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PETROLEUM RENT, INCOME, AND ENERGY TRILEMMA: EVIDENCE FROM SELECTED OIL PRODUCERS IN AFRICA

AMINU OSMAN

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PETROLEUM RENT, INCOME, AND ENERGY TRILEMMA: EVIDENCE FROM SELECTED OIL PRODUCERS IN AFRICA

BY

OSMAN AMINU

Thesis submitted to the Department of Economic Studies of the School of Economics, College of Humanities and Legal Studies, University of Cape Coast, in partial fulfillment of the requirement for the award of Doctor of Philosophy Degree in Economics

JULY, 2023

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: …………………………………… Date………………

Name: Aminu Osman

Supervisors' Declaration

We hereby declare that the preparation and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature…………………………… Date………………

Name: Professor Omowumi O. Iledare

Co-Supervisor's Signature: ………………………...……. Date………………

Name: Dr. Isaac Bentum-Ennin

VERITAS NOBIS LUMEN

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ABSTRACT

The trilemma of providing secure, affordable, and sustainable energy has become a much talked about issue in recent times due to concerns about climate change. Regarding the energy trilemma dimensions, focusing on one at the expense of the other two is likely to be just as harmful to improving human quality of life as ignoring environmental sustainability. This study employs a panel-ARDL approach and panel-GMM to analyze the effect of petroleum rent on energy trilemma in selected oil-producing countries in Africa. The study reveals petroleum rent and per capita income between, respectively, enhances countries' performance on the energy trilemma index in the long run, whereas, in the short run, income per capita decreases the energy trilemma. Petroleum rent and income per capita support countries in making energy systems environmentally sustainable and, at the same time, contribute to countries' improvements in energy equity. Petroleum rent of oil-producing African economies begins to be beneficial to energy poverty reduction and access to electricity when petroleum rent reaches 36.7% and 40.57% of GDP, respectively. Governments of oil-producing African countries should put measures towards increasing petroleum rent to improve the energy trilemma index, ensure energy poverty reduction, and reduce energy supply insecurity.

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KEYWORDS

Energy Equity

Energy Poverty

Energy Security

Energy Trilemma

Income

Petroleum Rent

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Finally, I would want to express my gratitude to my family and friends, especially my mother, Hajia Salamatu Azumi Yushaw, my wife, Fatimata Imoro Kalugui, my siblings and children.

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DEDICATION

To my late Father.

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LIST OF ACRONYMS

AMG	Augmented Mean Group
ARDL	Autoregressive Distributed Lag
DFE	Dynamic Fixed Effect
ESS	Energy Supply Security
ETI	Energy Trilemma Index
GDP	Gross Domestic Product
GMM	Generalised Method of Moment
IEA	International Energy Agency
LPG	Liquefied Petroleum Gas
MG	Mean group
OLS	Ordinary Least Squares
WEC	World Energy Council

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CHAPTER ONE

INTRODUCTION

Background to the Study

The Energy Trilemma Index (ETI), introduced by the World Energy Council (WEC) in 2010 in partnership with Oliver Wyman and Marsh McLennan, raises critical environmental concerns that chart a sustainable development path driven by minimal environmental consequences whiles ensuring energy security and energy equity (Grigoryev & Medzhidova; 2020 Gunningham, 2013). Energy poverty is apparent in most developing countries, especially in Africa. Energy poverty is less of a concern to the developed world compared to energy insecurity. Africa is characterised by widespread energy poverty and energy insecurity issues impeding sustainable economic growth and development (Acharya, 2019; Amin et al., 2020; Khennas, 2012; Ouedraogo, 2013; Raghutla & Chittedi, 2022). Yet, emitting just 3.8% of global greenhouse gases, African countries, per the Paris Agreement, have been assigned to cut down greenhouse gas emissions (largely carbon dioxide from fossil fuel) in energy production and consumption (Wojuade, 2018).

Africa is home to five of the top 30 petroleum-producing countries globally and accounted for more than 7.9 million barrels of oil per day in 2019 (U.S. Energy Information Administration [US EIA], "Petroleum and Other Liquids," 2020). Despite the abundant energy resources in Africa, particularly petroleum, the International Energy Agency (IEA) reported in 2020 that eighteen percent of the world’s energy-poor population is in rural Africa. Africa has the lowest per capita energy consumption and the highest incidence of energy deprivation. Sixty-five percent of the African population, comprising

633 million people, do not have access to electricity, and 792 million people, constituting 80% of the population, do not have access to clean and modern cooking fuels and technologies (Alloisio, Bonan, Carraro, Davide, Hafner, Ogundipe, Akinyemi & Ogundipe, 2018; Tagliapietra & Tavoni, 2017).

Coupled with the energy impoverishment in Africa, the energy insecurity situation is also gloomy. The Ukraine-Russia war, renewed on 24th February 2022, has reintroduced global energy supply security concerns (Benton, Froggatt, Wellesley, Grafham, King, Morisetti & Schröder, 2022). The recent turmoil in Europe has established the need for more concentration of energy supply insecurity on not just affordability and acceptability but accessibility anchored on energy import dependency, energy efficiency, and domestic energy production rate (Bielecki, 2002; Leung, 2011; Rabbi, Popp, Máté & Kovács, 20222). Energy efficiency helps control demand growth, lowers fuel imports, eases pressure on the current infrastructure, and keeps consumer costs down (IEA, 2022). In many developing countries, the internal sources of supply could equally be problematic due to skewed diversity in primary energy supply, diversity in power generation, and capacities in energy storage, system stability, and recovery (Bhattacharyya, 2019).

International concerns about energy supply insecurity, precisely, energy independence, arise from several factors: fossil fuel reserves are finite and non-renewable, rising energy consumption in emerging economies is putting more pressure on supply, and price volatility of fuels, mainly primary energy sources, creating energy affordability issues (Johansson, 2013). Sometimes, energy is available, but the financial means are not there to use them. The cost of electricity and transport fuels is relatively high in Africa.

With oil continuing to hold the largest share (33%) in the global energy mix, end-user prices of gasoline, diesel, and LPG were averagely high in Africa in 2018, ranging from $0.3 per liter to $1.2 per liter (IEA, 2019). African countries, mostly oil-producers, such as Libya, Nigeria, Angola, Egypt, and Algeria, with regulatory regimes (subsidies) in oil prices, have kept prices between the range of $0.5 and $1 per liter, whiles countries with deregulation regimes, such as Ghana, South Africa, and Mozambique have held the end-user price of gasoline between $1.05 and $1.5 (IEA, 2019).

There have been signs that current actions and inactions of states dire world energy systems and pose questions on the efficacies of existing energy management strategies which have not adequately prioritise the environmental sustainability of energy systems for the current and future generations (Ashagidigbi et al., 2020). Globally, the Sustainable Development Goals (Goal 7) underscore the strategic importance of energy for human existence, and nations have drawn spirits from the global policy to formulate national policies incorporating environmental concerns. The goal seeks to ensure affordable, reliable, and universal access to modern energy services. It has also recognized the vital role that zero-carbon energy, especially renewable energy, can play in the global energy mix and emphasises the need to double the global rate of improvement in energy efficiency to ensure environmental sustainability. The Millennium Development Goals (MDGs), implemented between 2000 and 2015, also explicitly targeted access to sustainable energy, among other goals (Mccollum et al., 2018).

However, government access to petroleum revenues in many countries has faced a high risk of uncertainties due to price fluctuation, poor resource management and policies, and institutions, as well as transparency, accountability, and corruption of public officeholders (Barnett & Ossowski, 2008; Campbell, Anderson, Daugaard & Naughton, 2018; Hausman, Rigobon & Rigobon, 2002). Investing petroleum revenues into the energy sector can increase economic growth and development, guaranteeing sustainable energy development. Scholars have shown a direct relationship between petroleum rent and economic growth and development (Arinze, 2011; Costa & Santos, 2013; Holden, 2013; Kubiszewski et al., 2013; World Bank [WB], 2018). That of establishing the relationship between petroleum rent and energy trilemma has not been adequately explored. Mayer (2022) found that oil rent does not impact energy insecurity, a dimension of the energy trilemma.

Most empirical studies have hinged on exploring oil resource curse hypothesis (Adams et al., 2017; Beck, 2011; Bjorvan et al., 2012; Hammond, 2011; Lucky & Nwosiand, 2016; Okpanachi et al., 2012: Parcero et al., 2016; Partey, 2016; Ross, 2011; Satti, 2011; Umar, Ji, Mirza & Rahat, 2021); and oil-economic growth relationships (Behmiri & Manso, 2013 & 2014: Tamba, 2017: Hong & Hsu, 2018: Lahiani, Benkraiem & Miloudi, 2019: Srimarut & Sittisom, 2020).

Specifically, studies on energy poverty have concentrated mainly on the levels of energy poverty index primarily associated with fuel sources, which oil-rich African countries are endowed with. For instance, Bazilian et al. (2013) found that oil wealth improved energy access in some African economies. Other scholars have established the link between energy poverty and economic growth and development. For example, Raghutla and Chittedi (2022) investigated the impact of energy poverty on the economic development of BRICS economies.

They found a unidirectional Granger causal relationship running from economic development to access to electricity in the short-run. The study by Bui (2020) revealed bidirectional granger causality between energy consumption and economic activities in Vietnam from 1984 to 2016. Shittu et al. (2021) and Le and Nguyen (2019) looked at the impact of energy security and economic rent on economic growth rather than establishing how rent impacts energy security. These studies have not looked at the reverse effect of how petroleum rent and income affect sustainable energy development.

Again, most scholars have focused on cross-sectional analysis by applying the Multidimensional Energy Poverty Index (MEPI) introduced by Alkire & Foster (2011) and other cross-sectional data analysis techniques (Erdal et al., 2015a; 2015b; Karakara & Dasmani, 2019; Kroon et al., 2013; Rupali et al., 2019). Others have employed just the time series analysis for specific countries offering country-specific analysis without providing a regional or group picture of the energy situation.

On the energy trilemma index few empirical studies have looked at Energy Trilemma Index (ETI), with most of them interested in creating the indices and appraising the ETI developed by WEC in measuring the national energy performance (Al Asbahi et al., 2019; Baloch et al., 2020; Iqbal & Mohsin, 2019; Hobson, 2019; Song et al., 2017). Song et al. (2017) employed Stochastic Multicriteria Acceptability Analysis (SMAA-2) to evaluate the national energy performance. The studies mentioned above have conceptualized energy trilemma in various ways applying different methodologies in different settings and yet not linking it to petroleum rent which is expected to play a critical role in oil rentier states. Some panel data analysis on the relationship between petroleum rent and some dimensions of energy trilemma have been explored in developed countries. There are few studies on this nexus in Africa, particularly in oil-producing African countries.

Statement of the Problem

Based on a rational economic mindset, the petroleum revenue presents an excellent opportunity to solve the challenging dimensions of energy trilemma index. Additional wealth from petroleum extraction for rentier states in Africa to national income could facilitate the reduction of energy poverty, ensure energy supply security and make energy systems environmentally sustainable.

Africa emits comparatively lower greenhouse gases (GHGs) but is under external pressure to cut emissions. Coupled with the increasing external pressure to transition from fossil, energy poverty and energy supply insecurity are still apparent among African oil-producing countries (Bazilian et al., 2013; Bekun et al., 2019; Mayer, 2022). The situation creates, unfortunately, what might be called “the irony of oil wealth” (Ross, 2011).

There have been limited empirical studies on how petroleum rent and income have been translated into energy poverty reduction, ensuring energy security, and keeping to the environmental sustainability of energy systems. Related studies are on the oil resource curse hypothesis (Adams et al., 2017; Bjorvan et al., 2012; Lucky & Nwosiand, 2016; Parcero et al., 2016; Partey, 2016; Umar et al., 2021). Others focus on oil-economic growth relationships (Behmiri & Manso., 2013 & 2014; Hong & Hsu, 2018; Lahiani, Benkraiem & Miloudi, 2019; Srimarut & Sittisom, 2020; Tamba, 2017). Most of these studies have used cross-sectional analysis using primary data and some rounds of data from demographic and health surveys, standard living surveys, etc. (Erdal et al., 2015; Karakara & Dasmani, 2019; Kroon et al., 2013; Rupali et al., 2019). There is, therefore, a gap in the conceptualisation of the energy trilemma index. Again, the study identified a gap in the methodological approaches and setting in assessing how petroleum rent and income affect the energy trilemma.

The study, therefore, seeks to fill this gap in the literature by employing panel-ARDL and panel-GMM to examine the effect of petroleum rent and income on the energy trilemma index and its dimensions in oil-producing countries in Africa. The WEC's approach in computing indices for the measurements of ETI looks composite. After assessing the effect of petroleum rent and income on the dimensions of energy trilemma, the study attempts to examine the effect of petroleum rent and income on energy poverty and energy supply security. The concentration on energy supply security again is because the index computation using the WEC's approach looks composite with both demand and supply indicators. Since energy supply is much more of a problem in Africa than demand, the study is interested in exploring the energy security of supply. Understanding the extent of the effect of petroleum rent and income on energy trilemma could help governments of Oil-producing African economies and Energy Sector Development Agencies to take proactive steps in response to the global call for the energy transition.

Aim and Research Objectives

The study investigates the effect of petroleum rent and income on the energy trilemma index in oil-producing African countries. The management of trade-offs in the trilemma of achieving a sustainable mix of policies is tracked by the energy trilemma index over time. It highlights a country's ability to provide sustainable energy through three dimensions – energy security, energy equity, and environmental sustainability of energy systems.

Specifically, the study seeks to:

i. Determine the effect of petroleum rent and income on energy trilemma in oil-producing African economies;

ii. Examine the effect of petroleum rent and income on energy poverty in oil-producing African countries; and

iii. Assess the effect of petroleum rent and income on energy supply security in oil-producing African countries.

Research Hypotheses

The study attempts to test the following hypotheses;

i. H_0: Petroleum rent and income do not affect energy trilemma.

H_1: Petroleum rent and income affect energy trilemma.

ii. H_0: Petroleum rent and income do not affect energy poverty.

H_1: Petroleum rent and income affect energy poverty.

iii. H_0: Petroleum rent and income do not affect energy supply security

H_1: Petroleum rent and income affect energy supply security

Significance of the Study

Oil producers in Africa are preoccupied with petroleum rent and sharing receipts from crude oil exportation to the detriment of value addition, making them susceptible to driving lower premiums from petroleum export. Consequently, it poses a risk to the extent of the effect of petroleum rent and income on sustainable energy development in the continent. Thus, the study seeks to investigate the effect of petroleum rent and income on energy trilemma in African oil-producing countries.

Although capabilities are unevenly spread, energy literacy remains poor in many stakeholder groups, especially in Africa and even among oil-producing African countries, not in the sense of professional know-how and engineering expertise. But instead, in the general lack of appreciation and understanding, our relationship with energy changes over time. Therefore, the study adds to the literature and offers insights and lessons to policymakers and scholars on the role of petroleum rent and income in sustainable energy development in African oil-producing countries. Deeper cross-country analysis over time, which is the purpose of this study, can give policymakers real insights on trajectories, correlations, and causalities that inform future priorities.

Thus, this study contributes to the literature on sustainable energy and benefits from petroleum extraction. It offers policymakers the opportunity to understand the dynamics and tradeoffs required to improve energy accessibility, availability, reliability, acceptability, and affordability. It provides an empirical basis for policy recommendations to invest petroleum revenues in cleaner energy sources. Establishing the role of petroleum in improving countries' performance in energy poverty reduction, ensuring the security of energy supply, and enhancing performance in energy trilemma is a prerequisite for sustainable economic growth and development. It is of the greatest importance for policymakers in constructing a successful energy policy framework (Dergiades et al., 2013).

Further, this study employs a lot of indicators across different data sources to make the scope and measurement of energy trilemma more

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comprehensive to analyse the relationships. The study has also decomposed the energy trilemma index, energy poverty index and has specifically used specific dimensions of energy supply security to observe specific relationships with petroleum rent. The findings of this study are relevant for a broader energy policy framework for improving energy sustainability in Africa and elsewhere through intra-regional collaborations. The study computes the performance of the energy trilemma and its dimensions for selected oil-producing African countries. The energy sustainability scores are a prerequisite for suitable energy policy formulation and establish the credence in translating petroleum rent and income to solve the core energy challenges that will accelerate industrialization to improve living standards in Africa and the world.

Delimitation

The study investigates the effect of petroleum rent and income on energy trilemma in oil-producing African economies. Specifically, the effect of petroleum rent and economic outcomes are essential for developing and hydrocarbon-rich countries in achieving acceptable levels of environmental sustainability of energy systems, energy poverty reduction, and mitigating energy supply insecurities. Annual data of oil-producing economies on the indicators used in creating the indices and making the analysis is from 2000 to 2020, focusing on some selected oil-producing African countries. Not all African countries were considered, and concentration was on some selected oil-producing African countries where data could be obtained.

In terms of the variables, the energy trilemma index is approached from the perspective of the WEC. Thus, the dimension and indicators were adopted from the index the WEC created from 2014 to 2020. The focus of energy

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poverty in this study is concerned with the deprivation of individuals and communities from getting access to energy services. Thus, relevant dimensions were access to electricity, access to clean and modern cooking fuels, and primary energy supply per capita. The scope of indicators used to measure energy security by the World Energy Council is very broad, with both demand and supply indicators considered. There is the need to concentrate on only the security of supply of energy, which is a challenge in Africa than demand, to observe how the individual indicators of security of supply are influenced by petroleum rent and income. In the third objective, unlike how other scholars have conceptualized energy supply security, the study used energy supply security based on three dimensions: energy import dependency, energy efficiency, and domestic energy production rate. Thus, the energy security concentration in this study is on supply instead of demand. Lastly, oil rent and gas rent are used to represent petroleum rent for the selected oil-producing African countries.

Macro panel data ($T = 19$) is constructed to address objectives one and two by applying the panel-ARDL approach. For objective three, the study constructed a micro panel data ($N = 19$) and used panel-GMM to analyse the effect of petroleum rent on energy supply security. These methods were applied rather than the fixed effect and random effect models based on the specific characteristics of the data and the nature of the research objective. For instance, the panel datasets for objectives one and two were found to have slope homogeneity and cross-sectionally independent. In addition, the first-generation panel unit root test showed that the series were a mix of integration of order zero and order one and, therefore, the choice of panel-ARDL approach for objectives one and two. Panel-GMM is situations where the panel dataset is micro (Arellano & Bond, 1991; Blundell & Bond, 1998; Wooldridge, 2002; Hsiao, 2003; Baltagi, 2008).

The delimitation of the study is very much on the scope of data, choice, and conceptualisation of the terms used in the study, estimation technique, and the focus on oil-producing African countries where sustainable energy development remains a daunting task.

Limitation

The main limitation of the study was the nonavailability of consistent long yearly data. Therefore, the study was restricted to the period 2000 to 2020 for the countries where data could be obtained. The data irregularity constrained the study to use different samples for the models in addressing the three objectives. The panel dataset can be declared as a macro panel with 19 years' time dimension and 13 countries for objective one and nine countries for objective two. The difference of one, below the criteria proposed by Baltagi (2008) for micro panels, is insignificant to invalidate the results of the study and hence the policies recommended. The constraints in obtaining adequate data points have also informed the construction of micro panel data to address objective three. This made the study relatively tedious to link the results of the first objective, whose data spans from 2002 to 2020, to the results of the second objective, which span from 2000 – 2018, and the results of the third objective. The difficulty arises from the fact the length of the panel in terms of the time dimension and the level of integration of the series for the panel constructed differs from period to period and country to country used in the study. Nevertheless, results obtained in the models still provide a clear idea of how oil-producing African economies utilize their rent from petroleum resource development in dealing with the triple challenge of energy production and consumption.

Regarding data quality, the study does not doubt the sources the data were solicited from as they were obtained from highly respected international data sources such as the World Bank database and the US Energy Information Administration. However, for missing observations, the scientific method of interpolation and extrapolation was adopted to fix them. In terms of the estimation technique, the potential of endogeneity was suspected in estimating the model for objective three. Hence, the panel-GMM approach, which deals with endogeneity, is applied.

The use of indices that the study used to observe and examine the effect of petroleum rent and per capita income on the energy trilemma has been largely criticized by several scholars. As a result, the individual indicators and dimensions were also used to examine the effect of our interest variables on them independently. They largely confirm results obtained from the indices.

Organisation of the Study

The study is organized into five chapters. Chapter one is an introduction highlighting the background of the study, problem statement, research objectives, research hypothesis, scope of the study, and significance of the study. Chapter two discusses relevant theoretical and empirical literature on how petroleum rent and income influence the energy trilemma. The chapter highlights measures of variables of interest that are used in the study. Chapter three covers the study’s research methodology that enabled the arrival of logical results. Chapter four presents the three sections in accordance with the

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objectives of the study. The energy trilemma index is generated and discussed, and the influence of petroleum rent and income as well as some control variables on energy trilemma, is assessed and presented in the last section of Chapter one. The second section of the discussion looks at the role of petroleum rent and income in energy poverty reduction in oil-producing African countries. The third section of the chapter presents results and discussions on the effect of petroleum rent and income on energy supply security in oil-producing African countries. Finally, chapter five covers the summary, conclusion, recommendations, and suggestions for future studies.

Chapter Summary

Chapter one presents the introduction by providing the problem statement, research objectives, and thesis structure. This chapter focuses on the essence of energy in economic transformation and development, admits, petroleum revenue boosting the African economy, the chapter presents how Africa is lagging in terms of energy acceptability, accessibility, availability, and affordability. It also presents the claim to suggest that African countries have a challenge in energy poverty and energy supply insecurity, making tradeoffs between secure energy supply, affordability, and environmental sustainability in energy systems. How sustainable energy development is influenced by petroleum rent and income is necessary for sound policy directions. Next, the pertinent research objectives are raised from the statement of the problem with a clearly stated hypothesis to be tested.

CHAPTER TWO

LITERATURE REVIEW

Introduction

In Africa, petroleum resource endowment presents the continent with a good foundation for improving the environmental sustainability of energy systems, energy access, and energy supply security. Existing studies on how petroleum rent impacted energy trilemma, especially energy poverty and energy supply security, have not been fully explored. Africa is noted to be more vulnerable to the impact of climate change, requiring them to reconsider the increasingly unviable traditional pathways for access to energy based on the burning of fossil fuels (Collier, Conway, & Venables, 2008).

The endowment of petroleum resources and their exploitation in oil-rich African nations is supposed to be an excellent opportunity to improve energy access and ensure energy supply security. However, the advocacy for climate change put oil-producing economies in a complex situation of either ignoring ever-supporting petroleum rent or transitioning to green energy. This chapter is devoted to reviewing related literature for the study and is divided into two sections. The first section examines the various theoretical perspectives on energy trilemma, poverty, and supply security. The second section covers empirical studies on how petroleum rent impacts energy trilemma, energy poverty, and energy supply security.

