log-cubic models have negative income elasticities. This proves that it takes time for the increase in real GDP per capita to affect CO_2 emissions level in low-income countries (LIC). That is, based on the different slopes of the curve, CO_2 emissions per capita rapidly rose at very low incomes but had a less rapid decline as income increased, and afterwards, it had a less than proportional increase at higher incomes (see Models 12B, 14B and 15B on Table 5.11). Hence the non-optimistic interpretation that further increase in real GDP per capita does not lead to increase in a cleaner CO_2 environment.

The decreased CO_2 emissions at low levels of income followed by an increase in CO_2 emissions at higher levels of income in LIC, according to Carvalho and Almeida (2010), may be explained by multilateral actions. Since 1999, SSA countries hoped for and initially enjoyed some level of incentives from carbon finance from multilateral schemes (like the World Bank carbon finance unit, the Clean Development Mechanism (CDM) and under reducing emissions from deforestation and forest degradation (REDD)) to reduce their emissions at low levels of income. Subsequently (around 2009), the multilateral incentives started declining due to, for example, the drop in carbon prices and demand and slow approval process under the CDM (Purvis *et al.* 2013) and uneven distribution of funds under the REDD+ (Nhamo 2011b). These declining multilateral incentives may have reduced the motivation to initiate more carbon sink projects and hence may increase CO_2 emissions at higher levels of income.

A study by Granados and Carpintero (2009) explained that decrease in emissions may occur if economic activities shrank as it occurred in the West in the 1930s and the 1980s and in the East in the 1990s. The collapse of economic growth (due to e.g. oil price shock of 1990) and increase in economic growth (e.g. increase in commodity prices during 2000-2007) in SSA (UNCTAD 2012) may have led to decreased CO_2 emissions at low levels of income followed by increased CO_2 emissions at higher levels of income. Another issue is the structural change (Friedl and Getzner 2002). The need and efforts to increase the share of industrial development (and more SSA countries are increasingly depending on fossil fuels, metallic and non-metallic minerals as the driver of their economic growth) while ignoring the constraint of a dirtier CO_2 environment may not have reduced emissions but may exert an influence that lead to higher CO_2 emissions increasing at higher income in an N and U-shape. These explanations are tenable for UMIC and HIC as their results indicate that CO_2 emissions increase at higher income levels.

Table 5.26: Income elasticity and turning point for LMIC

	Log-Linear			
	Model 1C	Model 3C	Model 4C	
Static models				
Income elasticity	0.418	0.406	0.412	
Turning Point	Nil	Nil	Nil	
	Model 16C	Model 18C	Model 19C	Model 20C
Dynamic models				
Short run:				
Income elasticity	0.359	0.321	0.199	0.32
Turning Point 1st	Nil	Nil	Nil	Nil
Turning Point 2nd	Nil	Nil	Nil	Nil
Long run:				
Income elasticity	0.882	0.997	0.614	1.092
Turning Point 1st	Nil	Nil	Nil	Nil
Turning Point 2nd	Nil	Nil	Nil	Nil

Source: Author (2016)

The income elasticity of demand for a cleaner CO_2 environment and the turning point between CO_2 emissions per capita and real GDP per capita in LMIC are in Table 5.26. The static models have a positive and less than one income elasticity for the linear relationship found between CO_2 emissions per capita and real GDP per capita for LMIC. The dynamic models obtained a positive and less than one income elasticity for log-linear models in the short run and a positive and higher but still less than one income elasticity under log-linear models in the long run except for under Model 20C. Model 20C depicts an income elasticity that is positive and slightly greater than one which means that an increase in real GDP per capita may lead to a proportionate decrease in CO_2 emissions per capita in LMIC in the long run.

Table 5.27: Income elasticity and turning point for UMIC

	Log-Cubic	
	Model 11D	Model 12D
Static Models		
Income elasticity	-135.02	-148.9996
Turning Point 1st	1971.34	2509.38
Turning Point 2nd	5741.73	4310.82

Source: Author (2016)

Like LIC, the dynamic models for upper-middle-income countries (UMIC) showed no statistically significant relationship between CO_2 emissions per capita and real GDP per capita. The static models, however, yielded a linear (Model 3D) and N-shape relationship between the two study variables (under Models 11D, 12D, 14D and 15D). Since Models 3D, 14D and 15D are non-cointegrating regressions (see Table 5.22), the income elasticity and turning points for Models 11D and 12D are in Table 5.27. The income elasticity is negative. This finding is similar to that of LIC under their log-cubic models. Whereby, based on the slopes of the shape, CO_2 emissions per capita rapidly rose at low incomes, but had a less rapid decline as income increased, followed by a less than but close to proportional increase at higher incomes (see Models 11D and 12D on Table 5.15). The first and second threshold point for UMIC is higher than that of LIC. This is because the sub-sample of UMIC consists of SSA countries with higher real GDP per capita. While the turning point where CO_2 emissions per capita starts to diminish as real GDP per capita rises is between US$1,971.34 and US$2,509.38, CO_2 emissions per capita started rising again as real GDP per capita increases between US$4,310.82 and US$5,741.73 (Table 5.27).

The income elasticity obtained from the coefficients of income in the cubic models is so high. This is explained by McConnell (1997) as the higher the negative income elasticity of demand for a cleaner CO_2 environment, the faster the decline may be in the growth of emissions. However, this may be the case for the EKC but may not be the case for LIC and UMIC because the N-shape found depicts an interpretation that CO_2 emissions later increased at higher income. Thus, preferences for a positive income elasticity of demand for a cleaner CO_2 environment (as obtained from the entire sample and HIC) are neither necessary nor sufficient conditions to explain the shape of the relationship between CO_2 emissions and income (McConnell 1997).

Table 5.28: Income elasticity and turning point for HIC

	Log-Quadratic				
	Model 21E	Model 22E	Model 23E	Model 24E	Model 25E
Dynamic models					
Short run:					
Income elasticity	1.053	2.639	0.481	2.101	2.000
Turning Point	4003.53	1741.82	6201.91	2065.35	2167.58
Long run:					
Income elasticity	Nil	Nil	Nil	2.827	2.696
Turning Point	Nil	Nil	Nil	2065.35	2167.58

Source: Author (2016)

The income elasticity of demand for a cleaner CO_2 environment and the turning point for the relationship between CO_2 emissions per capita and real GDP per capita for HIC under static modelling are not generated because Models 6E to 10E do not have an equilibrium relationship (see Table 5.23). Thus, Table 5.28 presents the income elasticity and turning point for dynamic models 21E-25E because they depict a statistically significant U-shape relationship between CO_2 emissions per capita and real GDP per capita. The short-run income elasticity and turning point are computed for all the log-quadratic models but the long run versions were computed only for Models 24E and 25E because Models 21E to 23E have no statistically significant lagged explained variable ($lnCO_{2t-1}$) (Table 5.28).

The entire short-run income elasticity (except for Model 23E) and the long-run income elasticity are positive and greater than one for HIC. This is contrary to the income elasticity for the entire sample and other sub-samples which are positive and less than one and LIC and UMIC with negative and greater than one income elasticity of demand for environmental quality. Whereby, CO_2 emissions per capita rapidly declined at low incomes but it increased less proportionally at higher incomes (see Models 21E to 25E on Table 5.18).

However, the income elasticity under Model 23E agrees with those of the entire sample to be positive and less than one, i.e. a cleaner CO_2 environment is decreasing at a less than proportionate level. The result under Model 23E corroborates the side of the U-shape relationship where CO_2 emissions are increasing as real per capita GDP increases while the other results (Model 21E, 22E, 24E and 25E) corroborate the side of the U-shape relationship where CO_2 emissions were reducing as real GDP per capita increases in HIC. All other models place the turning point where CO_2 emissions stopped reducing as real GDP per capita increases between US$1,741.82 and US$2,167.58, Models 21E and 23E place the turning point where CO_2 emissions started increasing as real GDP per capita increases at around US$4,003.53 and US$6,201.91, respectively.

One thing that is common to all under income elasticity of demand for a cleaner CO_2 environment (whether positive or negative) is that SSA countries (irrespective of the income level) are experiencing an increase in CO_2 emissions per capita as real GDP per capita increases. All turning points under the sub-samples are within the (respective) range of minimum and maximum real GDP per capita (*Y*) levels in Table 5.1 while the turning point obtained under the entire sample is higher than the maximum real GDP per capita (US$27,553.38 > US$15,912). This conforms to some studies in the literature that report a turning point(s) that is not within the studies' sample range and other studies that report a turning point(s) that is within their sample range. The explanation for the out-of-sample turning points may be that the economies are still widely practising the logic of 'grow now, clean up later'.

5.7 Conclusion

The broad objective of this study is to analyse the impact of economic and financial development on CO_2 emissions in sub-Saharan Africa (SSA) focusing on the period 1989-2012. In the bid to achieve this objective, this chapter reports the results obtained after the execution of the study's estimation procedure. The study finds (under the entire sample) that some indicators of economic development (real GDP per capita, trade openness, inflation rate, and energy consumption per capita) and financial development (domestic credit to private sector to GDP) significantly stimulate CO_2 emissions in SSA during the period of study. While the share of industry in GDP does not significantly affect CO_2 emissions, other control variables (population density and urban population to total population) contribute to CO_2 emissions. Other indicators of economic development (the share of agriculture in GDP and employment generation rate) and financial development (net inflow of foreign direct investment and official exchange rate) significantly reduce the level of CO_2 emitted in SSA. In addition, the results of the entire sample indicate that French-speaking SSA countries and Portuguese-speaking SSA countries emit a lower volume of CO_2 than English-speaking SSA countries. There is no statistically significant linkage between the later development of a financial sector (i.e. the degree of financial development) and lower CO_2 emissions but there is a statically significant linkage between the later development of an economy (i.e. the degree of economic development) and lower CO_2 emissions.

This study has found substantial evidence that empirical results differ in terms of estimation method, functional form and sample of countries. For instance, there is a disparity in the findings of the relationship between CO_2 emissions per capita and real GDP per capita for the four sub-samples with the results of the entire sample. The results show that both low-income countries (LIC) and lower-middle-income countries (LMIC) have monotonic increasing (i.e. linear) relationship, both LIC and upper-middle-income countries (UMIC) have an N-shape, and high-income countries (HIC) has a U-shape relationship, unlike the entire sample which has a linear and inverse U-shape relationship. This supports the reason why studies in the literature report different results for the CO_2-income relationship for different case studies.

In respect of other explanatory variables, different effects are observed under the sub-samples compared to the entire sample. For illustration, the results show that an increase in the share of agriculture in GDP bring down CO_2 emissions per capita in most SSA (LIC, UMIC and HIC) countries but not in LMIC. Another example is the effect of domestic credit to private sector to GDP, as it induces CO_2 emissions in LIC, LMIC and HIC, domestic credit to private sector to GDP reduces CO_2 emissions in UMIC, thus, it reflects as influencing CO_2 emissions in SSA. In the entire sample, there is evidence that all the explanatory variables (except the degree of financial development and the share of industry in GDP) are factors that determine a change in the volume of CO_2 emitted in SSA. However, considering the income levels of SSA countries, inflation rate, foreign direct investment and the share of industry in GDP do not have a significant effect on CO_2 emissions per capita in LIC. Employment generation rate, the degree of economic development, the degree of financial development, official exchange rate and urban population to total population do not significantly affect CO_2 emissions in LMIC. Population density and urban population to total population do not significantly have an effect on CO_2 emissions per capita in UMIC while the degree of economic development and net inflow of FDI to GDP ratio do not significantly affect CO_2 emissions per capita in HIC.