Review of Theoretical Literature

This section reviews the theoretical literature underpinning the energy trilemma study. It covers four main theoretical perspectives of energy trilemma and its dimensions – accessibility, availability, acceptability, and affordability. Sustainable energy is the type of energy source whose production and consumption do not harm human health, the environment, and the functioning of natural and economic systems. Sustainable energy aims to reduce energy poverty and ensure energy supply security for present and future generations. It is to be achieved through a combination of savings, efficient solutions, innovations and technologies, and the use of renewable energy (LG Action, 2012; Prandecki, 2014). Therefore, the energy ladder hypothesis and the energy stacking theory are relevant to this study. Resource-dependent economies sometimes do not translate their wealth into improving the citizens' livelihood; hence, the Rentier States Theory and Resource Curse Theory are also reviewed.

Lastly, since petroleum rent contributes greatly to national income, it is anticipated that petroleum rent and GDP will be related to the dimensions of the energy trilemma index. For the environmental sustainability of energy systems, the Environmental Kuznets Curve Hypothesis is reviewed to establish the direction of conclusions made in existing knowledge on the energy-economy-environment (EEE) nexus.

Petroleum Rent

The study contextualizes the term petroleum rent to mean the earnings from the exploration and production of crude oil that exceed the costs required to make the activity economically sustainable in the long term. Petroleum resources are non-renewable energy resources referring to the quantities of hydrocarbons naturally occurring on or within the Earth’s crust (Society of Petroleum Engineers [SPE], 2018)

. Petroleum refers to a naturally occurring mixture of hydrocarbons in the gaseous, liquid, or solid state. Petroleum may also contain non-hydrocarbons, typical examples of which are carbon dioxide, nitrogen, hydrogen sulphide, and sulphur. In rare cases, non-hydrocarbon content can be greater than 50% (SPE, 2018). The term resources used herein encompass all quantities of petroleum naturally occurring within the Earth's crust, both discovered and undiscovered (whether recoverable or unrecoverable), plus those quantities already produced (Mustafa, Khlifa & Shukr, 2021).

The resources that can be extracted from conventional petroleum resources include crude oil, condensate, and natural gas (Xiaoguang, Zhang, Zhaoming, Zhixin, Zuoji, Hongjun & Yiping, 2018). Refined products from petroleum resources include liquefied petroleum gas, fuel oils, petrol, diesel, kerosene, asphalt base, and others. Examples of unconventional oil resources include oil shales, oil sands, extra-heavy oil, gas-to-liquids, and coal-to-liquids. Oil shale is an example of a thermally immature source rock that has not generated and expelled hydrocarbons. The endowment of petroleum resources is at different levels depending on the geological formation. The extraction of petroleum resources presents what is commonly referred to as economic rent. Petroleum Economist categorises economic rent from extracting petroleum resources into oil and gas rent (Iledare, 2021).

The term petroleum rent is deduced from the concept of economic rent. In the context of a market transaction, economists define economic rent as any payment provided to an owner or factor of production that is larger than the expenses incurred to bring that factor into production. Economic rent, in accordance with classical economic theory, is any payment made (including imputed value) or benefit received in exchange for non-produced inputs like location (land) and assets made possible by allowing officials the sole right to exploit available opportunities (e.g., patents).

In the moral economy of neoclassical economics, economic rent is the income received by labour or state beneficiaries of various types of exclusivities that are "contrived" (presuming the market is natural and is not the consequence of state and social creation), such as labour guilds and covert corruption. Drawing insights from the neoclassical understanding of economic rent, Chevalier (1975) defined oil rent as the difference between the price of a unit of measurement of a natural resource sold to consumers in the form of refined products and the total average cost incurred to extract, transport, refine and distribute this same unit of measurement of the resource. The IEA (2020) defined natural gas rents as the difference between the value of natural gas production at regional prices and the total costs of production.

For the purposes of this study, petroleum rent is considered to mean the difference between the price of crude oil and the average cost of producing it. The IEA estimates the oil rent for countries by estimating the price of units of specific commodities and subtracting estimates of average unit costs of extraction or harvesting costs. These unit rents are then multiplied by the physical quantities a country extracts to determine the rents for petroleum as a share of gross domestic product.

Economic rent should not be confused with normal profit or surplus arising during competitive capitalist production. Economic rent is opposed to producer surplus, or normal profit, both of which are theorised to involve productive human action. Economic rent is viewed as unearned revenue, while economic profit is a narrower term describing surplus income earned by choosing between risk-adjusted alternatives. Economic profit is absolute, whereas economic rent is relative. Economic rent arises because of the relative advantage one set of application of factors has over the other. Economic Rent is a pecuniary quantification of a resource, property, or object's relative advantage over the least preferred but feasible resource, property, or object (Posnett, 1884).

Energy Trilemma Concept

As the difficulty of global coordination of climate change has become increasingly apparent, there is a need for a reaction to construct an adequate language for international energy affairs. The concept of “trilemma” first appeared in 1963 when the classical monetary trilemma was introduced in the popular Mundell–Fleming model (Schoenmaker, 2011). Since then, “trilemma” has become a fashionable term, with concepts such as “Trade (or globalization) trilemma” and “financial trilemma” (Schoenmaker, 2011). Recently, the phrase “energy trilemma” emerged as a symbolic term for the complexity of countries’ governmental objectives. Any government seeks to find the optimal answer to three requests from society to the fuel and energy complex, such as energy poverty, energy supply security, and environmental sustainability of the energy system.

The energy trilemma is a complex quandary for developing economies where energy poverty is still high, tedious to guarantee energy supply security and minimize climate change effects from the production and consumption of energy. Therefore, it requires a thoughtful tradeoff and well balance policies that will ensure energy security and equity while keeping an acceptable level of the environment at quality for sustainable reasons. Understanding the tensions between these different horns of energy trilemma and the tradeoffs necessary to manage them is a good beginning for sustainability. Consequently, the balance will facilitate the identification of credible governance strategies to achieve a transition that will not continue to deny the majority of the African population access to energy and ensure the security of the energy supply.

The energy trilemma is used to explain the political challenge of contemporaneously pursuing competing priorities of energy security, energy equity, and climate change. These three domains of energy trilemma encompass the broad dimensions of energy production and consumption issues such as availability, accessibility, affordability, and acceptability. The political challenge of simultaneously addressing the potentially competing goals of energy security, energy equity, and climate change has been a bane of international summits, with states interacting and setting targets. The energy trilemma is consistent with other policy discourses. The WEC sees the strategy for dealing with the energy trilemma quandary as adopting a system-wide approach to delivering sustainable energy for all based on the trilemma index, often used as an official indicator to measure energy performance.

The Venn diagram in Figure 1 shows a triangle that depicts the intersection of energy security, energy equity, and climate change representing an ideal sustainable energy development. The rest of the portions describe the interdependence and tradeoffs between each of the three dimensions of the energy trilemma.

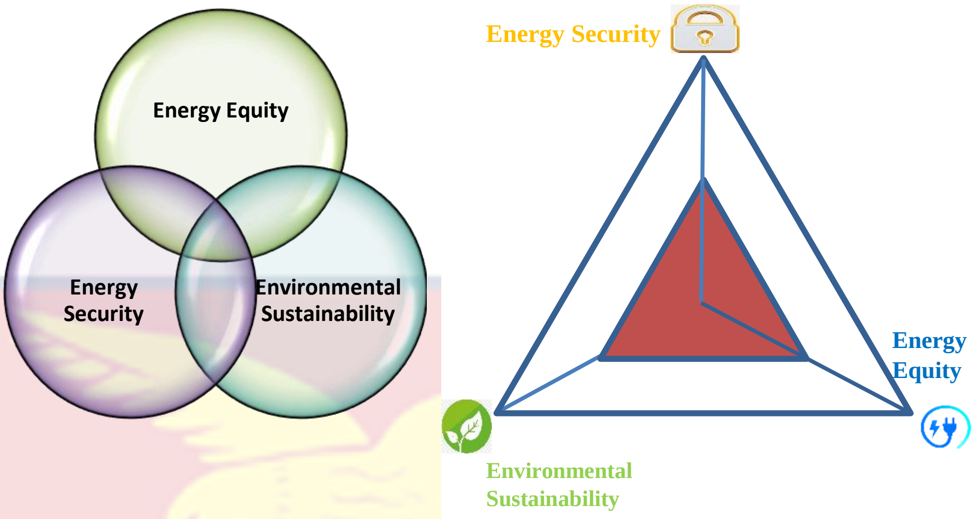

Figure 1: Energy Trilemma
Source: Author, 2022

There are many variations in the trilemma concept, but they have been condensed into economic, political, and environmental strands (Baloch et al., 2020; Heffron et al., 2015). Drawing the right balance among these core dimensions is a daunting task that governments, through international negotiations, need to tackle (Heffron et al., 2015; Rafiaani et al., 2018). A country in the worse form of the dimensions of energy trilemma can be seen to be triple burdened.

In collaboration with a global consultant, Oliver Wyman, the WEC introduced this official indicator to measure countries' energy performance called Energy Trilemma Index (ETI) in 2020. Countries are comparatively ranked based on the ability to provide safe, affordable, and environmentally sustainable energy systems using three competing dimensions of ETI. Energy security recognizes the effective management of energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of participating-energy companies to meet current and future demand. Energy equity reflects the accessibility and affordability of a country's energy supply across the population. Finally, environmental sustainability incorporates the achievement of supply and demand-side energy efficiencies and the development of renewable and other low-carbon energy supplies (World Energy Council [WEC], 2020).

The WEC, every year, starting from 2014, releases the rank of countries' energy performance to guide policymakers in developing solutions for sustainable energy systems. A corresponding balance score is usually assigned to show how well the government manages the tradeoff between energy security, energy equity, and environmental sustainability. The ranking computes countries' overall performance in achieving a sustainable mix of policies and how governments can tradeoff between the trilemma, with “A” denoting the best.

Song et al. (2017) advanced a measure of energy trilemma differently from the approach introduced by the WEC. They realized that the WEC measure could not recognize changes in countries’ preferences among the trilemma, a central issue of controversy but often undermined in policy discourse. The study included countries' preferences that exhibit a substantial degree of variability naturally arising from decision-making and social choice problems. It applied interval decision-making problems and a Stochastic Multicriteria Acceptability Analysis to present a holistic measurement of the country-specific energy performance.

Accordingly, there are multiple ways in which energy security might be addressed. For example, a country might establish strategic oil reserves, diversify sources of supply, switch to renewable energy, or engage in technological innovation (Bauen, 2006). In the case of Africa, energy poverty is alarming as, in most cases, the technologies and capital to exploit energy resources are readily unavailable. Infrastructure to deliver energy products to end-users is also inadequate, if not lacking. In cases where these technologies are present, most people lack the income to use these energy services. Most African countries, including some oil-producing economies, run a trade deficit in refined petroleum products; the majority meet local demands, with imports mainly from Europe and the Americas. Most of Africa’s crude oil is exported in its raw forms with little returns from foreign exchange compared to if they are to trade with refined petroleum.

Iddrisu and Bhattacharyya (2015) propose a composite measure, Sustainable Energy Development Index (SEDI), to address sustainability issues for intra- and inter-generational needs in producing and using energy services. The studies rely on four dimensions such as technical, economic, social, environmental, and institutional, to estimate the SEDI for a particular country. The SEDI represents a relative value that shows the level of performance of a given country base on the four dimensions of sustainability. Iddrisu and Bhattachayya (2015) found Angola and Gabon to be high-performing countries in terms of the rankings of developing countries.

The motivation to mitigate climate change is primarily external, inspired by the developed world's increasing expectation that developing countries can play a significant role in mitigation. The United Nations Framework Convention on Climate Change (UNFCCC) recognizes that countries bear “common but separate responsibility” for mitigation, with the developed world taking the lead. Other international institutions such as the IEA, the Organisation for Economic Cooperation and Development (OECD), and the G 20 are increasingly becoming influential and emphasising the need to avoid dangerous climate change and its attendant consequences. International development banks increasingly take account of climate change considerations in their lending criteria. In assessing funding from international banks, climate change issues are gradually being factored into the lending conditions (Durrani et al., 2020).

In contrast, the pressures driving energy supply insecurity and poverty reduction are almost exclusively domestic. The principal goal of energy security is an energy supply that meets the criteria of availability, accessibility, affordability, and acceptability and, in doing so, provides an essential underpinning to economic growth. In the short term, energy security is concerned with resolving widespread fuel and power shortages, which motivates public and private action. In the long run, it is concerned with improving Africa's economic output through enhanced reliability and significant expansion of electricity supply (Oyedepo, 2012).

On energy poverty, African countries have not only embarked on the extension of electricity grids but also have increased reliability and continuity of supply. Thus, reducing possible interruptions in electricity supply (blackouts) and providing alternative sources of electricity, especially in rural areas (Eberhard, 2003). In addition, though fuel subsidies have been regarded as an inappropriate remedy to protect the pro-poor and protect local industries by a large group of scholars, oil- and gas-producing countries such as Nigeria, Libya, and Gabon have adopted subsidies (Iddrisu & Bhattacharyya, 2015; Leigh & El Said, 2006; Siddig et al., 2014; Whitworth, 2017) to ensure cheap energy access as a poverty reduction strategy.

However, wrong targeting has made these subsidies not achieve their intended purposes due to corruption and the growing subsidy expenditure burden on the government. For example, in 2014, Libya’s fuel subsidy bill constituted 18% of the country’s GDP, higher than the international average for central government final expenditure of 17.8% in 2015 (Whitworth, 2017).

Energy poverty and energy supply insecurity are not much of a problem in developed economies compared to developing countries, especially in Africa. However, petroleum–prosperous African economies are better positioned to manage these essential policy areas through conscious investments from oil wealth to tackle the external pressure and reduce Greenhouse Gas (GHS) emissions that could improve performance in sustainable energy development. The question is how this climate change agenda fairs in petroleum-producing economies against their goals of improving energy poverty reduction and ensuring energy supply security.

Following the WEC (2022), Figure 2 presents an overview of the indicators required to measure the various indices for the dimension of the energy trilemma index. The energy security dimension of the energy trilemma focuses on two main domains: security of supply and security of demand. Energy equity targets indicators broadly categorised into three main domains: access to energy, affordability, and quality. The environmental sustainability dimension of energy services is captured with several indicators under the three broad categories: energy resource productivity, emissions and pollution, and decarbonisation.

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Environmental Sustainability

It is difficult, if not impossible, to maximize both environmental conservation and economic growth at the same time. The main concern of environmental sustainability is the fear of global warming resulting from the continuous release of GHGs. The main gases responsible for the greenhouse

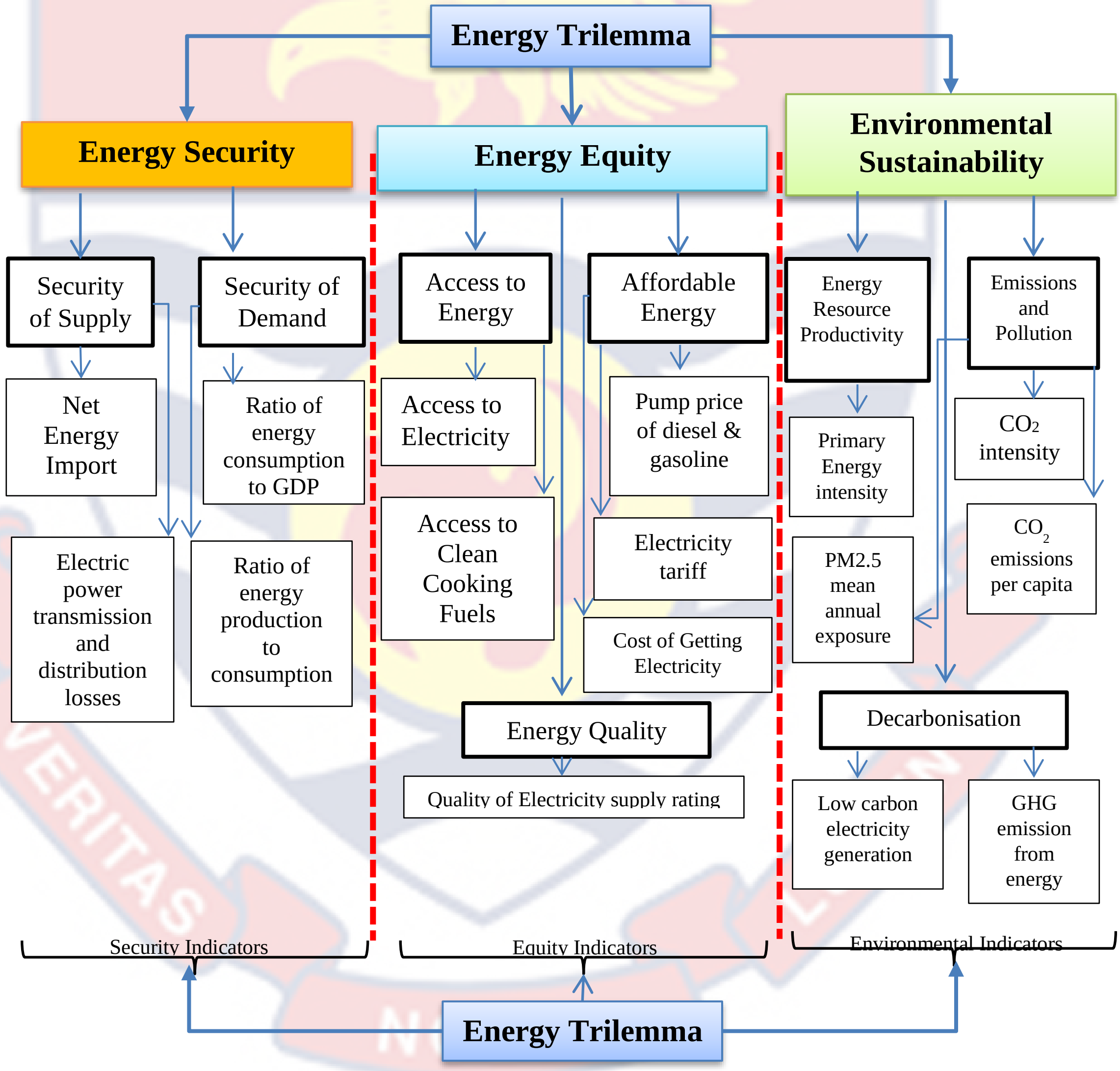

Figure 2: Indicators of Energy Trilemma Index
Source: Author's Sketch (Adapted from WEC, 2022)

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effect include carbon dioxide, methane, nitrous oxide, water vapour (which all occur naturally), and fluorinated gases (synthetic). CO2 is a gas that occurs in nature that is converted into organic matter during photosynthesis (World Bank [WB], 2022).

Atmospheric carbon dioxide (CO_2) is a nontoxic, colourless, odourless gas that constitutes a tiny portion of the Earth's atmosphere, making up only approximately 0.040% of the atmosphere (Easterbrook, 2016). Carbon dioxide makes up for every 100,000 air molecules, 78,000 nitrogen, 21,000 oxygen, 2000 - 4000 water vapour, and only 30 carbon dioxide molecules (Easterbrook, 2016). CO2 is a result of burning fossil fuels and biomass, as well as other activities from industries such as changing land usage (IEA, 2020). As the standard by which other GHGs are evaluated, carbon dioxide has potency of causing a Global Warming of unity and thus, it is the main anthropogenic GHGs that influences the Earth's radiative balance (WB, 2022).

Since the industrial revolution, using carbon-based fuels has dramatically increased carbon dioxide concentrations in the atmosphere, speeding up global warming and generating anthropogenic climate change (IEA, 2020). Because CO_2 dissolves in water to generate carbonic acid, it is a key contributor to ocean acidification (Barker & Ridgwell, 2012). The addition of artificial greenhouse gases to the Atmosphere disturbs the earth's radiative balance (Knutti & Hegerl, 2008). CO_2 leads to an increase in the earth's surface temperature and to related effects on climate, sea-level rise, and world agriculture is adversely hampered (Ebele & Emodi, 2016). Emissions of CO_2 are from the burning of oil, coal, and gas for energy use, burning wood and waste materials, and industrial processes (e.g., cement production) (Buchanan

& Honey, 1994; Worrell, Price, Martin, Hendriks & Meida, 2001; Ali, Saidur & Hossain, 2011).

The way carbon dioxide affects the environment is quite intriguing. The majority of GHGs that contribute to climate change and subsequently global warming is CO2 emissions. Methane (CH4), nitrous oxide (N2O), perfluorocarbons (PFCs), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), and sulphur hexafluoride (PFCs) are some of the other GHGs. The Kyoto Protocol is an environmental pact that was agreed in 1997 by numerous parties to the Paris pact, the UNFCCC, and other international agreements aimed at reducing CO2 emissions globally.

The biggest challenge to oil-producing African nations is to give up fossil fuel amidst the pronounced energy poverty and supply insecurity. However, Amal-Lee Amin, the Director of Climate Change at CDC Group, Britain's Development Finance Institution, observes that least-developed countries are the most vulnerable and have the least ability to adapt to climate impacts, underscoring the relevance of a holistic approach to dealing with the energy trilemma (Buchner, Falconer, Hervé-Mignucci & Trabacchi, 2012).

The Concept of Energy Poverty

The concept of energy poverty is widely acknowledged all over the world. Energy access forestalls development programmes, including the quest to achieve Sustainable Development Goals (Njiru & Letema, 2018). Access to energy is crucial for human activity and socioeconomic development. Energy access is critical to halting the growing economic poverty rate, epitomized by high child mortality, poor maternal health care, poor educational and social infrastructure, limited opportunities to realize the fullest potentials of the brightest minds, recurrent social instability, and underdevelopment in developing countries (El Badri, 2008).

Energy poverty is articulated in three main aspects – availability, accessibility, and affordability (Xia, Murshed, Khan, Chen & Ferraz, 2022). The IEA defines energy poverty as providing energy services so that the population with access to electricity and modern or clean cooking facilities such as fuels and stoves do not cause air pollution (Doğanalp, Ozsolak & Aslan, 2021). Another feature of energy poverty is reflected in situations where the well-being of large numbers of people is adversely influenced by little energy consumption, use of unclean and polluted fuels, and spending a lot of time to in fuel collection for basic needs. ("Energy Poverty," 2022).

All the definitions of the concept of energy poverty centre on accessible, available, acceptable, and affordable energy for everyone. Thus, the energy poverty concept is complex and multidimensional. As a result, the multifaceted approach to energy poverty measurement is employed to incorporate critical dimensions such as accessibility, availability, acceptability, and affordability. Energy poverty is mainly employed to describe the tragic situations in which a good proportion of the population lacks access to modern energy services. Being "energy poor" is when the required infrastructure is not in place for energy supply and/or when the population does not possess the means to acquire energy services, even if they have access to them – thus high cost or low income. A basic understanding of energy poverty in daily life can be situations of rampant power outages (popularly known as "dumsor dumsor" in Ghana) where access to electricity is sporadic.

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Energy Security

Energy security has a variety of meanings because different countries have different energy systems and hence different security concerns. Energy security has geopolitical, military, technical, and economic dimensions (Bielecki, 2002). In order to elevate the priority of other policy issues like energy poverty and climate change on the political agenda, the term “energy poverty” is occasionally attached to them (Cherp & Jewell, 2014). Energy security can be thought of as the opposite of energy poverty – a condition where energy services can be accessed affordably, equitably, and safely (Sovacool, 2011). Energy security is one component of energy justice. It is a broader term that encompasses the equity impacts of the entire energy system including climate change and the impacts of energy extraction and development (Jenkins, McCauley, Heffron & Stephan, 2014).

Energy security is a broad term with numerous definitions, but it is most frequently employed to refer to the stability of a nation's energy supply. (Von Hippel, Suzuki, Williams, Savage & Hayes, 2011; Von Hippel, Savage & Hayes, 2011). It is typically understood to mean having access to energy at all times, in a variety of forms, in sufficient quantities, consistently delivered at affordable costs, and without having an intolerable or irreversible influence on the economy or the environment. (De Paoli & Sacco, 2010).

Some scholars have included environmental sustainability of energy sources to satisfy the acceptability dimension of energy services (Vivoda, 2012). Energy services must be physically present and sustainable in order to be considered available. When energy services are delivered consistently and adequately, the needs of the global economy are met without any hiccups.

Affordable energy services have a less clear definition since they evolve over time and are viewed in a different way by energy producers and users.

Kalicki and Goldwyn (2005) express energy security as assurance of the capacity to access the energy resources required for the continued development of national energy infrastructure for the delivery of energy services. In more specific terms, it is the provision of affordable, reliable, diverse, and ample supplies of oil and gas and their future equivalents and adequate infrastructure to deliver those supplies to markets. Similarly, Costantini et al. (2007; 2008) conceptualized energy security to mean the availability of a regular supply of energy at an affordable price. For Barton et al. (2004), energy security is “a condition in which a nation or all, or most, of its citizens and businesses, have access to sufficient energy services at reasonable prices now and for the foreseeable future free from the serious risk of major disruption of service”. Slightly different from these definitions, IEA Ministers, in 1993, agreed on the elements of energy security as the diversity, efficiency, and flexibility of energy services within the energy sector (IEA, 1993).

Based on these definitions from the literature, it can be assumed that there is a general tendency to describe energy security with respect to supply security. Therefore, many authors discuss energy security as a supply security issue. The challenge of resource-rich and resource-poor countries is seen as vulnerability, reliability of supply, and price volatility. Thus, economies are concerned with policy interventions that will maximize the gains in energy resource management. The availability of energy at reasonable prices is what importer nations define as energy security, and they are worried about the impact of uncertain pricing on their balance of payments (Deese, 1979).

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On the other hand, energy-exporting economies prefer an increasing global energy demand since a large portion of their wealth comes from energy exports (Yergin, 2006). Affordability also conveys a different message to the public, private, civil society, consumers, producers, and developing countries. Yergin (2005) explains that “diversification of supply is the starting point for energy security as widening the sources of supply lessens the impact of any particular disruption and provides opportunities for compensating supplies”. Thus, energy security in the literature emphasises supply security, which is the regular, sustainable, and diverse supply of energy resources for the foreseeable future at an affordable price.

Energy supply security (ESS) is a term that refers to more than just the real presence of energy services; it also refers to their accessibility and secure transmission without interference from security threats, natural disasters, etc. (Jenny et al., 2007). Instead of the exhaustion of potential sources, the term "ESS" refers to the capacity to access a prospective energy source. This issue is particularly relevant for non-renewable fossil fuels and unevenly distributed energy sources, which are a crucial concern for ESS and are greatly influenced by the state of affairs of the supplying nation or location in the geopolitical landscape.

Winzer (2012) reviewed 36 definitions of energy security and found that all energy security definitions include the idea of avoiding risks, which affect the continuity of the energy commodity supply relative to demand. The study realized three main areas of focus by authors: approach on commodity reliability; introduction of additional subjective filters to establish a dichotomy between secure and insecure degrees of continuity; and extension of the impact of commodity supply to the continuity of services, continuity of the economy, and sometimes the continuity of sustainability.

The provision of energy services is absolutely necessary and depends on a safe supply chain. The chain can be complex and involves many steps, such as extraction, transportation, conversion, distribution, and final use. The chain can also stretch long distances across national borders (Månsson et al., 2014). Robust energy systems, primarily designed to supply energy services to end-users, require energy resources, infrastructure, and use linked together by energy flows that support critical social functions usually interconnected by sectoral or geographic boundaries (Cherp & Jewell, 2011; 2013). Differentiating between energy systems allows better measurement (metrics) as well as better targeting of energy security policies (Jewell, 2014). Energy security is also viewed as resilience of crucial energy infrastructure or systems (Cherp & Jewell, 2011; 2013). Combining exposure to potential risks with resiliency in capacities in energy access creates vulnerabilities.

According to Stockholm Environment Institute, energy efficiency initiatives hold great potential to support a green economic recovery, improve energy security and reduce energy poverty. At the macro level, low energy intensity implies energy efficiency gains. Kadri Simson, commissioner for energy at the European Commission has been quoted to have said: “The war against Ukraine is not only a watershed moment for the security architecture in Europe but our energy system as well. It has made our vulnerability painfully clear.” Hence, emphasising the urgency to invest in improved energy efficiency can improve energy security (Stockholm Environment Institute [SEI], 2022).

From the perspective mentioned above, five essential components make up a comprehensive energy security concept: supply and demand-side management and control, concern for the environment and technological advancement. The others include sociocultural aspects that influence acceptance and the emergence of economies following the COVID-19 pandemic's economic shocks brought on by higher energy commerce and pricing. There is no generally accepted meaning of energy security as a result of varied views among stakeholders and authors regarding the choice of possible threats to the security of supply. These are major modifications to the established supply-side perspectives. The current study will concentrate on energy supply security as emphasised by the aftermath of the Ukraine – Russia war. Hence, the term insecurity of energy supply is the situation where a country is less energy import-dependent, less energy efficient, and has a low domestic energy production rate.

Evolvement of Energy Security

The concept has evolved through varied understanding as an important global concept in the later 19th and early 20th centuries. Conversations on energy security gained attention due to high oil prices during the 1970s and geopolitical supply turmoil (Cherp & Jewell, 2014). Stabilising prices of oil during the 1980 and 1990s reduced the attention of scholars on energy security. In the 2000s, as a result of increasing energy consumption in Asia, the concept resurfaced following pressure to decarbonise energy systems, and gas supply disruptions in Europe.

An important turning point in the history of energy security occurred in the 1970s. The concern of energy losses that culminated from industrial production of power and wastage resulted in a narrow conception of energy security to mean “security of supply” (Cohn, 2020). After the 1970s, the political dynamics of energy business emerged. The combination of the numerous industries and supply networks of the various energy sources attracted a lot of interest (Patterson, 2008). "Energy security" is the emergence of interest that went transcend supply.

Churchill's response was structured under the guiding principle of diversification in response to mounting concerns about the accessibility and dependability of oil supplies from sources other than Persia (now Iran), price instability, and market distortions by a small number of businesses: “On no one quality, on no one process, on no one country, on no one route and no one field must we be dependent. Safety and certainty in oil lie in variety and variety alone” (Yergin, 1991). It is crucial to remember that, Churchill's political and military contributions demonstrates how the subject of energy security—then primarily concerned with the security of supply—was viewed as crucial to the security of a country. The dependence of industrialised nations and the significance that energy had come to have in socioeconomic wellbeing were both highlighted by this strategy, which persisted until the oil crisis of 1973 (Cherp & Jewell, 2014). The formation of the IEA took place in 1974 as a reaction. Its focus was on assisting the advancement of oil and gas fields not under the control of OPEC, while also advocating for the development of fresh technologies and alternative energy resources.

The notion of ensuring a stable energy supply was broadened to encompass the impact of price changes on the overall economy and to adapt to the utilization of different energy alternatives. As a result, the idea of safeguarding the energy supply evolved into the concept of "energy security," which was defined as the potential reduction in economic well-being due to alterations in energy price or availability (Bohi and Toman, 1996). This description addressed the susceptibility stemming from relying on energy imports and the process of privatizing and opening up domestic energy markets. The stability of energy security hinged on efficiently operating markets equipped with mechanisms for self-correction.

In recent times, an example of energy insecurity has arisen in the Central and Eastern Europe as political friction has grown between Ukraine and Russia. Russia exports a lot of natural gas to several European countries via pipelines, some of which pass through Ukraine. The war in Ukraine forces Germany to radically rethink its energy policy, given that it heavily depends on Russian fossil fuels (Hangso, 2022). Clearly, the war in Ukraine and growing concerns about energy security have led European countries and others to reconsider their timelines to transition from fossil fuels as a matter of urgency. That could profoundly impact the world’s race to reach zero greenhouse gas emissions and limit global warming to a tolerable 1.5ºC by the end of 2100.

Despite the difference in the conceptualisation of energy security in foregone literature, there appear to manifest common features with increasing scope over the years. Energy supply security from the classical approaches leads to the development of energy security that incorporates several blocks influencing it. Energy security from the angle of security in production is concerned with the rate of domestic energy production in relation to energy use. By intuition, as a country’s domestic energy production increases, given its consumption level, they tend to be more energy secure.

Similarly, where the country cannot meet domestic consumption and relies on the importation of energy, then the country becomes energy insecure (i.e., security of trade). Therefore, energy security of trade is concerned with the energy import dependency of a sovereign state. Increasing energy import dependency is undesirable since it decreases the security of energy of the economy. Lastly, consumption security recognizes the need to ensure efficiency in energy use. As shown in Figure 3, energy supply security can be viewed from the perspective of three blocks: security in consumption, security in production, and security in trade.

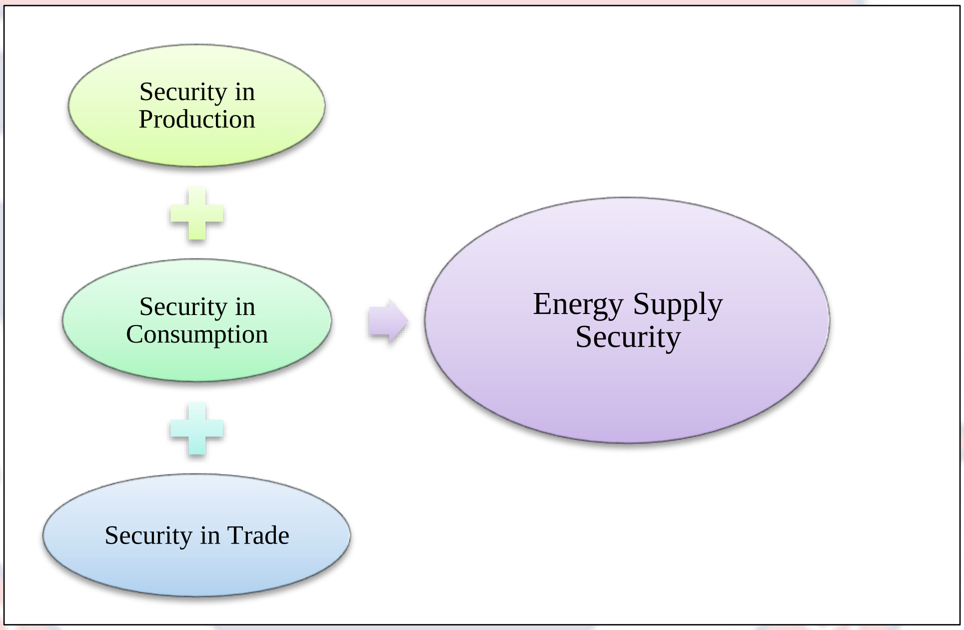

Figure 3: Structure of Energy Supply Security
Source: Author, 2022

A greater quantity of energy expended to achieve a specific level of output or task (referred to as energy intensity) tends to diminish a nation's energy security, particularly considering the limited availability of non-renewable energy sources, which constitute a significant portion of Africa's energy composition.

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Relevant Theories

As a significant source of revenue derived from oil and gas extraction, petroleum rent can influence the dynamics of the energy trilemma in several ways. This section discusses five main theories relevant to assessing the study objectives. They include the energy ladder hypothesis, energy ladder hypothesis, energy stacking theory, oil curse theory, and rentier state theory.

Environmental Kuznets Curve Theory (EKC)

Relevant theory to the environmental sustainability dimension of the trilemma index vis-a-vis the purpose of the study is the EKC hypothesis which elucidates the connection between economic advancement and the deterioration of the environment. Establishing this relationship is relevant to this study because petroleum rent in the form of revenues directly or indirectly, through national income (GDP), influences environmental degradation. The nexus gained considerable public attention as a result of the emergence of the famous EKC theory (Grossman & Krueger, 1991; 1995). The EKC is called in honour of Simon Kuznets, who postulated that as economic development advances, income disparity first rises and subsequently declines.

According to the EKC theory, environmental deterioration and per-capita income have an inverse U-shaped association. It can be interpreted to mean that economic progress will eventually mitigate the adverse effects at early stages on the environment. Pollution emissions rise, and quality of the environment decrease during the initial phase of economic development. At a point, the trend shifts beyond a certain level of per capita income where higher income (increased economic growth) results in improved quality of the environment (Stern, 2018). This causes the environmental impact usually proxy by CO_2 to assume a curve that reversed U-shaped of the per capita income, as shown in Figure 4.

When other factors are held constant, studies on the link between per capita emissions and income that try to avoid numerous statistical problems discover that per capita emissions of pollutants increase with increasing per capita income during the pre-industrial stage of an economy. However, modifications to these other elements held constant might be enough to cut back on pollution. The impact of growth outweighs these other factors in middle-income nations that experience rapid growth through industrialization. In advanced economies, post-industrialization sets in, and development is slower, and the growth effect can be offset by measures to reduce pollution (Stern, 2018).

Until now, increased economic activity was expected to result in greater wealth since wealthier people or nations would acquire more energy-intensive goods such as automobiles, home types of machinery, and air conditioning. Carbon dioxide emissions from anthropogenic activities are typically recognized as a significant precursor to anticipated global warming (Baloch et al., 2020). Additionally, the pursuance of economic transformation across the world has created a daunting challenge to operations in sectors such as power generation, industries, housing, and transportation services.

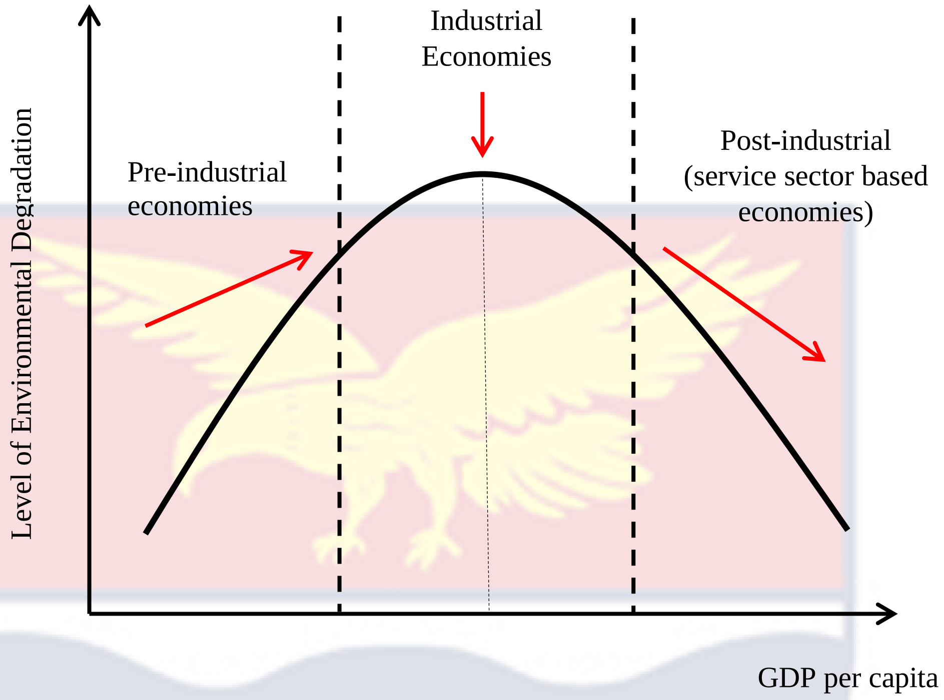

Figure 4: Environmental Kuznets Curve
Source: Adapted from Stern (2018)

These events have directly contributed to GHG emissions over the years (Ulucak, Danish & Ozcan, 2020). As opposed to rising economic growth, which denotes industrialization and increased energy demand, this stage is referred to as the pre-industrialization stage. Additionally, a rise in income promotes investment in cleaner technology and raises awareness of the need for a clean environment and improved livelihood.

Economic evolution causes structural changes, such as the shift from agriculture to industry and from heavy industry to services. Adopting energy-efficient technology and reducing reliance on fossil fuels during a country's shift from industry-led economy to the service-led economy directly influence quality of environment, as noted by Munasinghe in 1999. This change in economic structure reduces the adverse consequences on the environment from economic advancement. The turning point for reducing pollution is represented by this phase. However, environmental pollution declines as the economy expands and shifts from the pre-industrilisation to post-industrialization era (Destek & Sarkodie, 2019). Lastly, technical advancements from economic growth and adoption of more acceptable technology that are friendly to environment, result in lowering degradation of the environment (Dogan & Seker, 2016; Destek & Sarkodie, 2019; Baloch et al., 2020).

The theory of EKC has since been replicated in different countries to determine whether countries experience similar stylized facts or the contrary. Depending on the approach, the methodology adopted, and the setting of the studies, scholars have found different conclusions in examining the correlation between income and degradation of the environmental. Examples of such scholarly assessments are discussed in the ensuing paragraphs.

Álvarez-Herránz, Balsalobre, Cantos & Shahbaz (2017) there are three ways in which economic growth affects environmental quality: scale, composition, and technical consequences. Firstly, the relationship in terms of scale states that if the changes in economic structure and technology are held constant, a rise in production degrades environmental quality. Thus, where composition and technical effect are held constant, increased scale of production will place stress on the environment. This is because meeting the continuously growing demand will need more environmentally degrading resources and inputs. Secondly, assuming a constant scale and technology, the range of goods an economy produces sometimes is induced by international trade to assess the degree of deterioration of the environment. As the economy evolves and transitions from agricultural sector to heavy industry-led economy and eventually from the industry dominant economy to services sector, the country uses more energy efficient technologies that improves environmental sustainability of energy systems (Baloch et al., 2020).

Economic theory postulates that economic growth brought on by trade liberalization increases output, and wealthier nations typically have a greater willingness and capacity to direct resources toward environmental protection through the adoption of stricter environmental regulations and investments in more environmentally friendly technologies (Vilas-Ghiso & Liverman, 2007). The joint impact of incomes and a producer's reaction to institutions and market conditions define the Technique effect. Thus, based on the axiom of constant scale and composition effects, the technique impact quantifies the change in environmental damage resulting from a shift to more environmentally friendly production techniques (Copeland & Taylor, 2004; Vilas-Ghiso & Liverman, 2007).

Energy Ladder Hypothesis

Several empirical papers have explained energy production and utilisation at the household level, with limited studies conducted at the country or group level. Petroleum rent contributes to GDP, thereby increasing the county's income (Okonkwo & Madueke, 2016). Theoretically, the energy ladder hypothesises the association between income and type of energy consumed. The theory emerged during the fuel-wood crises in the 1970s – 1980s (Toole, 2015). Improved access to modern sources of energy guarantees households of enhanced welfare conditions (Guta, 2014). Additionally, the utilisation of conventional energy sources like firewood, animal dung, grasses, etc., presents a high risk of increased pollution and environmental degradation, which can result in poor health conditions in homes, low productivity, and welfare (Ajibola, Raimi, Steve-Awogbami, Adeniji & Adekunle, 2020).

Energy economist tries to take an analogy that households (countries) maximize the utility derived from energy services given their economic conditions (Kroon, Brouwer & Van Beukering, 2013). The energy ladder hypothesis depicts the sequential connection between increasing income levels and the choice of fuel for household cooking and heating purposes (Toole, 2015). The hypothesis follows the economic consumer theory, which states that consumer choice for superior goods compared to inferior goods increases with income.

As households' (countries') welfare increases through rising income, they tend to transition to modern energy services such as electricity, liquefied petroleum gas (LP gas), kerosene, etc. Thus, from rudimentary and traditional energy sources such as biomass – firewood, charcoal, animal dung, etc. to modern energy services. Figure 5 shows that the energy ladder consists of three phases; phase I reflects how households (countries) reach some socioeconomic status and transition from cheap and inefficient fuels such as biomass.

Phase II represents the moving away from biomass fuel into transition fuels like gas, kerosene, and coal. Finally, in phase II, the household moves to efficient secondary energy such as LP gas and electricity (Kroon, Brouwer, & Van Beukering, 2013; Paunio, 2018). The switch from using inferior fuel at the lower rung of the energy ladder to an efficient and superior fuel at the upper rung of the ladder is referred to as the household (country) energy transition (Paunio, 2018).

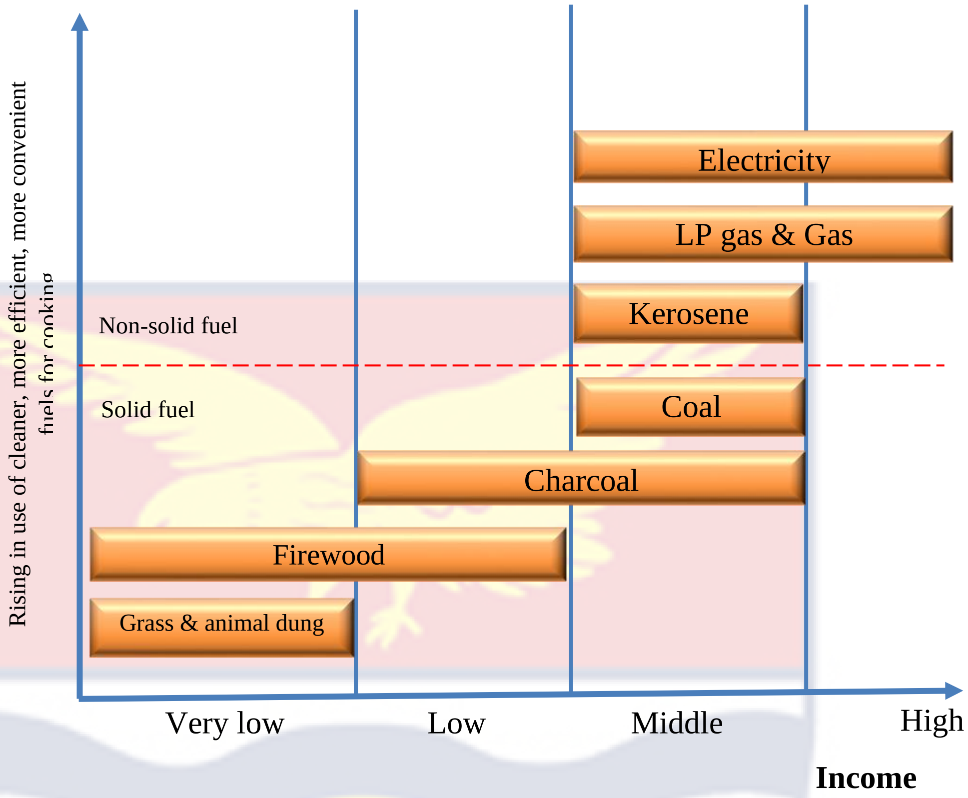

Figure 5: Energy Ladder Hypothesis
Source: Adapted from Paunio (2018)

This hypothesis has been criticized on the grounds that individuals (countries) keep using inferior fuels simultaneously for specific types of cooking. This situation has been referred to as energy-for-specific-tasks. In that regard Kohler, Rhodes and Vermaak (2009) express the plausibility of fuel stacking in the energy ladder hypothesis when unreliable supplies of some sources of energy cause households to depend on cost-effective energy sources rather than the unavailable superior energy sources.