On the issue of income elasticity of demand for environmental quality, environmental quality is still diminishing and CO_2 emissions are still increasing as real GDP per capita rises in SSA. This is because the results indicate that whatever reduction in CO_2 emissions experienced in SSA are temporary (LIC and UMIC) or has stopped (HIC). The observed turning points buttress this finding as they all fall within the sub-samples' range of minimum and maximum real GDP per capita. Meanwhile, the turning point under the entire sample of SSA is not within its range of minimum and maximum real GDP per capita which simply means that CO_2 emissions are still rising as real GDP per capita rises in SSA. That is, the region has not crossed the threshold where CO_2 emissions decrease as real GDP per capita rises. How the interpreted results in this chapter achieve the specific objectives of this study (in chapter one) and comparison of the findings with the empirical literature are adequately discussed in the next chapter.

CHAPTER SIX: CONCLUSION

"It is gradually been acknowledged that there is no one-fit-for-all growth-emission relationship" (He 2009:31).

6.0 Introduction

This study investigates the impact of economic and financial development on the level of carbon dioxide (CO_2) emissions in sub-Saharan Africa (SSA) for the period 1989-2012. The motivation for this investigation is a series of events that dates back to the awareness generated by the United Nations' World Commission on Environment and Development (WCED). The report of the Commission has since 1987 declared the accumulation of CO_2 as one of the environmental threats to the planet (GEO4 2007). The outcome of the increasing CO_2 concentration in the atmosphere causes global warming, which leads to global climate change (Cunha-e-Sá 2008).

The WCED's declaration was followed by the establishment of the Intergovernmental Panel on Climate Change (IPCC) in 1988. It also led the journey to the United Nations Conference on Environment and Development which produced a number of international environment treaties including the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 (UNSD 2013). This event is marked as an acknowledgement to address human-driven climate change (Lattanzio 2014). During the exploration of the way forward to mitigating climate change, the United Nations Environment Programme (UNEP) introduced the Global Green New Deal (GGND) in 2009. The Deal is to encourage economic transformation to a green economy thereby reducing CO_2 emissions and most likely its concentration in the atmosphere (GIZ 2013). Proactively, the African Development Bank (AfDB) introduced a ten-year strategy 2013-2022 to provide support for SSA countries on their climate change challenges and transition toward being a green economy (AfDB 2014a). Thus, this research examines how the selected explanatory variables affect CO_2 emissions in SSA *ex-post* the year in which the issue of climate change started developing and *ex-ante* the AfDB ten-year strategy. The relevance of studying *ex-ante* the AfDB ten-year strategy is so that the identified non-limiting factors of CO_2 emissions in each of the income groups in SSA can be considered as area(s) of interest by the executors and policymakers of the AfDB ten-year strategy before 2022 comes knocking.

The study commenced by presenting a comprehensive background on the link between carbon emissions and (economic and financial) development (see chapters one and two). It went on to uncover how SSA is the most vulnerable to the impacts of climate change even though it minimally contributes to global carbon emissions and collectively iterates the various international, continental, regional and national efforts committed to limiting CO_2 emissions and working towards green growth in SSA. Further, the background study revealed that, despite the global efforts, SSA is yet apportioned a small portion of international carbon and climate finance which has slowed down the development of clean investments that should reduce the region's large infrastructural deficit (see chapter two).

The study conducted an in-depth literature review on the theories, conceptual issues and theoretical models about the link between environmental quality and development, and reviewed the empirical evidence of studies on the CO_2-development relationship (see chapter three). The literature review supports the debate of He (2009) that there is no one-fit-for-all for not only the CO_2 emissions-income relationship but also the relationship between CO_2 emissions and other economic development indicators and financial development indicators (even when using the same estimation method). The literature shows a partial backing for Stern's (2004) suggestion that including more low-income countries in a study might yield a higher turning point. The literature reveals the gap that a panel study on the impact of economic and financial development on CO_2 emissions has not been conducted using SSA as a case study. This led to raising and seeking answers to these research questions:

1) Does the EKC exist in sub-Saharan Africa for CO_2 emissions?
2) What is the income elasticity of demand for a cleaner CO_2 environment and the turning point in sub-Saharan Africa?
3) What is the effect of economic development on CO_2 emissions in sub-Saharan Africa?
4) What is the effect of financial development on CO_2 emissions in sub-Saharan Africa?
5) Do sub-Saharan African countries with different colonial histories have different patterns regarding CO_2 emissions?

The hypotheses for the research questions are formulated and the selected study variables to proxy economic development and financial development are presented in chapter four. This thesis contributes in the following ways. The first contribution is by investigating whether agriculture is reducing or stimulating CO_2 emissions in SSA as panel studies in the literature neglect agriculture as part of the factors that determine CO_2 emissions because they assume every developing economy is undergoing industrial transformation. Meanwhile, giving regard to the literature, industrial activity is applied as a control variable (including population density and a proxy for urbanisation). Since major macroeconomic variables (like GDP and inflation rate) have been considered in the literature, the study introduced the rate of employment generated as its second contribution. Thirdly, in addition to Taguchi's (2012) consideration of the later degree of economic development on CO_2 emissions, the study considered the effect of later degree of financial development on CO_2 emissions. This is measured as the ratio of financial deepening of an economy relative to the maximum financial deepening among the sample economies for every year. The fourth contribution is to empirically confirm or negate the insight that foreign incursion may have an effect on the way carbon-related resources are being exploited and managed, thus, leading to high or controlled CO_2 emissions. This was done by applying dummy variables to identify whether there is a difference in the level of CO_2 emissions amongst the Anglophone, Francophone and Lusitanian SSA countries.

After specifying static and dynamic models for the sample of 45 SSA countries, the countries were divided into 24 low-income countries (LIC), 13 lower-middle-income countries (LMIC), six upper-middle-income countries (UMIC) and two high-income countries (HIC). The data (as sourced from the World Bank's database World Development Indicators (WDI) and Africa Development Indicators (ADI) and the United States Energy Information Administration (EIA)) are analysed for the entire sample using the Feasible Generalised Least Square (FGLS) for static models and Generalised Method of Moments (GMM) for dynamic models. The data for the sub-samples are analysed using the Panel-Corrected Standard Errors (PCSE) for static models and Instrumental Variable (IV) regression for dynamic models. The results from the data analysis are interpreted in chapter five.

This is the last chapter of this thesis and it starts by discussing the findings of the study from the results presented in chapter five in line with the attainment of the specific objectives and research questions. The second section presents a synthesis of the full sample and sub-samples results. The third part deliberates on the policy implications of this study for the benefit of policymakers in SSA countries, the academia and other interested persons. The findings on the study's contribution to the body of literature are identified and itemised in the fourth section. Since the issue of limiting carbon emissions is still evolving among scholars, the fifth and last sections give the limitation of the study and suggestions for further research in this area.

6.1 Discussion of findings

At the beginning of the analysis, the summary statistics obtained imply that the high emitters of CO_2 in SSA are concentrated in the upper-middle-income countries (UMIC) and high-income countries (HIC) and they consumed the highest energy per capita. They also connote that low-income countries (LIC) and lower-middle-income countries (LMIC) (24 and 13 SSA countries, respectively) are largely dependent on agriculture. UMIC and HIC are less dependent on agriculture while they have (six and two SSA countries, respectively) a higher share of industry than LIC and LMIC. This confirms the summation of UNCTAD (2012) that the region still has a high level of dependence on agriculture under the process of structural change. However, since the summary statistics are just a premise to the econometric analysis that would help to achieve the specific objectives of this study, the generated empirical results are discussed in the following subsections.

6.1.1 The entire SSA sample countries

The existence of the EKC

The effect of income (real GDP) per capita on CO_2 emissions is the first indicator of economic development that is investigated. The results suggest evidence for linear (monotonic increasing) and inverted U-shape (the Environmental Kuznets Curve -EKC) relationship between real GDP per capita and CO_2 emissions. This supports that the EKC holds for CO_2 emissions due to the relative decarbonisation witnessed in SSA during the study period (Schmalensee *et al.* 1998).

The EKC, however, has an estimated turning point (of US$27,553.38) that is above the maximum level of real GDP per capita in SSA during the period of study. This means that at the current stage of development in SSA, CO_2 emissions are increasing with income, after some threshold which SSA is expected to experience in a future time because the turning point is above its current income levels, the relationship may change to CO_2 reducing as income increases. That is, people are yet to value environmental quality in SSA. As such, the linear relationship between real GDP per capita and CO_2 emissions has the best fit. This supports the findings of Azomahou *et al*. (2009) and Taguchi (2012) for the samples of 107 (including some SSA countries) and 19 countries that a linear relationship exists between real GDP per capita and CO_2 emissions.

According to Shafik and Bandyopadhyay (1992) and Galeotti (2003), the inverted U-shape found for SSA is a case of free rider problem in which there is no local avenue whereby people pay for the cost of emitting CO_2. This is true because, for example, Ethiopia (IMF 2016), Mauritius (Dalmazzone 2015), South Africa (World Bank 2014) and Zimbabwe (Nyambura and Nhamo 2014) are the few countries with carbon tax policies in SSA.

The income elasticity of demand for a cleaner CO_2 environment and turning point

The income elasticity of demand for a cleaner CO_2 environment in SSA is positive and less than one which means that a cleaner CO_2 environment, as a commodity, is a necessity in the region and not a luxury. However, it depicts that CO_2 emissions increase more than proportionately at low incomes but begin to decline slowly at higher incomes. This finding supports the evidence found that there is a linkage between later developments of economies in SSA with lower CO_2 emissions, i.e. there is hope for SSA to experience a revised EKC in the early stages of industrialisation and at a lower level of income than the estimated turning point. According to Neumayer (1998), this means that the policymakers in SSA need to be more responsive than they are to achieve a cleaner CO_2 environment at a lower turning point.

The turning point is US$27,553.38 due to the inverted U-shape relationship found between CO_2 emissions per capita and real GDP per capita for the entire sample. This means that SSA may experience the EKC (i.e. CO_2 emissions may start to fall as income rises) in the future because the turning point is greater than the maximum real GDP per capita in the study's sample of countries (US$27,553.38 > US$15,912). With the evidence found for revised EKC, there is the expectation that CO_2 emissions might reduce at a turning point that is lower than the estimated US$27,553.38. This can only happen by ensuring a diligent and consistent adoption and implementation of climate change policies (market and non-market instruments). However, if SSA continues to conduct business-as-usual, then CO_2 emissions might not start to reduce until an estimated turning point of US$1,903,985.

This finding is consistent with the estimated income elasticity of demand for environmental quality as it depicts a case whereby most SSA countries are yet to place a price on CO_2 emitted locally by companies and individuals. It also supports the comment of the World Bank (2014) that SSA countries make little use of national carbon finance mechanisms to fund low-carbon projects. As identified by Navin (2005), this study is not the first to obtain an out-of-sample turning point, so did Shafik and Bandyopadhyay (1992), Neumayer (2004) and Grunewald and Martinez-Zarzoso (2011) for 149, 163 and 213 countries, respectively.

The effect of economic development on CO_2 emissions

Unlike Taguchi (2012), the study found evidence for a linkage between later developments of economies (degree of economic development measured as the ratio of GDP per capita of an economy relative to the maximum GDP per capita among the sample economies for every year) with lower CO_2 emissions in SSA. This means that, with an increasing adoption of climate change policy instruments which support low-carbon development, there is hope for SSA to experience revised EKC in the early stages of industrialisation and at a lower level of income to the estimated turning point.