Resource Curse Theory

According to the resource curse idea, nations with abundant natural resources, particularly petroleum, may suffer from poor economic and social outcomes as a result of resource mismanagement and dependency. The paradoxical circumstance in which a nation performs poorly economically despite having access to valuable natural resources is known as the "resource curse" (Ross, 2015; Venables, 2016).

Richard Auty is frequently cited as part of the pioneers of the resource curse hypothesis. Auty (1993) stressed resource-rich nations' difficulties in managing their wealth and preventing adverse economic effects (Auty, & Warhurst, 1993). Similarly, Ross (2012) presented a thorough analysis of the resource curse, concentrating primarily on the oil industry. He looked at the numerous ways that oil wealth influences the political and economic results in oil-producing nations.

The resource curse can manifest in the concentration of wealth and income among a small elite in the context of energy poverty and insecurity, while the rest of the populace will remain improvised. The benefits of resource exploitation mostly benefit the ruling elite or powerful organizations, while the general population, especially in rural areas, may not experience considerable advances in income or access to energy services. Petroleum rents can result in income discrepancies.

Regarding energy equity, the resource curse theory can be seen where petroleum rents worsen wealth disparity and obstruct a fair allocation of energy resources and benefits. Energy poverty may be sustained if the money associated with oil is concentrated within a small number of elites and energy infrastructure in underdeveloped areas is neglected. High oil prices could result in currency appreciation (Dutch Disease), hurting other industries' ability to compete and lowering average people's purchasing power, thereby hampering energy equity. Subsidies and price caps on energy products powered by petroleum rents may cause market distortions and inefficiencies that eventually influence energy affordability.

According to the resource curse theory, a country's significant reliance on oil exports may cause it to become economically dependent and more susceptible to changes in the world market. A nation may fail to diversify its energy sources and build a robust energy infrastructure if it largely relies on oil money. The nation's economy and energy security may suffer greatly during price volatility or geopolitical unrest.

Likewise, the resource curse theory can be linked to how petroleum rent in a rentier state can influence the environmental sustainability of the energy system. The government may find it less compelling to support clean energy practices and invest in renewable energy as a result of the presence of petroleum rents. The dominant position of the petroleum industry may be accompanied by insufficient environmental legislation and compliance, which could result in increased pollution and environmental harm. Oil production can disrupt ecosystems and negatively influence biodiversity if there are no adequate environmental safeguards in place.

Rentier State Theory

The impact of resource riches, notably petroleum rents, on numerous aspects of economic progression is examined base on the rentier state theory. The research of Beblawi and Luciani (2015) on the development of oil-rich nations, known as petrostates, in the Persian Gulf led to the widespread use of rentier states theories. They demonstrate that income is received by rentier states without an increase in domestic economic productivity. The unequal distribution of external income in rentier states has thus an inverse impact on political liberalism and economic advancement.

The concept of "rents" is the foundation for how rentier states is used. Rent, according to Ricardo (1817), is a benefit of resource ownership. In the context of natural resources, rents can be thought of as "the income derived from the gift of nature" (Marshal, 1920). The term "rentier states theory" refers to a political economy idea that examines the political and economic ramifications of states that significantly rely on money from natural resources, particularly petroleum or oil. These states are frequently referred to as "rentier states" since the rents or royalties they get from the export of natural resources serve as their primary source of income. The rentier states theory can be linked to the energy trilemma on three main dimensions.

On the tenets of energy security, petroleum rents can improve energy security by targeting petroleum revenue on energy infrastructure investments, source diversification, and developing strategic reserves. Energy security, however, can be compromised by an overreliance on petroleum rents that leaves industries vulnerable to changes in commodity prices, market disruptions, and geopolitical concerns.

The energy equity dimension can be linked from the angle that income generated may be used to build energy infrastructure to increase energy availability. Thus, petroleum rents can help improve energy access and make energy affordable. However, there is a chance that rentier nations may prioritize meeting domestic energy demand over investments aimed at granting underprivileged and vulnerable groups access to electricity and other energy services. Income inequality can arise inside rentier states when there is a significant petroleum rent. The government frequently uses oil earnings to finance massive projects or social welfare programs, which may only benefit certain demographic groups while ignoring others. Energy poverty in some areas may worsen due to income inequality and unequal access to resources and energy-related services.

In terms of energy systems' sustainability in the environment, it is observed that petroleum-rich economies are associated with higher CO_2 releases from burning of fossil fuels. Rentier states that rely heavily on oil exports may be less motivated to transition to cleaner energy sources, as their economic prosperity is directly tied to oil revenue. The situation can hinder efforts to address environmental degradation and promote renewable energy development.

It is essential to highlight that policies and administration of various rentier states can have an impact on how much petroleum rent influences the energy trilemma. While some nations may struggle to establish a balance between economic interests and sustainable energy regulations, others may leverage their oil resources to make advancement in energy efficiency technologies and practices and investment in alternative energy. The Rentier States theory emphasises the intricate interactions between using natural resources, economic growth, and energy policy. It also emphasises the necessity for sustainable and diverse energy solutions to deal with the problems brought on by the energy trilemma.

Conceptual Framework

In this section, we present how the above-discussed concepts and theories are being conceptualized and operationalized to address the objectives of the study. It begins with the association linking petroleum rent, income, and energy trilemma index and its components. Next, the energy poverty relationship with petroleum rent and income is presented. Lastly, the study shows, by sketches, the petroleum rent-growth-energy nexus.

Petroleum Rent, Income, and Energy Trilemma Index and Dimensions

As the foregone literature explained the concept of energy trilemma, this study considers the linkage and mechanism through which petroleum rent could affect the indicators and dimension of the energy trilemma index, as shown in Figure 6. Generally, the performance of countries in balancing the trilemma of enhancing energy supply security and equity and ensuring energy systems' sustainability could either be enhanced or hampered by petroleum exploration and production activities for economic rent. Increased energy systems' sustainability implies that oil-producing countries are able to decarbonise with low emissions and pollution in energy exploitation and use while enhancing capacities, technologies, and innovations for low energy intensity (i.e., energy efficiency).

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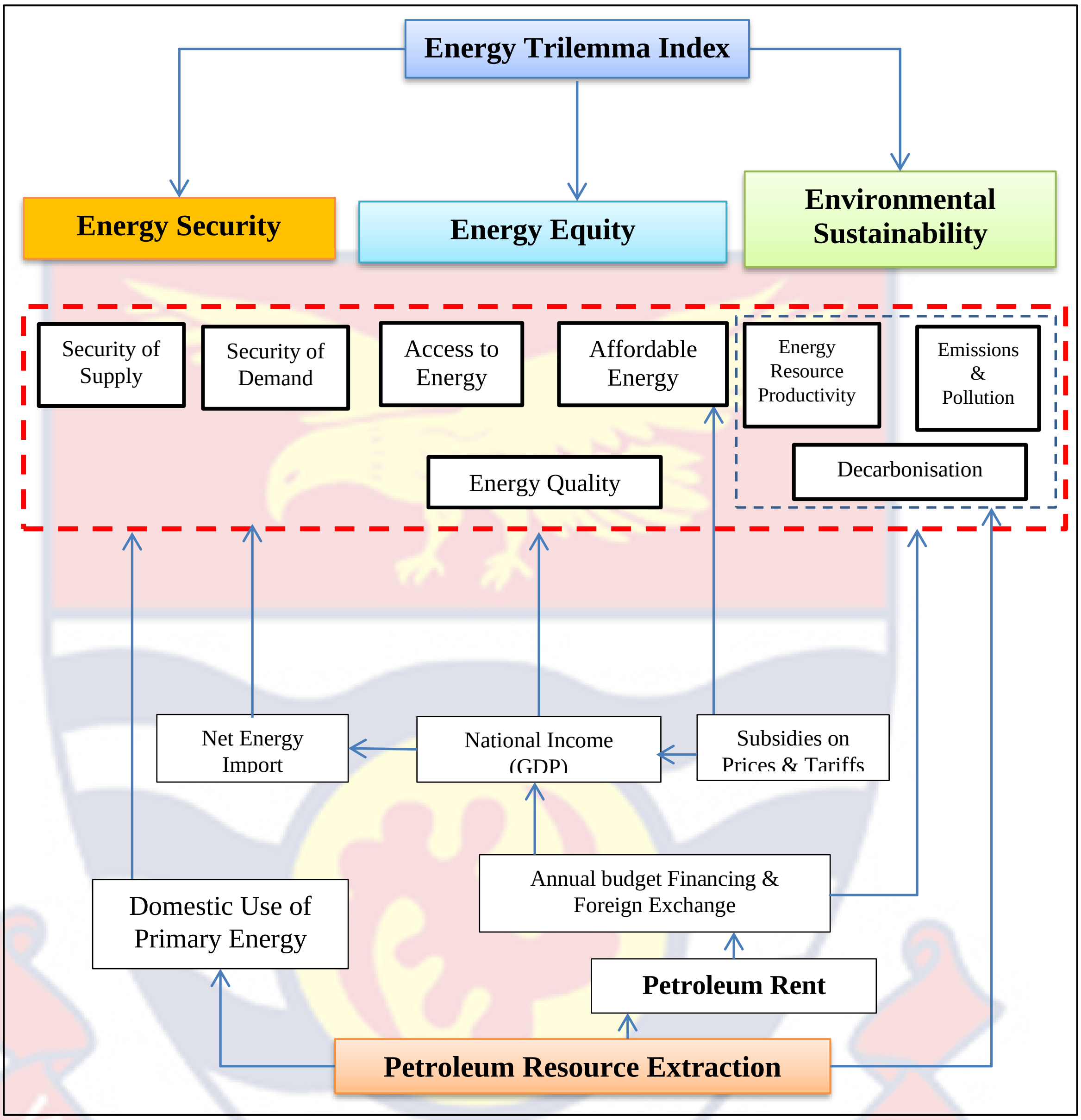

Figure 6: Conceptual Framework on Petroleum Economic Rent, Energy Trilemma Index and its Dimensions
Source: Author (2022)

Some countries could find translating petroleum earnings into improving energy equity and ensuring energy security difficult. This could be due to the heterogeneous nature of policy focus of sovereign states and hence a possibility of the petroleum rent not impacting the components of the triple challenge in energy production and use. Likewise, energy intensity, emissions and pollution, and decarbonisation could not be an area of policy focus of oil-producing countries. As a result, petroleum rent might enhance the environmental sustainability dimension of the trilemma index.

As explained earlier in the link between petroleum rent and energy security, it is obvious that petroleum exploitation will improve domestic energy supply and could make the host nation less dependent on imported energy, thereby ensuring ESS. In terms of energy equity, improving energy access, providing quality energy services, and making energy affordable could be guaranteed by petroleum rent if well managed. Petroleum rent in a given country can be inimical to environmental sustainability, if necessary, measures and policies on decarbonisation and low energy intensity and among others are not implemented. Petroleum rent can increase the capacity of some countries through increased incomes to better manage the environmental sustainability of energy systems. Conversely, the exploration activities for petroleum rent might result in increased emissions and pollution, endangering the environment.

It is obvious that petroleum rent can, directly and indirectly, impact energy supply security. However, the rent-growth-security hypotheses need to be tested to understand better the relationships to inform policy. Conclusions can be drawn that an oil-producing country will begin to perfume well in the international petroleum market, with oil revenue trickling in to support investments.

Petroleum Rent, Income, and Energy Poverty

Literature on energy poverty has shown that scholars have approached the concept in different dimensions and scopes depending on their focus of study. Most of these studies have built composite indices using the essential components of energy poverty including accessibility, acceptability, availability, and affordability.

Scholars have conceptualized energy poverty based on the setting and purpose of their studies. The most widely used approach in recent times is the multidimensional energy poverty index using survey datasets. Few studies have been conducted on times series and longitudinal data analysis to assess the energy poverty of countries and the effect of income and petroleum rent over time. This current study seeks to build a composite index of energy poverty over a period for oil-producing African countries based on the essential dimensions.

Resource endowment without innovations and technology to exploit and utilize in a well-managed manner has widely been affectionately termed a resource curse (Auty, 1994; Okpanachi et al., 2012; Bjorvan et al., 2012; Lucky & Nwosiand, 2016; Partey, 2016; Parcero et al., 2016: Adams & Klobodu, 2017; Umar, Ji, Mirza & Rahat, 2021). The link between petroleum rent and energy poverty is obvious. However, a clear relationship has not been shown with empirical evidence on the connection that exist between petroleum rent and energy poverty, especially among oil-producers in Africa.

It is undeniable that petroleum rent presents additional funding for rentier states to improve their energy poverty situations as a fundamental basis in economic advancement, especially on situation of energy-led growth hypothesis. Countries endowed with petroleum resources rely on its rent for annual budget financing, the lack of which would have compelled those economies to resort to expensive borrowings to provide critical socio-economic needs of the citizenry. Where states recognize the essential role of energy in industrialization, they make considerable investments in energy infrastructure towards improving access and reliability of energy services, keeping prices and tariffs at affordable rates while keeping watch on environmental sustainability.

The linkage of this conceptualisation and the interconnection establishing possible ways countries could translate petroleum rent into improving energy poverty is presented in Figure 7. Large deposits of petroleum resources are not an end by themselves, but exploring these resources, which involve substantial capital investments, and making optimal use of them, is what matters a lot. Successful explorations and production present revenues to the state through foreign exchange and other accompanying revenue benefits depending on the country's negotiation power in contract agreements and fiscal regimes.

These revenues received do not only support foreign exchange by making the local currencies strong but present additional financial support for governmental investments. Financing annual budgets and improved foreign exchange earnings greatly impact the Gross Domestic Product. This positive shock also goes a long way to enhance the delivery of energy services through government strategic investment in the energy sector.

Government investments using petroleum revenue into power generation, electricity expansion, construction of gas plants and pipelines, and creating domestic gas markets, as well as subsidizing energy services, support improving energy access, reliability, and affordability. Subsequently, energy poverty reduction of the country improves once the critical components of energy poverty, including accessibility, availability, reliability and affordability, are affected positively through investments from petroleum revenue.

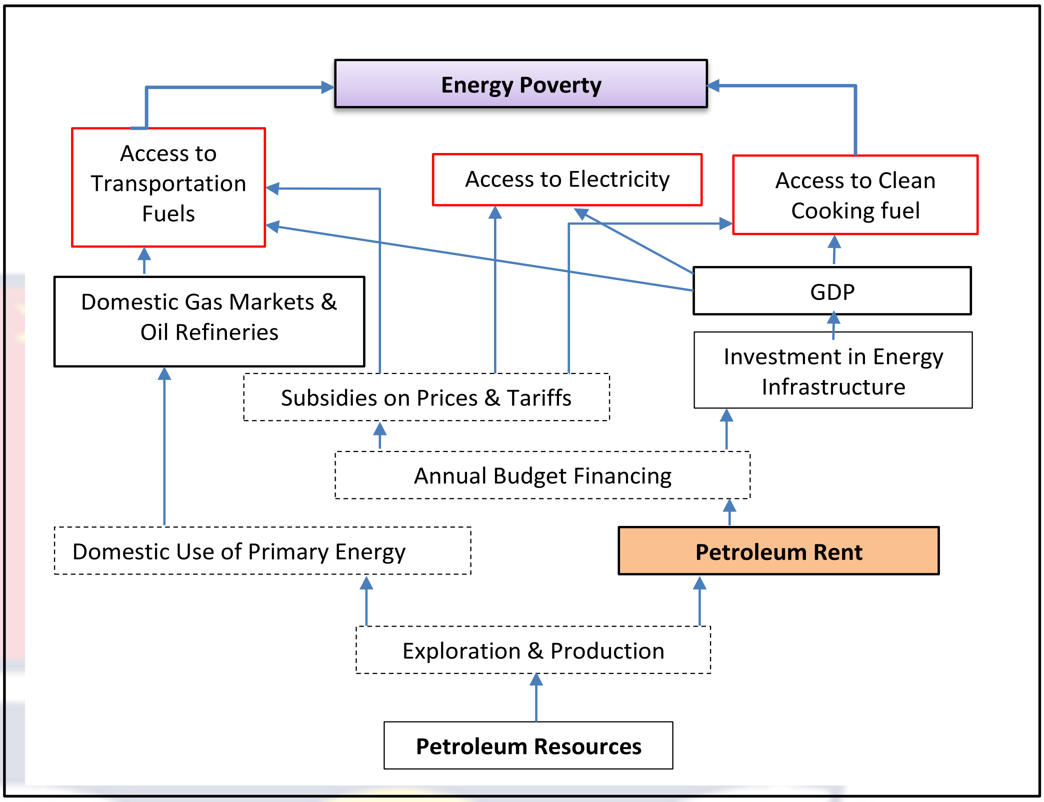

Figure 7: Conceptual Framework on the Petroleum Rent - Energy Poverty Nexus
Source: Author (2022)

Oil windfall is found to have a multiplier effect on economies when productive sectors are adequately targeted (Sadik-Zada et al., 2021). After decades of exploration, the petroleum sub-sector continues to contribute significantly to economy’s growth and development (EITI, 2022). For oil-producing countries to build firm basis for industrialization, it is a prerequisite for a targeted of investing to build resilient energy infrastructure and energy systems that improve electricity access, clean cooking fuels access, access to transport fuels, and concentration in value addition to the raw or crude oil.

The current exportation of unrefined petroleum products by most oil-producing African economies like Ghana does not give the countries optimal benefits. Most oil-producing economies in Africa operate a regulated oil market where subsidies are used to control fluctuating international fuel prices and electricity tariffs. Countries such as Libya, Nigeria, Angola, Egypt, and Algeria practice regulatory regimes in oil, whiles countries such as Ghana, South Africa, and Mozambique practice deregulation regimes. So volatile international crude oil prices directly pass through the economy unregulated.

It can be deduced from the above interconnections between petroleum rent, income and energy poverty is not straight forward. An improvement in energy poverty reduction through investments using petroleum revenue is not guaranteed in most oil-producing African countries. The study proposes a rent-growth-access hypothesis to examine whether petroleum rent and income contribute to energy poverty reduction.

Petroleum Rent, Income, and Energy Security

With reference to the conclusions drawn on the conceptualisation of energy security, Figure 8 presents how petroleum rent and income affect the critical indicators of energy supply security – energy import dependency, energy efficiency, and domestic energy production rate (self-sufficiency). The self-sufficiency dimension is expressed as the ratio of national primary energy output to consumption of primary energy in a given year. This rate may be calculated for each of the broad energy types or overall, for all types of energy. A rate of over 100% indicates a national production surplus in relation to domestic demand and, therefore, net exports.

Therefore, an energy production deficit is a threat to the ESS of a given nation. Energy efficiency is the use of less energy to undertake similar activity or produce the same result. Energy intensity measures an economy's energy inefficiency (Zheng, Qi, & Chen, 2011). Energy efficiency reduces energy demand, thereby reducing the nation's energy insecurity situation. The energy dependence rate shows the proportion of energy that an economy must import.

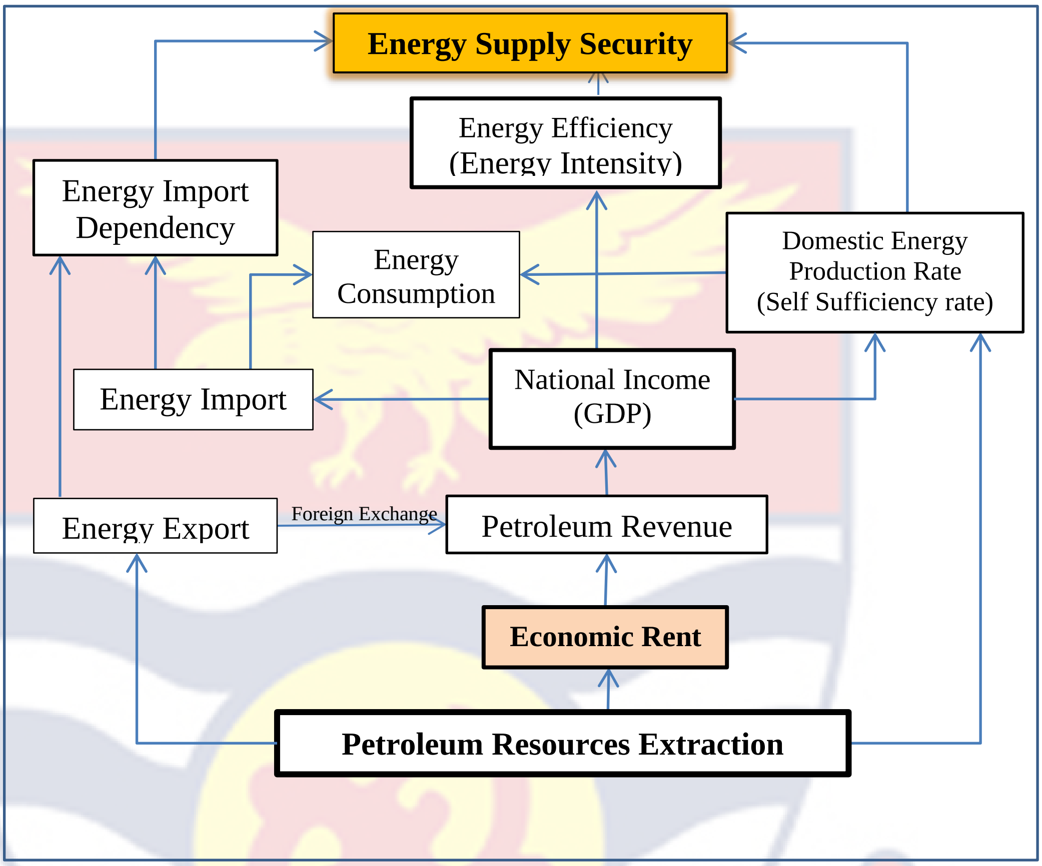

Figure 8: Conceptual Framework on Energy Security and Petroleum Rent
Source: Author (2022)

It is defined as net imported energy divided by overall inland energy consumed in addition to fuel supplied to international maritime bunkers, defined as a proportion (Acevedo & Lorca-Susino, 2021). High energy import dependency, implies the country is energy insecure.

The extraction of petroleum rent supports the host country in several ways that can support the economy to improve on their performance in their energy supply security. Earning foreign exchange has been an immediate benefit in most oil-producing African countries that export petroleum. As national income increases through oil revenue, it gives the countries the financial capacity to increase expenditure on energy infrastructure and import refined petroleum products or alternative energy sources that they otherwise do not have domestically.

National oil companies need income (GDP) to continue to raise capital for their participating interest to increase petroleum production. Funding is also required for investments in energy infrastructure and power generation to increase domestic production to improve energy insecurity. Lastly, higher GDP and low energy consumption have implications for energy efficiency, which reduces energy supply insecurity.

The extraction of petroleum resources guarantees domestic energy production and consumption. Where necessary technologies and innovations are in place to convert primary energy to secondary and consumable products, energy supply security is ensured since the country would not depend on energy imports.

Empirical Literature

Studies have rarely exploited the relationship between petroleum rent, income, and energy trilemma. Related studies mainly focus on the oil-economic growth nexus, energy-growth-environment relationship, and resource curse hypothesis. The review is conducted on three broad areas to establish from the literature the connection between rent from petroleum, income and the energy trilemma index, energy poverty, and energy supply security.

On the relationship between petroleum rent and income, scholars such as Behmiri & Manso (2013 & 2014), Hong & Hsu (2018), Lahiani, Benkraiem & Miloudi (2019), Sachs (2007), Srimarut & Sittisom (2020) and Tamba (2017), have not settled on common conclusions regarding the direction of causality on energy-growth relationship. There have also not been unanimous conclusions on the pattern of the EKC hypothesis, especially in rentier states, in explaining the growth-environment relationship. Studies such as Adams et al. (2017), Badeeb, Lean, & Shahbaz (2020), Beck (2011), Bjorvan et al. (2012), Hammond (2011), Lucky & Nwosiand (2016), Okpanachi et al. (2012), Parcero et al. (2016), Partey (2016), Ross (2011), Satti (2011) and Umar et al. (2021) have all drawn different level of conclusions on the growth-environment relationship.

The review concentrates on the literature of studies conducted from 2010 to date. Evidence has shown that conclusions on the relationships vary over time; therefore, the most recent studies provide the best indication of current situations across countries and regions. The review is based on related literature on the effect of petroleum rent on the components of the energy trilemma index. The first part of the review is on related literature on the nexus between petroleum rent, economic growth, and the energy trilemma index. They were followed by the nexus between petroleum rent, income, and energy deprivation, and lastly, the rent-growth-energy security relationship.

Energy Trilemma Index, Petroleum Rent and Income

Petroleum rent has been crucial in addressing development challenges towards economic transformation among oil producers in Africa (Mehrara, 2008; Snudden, 2016). This section is tackled based on how petroleum rent and income have affected the dimensions of the energy trilemma. The study starts with a review of the effect of petroleum rent and income on the environmental

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sustainability of energy systems. It follows up with the other dimension of the trilemma index.

The global call for a reduction in greenhouse gas creates undesirable threats to the economies of oil-rich nations that depend mainly on petroleum rent for development. Africa faces the worse threat of environmental consequences of GHG emissions as technologies and capacities in mitigating and adapting to the impact of climate change and climate variability are limited (Hussain et al., 2020; Tadesse, 2010). It is necessary to undertake research to offer evidence-based policies on the effect of petroleum rent on sustainable energy development in oil-producing African countries.

Most energy-growth-environment literature has focused mainly on a broad perspective, rarely concentrating on the nexus between petroleum rent, income, and energy trilemma. Few studies have specifically established how petroleum rent has impacted the environment quality over the years, and these studies concentrated on broader rent instead of particularising petroleum rent. Common among such studies have been the use of aggregate energy variables that do not show specific insight on the impact of petroleum exploitation through rent on the climate change (Dogan & Seker, 2016). In line with the theory of EKC, other broad spectra of studies have focused on how income or GDP has affected CO_2 emissions over the years. This literature is reviewed first to establish the critical role petroleum rent could play in improving or damaging the environment.

Literature has shown contradictory conclusions on the relationship between rent and the environment. Studies such as Awosusi et al. (2022), Hassan, Xia, and Lee (2021), Joshua and Bekun (2020), Kwakwa et al. (2019), Shen et al. (2021), Ulucak et al. (2020) and Wang, VO, Shahbaz, AK (2020) concluded that resource rent increases environmental degradation. Other studies found contrary and mixed conclusions on the nexus. Relevant to the field of study, other studies such as Álvarez-Herránz et al. (2017), Al-Mulali et al. (2016); Dogan and Seker (2016); Franco et al. (2017), Jebli, Youssef & Ozturk (2016), Liddle (2014); Martínez-Zarzoso and Maruotti (2011), Shafiei and Salim (2014) and Zoundi (2017) have dwelled on establishing the relationship between income (GDP), institutions, and environmental degradation with a conscious link to the theory of EKC.

In European Union (EU), Bekun, Alola, and Sarkodie (2019) found that environmental sustainability is negatively influenced by natural resource rent. The study by Bekun et al. (2019) on the link between alternative energy consumption, exhaustible energy consumption, and economic growth with a balanced panel for the period 1996 to 2014 showed that there exists a strong direct association between rent from natural extraction and carbon dioxide emissions, for some selected 6 EU countries, long term. The finding by Batmunkh, Nugroho, Fekete-Farkas and Lakner (2022) confirms that ignoring conservation and management policies and over-reliance on natural resource rent will harm environmental sustainability.

Similarly, Kwakwa, Alhassan and Adu (2019), Ulucak, Danish, and Ozcan (2020) revealed that environmental deterioration is influenced significantly by rent from natural resource extraction. The study used Augmented Mean Group (AMG) estimators to investigate the nexus between resource rent and CO_2 using data from some selected countries in OECD. Furthermore, Shen, Su, Malik, Umar, Khan and Khan (2021) revealed that resource rents are positively associated with carbon emissions. They used China's 30 provincial panel datasets spanning 1995 to 2017 and employed CS-ARDL approach and found evidence to make similar conventional conclusions on the resource extraction-environment nexus.

Badeeb, Lean and Shahbaz (2020) found that dependency on natural resource not only endangers the environment per se but has also had an enormous influence on the environment-growth relationship. With data from Malaysia, Badeeb et al. (2020) proved a resource-based EKC, which does not reject the inverted U-shaped curve but observes an upward shift to the right when controlling for natural resource dependence. Similarly, Sachs (2007) notes that significant earnings from petroleum and other natural resources are likely to have adverse effects on relevant economic sectors that contribute significantly to the performance of the macroeconomic indicators of a country. More present scenarios of this complex problem come in situations where oil wealth is used for consumption purposes instead of public investments that yield future economic returns. Sachs (2007) opined that creating growth in economic sectors using oil revenue cannot be done without increasing access to energy. This guarantees a solid foundation for industrialisation to escape from the famous resource curse hypothesis.

Additionally, in Mainland Southeast Asia, Srimarut and Sittisom (2020) found that petroleum exploration, consumption, and prices significantly impact economic growth. The study employed the stationarity test, cointegration test, and VAR model estimation using Thailand's annual data of 26 years. Srimarut and Sittisom (2020) found that petroleum exploration plays a significant role in economic growth. Similarly, the earlier study by Behmiri and Manso (2013)

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found a positively impact of consuming crude oil on economic growth. Empirical results from Arezki et al. (2017), Dahl and Duggan (1998), and Manners (1985) show that petroleum exploration has positively impacted both the host and importing economies. However, pressures on demand and supply have posted different levels of impact across countries.

Moreover, a wealth of academic literation has attested to the significant role of petroleum wealth in the trajectory of poverty and job creation dynamism (Ebegbulem, Ekpe, & Adejumo, 2013; Ugwu, 2009). These studies found conflicting results on the relationship between the exploitation of petroleum resources and poverty, which can affect the population's income levels, reducing their economic capacity to access energy services. Ebegbulem et al. (2013) argue that ecologically unfriendly activities of the multinational corporations in the Niger Delta region of Nigeria suffer environmental degradation, resulting in poverty.

On the environment-growth relationship, Tamba (2017) employed the stationary test, the cointegration test, and Granger causality based on error correction to examine the causal relationship between energy consumption, economic growth, and CO_2 emissions. The study used Cameroon's yearly data for the period 1971 – 2013, and revealed interesting results that there exists a direct relationship between energy consumption and income.

In South Asia, Hassan, Xia and Lee (2021) assessed the connection that exist among carbon dioxide emission, real income, and natural resources in Pakistan. The study applied ARDL and VECM method on a time series data of Pakistan spanning 1971 – 2017. Hassan et al. (2021) revealed that natural resource exploration significantly has a direct impact on CO_2 emission, and thus natural resource extraction damage the quality of the environment in Pakistan.

A study conducted in G7 countries by Wang, Vo, Shahbaz and Ak (2020) using yearly data spanning 1996 to 2017 also revealed an adverse impact of that natural resources rent on environmental sustainability. The study employed CS-ARDL approach to assess how carbon dioxide is influenced by rent from natural resource exploitation in G7 countries that were part of the countries that agreed, in 2015, to execute the policy directions of that emanated from the Paris Climate Agreement.

In South America, Awosusi et al. (2022) employed the FMOLS, DOLS, and ARDL approaches to investigate the relationship that exist among globalization, non-exhaustible energy, natural resources rent, income, and CO_2. The Columbian data that span 1970 to 2017 revealed that the path of development of Columbia is unsustainable as the study observed a growth-induced emission in Columbia. The Granger Shift Causality test illustrates that natural resource rent causes CO_2 emissions.

Joshua and Bekun (2020) used the South African yearly data spanning from 1970 to 2017 to examine the determinant of environmental degradation in South Africa using an augmented carbon income function. Pesaran's bound testing technique shows that natural resource extraction induces pollution emissions in South Africa. The study confirmed the result by using the dynamic ARDL bound test. The test showed that in the long-run equilibrium establishes some degree of association among the variables.

Some researchers have revealed that resource rent improves environmental degradation, contrary to the conclusions of the forgone findings by scholars. First, in developing countries, Tufail, Song, Adebayo, Kirikkaleli and Khan (2021) show that, the rent from extraction of natural resource enhances the environmental sustainability by lowering the emission of CO_2 in the long term. The study employed the Westerlund test and a CS-ARDL, focusing on emerging economies, to investigate the effect of fiscal decentralization and rent from natural resource extraction on the emission of carbon dioxide using data spanning 1990 and 2018. The findings could be linked to the recent low exploitation of energy resources and low levels of energy consumption in Africa.

Second, Arslan, Khan, Latif, Komal, and Chen (2022) found a positive effect of natural resource extraction on sustainable environment in China. Arslan et al. (2022) applied GMM and DOLS to China’s annual data spanning 1970 to 2017 to examine the nexus in rent from natural resource exploitation, environmental sustainability, and economic progress. Arslan, Khan, Latif, Komal and Chen (2022) show that resource rent improves environmental sustainability in China. Intuition cannot decipher the findings revealed by Arslan et al. (2022) because China is among the countries that have high emissions CO_2, especially in its consumption of coal for industrial production. The Union of Concerned Scientists (2019) reported that China emits that highest carbon dioxide with a global share of 29% and emissions amounting to 9.9 billion metric tons in 2019 notable resulting from coal burning. Given the circumstances in China, it is impossible that resource rent is improving environmental sustainability in China.

Literature has shown that some studies have found mixed results on the resource-environment relationship. For example, Ulucak, Danish and Ozcan

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(2020) employed a yearly panel data for the period 1990 – 2015 in BRICS countries to investigate the effect of natural resource wealth on CO_2 emissions. The study applied the augmented mean group (AMG) panel algorithm, robust to cross-sectional dependence and heterogeneity. Mixed results from these studies showed that natural resource abundance reduces carbon dioxide emissions in Russia but increases CO_2 emissions in South Africa. The study also found that natural resources contribute to the formation of the EKC theory in the BRICS nations.

As the introductory paragraphs in this literature review section mentioned, some studies have established empirical evidence on the environment-growth relationship. The nexus between income and environmental pollution is widely discussed. There is a lot of literature on the connection between energy use and deterioration of the environment, but the findings are inconsistent. The literature on energy and environment relationship is divided into two sub-streams; the first studies the overall energy while the second looks at the various effects of the different energy sources (renewable versus nonrenewable).

For instance, Dogan and Seker (2016) investigates the link between energy consumption, urbanisation, and environmental sustainability using US data spanning 1960–2010 and found interesting similar results that consumption of energy and urbanisation increase deterioration of the environment in the long run. Likewise, Franco, Mandla and Rao (2017) analysed the Indian yearly data spanning 1901–2011 and found than migration to urban areas enhance the likelihood of people to enjoy quality life and improve economic condition. Adversely, the study show that increased energy consumption and environmental degradation is apparent in the midst of urbanisation. In some other studies, the level of development moderates the effect of urbanisation (Martínez-Zarzoso & Maruotti, 2011). Conclusions have also been drawn among scholars that the effect urbanisation on the emission of CO_2 is not the same for different category of income levels of countries based on the World Bank's groupings. Analysing the relationship between urbanisation and population dynamics, Liddle (2014) showed that there exists an adverse effect of highly populated regions on the emission of CO_2.

Researchers have observed that when the energy composite variable is broken down into specific indicators, consumption of renewable energy lowers emission of carbon dioxide whereas consumption of nonrenewable energy increases them (Dogan & Seker, 2016; Jebli, Youssef & Ozturk, 2016; Shafiei & Salim, 2014). Al-Mulali et al. (2015) find that non-renewable energy consumption enhances CO_2 emissions, while renewable energy consumption has no effects on CO_2 emissions in Vietnam. Using Kenyan annual data spanning 1980 to 2012, and with the aid of ARDL estimation technique, Al-Mulali and Ozturk (2016) revealed that renewable energy enhances the reduction of emission of carbon dioxide whereas the consumption of non-renewable energy degrades the environment. With twenty-one (21) Kyoto countries, Mert and Bölük (2016) found that renewable energy consumption results in reducing emission of carbon dioxide and hence presents an opportunity as an alternative energy source for reducing environmental degradation. The study applied panel ARDL models to the Kyoto country's annual data compiled from World Bank Dataset. With a focus on twenty-five sub-Saharan African countries, Zoundi (2017) found an inverse relationship between renewable energy and emission of carbon dioxide.

Nevertheless, both in the short and long terms, primary energy use outweighs the effects of renewable energy. Using panel econometric technique to analyse a yearly data for the period 1990 to 2012, Paramati, Sinha and Dogan (2017) examined the relationship for developing nations and found that the use of renewable energy positively affects both economic growth and the quality of the environment.

Unlike the numerous studies which have used mainly parametric estimation methods, Ifran and Shaw (2017) observed that the carbon dioxide emission, energy use, and urbanisation relationships are is nonlinear, as several studies proposed. The study, therefore, employed a nonparametric additive model proposed by Chen and Chen (2015) with cross-country and time-specific effects on a dataset from South Asian nations spanning from 1978 to 2011. They found that the relationship is not linear and that energy consumption positively impacts carbon dioxide emissions. Nonparametric estimation techniques have been criticised on the grounds that it does not assist in identifying which covariate in a set is significantly linked with the likelihood of encountering an event. Thus, identifying a covariate that produces an estimate for each covariate's effect (adjusted for other predictors in the model) is not identified in nonparametric estimation (De Champlain, 2010).

Dogan and Seker (2016) also conveyed critiques of previous studies that have ignored the fact those countries in panel datasets are not likely to be homogeneous and cross-sectionally independent. Using data from some selected from Renewable Energy Country Attractiveness Index, Dogan and

Seker (2016) employed the heterogeneous panel estimation method taking cognisants of cross-sectional independence to examine the energy-growth-environment relationship. Dogan and Seker (2016) found the emission of CO_2 is deceased by the consumption of renewable energy whereas nonrenewable energy is revealed to increase emission of CO_2. The finding support that the EKC hypothesis exists among the nations selected in the Renewable Energy Country Attractiveness Index.

Contrary conclusions have been drawn by other scholars. With an annual data from 19 developed and developing countries, Apergis and Payne (2010) investigated the relationship between emission of carbon dioxide, consumption of nuclear energy, consumption of renewable energy, and income. The long-term coefficients from the panel error correction model indicate that adverse significant relationship exist between nuclear energy consumption and environmental pollution from CO_2. Renewable energy consumption is rather does not reduce emission of CO_2. The adverse finding might be attributed to inadequate energy storage technology for renewable energy sources to curtail interruption in delivery of energy services. The situation can be blamed for the frequent reliance on fossil dependent power generation plants to feed the ever-increasing demand for energy services. The result is in tandem with earlier findings by Menyah and Wolde-Rufael (2010) who found that emission of CO_2 is not influenced by the consumption of renewable energy in the US.

Furthermore, some scholars have failed to show differential impact of renewable and non-renewable energy on the emission of CO_2. With yearly data spanning from 1980 – 2009 of the Middle East and North Africa nations, Farhani and Shahbaz (2014) analyse the relationship between energy and CO_2

emissions using the FMOLS and DOLS. They revealed a directive relationship between emission of carbon dioxide and renewable and non-renewable energy. Similarly, analysis by Bölük and Mert (2014) in 16 European Union, revealed that renewable and nonrenewable energy consumption influences the degradation of the environment. The study applied OLS and fixed effects models to the EU's annual data spanning 1990 –2008. They further revealed that renewable energy accounts for barely half of a unit of energy to GHG in EU.

With regards to Middle East and North African nations, Bilgili, Koçak and Bulut (2016) applied panel FMOLS and DOLS techniques to an annual panel dataset from seventeen OECD nations spanning from 1977 to 2010 to examine the relationship between renewable, nonrenewable energy and the emission of CO_2. Bilgili et al. (2016) emphasised the existence of an inverted U-shaped nexus among CO_2 emission and per capita income. Increased consumption of renewable energy decreases degradation of the environment and hence the EKC theory is said to be implied.

Some scholars, however, reveal a positive effect of renewable energy environmental degradation only at a specific threshold. For instance, the study by Irfan and Shaw (2017) showed the presence of a threshold beyond which increasing urbanisation moderated by the level of development increase carbon emissions. After reaching this point, further increasing urbanisation rather decreases emission of CO_2.

Previous studies are in line with the findings by Irfan and Shaw (2017), as Chiu and Chang (2009) discovered that before any effect on reducing carbon dioxide emissions could be realized, renewable energy sources needed to make

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up 8.39% of the overall energy supply. The findings demonstrate that renewable energy worsens the environment below the threshold. Due to the inconsistency of output from renewable energy and the inadequate energy storage technologies, renewable energy may not be capable of reducing emissions (Forsberg, 2009; Heal, 2009).

With a specific focus on Africa, some scholars have established the relationships. For instance, Ologunde, Kapingura and Sibanda (2020) uses proxied oil revenue using oil rent to examine the relationship between petroleum revenue and sustainable development among 10 oil-producer in Africa with data spanning from 1992 to 2017. Oil revenue is the total amount of income earned each year from the sales of crude oil and refined petroleum products domestically and internationally in the host nation's currency (Olayungbo & Adediran, 2017).

Ologunde et al. (2020) employed the pooled mean group estimator on a panel autoregressive distributed lagged model. The empirical results of Olugunde et al. (2020) show that an increase in crude oil revenue has an adverse impact on the human development index (HDI) used to measure sustainable development in the selected countries in the long run. This result is consistent with major theories and previous studies (Arezki et al., 2017; Dahl & Duggan, 1998; Manners, 1985) that indicate that petroleum exploration has positively impacted both the host and importing economies.

Olayungbo and Abediran (2017) investigated the effect of oil revenue and institutional quality on economic growth in Nigeria. The study used the ARDL model with Nigeria’s annual data for the period 1984 to 2014 to show that there is long-run equilibrium between oil revenue, institutional quality, and economic growth. They found that institutional quality measured in terms of the corruption index enhances economic growth in the short-run, whereas the relationship is adverse in the long run. Similar to the convention, oil revenue is found to promote economic growth in the short run. The long-run negative effect of oil revenue on economic growth confirms the existence of the resource curse hypothesis in Nigeria. The finding by Olayungbo and Abediran (2017) is in line with the conclusions made by Baghebo and Atima (2013), that examined the impact of petroleum on economic growth in Nigeria; the resource curse and institutions in Nigeria by Ologunla et al. (2014). The study also corroborates with the findings on the "Nigerian disease" or "Dutch disease" by Mustapha and Masih (2016).

A quasi-experiment conducted by Cavalcanti et al. (2019) using data from oil wells drilled in Brazil from 1940 to 2000 revealed that oil discoveries and exploration have a constructive contribution to economic development in Brazil. The study found a positive impact of petroleum rent (i.e., discoveries and exploration) on domestic production and economic development through the movement of labour from the agriculture sector to high-end activities in the industry.

The conclusions drawn from various studies are influenced by the mythology applied, the setting, and the period of economic transformation. Time series analyses from studies such as Le and Nguyen (2019), Ebegbulem et al. (2013), and Ugwu (2009) turns to reveal an adverse impact of petroleum exploration on economic growth, whiles panel data analysis methodologies employed by Ologunde, et al (2020) and Olayungbo and Adediran (2017) found

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that petroleum resource extraction improved economic growth and development.

The body of evidence reviewed in this study suggests that the approach and conceptualisation of the energy trilemma index have varied across studies. Most of these studies have concentrated on the growth-energy nexus with little concentration on the rent-energy and rent-environment relationships. The methodological approaches adopted in the literature reviewed above do not showcase how African oil-producing countries have fared in translating petroleum rent into improvements in the energy trilemma index. Based on the established gap, it is particularly important for a study to unearth the relationship between petroleum rent, income, and energy trilemma

Petroleum Rent, Income, and Energy Poverty

Petroleum rent is fundamental to the economic growth and development of economies that are rentier states. However, Africa lags in tapping the most significant potential of the rich petroleum resources to improve energy poverty for economic transformation.