Agriculture cannot be neglected as a determinant of CO_2 emissions in SSA as the results gave evidence for lower levels of emissions as the share of agriculture in GDP increases. This implies that agriculture stands as a limiting factor to CO_2 emissions as more of organic agriculture (which support green growth) and less of conventional agriculture (which contributes to emissions) is being practised in SSA. However, there is no evidence that industrialisation has an increasing effect on CO_2 emissions in SSA. These empirical results oppose the suggestion of Hogarth *et al*. (2015) that agriculture produces more emissions than any other sector in SSA. Employment generation rate is also found to support green growth in SSA as there is evidence that CO_2 emissions reduce as new employments are generated (i.e. as employment generation rate increases). This supports Boopen and Vinesh (2010) who found a significant negative relationship between another social indicator (school enrolment ratio) and CO_2 emissions for Mauritius (one of the countries in the study's sample of SSA countries).

The results suggest that trade openness supports the pollution haven effect as there is evidence that trade openness reduces environmental quality in SSA by increasing emissions. This connotes that SSA countries mostly have comparative advantage in pollution-intensive goods for exportation and/or serve as a dumping ground for outdated technologies (which generates e-waste) through importation. This affirms the findings of Tamazian and Rao (2010) for transitional economies, Gholami and Shafiee (2013) for OPEC countries and Onafowora and Owoye (2013) for Mexico, Nigeria and South Africa. Unlike Tamazian and Rao (2010), the study found evidence for an increasing effect of inflation rate on CO_2 emissions. This finding supports Hoffmann (2011) that developing countries attract carbon-intensive commodities. That is, as the annual rate of price change rises in SSA, the same carbon-intensive commodities are consumed and substitute clean commodities are either not affordable or not available to buy resulting to higher emissions. The finding on energy consumption per capita confirms the popular view that energy consumption is a main source of CO_2 emissions as there is strong evidence backing the contributory role of energy consumption to emissions in SSA.

Since environmental pressures have been noted to intensify not only because of structural transformation and rising affluence but also by growing population and increasing urbanisation (UNCTAD 2012), the study controlled for population density and urban population as a percentage of total population. In support of the United Nations Conferences on Trade and Development (UNCTAD) (2012) and Onafowora and Owoye (2013), the study found that higher population density increases CO_2 emissions. The study found that increasing urban population leads to increasing CO_2 emissions which supports the finding of Shahbaz, Tiwari and Nasir (2011a) for South Africa (also a country in the study's sample).

The effect of financial sector development on CO_2 emissions

While the net inflow of foreign direct investment (FDI) to GDP and official exchange rate lessens environmental damage and domestic credit to private sector to GDP enhances CO_2 emissions, the study found no evidence that there is a linkage between later developments of financial sectors with lower or higher CO_2 emissions in SSA. This implies that domestic credit provided to the private sector in the region are loosely awarded without concern for its carbon (or environmental) implications. This same result was found for India, United Arab Emirates (UAE) and Pakistan by Boutabba (2013), Charfeddine and Khediri (2016) and Javid and Sharif (2016), respectively. Since FDI is a *de facto* measure of financial openness (Quinn *et al*. 2011), the results imply that more open SSA countries to capital may enjoy a decline in CO_2 emissions, thus improved environmental quality. This supports the observation made by Tamazian and Rao (2010) for transitional economies, Tamazian *et al*. (2009) for Brazil, Russia, India and China (BRIC) and Ajide and Oyinlola (2010) for Nigeria (one of the countries in this study's sample). Unlike Tamazian and Rao (2010), this study obtained a significant relationship between official exchange rate and CO_2 emissions which implies that past depreciation in the price of local currencies in terms of the US dollar led to an increase in environmental quality while appreciation in the price of currencies led to a decrease in environmental quality. This may be because importation becomes expensive when exchange rate depreciates which may reduce the import of unclean/outdated technologies and hence reduce emissions linked with the use of such, otherwise is the case when exchange rate appreciates.

The different patterns of CO_2 emissions amongst the colonies

The study observed that there is a significant difference in the level of CO_2 emissions among the Anglophone, Francophone and Lusitanian SSA countries through the use of dummy variables. The English-speaking countries (which are the benchmark) are found to emit more CO_2 than the French and Portuguese-speaking countries while the Portuguese-speaking countries emitted the least volume of CO_2 in the region. This is in spite of the fact that the sample consist of the same number of Francophone countries (20 SSA countries) as Anglophone countries (19 plus Ethiopia) while it has four Lusitanian SSA countries. This may be due to the foreign incursion experienced by the Anglophone from the British capitalists' exploration for surplus capital during the colonial era by exploiting the economies' carbon-related natural resources like coke and coal (Nwanosike and Onyije 2011). The extensive exploitation of carbon-related resources – leading to increasing emissions– may still be business-as-usual in the Anglophone as SSA countries' principal international trading partners continue to be their former colonial masters (Nhamo 2009a). Another reason that may explain why the Anglophone emits more CO_2 than the Francophone is that the Francophone has a lower population than the Anglophone SSA countries in the sample.

6.1.2 Low-income countries in SSA

The existence of the EKC

The effect of real GDP per capita on CO_2 emissions for LIC in SSA was found to be monotonically increasing and cubic (N-shape). The N-shape has two turning points that are within the current level of real GDP per capita of LICs in SSA. This depicts that CO_2 emissions had initially increased as income increased, reached a threshold point after which it started falling as income increased in LIC but for a while as later on CO_2 emissions are increasing again with increase in income. This return of CO_2 emissions increasing with increase in income corroborates the evidence for the linear relationship but the best fit is the N-shape relationship.

The study supports Grunewald and Martinez-Zarzoso (2011), Al-Mulali *et al*. (2015) and Baek (2016) that the EKC does not exist for low-income countries.

The decreased CO_2 emissions at low levels of income followed by an increase in CO_2 emissions at higher levels of income in LIC, according to Carvalho and Almeida (2010), may be explained by multilateral actions. This is because SSA countries had initially enjoyed some incentives from carbon finance from multilateral schemes (like the World Bank carbon finance unit, the CDM and under REDD) to reduce their emissions at low levels of income. Subsequently, the multilateral incentives started declining due to, for example, the drop in carbon prices and demand and slow approval process under the CDM (Purvis *et al.* 2013) and uneven distribution of funds under the REDD+ (Nhamo 2011b). These declining multilateral incentives may have reduced the motivation to initiate more low-carbon projects and hence make CO_2 emissions to increase again as income increases.

The income elasticity of demand for a cleaner CO_2 environment and turning point

The income elasticity of demand for a cleaner CO_2 environment for LIC is monotonically increasing under the significant linear relationship. However, under the N-shape relationship, the income elasticity of demand for a cleaner CO_2 environment for LIC is negative and greater than one which means that environmental quality may be an inferior commodity in LIC. In support of the N-shape relationship, the first turning point (within the range of US$186.15-US$221.94) and the second turning point (in the range US$305.82-US$355.59) are within the range of minimum (US$69.58) and maximum (US$722.04) real GDP per capita for the sub-sample of LIC. This means that CO_2 emissions had already increased as income increased, reached a threshold point after which it started falling as income increased in LIC but after a while, CO_2 emissions increased again with an increase in income. This affirms that a cleaner CO_2 environment is an inferior commodity in LIC. Thus, policymakers are not as concerned as they should be about the emissions of CO_2 in LIC. This finding aligns with Nhamo (2014b) and Kim (2015) that only some SSA countries have or are in the process of developing or integrating low-carbon and climate resilience strategies and action plans into their development plans.[32]

[32]The notable countries in the subsample of 24 SSA countries are Burkina Faso, Central Africa Republic, Ethiopia, Malawi, Mali, Mozambique, Rwanda, Sierra Leone, Tanzania and Uganda.

The effect of economic development on CO_2 emissions

The study found a weak evidence for a linkage between later developments of economies in LIC with lower CO_2 emissions. This means that, although the countries are experiencing the return of CO_2 emissions increasing as real GDP per capita increases, there is hope that the adoption of climate change policy instruments and changes in production techniques for low-carbon development will bring back a reduction in CO_2 emissions as income increases i.e. green growth for LIC.

Like the entire sample, there is evidence that increase in the share of agriculture in GDP leads to lower levels of emissions while industrialisation has no significant effect on CO_2 emissions in LIC. The finding on the CO_2 limiting quality of agriculture in LIC supports UNECA (2012a) that organic farming has become a trend in countries like Burundi, Burkina Faso, Mali, Rwanda, Tanzania and Uganda. Unlike Al-Mulali *et al*. (2015) who found that urbanisation and trade openness have no significant effect on the ecological footprint (which includes CO_2 emissions) of LIC, this study found evidence that environmental quality reduces due to increasing emissions as LIC becomes more open to trade. This supports that LICs in SSA have a comparative advantage in pollution-intensive goods for exportation and/or serve as a dumping ground for outdated technologies from advanced countries through importation. The results for LIC also support that of the entire sample that increasing population density and urbanisation lead to environmental pressure by raising CO_2 emissions. These findings were expected of LIC as increasing population density displaces natural resources through cutting of trees for building and firewood and not replacing them which is essential for carbon sink in SSA. Furthermore, increasing urbanisation can increase the demand for fuel combustion thereby increasing CO_2 emissions. Thus, the study empirically confirmed that energy consumption per capita is the main source of CO_2 emissions in LIC.

Contrary to the entire sample, there is no evidence that there is a relationship between CO_2 emissions and inflation rate but there is a weak evidence that employment generation rate increases the emission of CO_2 in LIC. This means that, so far, employment driven by public and private investments in LIC does not reduce CO_2 emissions. This may be due to the inadequacy of capital in the past to procure energy-efficient technologies for industries and energy generation in LIC.

The effect of financial sector development on CO_2 emissions

Domestic credit to private sector to GDP and official exchange rate are also found to enhance and limit CO_2 emissions, respectively, in LIC. This is unlike Al-Mulali *et al*. (2015) who found that there is no relationship between financial development and the ecological footprint of LIC (although their sample of LIC is different from this study's because they are made up of developing countries around the world). This means that the financial sector of LIC in SSA has not been focusing on providing sufficient credit facilities to eco-friendly projects while exchange rate depreciation might have been reducing the importation of energy-inefficient technologies which reduce emissions. The study found evidence that there is a linkage between later developments of financial sectors with higher CO_2 emissions in LIC. This means that if care is not taken from now on CO_2 emissions will continue to increase and may not reduce as financial development improves into the future in LIC. This is confirmed by the evidence found for the enhancing capacity of domestic credit to private sector to GDP on CO_2 emissions. Contrary to Baek (2016) who found that FDI increases CO_2 at low-income level, this study found no evidence for the effect of financial openness (net inflow of FDI to GDP ratio) on CO_2 emissions.