In one of the earliest investigations on this topic, Bazilian, Onyeji, Aqrawi, Sovacool, Ofori, Kammen and Van de Graaf (2013) showed that oil wealth significantly impacts the expansion of energy access. The study focused on smaller and emerging oil-rich countries such as Liberia, Nigeria, and Sierra Leone to establish the nexus between new-found oil revenue, energy poverty, and some key macroeconomic variables. Bazilian et al. (2013) underscore the enormous potential of oil wealth in expanding energy access as a major requirement in the path of industrialisation.

In a reverse relationship, Amin et al. (2020) found that energy poverty is the reason for low economic development in developing economies. The study used panel data from seven South Asian nations to investigate the interaction between energy poverty, employment, education, per capita income, inflation, and economic progress. For the period understudy 1995 to 2017, the results of the panel ARDL model revealed that energy poverty has a negative impact on economic development. Amin et al. (2020) saw the need to emphasise the use of modern, energy-efficient, and green technologies through financing a green and low-carbon economy.

On the energy-growth relationship, Okoye et al. (2022) investigated the effect of gas flaring, oil rent, and fossil fuels on economic performance in Nigeria. The study employed an autoregressive distributed lag error correction (ARDL-ECM) approach, fully modified ordinary least squares (FMOLS), and Canonical cointegration regression (CCR) methods to check for the robustness of the estimates. The study sustained the postulation of energy-led growth hypotheses. Results of the ARDL-ECM show that oil rent and fossil fuel production positively contribute to economic performance, while gas flaring from estimates of the FMOLS and CCR models shows a depressing effect on economic performance. The findings of Okoye et al. (2022) do not validate the presence of the Dutch disease hypothesis, but it is in line with the energy-led growth hypothesis.

Doğanalp et al. (2021) investigated the effect of energy poverty on economic growth for BRICS countries using PVAR, FMOLS, and DOLS for the period 2001 to 2018. Results of FMOLS and DOLS reported by Doğanalp et al. (2021) show that energy poverty proxy by energy consumption has a significant positive effect on income growth. The proxy used is too narrow for the definition of energy poverty. The direction of causality between energy poverty and growth is unidirectional, running from energy consumption to GDP growth. Using data covering 1973–2012, Ghodsi and Huang (2015) determined a two-way causality between energy consumption and economic growth for selected African countries. They obtained findings that confirm this relationship in energy-poor regions.

Sambodo and Novandra (2019) emphasised that 53% of households in Indonesia are energy poor according to the expenditure approach and 22% according to electricity use and suggested that the government should provide more support to improve energy access. Pye et al. (2015) attribute the prevalence of household energy poverty to low levels of household income, high prices of fuel and electricity tariffs, and low household energy efficiency.

Similarly, Raghutla and Chittedi (2022) examine the impact of electricity access on economic development using a panel data modelling approach from 1990-2018 for five emerging countries such as Brazil, Russia, India, China, and South Africa. The results show that energy poverty is a significant contractor to economic development across the five emerging BRICS economies. The long-run elasticities reported by Raghutla & Chittedi (2022) show that access to electricity, a measure of energy poverty, significantly enhances economic development. Similar to the findings by Doğanalp et al. (2021), they observed a unidirectional causality running from economic development to electricity access in the short-run.

Ashagidigbi, Babatunde, Ogunniyi, Olagunju and Omotayo (2020) investigated the determinants of household’s energy poverty in Nigeria using the Tobit regression model. Ashagidigbi et al. (2020) applied the Multidimensional Energy Poverty Index (MEPI) approach using the National Demographic and Health Survey (NDHS) dataset for Nigeria. They found that household income and access to credit are energy poverty reduction factors. Thus, income reduces the tendency of a household to be energy poor in Nigeria.

Bui (2020) applied the Granger causality test within the error correction modelling to examine the causal relationship between energy consumption and economic growth in Vietnam for the period 1984 to 2016. The study opines a bidirectional relationship between energy consumption and economic activities in the long-run. In the short-run, Bui (2020) rather found a unidirectional causality running from energy consumption to economic growth in Vietnam.

Twerefou, Iddrisu and Twum (2018) examined the relationship between energy consumption and economic growth in the West Africa sub-region using the panel cointegration technique. The study found a long-run unidirectional relationship from economic growth to electricity consumption. Electricity and petroleum consumption were also found to significantly influence economic growth positively in the long-run. The study failed to recognize the possibility that conservation policies that will improve energy efficiency could cause a bidirectional relationship between electricity consumption and economic growth (Rajbhandari & Zhang, 2018). Empirical findings by Rajbhandari & Zhang (2018) present evidence of long-run bidirectional causality between lower energy intensity achieved through energy conservation policies and higher economic growth for middle-income countries.

Li, Chien, Hsu, Zhang, Nawaz, Iqbal and Mohsin (2021) assess the empirical relationship between energy poverty and energy efficiency in developed and developing countries. The study applied the Data Envelopment Analysis (DEA) and entropy method via a mediating role of econometric estimation to analyses the relationship that exist in key variables such as energy poverty indicators, country-wide GDP, energy efficiency, and social welfare. Deducted result results show that energy poverty impedes GDP and that there is a nonexistence of modern electricity access in less energy-efficient areas across the study areas.

Brown and Nnamaka (2019) employed the Augmented Dickey-Fuller test to investigate the effect of oil revenue on economic growth in Nigeria for the period 1980 to 2017. The study found a positive and weak impact of oil revenue and oil rent on GDP in the long-run, whereas in the short-run, oil revenue and oil rent depress economic growth in Nigeria. Charles (2020) cautioned oil-rich developing countries that there is a potential for revenue from oil export to eventually cause a reduction in real per capita GDP growth. Quantile region model is employed by Charles (2020) to empirically identify the determinants of natural resource curse using a panel of 18 countries over a period of 2001 to 2017. The study applied the study observed that the state is more likely to resort to borrowing for public expenditures when there is an inertia in the oil boom.

The study by Adabor, Buabeng and Dunyo (2022) focused on Ghana, an emerging oil-producing country, to examine the causal relationship between oil resource rent on economic growth for the period 2011 to 2020. The choice of the period is influenced by the year Ghana started commercial production of crude oil offshore Cape Three Point. The study applied the autoregressive distributed lags model, Toda-Yamamoto test approach, nonlinear autoregressive distributed lags model, and nonlinear Granger causality to investigate the relationship between economic growths expressed as a function of oil resource rent, non-oil revenue, FDI, capital, and interest rate. The findings of Adabor et al. (2022) show a positive weak relationship between economic growth and oil rent in the short-run. The Toda-Yamamoto test shows a unidirectional causality from oil resource rent to economic growth, justifying that Ghana is not trapped in the Dutch disease. Thus, Adabor et al. (2022) provide evidence in support of the resource blessing hypothesis in Ghana.

The evidence overwhelmingly supports few studies that have examined the effect of petroleum rent on energy poverty in oil-producing African countries. The conclusion is that there are contradicting results on the relationship between petroleum rent, economic growth, and energy poverty. Contextual and methodological gaps can be established from the empirical literature discussed above. First and famous, most of these studies on rent-growth-energy poverty literature have used just energy access, with some using energy consumption to measure energy poverty, concentrating mainly on the household domestic issues (cross-sectional analysis), leaving out the transport sector. Again, some have focused on household energy poverty and country-specific analysis concentrating on cross-sectional and time series analysis rather than regional analysis involving panel data analysis in oil-producing African countries to establish a regional picture of energy development over time.

Petroleum Rent, Income, and Energy Security

Modelling energy supply security has attracted considerable attention in current literature. Several approaches have been employed with different indicators to measure relationships in energy supply security and country/household socioeconomics development indicators such as income and economic growth. Energy supply security has colloquially been referred to as reduced dependence on imported energy, particularly crude oil (Böhringer & Keller, 2011). Other studies also recognise the relevance of energy intensity and domestic energy production rate in measuring energy security. This study, among others, builds an energy-growth-security hypothesis to establish the effect of petroleum rent and income energy supply security in oil-producing African countries. The review is conducted in two-fold. The study first assesses the differences in the measurement and scope of energy security by scholars and, lastly, reviews the related empirical literature on the energy-growth-security hypothesis.

As indicated earlier, energy security has been measured differently by different scholars based on the purpose of their study. Many of the indices suggested in empirical literature require data that are virtually not accessible when conducting such studies in Africa and elsewhere (Narula & Reddy, 2016). Martchamadol and Kumar (2013) proposed Aggregated Energy Security Performance Indicator (AESPI) to measure sustainable energy by employing 25 indicators intending to incorporate socioeconomic and environmental dimensions of energy production and use. The measure gives a clear picture of the past security performance of a country ranging from zero to one. In developing countries, Narula and Reddy (2016) computed an index using scores consisting of objective values and weights comprising subjective values representing tradeoffs aggregated bottom-up. The literature revealed that studies evaluating the performance of energy supply security present quite some

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debates in their conclusions. Some of these studies include Alemzero, Sun, Mohsin, Iqbal Nadeem and Vo (2021), Jansen and Seebregts (2010), Ang et al. (2015b), Radovanović, Filipović and Pavlović (2017) as well as Stavytskyy, Kharlamova, Giedraitis and Šumskis (2018).

The study by Jansen and Seebregts (2010) focuses on the scope of the security of end-use energy services. They observe that approaches neglect critical aspects for resilience performance to incorporate energy services security on the demand side, such as energy efficiency and underlying aspects such as spatial and plans for infrastructure and patterns of consumption. The study also looks at the socioeconomic feedback mechanisms from the politics and accompanying social inequity of resource rent transfers to exporting countries of fossil fuels deserve special attention.

The study by Alemzero et al. (2021) did not pay particular interest in end-user security of energy services. With a series of 13 variables, Alemzero et al. (2021) creates a composite energy security index based on a sample of 28 countries for the period 2000 to 2018 for the African continent. The study employed the principal component analysis (PCA) and found Cronbach's alpha test coefficient of 0.8797 above the standard of 0.6. Implying that, the energy security index created is fit and reliable suggesting that the three should be an increased intra-regional energy trading among power pools in Africa.

Observing large variations among studies on the construction of energy security index, Ang et al. (2015a) proposes a structure with a composite index and three sub-indices for evaluating the energy security of Singapore. The study uses 22 indicators aggregated for selected years from 1990 to 2010. Whiles observing a fairly stable energy supply trend in Singapore, the energy supply

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chain and the environmental dimensions were found to have also improved over the period. The approach developed by Ang et al. (2015a) is particularly suitable for creating an energy index for energy import-dependent countries.

In the aforementioned studies, measurement and conceptualisation of energy security have recognized common interconnected factors such as availability, affordability, efficiency, acceptability, and accessibility. These studies, however, vary in the degree to which importance is placed on these interconnected factors of energy security and are also not conducted in the same geographical locations, specifically in Africa, with yet different period spans. It is worth noting that energy security and energy transition have a conflicting relationship, especially in oil-producing economies, with evidence from a study conducted in South Africa by Bellos (2018). Bu et al. (2019) also found that the integration of renewable energy, such as wind and solar, poses a potential security risk in Asian countries regarding electricity supply capacity and the costs during the transition period.

Studies assessing the rent-growth-security relationship have not been found in the literature to the best of the researcher's knowledge. Therefore, literature is reviewed on the energy-growth-security relationship. Related literature has concentrated on the impact of natural resources on energy security. Scholars have shown that natural resource dependence improves energy insecurity through various mechanisms (Mayer, 2022). Reliance on natural resources brings inherent unpredictability, making it difficult for governments to bring in regular funding to ensure energy security. In the next section, we describe the relevant literature on energy insecurity.

According to Mayer (2022), oil rents do not impact energy insecurity. The study, however, found a positive relationship between oil rents and energy access. Mayer (2022) used entropy-balanced fixed effects models to analyze how dependence on natural resources, as measured by oil rent, affects energy security. The study concludes that fossil fuel-producing nations often perform no better than their non-oil-rich countries in supplying reliable energy systems to their people. Mayer (2022) also opines that the issue of energy justice can be used to examine national-level energy insecurity. This was made to mean that a country is committing a distributional injustice if it produces fossil fuels but does not see an increase in its own energy security over time.

Shittu et al. (2021) examine the relationship between natural resources, environmental performance, energy security, and environmental degradation. The study found that rent from natural resources and energy security decrease ecological footprint whereas energy security. The study failed to establish a specific direction on the effect of resource rent on energy security. Similarly, Le and Nguyen (2019) found an adverse impact of energy security on economic growth using panel data from 74 countries for the period 2002 to 2013. The adverse impact of energy security on economic growth was found to be greater when energy intensity and carbon intensity were used as indicators to measure energy security. In earlier studies, Le et al. (2016) assessed the energy-led growth relationship among resource-poor countries. The study found that the extent of the impact of energy insecurity on economic growth is negative and varies across resource-poor countries. The relationship established is a unidirectional effect of energy insecurity on economic growth rather than

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exploring a possible reverse relationship that establishes economic growth affecting energy security.

Radovanović et al. (2017) examine the extent to which energy security can be influenced by energy forecasting variables such as coal, crude oil, and natural gas prices, year, and state in 28 European Union (EU) states for the period 1990 to 2012. The study found that prices of fossil fuel directly influence energy security in the EU. The study proposes a continuous but annual assessment of the influence of the energy mix on the individual indicators and parameters of energy security to provide up-to-date policy directions to lessen the shocks of energy security.

Stavytskyy et al. (2018) investigated the interrelationship between energy security and macroeconomic factors in European countries. The study revealed that GDP is positively correlated with New Energy Security Index (NESI) and negatively correlated with CPI in Europe. The results imply that ensuring energy security will ultimately result in lower prices of goods and services and, consequently, higher national outputs. The NESI constructed by Stavytskyy et al. (2018) is based on indicators such as consumption, production, distribution, and efficiency of energy use.

Furthermore, in Asia, Yao, Shi and Andrews-Speed (2018) found that energy insecurity hampered the economic growth of nations based on the nature of their economy. In resource-poor economies such as Singapore, South Korea, Japan, and Taiwan, Yao et al. (2018) examine the role of the economy's structure on the nexus between energy insecurity and economic growth. A similar conclusion has been drawn in East Asia by Ji, Zhang, and Zhang (2019). The study investigated how OPEC affects the security of oil imports in East

Asian nations such as China, Japan, and South Korea using a modified two-stage DEA-like model. They discover that these countries' ability to secure their oil imports is essential for long-term economic growth. The nexus between oil import security provided by OPEC and sustainable economic growth varies among the Asian economies. The impact of OPEC on oil import security in China increased over the period, whiles in Japan, the effect has reduced.

Energy-growth-security relationship has also been studied by Xu et al. (2021). The study established a negative relationship between energy insecurity and economic growth. Xu, Yu, Zhang and Ji (2021) used cross-country panel data to estimate the relationship between energy insecurity and economic growth. Energy insecurity is measured from a multi-dimensional approach with indicators such as energy dependency, the share of renewable energy, and pricing. Xu et al. (2021) ignored the critical role of energy intensity and domestic energy production rate, which could be vital in reducing energy insecurity. In effect, the studies failed to exhaust the dimensions of energy security, such as availability, accessibility, affordability, and acceptability.

Earlier studies by Auty (2007) made a case that oil-rich nations frequently experience unstable commodity prices and that, in many nations, foreign interests own or significantly influence oil extraction. This leads to a situation where countries that produce oil are unable to keep and reinvest a large portion of the money made from it to increase energy security. The resource curse literature frequently discusses price volatility, which has been blamed widely as the barrier that causes resource-rich countries (or subnational regions) to lag behind their less resource-rich counterparts. The study considered oil-producing nations and their industrial and fiscal policies.

Similarly, Le and Nguyen (2019) revealed that energy security enhances economic growth for the whole sample and subsamples of countries divided based on the World Bank's income classification as of July 2018. Meanwhile, energy insecurity measured by energy intensity and carbon intensity variables has a negative impact on economic growth. Le and Nguyen (2019) built an extension version of the Cobb-Douglas production function using a global sample of 74 countries covering 2002 to 2013. The study used ten approaches of energy security to construct the index over five dimensions such as accessibility, availability, and affordability. The study also built panel data to make further analysis using Panel-Corrected Standard Errors (PCSE) and Feasible General Least Squares (FGLS) techniques to make room to correct for heterogeneity and autocorrelation and produce robust standard errors.

Natural resource dependence might create a situation where energy-producing resources are exported for foreign exchange instead of adding value to improve energy security. Given the centrality of energy services for economic and human development, a lack of investment in petrodollar might create worse socioeconomic outcomes as a result of an insecure energy supply in the long run. Energy insecurity could be another mechanism by which petroleum resource dependence reduces nations' long-run fortunes or their populations' well-being. Still, this relationship has undergone remarkably little evaluation.

The literature has not converged on a simple consensus on the link between natural resource rent, economic growth, and energy security. The energy security literature identified a series of significant research orientations. First, when considering energy security, it is essential to have a multifaceted perspective to adequately capture critical indicators of concern that address the dimensions of energy security. Some of these indicators in measuring energy security include energy import dependency, energy intensity, and domestic energy production rate. But for Mayer (2022), the mechanism linking energy security to petroleum rent is unavailable. These directions are the main motivation for this study.

Summary and Conclusion

This chapter reviewed existing related literature relevant to the study. The literature review was conducted in two parts. The first part tackled the theoretical framework in terms of the definition of concepts and related theories on the link between petroleum rent, income, and energy trilemma. Specifically, the energy ladder hypothesis, energy stacking theory, EKC hypothesis, resource curse theory, and theory of rentier state were reviewed. The second part established the study's conceptual framework with linkages shown based on the variables of interest in the study objectives.

The third section explores the empirical literation on the relationships. Even though there have been some related studies on the relationship, research gaps are noticed in the conception, level of analysis, and setting. Some of these studies have used cross-sectional and time series techniques, making recommendations based on one-off analysis and country-specific analysis. The current studies develop indices different from the approaches used in the literature reviewed above for selected oil-producing African countries and assess the effect of petroleum rent and income on them.

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CHAPTER THREE

RESEARCH METHODOLOGY

Introduction

The chapter presents the research methodology employed to achieve the research objectives. It describes the research design, data sources and sample size, model specification and empirical estimation, variable description and statistics, establishing workable definitions, and data analysis.

Research Philosophy

Research philosophy is generally defined as the school of thought that underpins the development of knowledge and the nature of that knowledge in relation to research (Saunders, Lewis & Thornhill, 2007). Research philosophy is a research paradigm, belief system or theoretical framework that guides research in a discipline (Willis, Jost & Nilakanta, 2007). Several paradigms govern the practice of research. However, four paradigms are widely followed in social science inquiry: positivism, post-positivism, constructivism, and critical theory (Denzin & Lincoln, 2011; Gratton & Jones, 2004; Myers & Avison, 2002). Positivism is recognized as the first and the traditional paradigm developed for social inquiry, and the others are viewed as an extension (Clark, 1998). According to Clark (1998), only positivism and post-positivism need to be explored and understood before deciding on a sound research method. Galliers (1992) advanced that positivism and post-positivism are the two principal philosophical dimensions in the tradition of science.

This study adopted the positivist philosophy within the tenets of liberal economics. Positivism is based on the rationalistic and empiricist philosophy

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that originated with the classical writings of August Comte (1896) and Emile Durkheim (1983). Positivism is a deterministic worldview in which effects or outcomes are defined by causes (Creswell, 2003). As Aliyu et al. (2014) outlined, positivism is a research strategy and approach rooted in the ontological principle and doctrine that truth and reality are free from the viewer or observer.

The positivist paradigm posits that social behaviour can be studied empirically by applying the methods of natural science. In other words, the social world can be explored in the same way as the natural world. The positivist emphasises that there is a method for conducting a study in the social world that is value-free and presents a causal nature explanation therefrom (Mertens, 2005; Mackenzie & Knipe, 2006; Hasan, 2016). The positivist paradigm assumes that in social sciences, the observer or researcher can be separated from the object of their research, just like in the case of natural sciences. This paradigm relies on a quantitative approach for testing theories underlying objectives by examining the relationship among measurable variables (Creswell, 2003). Positivists assume that the social sciences also apply patterns (trends), generalizations, methods, procedures, and cause-and-effect issues. For example, the positivist maintains that the objects of the social sciences, namely people’s behaviour, are suitable for implementing scientific methods (Miller, 2019).

Although positivist philosophy continues to influence social science research, especially economic inquiries, its central assumptions and applicability to studying human behaviour have been challenged by several writers. One major criticism raised against positivism is the lack of subjectivity in interpreting social reality. It is argued that objectivity needs to be sometimes replaced by subjectivity in the process of social inquiry (Buchanan, Henig &

Henig, 1998). Rolston (1982), for example, points out that everybody acts, thinks, and interprets subjectively to a certain extent. According to Johnson, Buehring, Cassell and Symon (2006), subjectivity is unique to any individual; and the endeavour for objectivity could best be obtained by discovering intersubjective interests between individuals.

Opponents of the positivism philosophy have challenged the claim that studies based on the positivist research philosophy are more robust and value-free (Ladyman, 2012). For instance, Kuhn (1962) argues that there is a thin line between dogma and reasoned belief, and it is not always as clear as the traditional philosophy of science assumed by social scientists. As Kuhn (1962) opines, it is sometimes difficult to assess when it is reasonable to maintain faith in an unconfirmed hypothesis and when to abandon such a hypothesis. It shows that the comprehension of science and the world cannot rely exclusively on objectivity. There must be an account for subjective perspectives since all objective conclusions are ultimately founded upon subjective conditions. Besides, Nagel (1961) suggests that the scientific method itself is not against dogma. Where dogma is applied with integrity, it can minimize unwanted beliefs on the basis of logically sound and statistically appealing theories that are no less precise than dogmas in their attempts to explain and predict reality.

Although the criticisms raised against positivist research philosophy are sound and valid, it is imperative to note that the other research philosophies have equally been criticized. There is no research philosophy that is completely free from criticism. All the research philosophies have their strengths and weaknesses. Thus, what matters is the suitability of a research philosophy to the type and purpose of the research.

The choice of the positivist philosophy for the study was informed by the fact that the positivist approach favours quantitative research design and therefore advances the application of statistical and mathematical rigour, which could provide more valuable findings and explanations. Furthermore, positivism allows researchers to move away from unobservable beliefs and desires and to focus on objective facts. Friedman (1953) states that the design of positivism and the quantitative approach to research provides a system of generalisation that makes correct predictions about the consequences of events achievable.

Research Design

A research design describes the detailed plan of how a research study is to be completed (Thyer, 2011). It provides the overall structure and orientation of investigation and a framework within which data can be collected, analysed, and interpreted (Bryman & Bell, 2007; 2008). This study is built on the positivist and empiricist's philosophy, emphasising the quantification of objective knowledge of the social world. This paradigm relies on a quantitative approach for testing theories underlying the objective by examining the relationship among measurable variables (Creswell, 2003). Underlying the positivist ideology is quantitative research, which purports to describe, compare and detect causal relationships between variables (Gall & Borg, 1989; Stainback & Stainback, 1988). It employs the deductive approach and rests on testing theories based on measurable indicators, which are analysed in line with the theories per the set objectives and reproducible statistical techniques.