The different patterns of CO_2 emissions amongst the colonies

The study observed that there is a significant difference in the level of CO_2 emissions among the Anglophone, Francophone and Lusitanian countries in LIC. This sub-sample of LIC consists of eight Anglophone countries (plus Ethiopia), 13 Francophone countries and two Lusitanian countries.[33] Here also, the English-speaking countries among LIC emit more CO_2 than the French and Portuguese-speaking SSA countries, even though the French-speaking countries are more than the English-speaking countries (plus Ethiopia) in this sub-sample. This is because the Francophone SSA countries have at least 0.171 percent higher CO_2 limiting effect than Anglophone SSA countries among LICs, all variables remaining the same. This means that the English-speaking countries (plus Ethiopia) engage in resource exploitation and consumption that yield higher emissions (like deforestation and energy consumption) than the French-speaking countries. This may be enhanced not only because of the Anglophone's foreign incursion but also because they have a marginally higher population than the Francophone SSA countries in

[33] ANGLOPHONE COUNTRIES: Eritrea, Gambia, Liberia, Malawi, Sierra Leone, Tanzania, Uganda and Zimbabwe.
FRANCOPHONE COUNTRIES: Benin, Burkina Faso, Burundi, Central Africa Republic, Chad, Comoros, Congo Democratic Republic, Guinea, Madagascar, Mali, Niger, Rwanda and Togo.
LUSITANIAN COUNTRIES: Guinea Bissau and Mozambique.

LIC. With just two Portuguese-speaking SSA countries in LIC, the Portuguese-speaking SSA countries emit the least volume of CO_2 in LIC with at least 0.413 percent more limiting effect than English-speaking SSA countries, all variables remaining constant.

6.1.3 Lower-middle-income countries in SSA

The existence of the EKC

The effect of real GDP per capita on CO_2 emissions for LMIC was found to be monotonically increasing i.e. the linear relationship is the best fit. Thus, like Grunewald and Martinez-Zarzoso (2011) and Al-Mulali *et al*. (2015), the study found that the EKC does not exist for lower-middle-income countries.

The income elasticity of demand for a cleaner CO_2 environment and turning point

The income elasticity of demand for a cleaner CO_2 environment for LMIC reveals that CO_2 emissions monotonically increase with income under the linear relationship. Thus, no turning point was obtained for LMIC. Just as policymakers in LIC are not as concerned as they should be about the emissions of CO_2, policymakers in LMIC are not giving a cleaner CO_2 environment the priority it deserves. This finding aligns with Nhamo (2014b) and Kim (2015) that only some SSA countries have or are in the process of developing or integrating low-carbon and climate resilience strategies and action plans into their development plans. Ghana, Kenya, Senegal, Swaziland and Zambia are the only notable countries in this sub-sample of 13 SSA countries. That is, other countries may be developing by ignoring the constraint of energy generation and consumption by fossil fuels which lead to a dirtier CO_2 environment (Carvalho and Almeida 2010).

The effect of economic development on CO_2 emissions

Unlike the findings for LIC, the study found no evidence for a linkage between later developments of economies in LMIC with lower or higher CO_2 emissions. Also, employment generation rate, industrialisation and urbanisation are found to have no significant effect on CO_2 emissions level in LMIC. This opposes Al-Mulali *et al*. (2015) that urbanisation positively affects the ecological footprint of LMIC. Meanwhile, there is evidence that increasing agriculture leads to higher levels of emissions in LMIC. This finding may be due to increasing livestock production for consumption of the growing population in LMIC as the grazing of the increasing livestock negatively affects forest carbon sink potentials and so are the increasing CO_2 they exhale. This may also imply that less of organic agriculture which supports green growth and more of conventional agriculture which contributes to emissions is being practised in LMIC. For illustration, this finding aligns with Enete and Amusa (2010) who raised concern on the slow change to agricultural practices that are essential for climate change adaptation in Nigeria, the largest economy in terms of population density in this sub-sample. Such slow motion actions to the adoption of green agricultural practices may be what undermined the efforts of other countries (like Kenya and Senegal) in this income group. The results depict that increasing annual rate of price change enhances environmental degradation which implies that an effort to increase production of goods when there is an increase in inflation rate to bring prices down in LMIC raises the level of CO_2 emissions.

Similar to Al-Mulali *et al.* (2015), this study found evidence that trade openness reduces environmental quality in LMIC by increasing emissions. This supports that LMIC in SSA have a comparative advantage in pollution-intensive goods for exportation and/or serve as a dumping ground for outdated technologies from advanced countries through importation. With illustrations like Côte d'Ivoire has the third largest hydropower plants system in West Africa after Nigeria and Ghana (AfDB 2013b) and Kenya is the world leader in the number of solar power systems installed per capita (AlliedCrowds 2015), energy consumption per capita is still found to be the main source of CO_2 emissions in LMIC. However, the African Renewable Energy Initiative (AREI) that was announced in Paris in 2015 has the goal to build new and additional renewable energy generation plants by 2020 (Climate Council 2015).

The results for LMIC support that of the entire sample and LIC that increasing population density leads to environmental pressure by raising CO_2 emissions while no significant relationship was found between urban population as a percentage of total population and CO_2 emissions.

The effect of financial sector development on CO_2 emissions

The study found weak evidence that domestic credit to private sector to GDP lessens environmental quality in LMIC. This is unlike Al-Mulali *et al*. (2015) who found that domestic credit to private sector to GDP lessens environmental damage. There is no evidence to suggest that financial openness and official exchange rate have an effect on CO_2 emissions. Also, the study found no evidence that there is a linkage between later developments of financial sectors with lower or higher CO_2 emissions in LMIC. All these findings imply that the financial sector in LMIC may not be offering green financial services or may be offering green financial services that are not substantial enough to significantly have a reducing effect on CO_2 emissions.

The different patterns of CO_2 emissions amongst the colonies

Under this sub-sample there is only one Portuguese-speaking country (Cape Verde), thus, one would expect the country's level of emissions to be smaller than that of six[34] English-speaking countries (plus Sudan) but the evidence does not support this expectation. Instead, the study observed no significant difference in the level of CO_2 emitted among the Anglophone, Francophone and Lusitanian countries in LMIC. Since Cape Verde has no significant difference in its level of CO_2 to the level of CO_2 emissions among the English-speaking countries, the management of carbon-related resources in the said country may neither be efficient nor effective. This can be said of the five[35] French-speaking countries in LMIC too because they have no significantly lower level of CO_2 emissions to those of the English-speaking countries which have the highest number of countries in the sub-sample.

6.1.4 Upper-middle-income countries in SSA

The existence of the EKC

The effect of real GDP per capita on CO_2 emissions was found to be cubic (N-shape) only for UMIC, unlike LIC. The turning points for the N-shape, like LIC, are within the current level of real GDP per capita of the UMICs in SSA. This depicts that CO_2 emissions had initially increased as income increased, reached a threshold point after which it started falling as income increased in UMIC. This is for a while as later on, CO_2 emissions started increasing again with the increase in income. The return of CO_2 emissions increasing with increase in income corroborates the evidence for the linear relationship found under the entire sample. Like Grunewald and Martinez-Zarzoso (2011) but unlike Al-Mulali *et al*. (2015), the study does not support that the EKC exists for UMIC. Another explanation for the N-shape (in UMIC) may be that the decrease in emissions at low-income level occurred when economic activities shrank due to, for example, oil price shock of 1990 and emissions increased at high-income when, for example, there was increase in commodity prices during 2000-2007 in SSA (Granados and Carpintero 2009; UNCTAD 2012).

[34] ANGLOPHONE COUNTRIES: Ghana, Kenya, Lesotho, Nigeria, Swaziland and Zambia.
[35] FRANCOPHONE COUNTRIES: Cameroon, Congo Republic, Cote d'Ivoire, Mauritania and Senegal.

The income elasticity of demand for a cleaner CO_2 environment and turning point

The income elasticity of demand for a cleaner CO_2 environment (for UMIC) implies that a cleaner CO_2 environment may be an inferior commodity. The first turning point of the N-shape relationship (within the range of US$1,971.34-US$2,509.38) and the second turning point (in the range US$4,310.82-US$5,741.73) are within the range of minimum (US$973.81) and maximum (US$8,280.30) real GDP per capita for the sub-sample of UMIC. This means that CO_2 emissions had already increased as income increased and reached another threshold point after which it started falling as income increased in UMIC but after a while, CO_2 emissions increased again with the increase in income. This means that, although they have been making efforts by developing or integrating low-carbon development and climate resilience policies into their development plans and executing these plans by investing in low-carbon projects like bottling liquefied natural gas (in Angola) and converting landfill gas to electricity (in South Africa), the effect of these efforts by policymakers are yet to be effective in contributing to a cleaner CO_2 environment in UMIC.

The effect of economic development on CO_2 emissions

The study found evidence for a linkage between later developments of economies with lower CO_2 emissions in UMIC. This means that, although the countries are experiencing the return of CO_2 emissions increasing as real GDP per capita increases, there is hope that UMIC may experience green growth which will bring back reduction of CO_2 emissions as income increases.

Like the entire sample and LIC, there is evidence that increase in agriculture leads to lower levels of emissions while (unlike the entire sample and LIC) industrialisation leads to higher CO_2 emissions in UMIC. Unlike Al-Mulali *et al*. (2015) who found that trade openness has an increasing effect on the ecological footprint of UMIC, this study found evidence that trade openness increases environmental quality in UMIC by limiting emissions. This supports that UMIC in SSA may have a comparative advantage in less-pollution-intensive (cleaner) goods for exportation and/or the countries have been investing in energy-efficient technologies for the production of their export goods. An illustration on the exportation of cleaner goods in UMIC is the export of clothing from Mauritius (U.S. Commercial Service 2014) while the municipal landfill gas to electricity projects at Mariannhill and Bisasar in South Africa (Pather-Elias *et al*. 2014) are examples for investing in energy-efficient technologies. In another word, this finding supports Shahbaz Tiwari and Nasir (2011a) and Charfeddine and Khediri (2016) that the pollution haven effect does not apply to all developing countries.

Like LMIC, there is (weak) evidence that increasing inflation rate enhances CO_2 emissions in UMIC while, unlike LIC, there is evidence that employment generated by public and private investments in UMIC does reduce CO_2 emissions. Energy consumption as a source of CO_2 emissions was also confirmed for UMIC. Opposite to Al-Mulali *et al*. (2015) who found that urbanisation increases the ecological footprint of UMIC, this study found that population density and urbanisation has no significant effect on CO_2 emissions.

The effect of financial sector development on CO_2 emissions

Domestic credit to private sector to GDP, the net inflow of FDI to GDP ratio and official exchange rate are found to limit CO_2 emissions in UMIC. These findings agree with Al-Mulali *et al*. (2015) who found that financial development has a decreased effect on the ecological footprint of UMIC. This means that, as they become more open to capital and allow their financial sectors to develop, UMIC in SSA has been working on providing, increasing and improving green financial products and services. This might have been twined with providing foreign exchange facilities to investors who are willing to import energy-efficient technologies. For illustration, the Namibian SME Bank provides household green loans for eco-friendly appliances and green soft loans for green technologies (SME Bank Ltd 2013). The study found evidence that there is a linkage between later developments of financial sectors with lower CO_2 emissions in UMIC which implies that, if the said efforts continue and not relapse, CO_2 emissions will continue to reduce as financial development improves in UMIC.

The different patterns of CO_2 emissions amongst the colonies

Under the sub-sample of UMIC, there is only one Portuguese-speaking country (Angola) and one French-speaking country (Gabon). The study observed that there is a significant difference in the level of CO_2 emitted between the Anglophone and Lusitanian countries in UMIC but not between the Anglophone and Francophone countries. Evidence shows that Angola emits more CO_2 than the English-speaking countries in UMIC while the level of CO_2 emissions in Gabon is not significantly different from those of the English-speaking countries. This finding is not surprising due to Angola's status of Africa's top crude oil-producing country and the country's liquefied natural gas plant which is to reduce emissions from gas flaring is a relatively new project (UNECA 2012a). Also, the management of carbon-related resources in Gabon, although more efficient than Angola, is not as efficient as it should be.

6.1.5 High-income countries in SSA

The existence of the EKC

Unlike Grunewald and Martinez-Zarzoso (2011), Al-Mulali *et al*. (2015) and Baek (2016) who found the EKC (inverted U-shape) for high-income countries (HIC), the effect of real GDP per capita on CO_2 emissions for HIC in SSA was found to be U-shaped. The turning point of the U-shape is within the current level of real GDP per capita in HIC. This means that CO_2 emissions had been decreasing as income increased but reached a threshold after which it started increasing as income increased. The finding that CO_2 emissions are now increasing as income increases affirm the evidence for the monotonic increasing relationship found under the entire sample.

The income elasticity of demand for a cleaner CO_2 environment and turning point

The income elasticity of demand for a cleaner CO_2 environment for HIC is, mostly, found to be positive and greater than one (i.e. environmental quality is a luxury/superior commodity). This applies to the left side of the U-shape relationship where CO_2 emissions reduced as income increased in HIC. That is, on the left side, increase in income was accompanied by more than proportionate increase in the demand for a cleaner CO_2 environment. The finding that the income elasticity of demand for a cleaner CO_2 environment in HIC is positive but less than one (i.e. environmental quality is a necessary commodity) agrees with the right side of the U-shape relationship between CO_2 emissions and income for HIC. In that, on the right side of the U-shape where CO_2 emissions are increasing as income increases, the demand for a cleaner CO_2 environment is decreasing at a less than proportionate level as income increases in HIC.

Also, the highest turning point obtained for the U-shape relationship in HIC is US$6,201.91 which is within the range of minimum (US$374.12) and maximum (US$15,912) real GDP per capita for HIC. This means that CO_2 emissions have stopped decreasing as income increases and are already increasing as income increases in HIC. As such, environmental quality is no more a superior commodity but now a necessary commodity in HIC. This speaks to Seychelles lateness to draft and execute its low-carbon development and climate resilience policies (enforced in September 2016) (UNFCCC 2015b) while Equatorial Guinea submitted its climate change action plan to UNFCCC in 2015 (UNFCCC 2015c). This is unlike countries (like Gabon, Mauritius, Namibia and South Africa) in UMIC that had an early start in the development of their climate change strategies.

The effect of economic development on CO_2 emissions

Similar to LMIC but unlike the results for LIC and UMIC, the study found no evidence for a linkage between later developments of economies with lower or higher CO_2 emissions in HIC. Meanwhile, like LIC and UMIC but not LMIC, there is evidence that increasing agriculture limits CO_2 emissions in HIC. The study agrees with Zugravu *et al*. (2008) and Al-Mulali *et al*. (2015) that the pollution haven effect can apply to high-income countries too as there is evidence that the more open HIC is to trade the higher the CO_2 emitted. Like Tamazian and Rao (2010), the results depict that increasing annual rate of price change (inflation rate) diminishes environmental degradation in HIC. This finding supports Hoffmann (2011) that rich countries attract carbon extensive commodities because they have the financial resources to buy them. Unlike UMIC, there is evidence that employment generated in HIC does not reduce CO_2 emissions while, surprisingly, there is evidence that industrialisation leads to lower CO_2 emissions in HIC. This may be that public and private investments were made in low-carbon projects while household consumption of carbon-related resources was not controlled. Energy consumption per capita was also found to be a determinant of CO_2 emissions in HIC. This implies that fossil fuel was largely used to generate energy in HIC.

Unlike all the other income groups, the results for HIC depict that increasing urbanisation leads to environmental quality by limiting CO_2 emissions which imply that as urbanisation increases in HIC the economies develop clean by expanding their renewable energy sources instead of fossil fuel. This finding supports Charfeddine and Khediri (2016) for the case of UAE but opposes Al-Mulali *et al*. (2015) for the case of high-income countries. Like other income groups, population density was found contributing to environmental pressure by raising CO_2 emissions.

The effect of financial sector development on CO_2 emissions

Unlike Al-Mulali *et al*. (2015), the study found that domestic credit to private sector to GDP enhances CO_2 emissions in HIC. It also found that the net inflow of FDI to GDP ratio has no significant effect on CO_2 emissions. According to Baek (2016), this insignificant relationship may be that the service industries enjoy a dominant part of the inflow of capital which would not lead to a significant increase in CO_2 emissions. Like other income groups, the results suggest that the appreciation of the official exchange rate may have been contributing to emissions while the depreciation of the official exchange rate may have been reducing emissions in HIC. The study also found evidence that there is a linkage between later developments of financial sectors with higher CO_2 emissions in HIC. This means that if care is not taken -like increasing the awareness and provision of green financial products and services- from now on, CO_2 emissions may continue to increase and may not reduce as financial development improves in HIC.

The different patterns of CO_2 emissions amongst the colonies

The HIC income group in SSA contains only two countries (Equatorial Guinea and Seychelles).[36] The study observed that Seychelles emitted more CO_2 than Equatorial Guinea which implies that the utilisation of carbon-related resources in Seychelles is less efficient than in Equatorial Guinea. This finding supports that of the entire sample and LIC that English-speaking SSA countries have higher levels of CO_2 emissions compared separately to the French and Portuguese-speaking countries in SSA but it does not support the finding of LMIC that there is no significant difference and UMIC that the Portuguese-speaking country (Angola) emits more.

6.2 Conclusion on findings

In order to extensively explore the impacts of economic and financial development on CO_2 emissions in SSA, the study, after estimating for the entire sample, conducted additional estimations based on the income levels of the sample of countries. This section synthesises the findings from the results of the sample and sub-samples, as observed in the previous section, under the specific objectives of the study.

The existence of the EKC in sub-Saharan Africa

Although the EKC holds for SSA, the findings on the relationship between CO_2 emissions and income support the view of He (2009) that there is no one-fit-for-all on CO_2 emissions-income relationship for the income groups. However, they all indicate that CO_2 emissions are increasing as income increases, i.e. income has an adverse effect on emissions, in SSA. The results can be explained by the UNFCCC principle of common but differentiated responsibilities between

[36] Equatorial Guinea is a Lusitanian country while Seychelles is both Anglophone and Francophone but for the purpose of this study, it is considered as an Anglophone country.

developed and developing countries (Mahendra 2015). That is, SSA countries may be taking for granted their no financial but voluntary responsibilities to take unilateral actions to reduce CO_2 emissions.

The income elasticity of demand for a cleaner CO_2 environment and turning point in sub-Saharan Africa

The obtained income elasticity of demand for a cleaner CO_2 environment suggests that a cleaner CO_2 environment is an inferior commodity in low, lower- and upper-middle-income countries in SSA. It also indicates that a cleaner CO_2 environment used to be a superior commodity but has become a necessary commodity in high-income countries in SSA. However, the CO_2 emissions-income relationship found for the income groups depicts that CO_2 emissions increased at higher income. These imply that the effect of policymakers' efforts (like drafting and executing low-carbon development and climate resilient action plans) on limiting emissions in SSA are yet to be effective in protecting the environment. Thus, confirming that SSA experiencing the EKC may be a thing of the future.

The N-shape was found for CO_2 emissions-income relationship for low and upper-middle-income countries and the linear relationship was found for lower-middle-income countries but the U-shape was found for the high-income countries in SSA. It was observed that the obtained turning points increase with income level. That is, the turning point for high-income countries is higher than those of the upper-middle-income countries and the turning points of the upper-middle-income countries are greater than those of the low-income countries. Based on this, the study opposes the suggestion of Stern (2004) that including more low-income countries in a cross-country study might yield a higher turning point but supports the proposition of Al-Sayed and Sek (2013) that high(er) income countries have higher turning points than low(er) income countries.

The effect of economic development on CO_2 emissions in sub-Saharan Africa

There is a linkage between later developments of the economies of low and upper-middle-income countries in SSA with lower CO_2 emissions while there is no linkage between later developments of the economies of lower-middle and high-income countries in SSA with lower or higher CO_2 emissions. An increase in agriculture leads to lower levels of emissions in all income groups except in lower-middle-income countries where the increase in agriculture leads to higher levels of emissions. Industrialisation is so low in low and lower-middle-income countries that it influences CO_2 emissions in only upper-middle and high-income countries in SSA. Interestingly, while the increase in the share of industry contributes to emissions in upper-middle-income countries, it limits emissions in high-income countries. Employment generation rate supports green growth only in upper-middle-income countries in SSA as it raises CO_2 emissions in low and high income countries but has no effect on emissions in lower-middle-income countries.

The pollution haven effect applies to low, lower-middle and high-income countries but it does not apply to upper-middle-income countries in SSA. This implies that the pollution haven effect does not apply to all developing countries. That is, the more open the upper-middle-income economies are to trade the lower the level of CO_2 they emit, the reverse is for other income groups. Although inflation rate does not have any effect on CO_2 emissions in low-income countries, it increases CO_2 in lower- and upper-middle-income countries while it decreases CO_2 in high-income countries in SSA. Energy consumption is an important determinant as it has a direct effect on CO_2 emissions in all the income groups. Population density causes more CO_2 emissions in all the income groups in SSA, except in upper-middle-income countries where population density has no effect on CO_2 emissions. Increasing urban population generates more CO_2 emissions in low-income countries and less CO_2 emissions in high-income countries but no effect on the level of CO_2 emissions in lower- and upper-middle-income countries in SSA.

The effect of financial sector development on CO_2 emissions in sub-Saharan Africa

Domestic credit to private sector to GDP magnifies environmental damage through its increasing effect on CO_2 emissions in low, lower-middle and high-income countries in SSA while it lessens environmental degradation through its negative effect on CO_2 emissions in upper-middle-income countries. Foreign Direct Investment also reduces emissions in upper-middle-income countries alone as it has no effect on emissions in other income groups. That is, just as it is for trade, the more open the upper-middle-income economies are to finance the lower the level of CO_2 they emit. The official exchange rate has a reducing effect on CO_2 emissions in all the income groups, except in lower-middle-income countries where it has no effect on emissions. There is a linkage between later developments of financial sectors with higher CO_2 emissions in low and high-income countries and there is a linkage between later developments of financial sectors with lower CO_2 emissions in upper-middle-income countries in SSA. Otherwise, there is no linkage between later developments of financial sectors with higher or lower CO_2 emissions in lower-middle-income countries of SSA.

The different patterns of CO_2 emissions amongst the colonies in sub-Saharan Africa

Anglophone countries exhibited significantly higher CO_2 emissions relative to their Francophone and Lusitanian neighbours in low-income countries while the Lusitanian countries emitted the least volume of CO_2. The French-speaking countries and the Portuguese-speaking country (Cape Verde) emitted CO_2 that is not significantly different from the level of CO_2 emitted among the English-speaking countries in lower-middle-income countries. The Portuguese-speaking country (Angola) emitted more CO_2 than the English-speaking countries while the level of CO_2 emitted in the French-speaking country (Gabon) is not significantly different from those of the English-speaking countries in upper-middle-income countries. Seychelles emitted more CO_2 than Equatorial Guinea under the high-income group.