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For the purpose of this study, an econometric approach to testing and verifying relationships between quantitatively measured variables and parameters is used. Table 1 provides a summary of the features employed for the analysis in this study. Specifically, since the main focus of the study is to establish the relationship between petroleum rent and energy poverty, energy supply security, and sustainability of energy systems, the explanatory research design under the quantitative approach is employed.

Table 1: Summary of Research Design and Philosophy

S/N	Research Layers	Research Components
1	Philosophy	Positivism, realism, interpretivism and pragmatism
2	Approach	Deduction, abduction and induction
3	Methodology choice	Secondary data and quantitative
4	Research strategies	Experiment, survey, archival, case study, ethnography, action research, ground theory, narrative inquiry
5	Time horizon	Longitudinal
6	Technical and procedures	Data collection and data analysis

Source: Author, 2022

Data and Sources of Data

The study is a departure from extant literature on studies on the role of petroleum rent on economic growth and development. It focuses on how oil-producing African countries are able to improve on energy trilemma over time using petroleum rent. Lack of data is a significant problem when conducting quantitative studies in energy (Belen & The, 2020), especially in constructing longitudinal data. Another challenge is the selection of the indicators to be used for this study to achieve the research objective.

According to Ciegis et al. (2009), indicators are a valuable tool for creating a feedback system that identifies areas where adequate policy actions are being taken and where additional focus is needed. Since perfect indicators are uncommon, there is a need for a methodological commitment to ensure that policy recommendation is not wrongly administered. Energy development strategies that keep in mind the energy trilemma index without indicators would lack a solid scientific foundation (Ciegis et al., 2009).

Indicators are a useful tool used to simplify, determine in quantitative terms and, summarise enormous flows of information, develop useful mechanisms of feedback, which highlights spheres where we act properly and where major attention is needed (Pravitasari, Saizen & Rustiadi, 2016). Actually, indicators are used in order to reduce the number of complex interrelationships by converting them into simple formulations, which makes assessments easier (Ciegis, 2009).

In general terms, an indicator is a quantitative or a qualitative measure derived from a series of observed facts that can reveal relative positions (e.g., of a country) in a given area (Carlucci, Cirà, Ioppolo, Massari & Siviero, 2018; Gopal & Thakkar, 2015; Hermans, Van den Bossche & Wets, 2009). When evaluated at regular intervals, an indicator can point out the direction of change across different units and through time. Therefore, indicators are quantitative information, which helps to explain how specific concerns (phenomena) change over time. For many years limited number of the main economic constraints was used to assess economic activities (production, rate of employment, rate of inflation, balance of payment, state debt, etc.). Such statistics present a general situation, but it does not explain sources of specific trends and does not necessarily reflect the situation of a particular sector of industry, community, or territory.

Perfect indicators are uncommon; therefore, their development in a general case involves methodological compromise among technical feasibility, public availability to use, and systemic consistency. The effectiveness of energy-related indicators focusing on the three dimensions of energy trilemma can be characterised by credibility, legitimacy, and salience. The energy trilemma is a multi-dimensional issue involving huge amounts of complex information. There is some need to systematically reduce this information to a more concentrated form while constructing the pyramid of information aggregation, at the base of which are raw data. At the top, there are indexes (Cruz, Mena & Rodríguez-Estévez, 2018).

Though there have been a lot of indices in the literature using several indicators in the measurement of energy trilemma, energy poverty, and energy supply security, there are some disagreements on the choice of indicators, weighting, significance, scoring, scale, comprehensiveness, time dimension and the context (Valdés, 2018). All the controversies are a result of data scarcity. In macro-studies involving country self-assessment, progress monitoring, scenario analysis, and cross-country comparison, creating indices with appropriate indicators are very relevant and useful (Ang et al., 2015a). Following the index created by scholars and policy think tanks, the study leverages building a model with the aid of a composite index. The significance of indicators as important instruments on the path to sustainable energy is based on the need to measure and assess the progress of reaching goals. Without indicators or a quantitative framework, sustainable energy development policies lack a solid foundation on which to advance.

Literature on energy trilemma, energy poverty, and energy supply security has concentrated more on the use of survey data such as Standard Living Survey, Demographic and Health Survey data etc. This current research, however, employs panel data analysis using annual macro data sourced from the World Bank's World Development Indicators, Country Policy, and Institutional Index, Doing Business and Competitiveness Index, as well as the US Energy Information Administration (EIA).

The availability of data determines the countries and the sample period for the study. The first objective investigates how petroleum rent influences the performance of the energy trilemma index in oil-producing African countries. The challenge of data constrained the study to use thirteen (13) countries for 19 years (2002 – 2020). The total observation for the study is 247 points. Specific oil-producing countries that were considered in the energy trilemma – petroleum rent studies include Angola, Cameroon, Chad, Democratic Republic of Congo, Republic of Congo, Cote d'Ivoire, Equatorial Guinea, Gabon, Ghana, Mauritania, Niger, Nigeria, and Sudan. Missing data means that the effective number of observations is lower. The panel approach is suited for this study because of data availability challenges (Baltagi, 2008).

The countries under study have short time spans for the variables of interest, which is insufficient for fitting panel data analysis. Data for objective one was sourced from the World Bank's World Development Indicators (WDI), Country Policy and Institutional Index (CPCI), Doing Business and Competitiveness Index (DBCI), as well as the US EIA. Specific data sourced from WDI include net energy imports, the ratio of energy consumption to GDP, the ratio of energy production to consumption, electric power transmission and distribution losses, access to clean and modern cooking fuel, access to electricity, the pump price of diesel, pump price of gasoline, energy intensity, low carbon electricity generation, GHG emissions from energy, CO2 intensity, CO2 emissions per capita, and PM2.5 mean annual exposure. Data from WB' DBCI for objective one includes electricity tariff and cost of getting electricity. The quality of electricity supply rating, policies and institutions on environmental sustainability rating, and transparency, accountability, and corruption rating variables were sourced from the WB's CPCI.

For the study's second objective, which examines the effect of petroleum rent on energy poverty, annual data from 2000 to 2018 are obtained from the World Bank data and the EIA's websites for nine (9) oil-producing African countries. Therefore, the potential maximum number of observations is 171. The oil-producing African countries included in the energy poverty study are the Democratic Republic of Congo, Gabon, Ghana, Mauritania, Morocco, Niger, Nigeria, South Africa, and Sudan. Countries such Algeria, Angola, Cameroon, Chad, Congo Republic, Cote d'Ivoire, Egypt, Equatorial Guinea, Libya, and Tunisia, were excluded from the analysis due to missing data on important variables such as total population with access to electricity (%), access to clean fuels and technologies for cooking (% of the population), and the primary supply of energy per capita. The former two variables were sourced from the WB's WDI, and the latter variable was obtained from the US-EIA.

For the third objective, data are available for nineteen (19) countries on the variables/indicators that constitute energy security for the period 2006 –

2020 sourced from the World Bank's WDI and EIA. Variables such as net energy import (billion Koe), energy intensity (Koe), GDP per capita (US$), carbon dioxide emission (thousand kt), fossil fuel consumption (billion Koe), oil rent (% of GDP), and gas rent (% of GDP) were sourced from WDI whereas variables such as renewable energy consumption (billion Koe), energy consumption (billion Koe), energy consumption (billion Koe), and fossil fuel consumption (billion Koe) were sourced from the US EIA. The number of cross-section dimensions (19 countries) is more than the time dimension of 15 years, yielding data points of 285 observations.

Oil-producing African countries that have adequate data for the study include Algeria, Angola, Cameroon, Chad, Democratic Republic of Congo, Republic of Congo, Cote d'Ivoire, Arab Republic of Egypt., Equatorial Guinea, Gabon, Ghana, Libya, Mauritania, Morocco, Niger, Nigeria, South Africa, Sudan, and Tunisia.

Panel Data Analysis

The need to study multi-dimensional socioeconomic realities involving measurement over time has made panel data analysis displacing cross-sectional methods in social science studies (Halaby, 2004). Panel data contains observations of multiple phenomena obtained from multiple periods for the same country, individuals, or firms. Thus, it includes repeated observations over the same country for several periods. Depending on the number of countries and the time period, it can be classified as a micro or macro (short or long) panel. Data containing a small number of countries with a long period is termed a macro panel (long panel), whiles data containing a large number of countries with a short period is called a micro panel (short panel).

There is also a balanced panel that has countries observed at every period. A macro panel dataset is constructed to address objectives one and two, whereas a micro panel is constructed to deal with the last objective due to data scarcity for some years. The qualities of panel data and strict adherence to steps and rules in estimation techniques overcome bias and inconsistent and inefficient estimates often produced by time series and cross-sectional studies (Baltagi, 2005). Second, panel data analysis allows us to combine time series and cross-sectional data to significantly increase the number of observations whiles producing consistent results even in the case of omitted variables (Wooldridge, 2005), which would have otherwise led the researcher to recommend a wrong policy.

Estimation Techniques

The literature on panel data econometric analysis highlights the importance of panel cointegration techniques. These techniques capture heterogeneity across two dimensions and overcome some problems associated with limited data availability (Baltagi 2013). The study undertook two pre-estimation tests for the first and second objectives, which required the use of panel-ARDL. Before the estimation of the respective models in the first two objectives, tests for slope homogeneity, cross-sectional dependence, and unit-roots of the series are conducted on the panel dataset. The panel GMM is used to examine the last objective of the study.

Homogeneity and Cross-sectional (CD) Independence Test

When analyzing panel data, it is important to consider the potential presence of slope homogeneity and cross-sectional dependence. If slope

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heterogeneity and cross-sectional dependence exist, it violates the assumption of independence, leading to biased parameter estimates and invalid statistical inferences for the macro panel using the panel-ARDL approach. Cross-sectional dependence can arise for various reasons, such as shared unobserved factors, spatial dependence, or contagion effects. For example, suppose the behaviour of countries within a region is influenced by common economic factors or policies (e.g., crude oil price). In that case, the observations for countries within that region may not be independent.

As a result, we investigate the homogeneity and cross-sectional independence of the panel data used in this study to examine if we can actually identify the problems of cross-sectional dependence and heterogeneity. In examining the homogeneity of the slop coefficients, the study employed the technique by Pesaran and Yamagata (2008), which builds on the Swamy (1970) approach to estimate the delta ($\tilde{\Delta}$) and the adjusted delta ($\tilde{\Delta}_{adj}$) shown in equations (1) and (2). This allowed for the test of the null hypothesis of the slope homogeneity ($H_0\colon \beta_i = \beta$) for all individual countries, against the alternative hypothesis of slope heterogeneity ($H_1\colon \beta_i \neq \beta_j$) for a non-zero fraction of pairwise slopes for $i \neq j$.

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{\sqrt{2k}}\right) \sim X_k^2 \tag{1}$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\bar{S}-k}{v(T,k)}\right) \sim N(0,1) \tag{2}$$

where, N denotes the number of cross-section units, S represents the Swamy test statistic, and k represents independent variables. If the p value of the test is larger than 5%, then the null hypothesis is accepted at a 5% level, and the cointegrating coefficients are considered homogeneous. This approach is

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appropriately applied for large and small samples, respectively, for $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$. The adjusted delta is a mean adjusted version of the delta. The standard delta demands that the error is not serially correlated. In the presence of heteroscedasticity and autocorrelation of equations (3) and (4), they introduced a heteroscedasticity and autocorrelation consistent robust version of the slope homogeneity test; Δ_{HAC} and $(\Delta_{HAC})_{adj}$:

$$\Delta_{HAC} = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{\sqrt{2k}}\right) \sim X_k^2 \qquad (3)$$

$$(\Delta_{HAC})_{adj} = \sqrt{N}\left(\frac{N^{-1}S_{HAC}-k}{v(T,k)}\right) \sim N(0,1) \qquad (4)$$

In testing for cross-sectional independence in the residuals of a fixed effect regression model of the first and second objectives, the study used the Lagrange multiplier (LM) test, developed by Breusch and Pagan (1980), following Greene (2000). The choice of the Breusch-Pagan statistic for the test of cross-sectional independence was made since $T > N$ in the panel dataset for the two objectives. For the third objective, the panel dataset is micro ($T < N$); therefore, cross-sectional dependence was not tested. According to Baltagi (2008), cross-sectional dependence is a problem in macro panels with long time series (over 20-30 years). Thus, cross-sectional dependence is not much of a problem in micro panels (a few years and large number of cross-sectional).

In the case of testing CD in objectives one and two, the difference between the T (19) and the target given by Baltagi (2008), which is 20, is very insignificant to invalidate the study. Given in equation (5), the null hypothesis of no cross-sectional dependence (thus, all pairwise correlations are zero), according to Breusch-Pagan (1980), is derived from the correlations of error terms and different cross-sectional units. The Breusch-pagan LM test is based on the average of the squared estimates of pairwise correlations, and under standard regularity conditions, it is shown to be asymptotically $(T \rightarrow \infty)$ distributed as (χ^2) with $N(N-1)/2$ degrees of freedom.

$H_0: \hat{\rho}_{ij} = Corr\left(u_{ij}, u_{jt}\right) = 0$ for $i \neq j$.

The Breusch-pagan LM test is given in equation (5).

$$CD_{LM} = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{T-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}\right) \tag{5}$$

where $\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t=1}^{T} u_{it}u_{jt}}{\sqrt{\sum_{t=1}^{T} u_{it}^2}\sqrt{\sum_{t=1}^{T} u_{jt}^2}}$ with u_{it} denoting the OLS residuals based on T observations for each $i = 1, \ldots N$.

Panel Stationarity Test

The panel unit-root test ascertains that no variable is integrated of order two (i.e., I (2)). ARDL model is specified if the variables are integrated of different orders (i.e., a combination of I (0) and I (1) order or just I (1)) but not I (2) and above. The study employed several first-generation panel unit-roots tests due to their different assumptions, strengths, and weaknesses. These unit root tests conducted include the Im, Pesaran, and Shin W-stat test (IPS) and Levin, Lin & Chu (2002) test (LLC). The IPS assumes that the slopes are heterogeneous, whiles the LLC assumes homogenous slopes. The LLC test requires a strong balance panel and, therefore not appropriate when there are gaps in the series.

Depending on whether there exists cross-sectional dependence or not, the study has to consider adopting either the first-generation or second-generation panel unit root test. The first and second-generation panel unit root tests are used to analyze whether a variable in a panel dataset follows a unit root

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process. A unit root implies that the variable has a stochastic trend and is non-stationary.

The main difference between the first and second-generation tests lies in their treatment of cross-sectional dependence, which refers to the potential correlation between the individual units in the panel. First-generation panel unit-root tests, such as the Levin, Lin, and Chu (LLC) and Im, Pesaran, and Shin (IPS) tests, assume cross-sectional independence. These tests treat each individual unit as independent and conduct individual unit root tests. They then combine the individual test statistics to obtain an overall panel test statistic. Second-generation panel unit root tests, such as the Hadri (2000) test, the Pesaran (2007) test, and the Choi (2001) test, account for cross-sectional dependence.

These tests explicitly model the potential cross-sectional correlation in the panel and incorporate it into the unit root testing framework. They provide more efficient estimates and valid inferences in the presence of cross-sectional dependence. The second-generation tests generally yield more accurate results when cross-sectional dependence exists in the panel dataset. However, it's important to note that the choice between the first and second-generation tests depends on the specific characteristics of the data and the research question.

It is also worth mentioning that there have been further advancements in panel unit-root testing beyond the second generation, such as the third-generation tests that incorporate cross-sectional dependence and heterogeneity in a more robust manner. These advanced tests address some of the limitations of the earlier approaches and provide more accurate inferences in the presence of various data characteristics.

Panel Unit Root Test for Cointegration

Pedroni (1999; 2004), Kao (1999), and Westerlund (2005) tests are performed to establish whether the series are cointegrated in the long run. Cointegration is ascertained from the statistical significance of the long-run coefficients and error correction term. Essentially, cointegration (or, more generally, a long-run relationship) is the joint significance of the level's equation. Where some variables are non-stationary at levels, and some become stationary after first differencing (i.e., the series has a mixture of both I (0) and I (1)), then an examination for cointegration is not applicable (Pedroni, 1999). Cointegration can be inferred from the statistical significance of the Pool Mean Group (PMG), Dynamic Fixed Effect (DFE), and Mean Group (MG) analysis (Mehmood et al., 2014).

Theoretical Model Specification

To analyze objectives one and two, we employed the panel-ARDL model, whereas objective three is investigated using the Panel Generalized Method of Moment (GMM). This conclusion was reached based on available data and the decision criteria on either GMM or ARDL. It is noted that, due to missing data for some oil-producing African countries and some year(s), the number of countries is less than the number of years for which there is data and, hence, the choice of panel-ARDL as an appropriate approach to analyze objectives one and two. For objective three, the time dimension is less than the number of countries, justifying the preference for panel GMM.

Panel ARDL Model Specification

The standardise panel model to analyse the relationship between stochastic variables is specified in equation (6) as follows.

$$Y_{it} = \alpha_i + \sum_j \alpha_j X_{jit} + \sum_k \gamma_k Z_{kit} + \sum_l \delta_l M_{li} + u_{it} \quad (6)$$

where; Y_{it} represents the dependent variable, I ($I = 1,2,\dots,N$) in the period t ($t = 1,2,\dots,T$), N is the total number of countries, T is the total number of periods, α_i, α_j, γ_k, δ_l are vectors of unknown parameters to be estimated. X_{jit} is a vector of j explanatory variables, varying in time and by individual country, Z_{kit} is a vector of k unobservable country characteristics, M_{li} is a vector of l variable, varying by country but constant over time, and u_{it} is the error term ($k = j + 1$).

The error term equation can be broken down in equation (7) as:

$$u_{it} = u_i + \lambda_t + v_{it} \quad (7)$$

where $u_i, \lambda_t \; and \; v_{it}$ respectively represent unobservable country-specific effect, unobservable time effect, and the new random error term.

Equation (6) can be rewritten in equation (8) as:

$$Y_{it} = \beta_i + \sum_j \beta_j x_{jit} + \sum_t \lambda_t D_t + v_t \quad (8)$$

where Y_{it} is the dependent variable, β_i is a vector of overall and $N - 1$ country-specific intercept terms, D_t is a vector of $T - 1$ time dummy variables, x_{jit} is a vector of the explanatory variables, β_j is a vector of the associated unknown parameters. An autoregressive distributed lag model is specified from equation (8) as:

$$Y_{it} = \varphi_i + \delta_i Y_{i,t-1} + \beta_i X_{it} + \varepsilon_{it} \quad (9)$$

$$y_{it} = \sum_{j=1}^{p} \delta_i y_{i,t-j} + \sum_{j=0}^{q} \beta`_{ij} X_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (10)$$

where y_{it} is the dependent variable, $(X`_{it})`$ is a $k \times 1$ vector that is allowed to be purely $I(0)$ or $I(1)$ or cointegrated; δ_{ij} is the coefficient of the lagged dependent variable called scalar; β_{ij} are $k \times 1$ coefficient vectors; φ_i is the unit-specific fixed effects; $i = 1,2, \dots, N$; $t = 1,2, \dots, T$; p, q are optimal lag orders; ε_{it} is the error term.

The long-run parameter of the panel can be written as: $\theta_i = \frac{\beta_i}{1-\gamma_i}$. Consequently, the Mean Group (MG) estimator proposed by Pesaran and Smith (1995) for the whole panel can be written as follows:

$$\hat{\theta} = \frac{1}{N}\sum_{i=1}^{N} \theta_i \quad (11)$$

$$\hat{a} = \frac{1}{N}\sum_{i=1}^{N} a_i \quad (12)$$

Equations (11) and (12) reveal how the model estimates separate the regressions for each country and calculate the coefficients as an unweighted mean of the estimated coefficients for the individual countries. It does not impose any restrictions. It allows all coefficients to vary and be heterogeneous in the long and short run. The PMG developed by Pesaran et al. (1999) is also adopted to detect the presence of a long and short-run association between relationship(s) and investigate the possibly heterogeneous dynamic issue across countries.

The appropriateness of the choice of MG, PMG, and dynamic fixed effect (DFE) estimators is chosen with the help of the Hausman test (Hausman, 1978; Hausman et al., 2002). The pre-parametrised ARDL $(p, q, q, \dots, q)$ error correction model is specified as:

$$\Delta y_{it} = \theta_i\left[y_{i,t-1} - \lambda`_i X_{i,t}\right] +$$

$$\sum_{j=1}^{p-1} \xi_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \beta`_{ij} \Delta X_{i,t-j} + \varphi_i + \varepsilon_{it} \quad (13)$$

where $\theta_i = -(1 - \delta_i)$ is the group-specific speed of adjustment coefficient expected that $\theta_i < 0$). $\lambda`_i = [y_{i,t-1} - \lambda`_i X_{i,t}]$ is the error correction term, and $\xi_{ij}, \beta`_{ij}$ are the short-run dynamic coefficients.

Dynamic Fixed Effect, Mean Group, and Pooled Mean Group Estimators

The dynamic fixed effect (DFE) estimator is remarkably similar to the PMG estimator; however, it confines the coefficient of the co-integrating vector to be equal across all panels in the long run. The DFE model further restricts the speed of the adjustment coefficient and the short-run coefficient to be equal. The dynamic fixed effect model allows panel-specific intercepts and calculates the standard error while making allowance for intragroup correlation. Baltagi, Griffin & Xiong (2000) discussed that DFE models are subject to a simultaneous equation bias from the endogeneity between the error term and the lagged dependent variable. The Hausman test can be easily performed to measure the extent of this endogeneity.

The PMG estimator assumes long-run slope homogeneity. Therefore, the estimator increases the efficiency of the estimates compared to the mean group estimators (Pesaran et al., 1999).

Africa has the lowest energy access rates globally (IEA, 2018), resulting in profound implications for the continent’s performance in energy poverty, energy security, and sustainability in energy systems. Because of a homogeneous low energy access rate that characterises African economies, the study assumes a possible long-term relationship between the energy trilemma index, energy poverty, petroleum rent, and GDP per capita. However, the short-run impacts of petroleum rent on energy poverty, energy security, and the energy trilemma could be affected by the heterogeneous country paths and transmission mechanisms influenced by different country-specific budget provisions, local laws, and regulations; hence it is reasonable to argue that country heterogeneity is particularly relevant in the short-run. Tests are conducted to give credence to the choice of panel-ARDL.

Panel Generalized Method of Moments

The generalized Method of Moment is a generic method for estimating parameters in statistical models. It is a dynamic panel data estimator that uses moment conditions (i.e., instruments) that are functions of the model parameters and data, such that their expectation is zero at the parameter's true value. GMM controls for the endogeneity of the lagged dependent variable in a dynamic panel model. Endogeneity is when a model has a correlation between the explanatory variable and the error term. GMM also controls for omitted variable bias. Thus, independent variables are not strictly exogenous but are correlated with past and possibly current realizations of the error term.