Thus, the study concludes that not all economic development increases the level of CO_2 emissions and not all financial development limits the level of CO_2 emissions in SSA during the period of study. The main contributory variables (economic development indicators) to CO_2 emissions in SSA are income (real GDP per capita), trade openness, energy consumption, and population density. The main contributor (financial development variable) to CO_2 emissions in SSA is the domestic credit to private sector to GDP. Agriculture is the main reducing factor (economic development variable) to CO_2 emissions in SSA while the official exchange rate is the main reducing factor (foreign development variable) to CO_2 emissions in SSA. Although the EKC was found for SSA (under the entire sample), the study concludes that the region suffers from free rider problem because it is yet to experience the estimated turning point. The free rider problem exists because local carbon cost (carbon tax) exists in just a few SSA countries (like Ethiopia, Mauritius, South Africa and Zimbabwe). The free rider problem means that consumers of carbon-related resources in other SSA countries are allowed to use these resources without paying for the resulting CO_2 emissions. The study also concludes that environmental quality can generally (under the entire sample) be regarded as a necessity in SSA.

6.3 Contribution to Knowledge

This research has conceptually made contributions to the literature on the impact of economic and financial development on carbon emissions. The contributions are, in the angle of what variables may be used to model the EKC for policy purpose of limiting emissions, as follows:

I. Agriculture is a neglected factor of CO_2 emissions by studies in the literature. However, due to these arguments (SSA still has a high dependence on agriculture and low dependence on industrial development, and agriculture produces more emissions than any other sector in SSA) found in the literature, this study introduced the economic development indicator 'agriculture as a percentage of GDP'. Evidence shows that agriculture cannot be left out when modelling CO_2 emissions-development relationship. The results affirm that truly SSA still has a high dependence on agriculture and low share of industrial development. This is because there are significant relationships between agriculture and CO_2 emissions across all income levels in SSA but there are significant relationships between industry and CO_2 emissions in only upper-middle and high-income countries in SSA. Meanwhile, evidence suggests that agriculture does not produce higher CO_2 emissions than any other sector in SSA. This is because an increase in agriculture significantly limits the level of CO_2 emissions in all income groups except lower-middle-income countries in SSA.

II. The variable 'employment generation rate' was introduced into the debate of CO_2 emissions and economic development based on the argument of the green economy that public and private investment in low-carbon projects will lead to growth in income and employment. The influence of income (and not employment) on emissions has satiated in the debate of emissions and economic development. Thus, the study explored the influence of employment generated on CO_2 just as it did for income. Evidence points that the employment generated during the period of study support green growth (i.e. low emission development) only in upper-middle-income countries, it does not support green growth in low and high-income countries and it is so low in lower-middle-income countries that it has no significant effect on emissions.

III. In addition to exploring the link between later development of an economy with lower CO_2 emissions that was introduced by Taguchi (2012), the study explored the link between the later development in a financial sector with lower CO_2 emissions. This refers to the debate on CO_2 emissions and financial development. Evidence identified that later developments of financial sectors are associated with lower CO_2 emissions in only upper-middle-income countries while later developments of financial sectors are associated with higher CO_2 emissions in low and high-income countries in SSA. It is notable from the results that when financial development (domestic credit to private sector to GDP) enhances CO_2 emissions, the later development of the financial sector may likely lead to higher CO_2 emissions (as found in low and high-income countries in SSA). When financial development limits CO_2 emissions, the later development of the financial sector may likely lead to lower CO_2 emissions (as found in upper-middle-income countries in SSA).

IV. Dummy variables were applied to observe the difference in CO_2 emissions level among the Anglophone, Francophone and Lusitanian SSA countries. The United Kingdom is noted to have the highest colonised territory in SSA (Nwanosike and Onyije 2011). As such, evidence supports that, in the course of development, the English-speaking countries emitted more CO_2 than other countries in the region. However, evidence identifies that Cape Verde consumes as many carbon-related resources as that of the English-speaking countries in lower-middle-income countries. Angola emitted more CO_2 than the English-speaking countries in upper-middle-income countries while Gabon emitted as much CO_2 as that of the English-speaking countries in the same income group. Seychelles emitted more CO_2 than Equatorial Guinea in the high-income group.

6.4 Policy Implications

Assessing human-induced carbon emissions, the study found that not all economic development increases the level of CO_2 emissions and not all financial development limits the level of CO_2 emissions in SSA. Meanwhile, the obtained results for income elasticity of demand for environmental quality suggests that a cleaner CO_2 environment is an inferior commodity in low, lower- and upper-middle-income countries while it is a necessary commodity in high-income countries in SSA. Under the entire sample, the income elasticity of demand for environmental quality also depicts a cleaner CO_2 environment as a necessity. As such, the income elasticity of demand for environmental quality suggests that (both national and regional) policymakers in

SSA need to be more responsive to environmental problems, i.e. green investments and adopted climate change measures should be intensified. Policymakers, especially those in SSA countries that still conduct business-as-usual, should consciously and successfully deviate from unclean development strategy to pursue clean economic development if the transition to a green economy is to be achieved well before 2050. This move would align SSA with the outcome of Paris 2015 which is ‘moving away from the action by a few to action by all’.

Agriculture is a reducing factor to CO_2 emissions in all income groups but not in lower-middle-income countries in SSA. It is important for policymakers in lower-middle-income countries to promote, improve and execute low-carbon development strategies in their agriculture sectors. Examples of adoptable low-carbon development strategies for agriculture sector are organic farming, perennial farming, grazing land management and restoration of cultivated peaty soils and degraded soils so as to increase soil carbon sequestration capacity. Policymakers could go into partnership with non-governmental organisations (NGO) and universities to provide agricultural extension services that would introduce and engage farmers in the low-carbon development strategies (Bassi and Lombardi 2013). The NGOs and universities could also train and create a network of personnel that could go out to train and advise farmers on what they have been doing that enhance emissions and what they should be doing that could reduce emissions.

The extension services could also be adopted to share knowledge on low-carbon technologies and production practices (especially energy-saving technologies) to small and medium-scale firms. Knowledge on domestic low-carbon practices should also be communicated to households (UN DESA *et al*. 2013). A form of feebate and rebate can be introduced as incentives for the adoption of the promoted low-carbon technologies and practices to farmers, firms and households. Jobs generated by the NGOs, universities and extension services and jobs generated due to demand for low-carbon commodities by farmers, firms and households should enhance employment generation rate to limit CO_2 emissions in SSA. The increase in production of goods and services from such generated jobs and investments in promoted low-carbon technologies so as to bring down inflation rate should raise the limiting effect of inflation rate on CO_2 emissions. Also, since SSA is largely dependent on agriculture, the execution of low-carbon development strategies in agriculture sector should contribute to obtaining lower emissions from increasing population density.

All the chosen financial development indicators and some economic development indicators (agriculture, trade openness and employment generation rate) limit CO_2 emissions in upper-middle-income countries in SSA. However, rising inflation rate, real GDP per capita, energy consumption and industrialisation can pose a threat that could derail the efforts of policymakers in upper-middle-income countries to reduce their emissions. The inflation rate is also a contributory factor in lower-middle-income countries while the real GDP per capita and energy consumption are a contributory factor for all income groups. This study is of the opinion that if policymakers in SSA continuously and relentlessly make and implement policies that would increase renewable energy sources and invest more into renewable energy and energy efficient technologies (like South Africa) then the increase in real GDP per capita (i.e. production of goods and services) and energy consumption may limit emissions. This is because a higher percentage of energy consumed will be coming from renewable and energy efficient sources like solar, wind, hydropower, cogeneration and oxy-fuel combustion thereby switching away from carbon-rich fossil fuels such as coal.

Tax incentives could be given for the production and consumption of renewable or low-carbon energy sources (like the use of biofuel and ethanol). The policy of feed-in-tariff should be widely adopted by all SSA countries to increase the use of renewable energy sources. All national governments (not just Ethiopia, Mauritius, South Africa and Zimbabwe) should endeavour to internalise the cost of CO_2 emissions (Shafik and Bandyopadhyay 1992) by adopting carbon tax policies and energy tax policies for the reduction in the consumption of fossil fuels. These should also reduce emissions while income is increasing and minimise the free rider problem detected in the results. In addition to investing in renewable energy sources, policymakers (especially low-income countries) in SSA should make infrastructural provisions (like biogas, natural gas and municipal solid waste-to-energy plants facilities, energy saving buildings like earth-ships which are cost effective, green rooftops and the use of fly ash mixed with cement instead of the sole use of cement) and environmental legislation (like all household must use energy saving bulbs and cooking stoves). These could support low-carbon urbanisation and may make citizens be more socially conscious to environmental issues which may support lower emissions as population density and employment generation increases.

Governments of other income groups need to become selective in accepting foreign direct investments (FDI) so that it can help reduce their emissions as it does in upper-middle-income countries in SSA. For example, Chad, Equatorial Guinea, Nigeria and Sudan are a relatively mono-cultural economic system that relies on fossil fuels extraction for government revenue and international trade and as such attracts resource extracting FDI (UNCTAD 2012). Such SSA countries need to explore other comparative advantageous commodities so that they can reject FDI that promotes unclean technology for resource extraction and accept FDI that promotes clean technology know-how and environmental protection. If the need for FDI inflow is to earn foreign capital to pay off foreign debts, SSA countries can take a cue from Cameroon, Ghana and Tanzania for the debt-for-nature swap they received for forest biodiversity conservation (The International Conservation Budget 2012).

Like FDI, governments of other income groups can look into how they can use trade actions and strategies to improve environmental quality like the upper-middle-income countries in SSA. This may be done by adopting low import tariffs for eco-friendly technologies and higher import tariffs for dirty technologies. As such, using the economies' openness to capital and trade to achieve green development in SSA (i.e. promote environmentally non-damaging development) may delink income from emissions (WDR 1992) in the future.

They also need to inculcate green values into the financial sectors (especially the banking sector which predominates in SSA) so that the effect of domestic credits given to the private sector can be limiting emissions as it is in upper-middle-income countries in SSA. Policymakers can infuse green values into the financial sectors by applying selective credit controls like monetary authorities giving direction and persuasion to banks to: (1) Give priority and preferential treatments to firms and households that seek credit and/or foreign currencies for the procurement/importation of cleaner technologies. (2) Develop green financial products and services that have lower administrative charges and interest rates as incentives to drive low-carbon investments.

Green values can be infused into stock markets by moral pressure, i.e. monetary authorities in SSA could publicise the pollution status of companies quoted and unquoted on the stock exchange (like it is done in South Africa) and the effect of such status on the environment for public awareness. The public awareness on the environment may increase the citizens' demand for improved environmental quality. This may also serve as an incentive to industries to explore and adopt low-carbon production practices while the available green financial products and services give the financial muscle for the change required. This process of encouraging low-carbon investments in the private and public sector also should transform employment generation rate and inflation rate into a reducing factor too. South Africa's National Business Initiative (NBI), which is a coalition of the South African government and multinational companies working together on making South Africa a sustainable society, confirms the solidity of this policy suggestion (see the NBI website www.nbi.org.za).

From the estimated results, it is apparent that SSA countries were prioritising short term goals like economic growth and employment generation and lower-middle-income countries were prioritising food security at the expense of climate change mitigation action plans. Thus, all of the above-made suggestions are intended to control and reduce carbon footprints in a manner that would not deter the achievement of the prioritised short term goals but for them to work effectively a better practice of democracy is essential to achieve the goal of better environmental quality (Al-Mulali *et al*. 2015).

6.5 Limitation of the study

The findings of this study are limited to the use of an unbalanced panel data (divided into income groups) and so they should be adopted with caution because they are based on the assumption that a causal relationship may be inferred or rejected when it is present only in a subset of cross-sections. Hence, country-specific studies may be more precise as to the elasticity and turning points from SSA countries. Due to lack of reliable data on green jobs created or the share of employment generated as green jobs in the past, the study used the data for the rate of employment generated. As such, the study could not make a definitive examination of the impact of green jobs on CO_2 emissions in SSA.

Some SSA countries have developed, passed and started implementing green growth and climate change policies/strategies/action plans. This is, however, not considered in the specified models and it might have reduced the non-optimistic relationship found or influenced an optimistic relationship between CO_2 emissions and income under the income groups. Another limitation relates to the different levels of integration of the variables used in the analysis. Although cointegration tests were conducted to identify spurious estimated regression, estimation methods like the autoregressive distributed lag (ARDL) or pooled mean group (PMG) may be a better choice to FGLS and PCSE because they are non-stationary estimation methods. However, ARDL/PMG could not have handled the volume of variables modelled in this study.

These limitations infer that there is a need for further research work in this area of study and some of them are suggested in the last section.

6.6 Suggestions for further research

This thesis has succeeded in conducting a panel study on the impact of economic and financial development on CO_2 emissions in SSA during a period (1989-2012) when the issue of climate change started developing and when the AfDB ten-year strategy (2013-2022)[37] was about to commence. It is noted that "estimating alternative models to study the same question can be a useful reminder of the limits of our knowledge" (Feldstein 1982:10). Thus, further studies are required to continuously point the policymakers in the direction of what aspect of development requires attention for responsive environmental protection.

Although studies on Nigeria, Mauritius and South Africa have been conducted, time series studies on all SSA countries should be conducted to test whether the Environmental Kuznets Curve (EKC) may occur in any country as suggested by Bilgili *et al*. (2016). It does not matter if the country is low-income or high-income country. Also, there is a scarcity of both panel and time series studies that considers strictly the CO_2-income relationship without additional variables in the case of SSA countries. Although the study considered population density, it would be desirable to explore the elasticity of CO_2 emissions with respect to population in SSA in subsequent research.

Even though some SSA countries have developed, passed and started implementing green growth and climate change policies/strategies/action plans, so many SSA countries are behind on the issue of climate change mitigation actions (like renewable energy sources, cable car network, solar water heaters, converting biogas to electricity and reforestation). As such, applying a qualitative data on climate change policies to re-examine the impact of development on CO_2 emissions is another research effort worth exploring. Other environmental issues aside CO_2

[37] This study, which commenced in 2013, is a case study of SSA and so the period of study was selected based on the region's efforts on reducing emissions and data availability of carbon dioxide emissions and not on the draft of the Paris Agreement 2015.

emissions like sanitation, deforestation, etc. are also interesting phenomena that should be considered for SSA in this area of study.

The study found a positive relationship between trade openness and CO_2 emissions for all the income groups but not upper-middle-income countries. According to Zugravu *et al*. (2008), the positive relationship is only a necessary but not a sufficient condition to confirm the ‘race to bottom’ scenario (i.e. international trade and investment reduces environmental standards). Since this is not in the purview of this research, whether the ‘race to bottom’ scenario exist in SSA is a problem that is recommended to be considered in further studies.

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Appendix

Table A.I: List of countries according to international recognition

Annexe B countries as at 1990[1]	Annexe I Parties to UNFCCC[2]	Annexe II Parties to UNFCCC
Australia	Australia	Australia
Austria	Austria	Austria
Belgium	Belarus	Belgium
Bulgaria	Belgium	Canada
Canada	Bulgaria	Denmark
Croatia	Canada	European Economic Community
Czech Republic	Croatia	Finland
Denmark	Cyprus	France
Estonia	Denmark	Germany
Finland	Estonia	Greece
France	European Union	Iceland
Germany	Finland	Ireland
Greece	France	Italy
Hungary	Germany	Japan
Iceland	Greece	Luxembourg
Ireland	Hungary	Netherlands
Italy	Iceland	New Zealand
Japan	Ireland	Norway
Latvia	Italy	Portugal
Lithuania	Japan	Spain
Luxembourg	Latvia	Sweden
Netherlands	Lithuania	Switzerland
New Zealand	Luxembourg	Turkey
Norway	Malta	United Kingdom
Poland	Monaco	United States of America
Portugal	Netherlands	
Romania	New Zealand	
Russia	Norway	
Slovakia	Poland	
Slovenia	Portugal	
Spain	Romania	
Sweden	Russia	
Switzerland	Slovakia	
Ukraine	Slovenia	
United Kingdom	Spain	
United States of America	Sweden	
	Switzerland	

	Turkey	
	Ukraine	
	United Kingdom	
	United States of America	

Source: UNFCCC's website (www.unfccc.int)
[1]Every other country is a non-Annexe B country
[2]Every other country is a non-Annexe I party

Table A.II: List of member states in SSA's RECs

COMESA	EAC	ECCAS	ECOWAS	IGAD	SADC
Burundi	Burundi	Angola	Benin	Djibouti	Angola
Comoros	Kenya	Burundi	Burkina Faso	Eritrea	Botswana
Democratic Republic of Congo	Rwanda	Cameroon	Cote d'Ivoire	Ethiopia	Democratic Republic of Congo
Djibouti	Tanzania	Central African Rep.	Cape Verde	Kenya	Lesotho
Egypt	Uganda	Chad	Gambia	Somalia	Madagascar
Eritrea		Congo Rep.	Ghana	Sudan	Malawi
Ethiopia		Equatorial Guinea	Guinea Bissau	Uganda	Mauritius
Kenya		Gabon	Guinea		Mozambique
Libya		Sao Tome	Liberia		Namibia
Madagascar		Rwanda	Mali		Seychelles
Malawi			Niger		South Africa
Mauritius			Nigeria		Swaziland
Rwanda			Senegal		Tanzania
Seychelles			Sierra Leone		Zambia
Sudan			Togo		Zimbabwe
Swaziland					
Uganda					
Zambia					
Zimbabwe					

Source: www.wikipedea.org
Note: All the countries, except Djibouti, Egypt, Libya and Somalia, are included in the sample countries of this study. Rep. means Republic.

Table A.III: SSA winners of SEED Awards for reducing carbon emissions for the period 2010 to 2015

COUNTRY	SUMMARY OF PURPOSE OF AWARD AND YEAR
Burkina Faso	Manufacturing briquettes with fallen leaves to replace wood and charcoal (2010) Distribution of bio-pesticides (2010) Solar bread oven (2011)
Ethiopia	Energy saving cook stoves and briquettes (2013) Clean cook stoves that use biogas or ethanol (2014) Fuel efficient cook stoves made from ceramics (2015)
Gambia	Manufacture of briquettes from groundnut shells (2011)
Ghana	Biofuel production (2010)
Kenya	Replacing kerosene lanterns with solar lanterns (2010)
Malawi	Energy saving cooking stoves (2014) Solar batteries (2014) Solar home systems with pay-as-you-go plans (2015)
Rwanda	Production and distribution of pressurised biogas in gas cylinders (2010)
Senegal	Micro Power Economy for rural electrification (2010) Photovoltaic solar energy for rural electrification (2010)
South Africa	Distribution of bio-pesticides (2010) Cook stoves that use bio-energy (2013) Savings club to have access to solar technologies (2013) Supply of solar water heating (2013)
Tanzania	Solar power at affordable prices (2013)
Uganda	Micro-gasifier stoves (2013) Mobile solar computer (2014) Door-to-door liquefied petroleum gas delivery (2014)

Source: SEED awards website (https://www.seed.uno/awards/all.html)
Note: all these countries are part of this study's sample countries

Table A.IV: Summary of CO_2 emissions and economic development cross-country studies

NAME	REGRESSORS	METHOD	MODEL	PERIOD	COUNTRIES	EKC
Panayotou, Peterson & Sachs (2000)	GDP, population density, exports per unit of GDP, Capital per unit of GDP	FGLS	Log-quadratic	1870-1994	17 OECD	Yes
Neumayer (2004)	income per capita, climate, % of total energy consumption derived from renewable energy sources, transportation, and year	GEE	Log-quadratic	1960-1999	163	Yes
Navin (2005)	GDP, population density, GDP growth rate	OLS, GLS & Kernel regression	cubic &semi-parametric	1975-1996	103	N-shape
Zugravu, Millock & Duchene (2008)	GDP, manufacturing sector as a share of GDP, manufacturing sectors (food, textile, wood, paper, non-metal, metal, chemical, machine & others) as a share of total manufacturing production, trade openness, & corruption	2SLS & 3SLS	Simultaneous equation model	1995-2003	60	N/A
Carvalho & Almeida (2010)	GDP, trade intensity, energy consumption, & population density	OLS & FGLS	Cubic	2000-2004	167/187	N-shape
Azomahou, Goedhuys & Nguyen-Van (2009)	GDP, primary energy use, FDI, population density, investment net inflows, trade openness	N/A	GAM	1961-2004	107	Linear
Grunewald & Martinez-Zarzoso (2009)	GDP, share of manufacturing industry in GDP, Kyoto protocol & CDM	OLS & 2SLS IV	Log-quadratic	1975-2004	123	Yes for high-income countries
Poudel, Paudel & Bhattarai (2009)	GDP, forestry, population density, illiteracy rate	Kernel estimator	semi-parametric	1980-2000	15 Latin American	N-shape
Choi, Heshmati & Cho (2010)	GDP, openness, contribution to renewable energies, and fossil consumption per capita	OLS, VAR, VECM, impulse response & variance decomposition	log (quadratic &cubic)	1971-2006	3	inconclusive
Grunewald & Martinez-	GDP, share of manufacturing industry in GDP and Kyoto	GMM	Log-quadratic	1960-2009	213	Yes for high-income

Zarzoso (2011)	obligations					countries
Jeßberger (2011)	GDP, MEA	N/A	spline model	1960-2006	160	Yes
Arouri, Youssef, M'henni & Rault (2012)	GDP, energy consumption	ECM	Log-quadratic	1981-2005	12 MENA	Yes for panel analysis
Pandelis (2012)	GDP, trade intensity, physical capital stock per worker, GINI coefficient, government debt as a share of GDP, investment, tropical climate, executive constraints, average years of schooling over prior five years and population growth rates	2SLS MA	quadratic & Bayesian model	1971-1990	35	Yes
Taguchi (2012)	GDP and degree of economic development	GMM	quadratic	1950-2009	19	Linear
Gholami & Shafiee (2013)	GDP, share of manufactured goods value added to GDP, trade openness and energy intensity	GMM	quadratic	1977-2004	OPEC countries	N-shape
Onafowora & Owoye (2013)	GDP, energy consumption, trade openness and population density	ARDL bounds testing approach to cointegration & UECM	Log-cubic	1970-2010	8	Yes for 2 countries
Liddle (2015)	GDP, population and energy intensity	CMG & AMG	Log-linear	1971-2011	26 OECD 54 non-OECD	Yes for CO_2 intensity No for CO_2 per capita
Al-Mulali and Ozturk (2016)	GDP, renewable energy consumption, non-renewable energy consumption, urban population as a share of total population, trade openness and energy prices	FMOLS & VECM Granger causality	Log-quadratic	1990-2012	27 advanced economies	Yes
Bilgili, Koçak & Bulut (2016)	GDP, renewable energy consumption	FMOLS & DOLS	Log-quadratic	1977-2010	17 OECD	Yes
Baek (2016)	GDP, FDI and renewable energy	PMG	Log-quadratic	1981-2010	5 ASEAN	Yes for HIC No for LIC
Mitić, Ivanović &	GDP	FMOLS & DOLS	Log-linear	1997-2014	17 transitional	Linear

Zdravković (2017)					economies	
Casey & Galor (2017)	GDP, total population, age structure, urban population as a share of total population and trade openness	Linear regression Fixed Effects	Log-linear	1950-2010	147	Linear

Source: Author (2017)

N/A means not available; Note: see section 3.4.1.1 of chapter three for details.

Table A.V: Summary of CO_2 emissions and economic development country-specific studies

NAME	REGRESSORS	METHOD	MODEL	PERIOD	COUNTRY	EKC
SSA countries:						
Boopen & Vinesh (2010)	GDP, investment divided by GDP, total of export and import divided by the GDP, secondary enrolment ratio, regulation variable, population level, and number of vehicles on the road.	VAR & OLS	linear & quadratic	1975-2009	Mauritius	No
Alege & Ogundipe (2013)	GDP, FDI, trade openness, corruption and population density	fractional cointegration approach	cubic	1970-2011	Nigeria	Linear
Non-SSA countries:						
He & Richard (2009)	GDP, price of crude oil, industrial production in GDP, share of oil exports in total exports, share of oil imports in total imports, exports to US and imports from US	Gaussian kernel estimator & PLM	semi parametric & nonlinear parametric	1948-2004	Canada	Linear
Asghari (2012)	GDP, FDI and openness	2SLS	cubic	1980-2011	Iran	U-shape
Li *et al.* (2016)	GDP, energy consumption, trade openness and Urbanisation	System GMM & ARDL	Log-quadratic	1996-2012	China	Yes
Balaguer & Cantavella (2016)	GDP and real crude oil prices	ARDL	Log-quadratic	1874-2011	Spain	Yes

Source: Author (2017)

N/A means not available; Note: Nigeria and Mauritius are part of this study's sample of countries. See section 3.4.1.2 of chapter three for details.

Table A.VI: Summary of CO_2 emissions and economic and financial development cross-country studies

NAME	REGRESSORS	METHOD	MODEL	PERIOD	COUNTRIES	EKC	FD
Tamazian, Pinẽiro & Vadlamannati (2009)	GDP, share of industrial output in GDP, financial openness, energy and oil consumption, R&D expenditure as a percentage of GDP, financial liberalisation, stock traded in market divided by GDP, the ratio of deposit money bank assets to GDP, FDI inflow stock, capital account convertibility index, and share of total energy imports divided by GDP	Regression (method not clearly stated)	Linear & quadratic	1992-2004	4	Yes	reduce emissions
Tamazian & Rao (2010)	GDP per capita, inflation, FDI, price liberalisation, FOREX, trade liberalisation, trade openness, financial liberalisation, institutional efficiency, energy consumption and energy imports	GLS &GMM	Linear & quadratic	1993-2004	24	Yes	reduce emissions
Asghari (2013)	GDP per capita, financial development in relation to: trade openness, FDI to gross fixed capital stock, and openness by FDI	Regression (method not clearly stated)	simultaneo us-cubic	1980-2011	4	Yes	reduce emissions
Al-Mulali, Chong, Low and Mohammed (2015)	GDP, energy consumption, urban population as a share of total population, trade openness and domestic credit to private sector	Fixed Effect & GMM	Log-quadratic	1980-2008	93 countries	Yes for UMIC & HIC No for LIC & LMIC	reduce emissions (in LMIC, UMIC & HIC)
Salahuddin, Gow and Ozturk (2015)	GDP per capita, electricity consumption and domestic credit to private sector as a share of GDP	DOLS, FMOLS & DFE	Linear	1980-2012	6 GCC	N/A	reduce emissions

Source: Author (2017)

FD means Financial Development

N/A means not available; Note: none of the countries is in the sample of this study. See section 3.4.2.1 of chapter three for details.

Table A.VII: Summary of CO_2 emissions and economic and financial development country-specific studies

NAME	REGRESSORS	METHOD	MODEL	PERIOD	COUNTRY	EKC	FD
SSA countries:							
Ajide & Oyinlola (2010)	GDP, share of manufacturing in GDP, FDI, traded value of stock market to GDP and energy consumption	Regression (method not clearly stated)	linear & quadratic	1980-2008	Nigeria	No	inconclusive
Shahbaz, Tiwari & Nasir (2011)	GDP, per capita domestic credit of private sector, coal consumption, trade openness and urban population as a share of total population	ARDL approach to cointegration & ECM	Log-linear & log-quadratic	1965-2008	South Africa	Yes	reduce emissions
Non-SSA countries:							
Shahbaz, Islam & Butt (2011)	GDP, energy consumption, real market capitalisation and population growth	ARDL approach to cointegration & ECM	Log-linear & log-quadratic	1974-2009	Pakistan	Yes	reduce emissions
Zhang (2011)	GDP, FDI net inflows as percentage of GDP, ratio of loans in financial intermediation to GDP, ratio of stock market capitalisation to GDP, ratio of stock market turnover to GDP, ratio of the sum of loans to township enterprises, enterprises with foreign fund and private enterprises and self-employed individuals to GDP	cointegration test, granger causality test, VECM and variance decomposition	system equations (3×3 matrices)	1980-2009	China	N/A	increase emissions
Shahbaz, Adnan & Tiwari (2012)	GDP, energy consumption, real domestic credit to private sector per capita, trade openness per capita	ARDL approach to cointegration OLS, ECM and VECM Granger causality technique	Log-linear	1975-2011	Indonesia	Yes	reduce emissions
Shahbaz (2012)	GDP, energy intensity, and real domestic credit to private sector per capita	ARDL approach to cointegration VECM Granger causality technique and IAA	Log-linear	1971-2009	Portugal	Yes	reduce emissions

Shahbaz, Solarin & Mahmood (2012)	GDP, energy consumption, domestic credit to private sector per capita, FDI and trade openness	ARDL approach to cointegration and VECM Granger causality technique	Log-linear & log-quadratic	1971-2008	Malaysia	linear	inconclusive
Boutabba (2013)	GDP, energy consumption, domestic credit to private sector as a share of GDP and trade openness	ARDL approach to cointegration and VECM	Log-quadratic	1970-2008	India	Yes	increase emissions
Shahbaz (2013)	GDP, index of financial instability, energy consumption and trade openness	ARDL approach to cointegration & ECM	Log-linear & log-quadratic	1972-2009	Pakistan	Yes	reduce emissions
Charfeddine & Khediri (2016)	GDP, electricity consumption, domestic credit to private sector as a share of GDP, urban population as a share of total population and trade openness	Cointegration & VECM Granger causality technique	Log-quadratic	1975-2011	UAE	Yes	increase emissions
Javid & Sharif (2016)	GDP, energy consumption, domestic credit to private sector as a share of GDP and trade openness	ARDL	quadratic	1972-2013	Pakistan	Yes	increase emissions
Ozatac, Gokmenoglu & Taspinar (2017)	GDP, energy consumption, trade openness, urbanisation and financial development	ARDL	quadratic	1960-2013	Turkey	Yes	reduce emissions

Source: Author (2017)

FD means Financial Development

N/A means not available; Note: Nigeria and South Africa are part of this study's sample of countries. See section 3.4.2.2 of chapter three for details.

Table A.VIII: Summary of panel studies on SSA

NAME	REGRESSORS	METHOD	MODEL	PERIOD	COUNTRY	EKC	FD
Al-Mulali & Che (2012)	CO_2 emissions, domestic investment, broad money, domestic credit to private sector, total primary energy consumption	panel cointegration & panel granger causality	linear	1980-2008	30	N/A	N/A

Source: Author (2017)

Note: FD means Financial Development. N/A means not available. This panel study is the closest (in relevance) found for SSA. See section 3.4.3 of chapter three for details.

Table A.IX: List of studies that found linear, inverted U and N-shape

LINEAR SHAPE	INVERTED U-SHAPE (EKC)	N-SHAPE
Azomahou, Goedhuys & Nguyen-Van (2009)	Panayotou, Peterson & Sachs (2000)	Navin (2005)
He and Richard (2010)	Neumayer (2004)	Poudel, Paudel & Bhattarai (2009)
Boopen and Vinesh (2010)	Grunewald & Martinez-Zarzoso (2009)	Carvalho & Almeida (2010)
Taguchi (2012)	Tamazian, Pinẽiro & Vadlamannati (2009)	Gholami & Shafiee (2013)
Shahbaz, Solarin & Mahmood (2012)	Tamazian & Rao (2010)	
Alege & Ogundipe (2013)	Grunewald & Martinez-Zarzoso (2011)	
	Jeßberger (2011)	
	Shahbaz, Islam & Butt (2011)	
	Shahbaz, Tiwari & Nasir (2011)	
	Arouri, Youssef, M'henni & Rault (2012)	
	Pandelis (2012)	
	Shahbaz, Adnan & Tiwari (2012)	
	Shahbaz (2012)	
	Asghari (2013)	
	Boutabba (2013)	
	Onafowora & Owoye (2013)	
	Shahbaz (2013)	
	Al-Mulali, Chong, Low and Mohammed (2015)	
	Liddle (2015)	
	Al-Mulali & Ozturk (2016)	
	Baek (2016)	
	Balaguer & Cantavella (2016)	
	Bilgili, Koçak & Bulut (2016)	
	Charfeddine & Khediri (2016)	
	Javid & Sharif (2016)	
	Li, Wang & Zhao (2016)	
	Ozatac, Gokmenoglu & Taspinar (2017)	

Source: Author (2017)

See section 3.5 of chapter three for details.

Table A.X: Turning points for studies with inverted U, U, N and inverted N-shape

NAME	PERIOD	COUNTRIES	METHOD	TURNING POINT	COMMENT
INVERTED U-SHAPE:					
Panayotou, Peterson & Sachs (2000)	1870-1994	17 OECD	FGLS	$29732 -$40906	range for 17 countries
Neumayer (2004)	1960-1999	163	GEE	$55,000 & $90,000	2 specifications
Grunewald & Martinez-Zarzoso (2011)	1960-2009	213	GMM	$209,452	
Arouri, Youssef, M'henni & Rault (2012)	1981-2005	12 MENA	ECM	$37,263	
Pandelis (2012)	1971-1990	35	2SLS MA	$17,600	
Al-Sayed & Sek (2013)	1961-2009	40	OLS & GLS	$8,673 & $67,846	Developing & Developed countries
Skaza & Blais (2013)	1960-2010	190	OLS	$59,309	
Li *et al*. (2016)	1996-2012	China	System GMM & ARDL	$10,403.96	
U-SHAPE:					
Choi, Heshmati & Cho (2010)	1971-2006	Korea	OLS, VAR, VECM, impulse response & variance decomposition	$8,210	
Asghari (2012)	1980-2011	Iran	2SLS	$2,655 & $3,049	2 specifications
N-SHAPE:					
Navin (2005)	1975-1996	103	OLS & GLS	$10,000 & $20,000	
Almeida & Carvalho (2009)	2000-2004	167/187	OLS & FGLS	$13,326 & $27,488	
Poudel, Paudel & Bhattarai (2009)	1980-2000	15 Latin American	Kernel estimator	$3,500 & $4,500	
INVERTED N-SHAPE:					
Choi, Heshmati & Cho (2010)	1971-2006	Japan	OLS, VAR, VECM, impulse response & variance decomposition	$19,600 & $29,700	

Source: Author (2017)
See section 3.5 of chapter three for details.