In ordinary least squares, the relevant assumption of the classical linear regression model is that the error term is uncorrelated with the regressors. The presence of omitted-variable bias violates this particular assumption. Unlike in GMM, the violation causes the OLS estimator to be biased and inconsistent. GMM also controls for unobserved panel heterogeneity and measurement errors. It is also designed for situations where there are arbitrarily distributed fixed effects, heteroscedasticity, and autocorrelation within panels and groups.

Assuming a linear regression model with endogenous regressors in equation (14) specified as.

$$y = X'\beta + u \tag{14}$$

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where: y and u are $N \times 1$ vectors; β is a $K \times 1$ vector of unknown parameters; X is a $N \times K$ matrix of explanatory variables.

By the assumption of the presence of endogeneity, suppose that a matrix Z is a $N \times L$, where $L > K$. The Z matrix is assumed to comprise a set of variables that are highly correlated with X but orthogonal to u (i.e., a set of valid instruments). Thus, the Z matrix comprises variables that are not correlated with the error term, u.

The GMM is applied when the number of cross-sections or groups (N) is greater than the time span (T) (i.e., $N > T$). The data for the study is a typical form of the $N > T$ and hence the application of the GMM is appropriate. GMM uses instrumental variable (IV) estimation. The instruments, Z are expected to be exogenous, $E(Z'u) = 0$ and the number of instruments less than or equal to the number of groups, N. These instruments can be internal and external. By using the extabond2 command, variables listed within the brackets of the *gmmstyle* instruments are referred to as internal instruments whiles variables listed within the bracket of the *ivstyle* instruments are referred to as external instruments.

Difference and System GMM

Difference GMM, proposed by Arellano and Bond (1991), corrects endogeneity by transforming all regressors through differencing and removes fixed effects. However, a hindrance to the first difference transformation is that it subtracts previous observations from the contemporaneous ones, thereby widening gaps in an unbalance panel. Applying difference GMM in an unbalanced panel may weaken the results to some extent.

System GMM, proposed by Arellano and Bover (1995) and Blundell and Bond (1998), corrects endogeneity by introducing more instruments to dramatically improve the efficiency of the estimator. It transforms the instruments to make them uncorrelated (exogenous) with fixed effects. Systems GMM builds a system of two equations: the original and the transformed. Unlike in the case of difference GMM, system GMM uses orthogonal deviations. Instead of subtracting previous observations from the contemporaneous ones, it now subtracts the average of all future available observations of a variable. Meaning that, no matter how many gaps contain in a data, it is computable for all observations except the last for each individual, thereby minimizing data lost than in the case of difference GMM.

Given an initial model in equation (15).

$$Y_{it} = \phi Y_{it-1} + \beta X'_{it} + (\eta_i + \varepsilon_{it}) \tag{15}$$

$$\Delta Y_{it} = \phi \Delta Y_{it-1} + \beta \Delta X'_{it} + \Delta \varepsilon_{it} \tag{16}$$

In panel GMM, regressors are classified into three: predetermined regressors, endogenous regressors, and strictly exogenous regressors. The predetermined regressors are assumed to be correlated with past errors but not current and future errors. Endogenous regressors are assumed to be correlated with past and possibly present errors, whereas strictly exogenous regressors are supposed to be uncorrelated with errors in all temporal periods.

As required by difference GMM and by transforming the regressors through first differencing, as shown in equation (15), the fixed effect is removed since it does not vary with time, but the problem of endogeneity remains. Thus, equation (15) still shows that there is endogeneity in the model to the lagged

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dependent variable being correlated with the error term. The composition of the error term is $\varepsilon_{it} - \varepsilon_{it-1}$ and y_{it-1} and shown to be correlated with ε_{it-1}.

From equation (15), the model becomes: $\Delta u_{it} = \Delta\eta_i + \Delta\varepsilon_{it}$ or $u_{it} - u_{it-1} = (\eta_i - \eta_i) + (\varepsilon_{it} - \varepsilon_{it-1}) = \varepsilon_{it} - \varepsilon_{it-1}$. The unobserved fixed effects no longer enter the equation as they are, by assumption, constant between periods. Also, the first-differenced lagged dependent variable is instrumented with its past levels, and now changes in the dependent variable are assumed to be represented by equation (15).

For the system GMM models specification, equation (14) is assumed to be a random walk model, and the dependent variable, y is persistent. In this case, applying a difference GMM estimator yields both a biased and inefficient estimate of ϕ in infinite samples, and this is particularly acute when T is short. ϕ is the parameter to be estimated for the lagged dependent variable, y_{it}. The poor performance of the difference GMM estimator, in this case, is attributed to the use of poor instruments (Blundell & Bond, 1998). It therefore underscores the rational for the use of the system GMM. It expresses one equation in level form with the first difference as instruments, and the second equation is expressed in the first difference form with levels as instruments. The system GMM approach involves the use of a greater number of moment conditions (thus, instruments). However, Monte Carlo evidence suggests that when the time span (T) is short and the dependent variable is persistent, there are gains in precision, and the small sample bias is reduced.

In the presence of heteroscedasticity and serial correlation, a two-step system GMM estimator should be used by exploiting a weighting matrix using residuals from the first step. However, in finite samples, such standard errors tend to be downward biased, and the conventional approach by scholars in such instances is to apply what is referred to as the Windmeijer adjustment to correct for such a small sample bias.

Choice between Difference and System GMM

There are two rules of thump to the selection of either approach. Blundell-Bond (1998) rule of thumb states that if the dependent variable is persistent and close to being a random walk (i.e., $\phi \rightarrow 1$), then the application of the difference GMM estimators yields both biased and inefficient estimates of ϕ in finite samples especially when the time is short. Blundell and Bond (1998) associate the poor performance of the difference GMM estimator in such instances with poor instruments.

The second rule study adopts the rule-of-thumb by Bond et al. (2001). The first step rule of thumb is from Bond et al. (2001), which starts with the estimation of a dynamic model by pooled OLS and the LSDV estimation technique (i.e., using the 'within' or fixed effects approach). The pooled OLS estimates the lagged dependent variable, ϕ considered an upper-bound estimate, while the corresponding fixed effects estimate is considered a lower-bound estimate. If the difference GMM estimate obtained is close to or below the fixed effects estimate, it suggests that the former estimate is downward biased because of weak instrumentation, and the system GMM estimator is preferred instead (Roodman, 2009). Where the dependent variable exhibits a random walk, it is advisable to use the system GMM.

Arellano-Bond estimator has one- and two-step variants. The one-step difference GMM is the initial regression (Roodman, 2009). The two-step difference GMM is efficient and robust to heteroscedasticity and autocorrelation (Roodman, 2009). However, simulation studies suggest that there are very modest efficiency gains from the two-step procedure, even when heteroscedasticity is present. As a result, empirical studies still apply one-step estimates. The two-step system GMM is an augmented two-step difference GMM which is more robust than the one-step system GMM because it is more efficient and robust to heteroscedasticity and autocorrelation.

The main challenges in the utilisation of GMM are instrument proliferation and serial autocorrelation of the error term. The study uses few time periods; hence, the estimates will not be much affected since these two issues are higher when the panel used has a long-time dimension and a small number of individuals (Labra and Torrecilla, 2018). The term "proliferation of instruments" describes the presence of higher levels of instruments which causes overidentification in the model. More instrumental variables are most likely to be generated in differences and levels. However, in the case of Arellano and Bond estimator, only the instrumental variable lags in differences are used (Labra & Torrecilla, 2018).

Empirical Model Specification

The empirical model specification to address the study's objectives is presented in terms of three broad areas: Energy Trilemma, Energy Poverty, and Energy Security. The purpose of the study is to consider the effect of petroleum rent and income on the energy trilemma index, energy poverty, and energy supply security.

Energy Trilemma Model

The empirical model employed in this study is adapted from Parker et al. (2006) and Khanna (2019). With the aid of a panel-ARDL approach, the study examines the effect of petroleum economic rent on the energy trilemma index and its components, as shown in equation (17).

$$
\begin{aligned}
&\Delta ETI_{it} = \alpha_0 + \alpha_1 ETI_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 lnPetroleum\_Rent_{it-1} + \\
&\alpha_4 Policy\_Env\_Sust_{it} + \alpha_5 Corruption_{it} + \beta_1 \textstyle\sum_{i=0}^{m} \Delta ETI_{it-1} + \\
&\beta_2 \textstyle\sum_{i=0}^{n} \Delta lnGDPpc_{it} + \\
&\beta_3 \textstyle\sum_{i=0}^{p} \Delta lnPetroleum\_Rent_{it} + \beta_4 \textstyle\sum_{i=0}^{q} \Delta Policy\_Env\_Sust_{it} + \\
&\beta_5 \textstyle\sum_{i=0}^{q} \Delta Corruption_{it} + \varepsilon_{it} \qquad (17)
\end{aligned}
$$

where the explanatory variables include a log of income ($lnGDP_{pc}$), log of petroleum rent ($lnPetroleum\_Rent$), country ratings on policies and institutions on environmental sustainability ($Policy\_Env\_Sust$), and countries' ratings on transparency, accountability and policy ($Corruption\_Account$) and energy trilemma index (ETI) representing the dependent variable.

The ETI is decomposed to show the effect of petroleum rent and income on the individual indicators that make up the energy trilemma index, such as energy security, energy equity, and environmental sustainability of energy systems. Estimates of the three additional models to measure the effect of petroleum rent and income on the indicators as dependent variables follow the same empirical model specified in equations (18) to (20):

$$\Delta ESustI_{it} = \alpha_0 + \alpha_1 ESustI_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 lnPetroleum\_Rent_{it-1} + \alpha_4 Policy\_Env\_Sust_{it} + \alpha_5 Corruption_{it} + \beta_1 \sum_{i=0}^{m} \Delta ESustI_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGDPpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta lnPetroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Policy\_Env\_Sust_{it} + \beta_5 \sum_{i=0}^{q} \Delta Corruption_{it} + \varepsilon_{it} \tag{18}$$

$$\Delta ESI_{it} = \alpha_0 + \alpha_1 ESI_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 lnPetroleum\_Rent_{it-1} + \alpha_4 Policy\_Env\_Sust_{it} + \alpha_5 Corruption_{it} + \beta_1 \sum_{i=0}^{m} \Delta ESI_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGDPpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta lnPetroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Policy\_Env\_Sust_{it} + \beta_5 \sum_{i=0}^{q} \Delta Corruption_{it} + \varepsilon_{it} \tag{19}$$

$$\Delta EEI_{it} = \alpha_0 + \alpha_1 EEI_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 lnPetroleum\_Rent_{it-1} + \alpha_4 Policy\_Env\_Sust_{it} + \alpha_5 Corruption_{it} + \beta_1 \sum_{i=0}^{m} \Delta EEI_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGDPpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta lnPetroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Policy\_Env\_Sust_{it} + \beta_5 \sum_{i=0}^{q} \Delta Corruption_{it} + \varepsilon_{it} \tag{20}$$

where $ESustI, ESI$, and EEI are dependent variables in equations (18), (19), and (20), respectively, representing the dimensions of energy trilemma index such as environmental sustainability of energy systems, the energy security index and energy equity index. The explanatory variables of the country I for year t include a log of income ($lnGDP_{pc}$), log of petroleum rent ($lnPetroleumRent$), country ratings on policies and institutions on environmental sustainability ($Policy\_Env\_Sust$), and countries' ratings on corruption ($Corruption\_Account$).

Following the EKC hypothesis discussed in the literature review, it would have been proper to include squared terms of the variables, such as petroleum rent and GDP per capita, to observe whether oil-producing African economies reflect the hypothesis. Preliminary investigation using *lowess smother* showed that both a U-shape and an inverted-U shape were not visible for the relationship between the petroleum rent, income, and the dimensions of the energy trilemma. The squared terms were not significant, even at a 10% level, hence the none inclusion of the squared terms in the estimation.

Diagnostic Test

The Hausman test is used to choose between the MG, PMG, and DFE estimators in order to find the best estimator for the model. Per the Hausman test, the null hypothesis is that the difference between PMG and MG estimations is not significantly different. PMG estimator is used when the null hypothesis is not rejected, and thus, there are statistical differences between PMG and MG. An additional explanation for this situation is that PMG and MG differ significantly. The PMG and the MG diverge significantly if the null hypothesis is not accepted.

A priori Expectations

The expected signs of the explanatory variables used in this section are presented in Table 2. It is expected that the energy trilemma index will be influenced positively by petroleum rent, GDP per capita, policy on environmental sustainability as well as corruption and accountability index.

Table 2: Signs of Variables in the Energy Trilemma Model

Variable	Definition	Expected Sign			
		ETI	ESI	EEI	EsustI
$lnGDP_{pc}$	Log of GDP per capita	+	+	+	+
$lnPetroleum\_Rent$	Log of petroleum rent	+	+	+	+
$Policy\_Env\_Sust$	Countries' ratings on policies and institutions on environmental sustainability	+	+	+	+
$Corruption\_Account$	Countries' ratings transparency, accountability, and corruption	-	-	-	-

Note: ETI, EsustI, ESI, and EEI, respectively, represent Energy Trilemma Index, Environmental Sustainability Index, Energy Security Index, and Energy Equity Index.

Source: Author (2022)

The dimensions of the energy trilemma index, such as energy security, energy equity, and environmental sustainability of energy systems, are expected to be positively associated with petroleum rent, GPD per capita, and policy on environmental sustainability. Petroleum rent and GDP per capita are expected to increase the dimensions because it gives a given nation the financial muscle to tackle the bottlenecks of energy accessibility, acceptability, affordability, and availability. Increasing corruption and accountability index impedes progress in energy development, and hence it is anticipated that the corruption index will take a negative *apriori* sign and, thus, will adversely influence the dimensions of energy trilemma (Mombeuil, 2020).

Environmental sustainability of energy systems as a dimension of the energy trilemma index is very critical in keeping the world mindful of climate change as nations continue to exploit energy resources for economic growth and development. Indicators to measure environmental sustainability and their *a priori* expectation have been discussed below.

Data on Energy Trilemma Index

The study creates an energy trilemma index as an average of the three tradeoffs made by governments regarding environmental sustainability, energy security, and energy equity. Indices computed and published by the World Energy Council have a limited time horizon starting from 2014 to 2018 for time series and longitudinal analysis. Unlike the conventional methods used by the World Energy Council, Yoon and Klasen (2018) used Principal Component Analysis (PCA) on the basis that the PCA has the advantage of not assigning ad hoc and subjective weights to different indicators in index construction. Contrary, Principal Component Analysis is a linear combination of feathers from original data, which are not as easy to interpret when generated. There might be instances of outliers dealing with larger datasets, especially in panel data with several countries and indicators. PCA is criticized for its weakness of not being robust in the presence of outliers. Again, PCA assumes a linear relationship between features. In real-life, some relationships might not be linear.

Due to the scarcity of data, the application of PCA will mean that some features might not be well represented since the technical application of PCA assumes there are no missing values (Ilin & Raiko, 2010). Therefore, instead of applying PCA, the study adopted and revised the approach of the World Energy Council in the estimation of the energy trilemma index. A weighted average approach is adopted with much interest in the indicators used by the World Energy Council and the approach by Al Asbahi et al. (2019) to compute the indices as shown in Table 3.

The aggregate index is computed as an average of the three dimensions of energy trilemma index for a given country for a specific year, as shown in equation (21).

$$ETI_{i,t} = \sum(W_n^* X_{i,t}) \tag{21}$$

where $ETI_{i,t}$ represents the energy trilemma index of a country *I* for year *t*, W_n^* represents weight assigned to the dimensions and $X_{i,t}$ is the dimensions (i.e., energy security, energy equity, and environmental sustainability) of country *I* for year *t*. In line with the WEC, the computation of the ETI uses indicators and dimensions with their respective weights assigned

Description of Data for Variables Used to Create ETI

Over the sample period and across countries, the mean energy intensity is 5.88 MJ per $2011 PPP GDP (see Table 4). Energy intensity varies between 0.14 and 24.32 MJ per output and deviates from its mean on average by 4.6 MJ per output. Energy intensity is an indication of how much energy is used to produce one unit of economic output. The yearly average energy intensity is lower than the 2015 intensities of China and Russia, which are

Table 3: Dimensions and Indicators of Energy Trilemma and Weights

No.	Dimension	Indicators	Measurement Unit	Source	Group Weights
	Energy security				
1	Security of supply and demand	Net energy imports	Percentage	WDI – World Bank Group	0.2
2		Ratio of Energy consumption to GDP	Koe	EIA	0.15
3		Ratio of energy production to consumption	Percentage	EIA	0.15
4		Electric power transmission and distribution losses	Percentage	WDI – World Bank Group	0.3
	Energy equity				
5	Energy Access	Access to clean and modern cooking fuel	Percentage	WDI – World Bank Group	0.2
6		Access to electricity	Percentage	WDI – World Bank Group	0.2
7	Affordability	Pump price of diesel	US$ per liter	WDI – World Bank Group	0.1
8		Pump price of gasoline	US$ per liter	WDI – World Bank Group	0.1
9		Electricity tariff	US$ per kWh	DBCI – World Bank	0.1
10		Cost of getting electricity	US$ per kwh	DBCI – World Bank	0.3
11	Energy quality	Quality of electricity supply rating	Rating (1-7)	DBCI – WB	0.3

Table 3: (continued)

No.	Dimension	Indicators	Measurement Unit	Source	Group Weights
	Environmental sustainability				
12	Energy Resource Productivity	Primary energy intensity	Kgoe	WDI/WB	6%
	Decarbonization	Low carbon electricity generation	Kgoe	WDI/WB	7%
13		GHG emissions from energy	Mt CO_2 eq	WDI/WB	5%
14	Emissions and pollution	CO_2 intensity	kg per $ of GDP	WDI/WB	5%
15		CO_2 emissions per capita	Metric tons per capita	WDI/WB	5%
16		PM2.5 mean annual exposure	Micrograms per cubic meter	WDI/WB	6%

Source: Adopted from World Energy Council (2022)

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Table 4: Descriptive Statistics of the Variables/Indicators used in the Energy Trilemma Index

Variables	Mean	Std Dev	Min	Max	Variance	Skewness	Kurtosis	Sum
Energy Intensity	5.878	4.608	0.14	24.32	21.23	2.649	9.732	1,223
Low carbon power generation	41.73	31.93	-19.3	99.91	1020	0.161	1.933	8,680
GHG emission from energy	25.91	42.24	1.67	197.2	1785	2.855	9.985	4,716
CO_2 Intensity	0.558	3.255	-19.14	6.477	10.59	-4.004	21.09	98.13
CO_2 emission per capita	1.418	2.265	0.0225	11.68	5.131	2.766	10.71	294.8
PM2.5 mean annual exposure	46.04	18.47	14.35	113.1	341.1	0.505	3.635	9,576
Access to clean cooking fuels	24.54	21.06	1.26	83.08	443.7	0.969	3.364	5,104
Access to electricity	45.15	23.23	4.956	91.53	539.5	-0.0269	2.17	9,390
Pump price of diesel	0.865	0.29	0.135	1.67	0.0838	-0.0252	2.56	166.2
Pump price of gasoline	0.951	0.315	0.195	1.68	0.0994	0.00891	2.394	181.6
Cost of getting electricity	5,800	8,439	91.7	4,7816	71,220,000	3.318	14.83	1,189,000
Electricity tariffs	17.34	8.25	0.4	42.4	68.06	0.246	2.629	3,467
Quality of electricity supply	2.577	1.01	0.16	5.851	1.021	0.623	3.208	329.9
Energy Intensity	5.878	4.608	0.14	24.32	21.23	2.649	9.732	1,223
Net energy imports	-175.1	270.5	-1155	45.91	73,152	-1.639	4.716	-2,8013
Domestic energy production rate	791.6	1640	0	10758	2,689,000	3.71	17.68	164,643
Electric power transmission and distribution losses	27.92	21.83	4.972	116.1	476.5	1.667	5.605	4,189
Ratio of Energy consumption to GDP	124.6	81.53	51.45	408.8	6,648	2.104	6.775	21,926

respectively 6.69 and 8.4 MJ per PPP of Gross Domestic Product (GDP) 2011 Price. Hence, less energy is used to produce one unit of output in oil-producing African countries compared to the 2015 emissions of China and Russia.

The data for the energy intensity indicator are positively skewed, with the value of the skewness standing at 2.649 and leptokurtic with the value of excess kurtosis of 9.73. The latter suggests that the distribution of energy intensity across countries and over time features heavy tails, whereas the former suggests that positive deviations from the mean tend to be more dispersed than negative deviations. Overall, positive skewness and excess kurtosis collectively result in a non-normal distribution.

Real GDP per capita varies between 104 and 15,597.28 USD per capita. The degree of variability is also witnessed by the standard deviation. The real GDP is 2,235.85 USD per capita. The data for this variable are positively skewed (with the value of the skewness standing at 2.2781) and leptokurtic (with the value of excess kurtosis of 9.6855). The latter suggests that the distribution of real GDP across countries and over time features heavy tails, whereas the former suggests that positive deviations from the mean tend to be more dispersed than negative deviations. Overall, positive skewness and excess kurtosis collectively result in a non-normal distribution, as indicated by the Jarque-Bera test statistic and the associated probability value.

Since renewable energy in Africa is mainly used for cooking or residential purposes and power generation, the study further uses data on carbon emissions that are generated as a result of electricity production. According to Bhattacharya (2011), global warming is highly associated with emissions from energy consumption and production. Moreover, as developing countries move from agrarian to manufacturing economies, they produce more energy and hence emit more carbon. This requires the effect of energy-related carbon emissions to be estimated separately.

Data and Choice of Variables / Indicators for the Energy Trilemma Index

Following the approach applied by the World Energy Council, each country's overall Index ranking is based on the calculation of 16 underlying indicators, which aggregate up to 9 categories across the three dimensions of the energy trilemma. Some of these indicators for the estimation are based on multiple datasets. For example, the category "Affordability" is measured using four indicators, such as pump price of diesel, pump price of gasoline, electricity tariff, and the cost of getting electricity. Each indicator supports explaining the affordability dimension of energy. Increased fuel prices and electricity tariffs will certainly be a disincentive to the consumption of energy services, thereby affecting energy affordability.

Energy Security in the construction of the energy trilemma index is measured under one broad category (security of supply and demand) with indicators such as net energy imports, the ratio of energy consumption to GDP, the ratio of energy production to consumption, and electric power transmission and distribution losses. The IEA (2020) estimates net energy imports as energy use less production, measured in oil equivalents. A negative sign of the net energy import indicates that the country is a net energy exporter and, therefore, not over-dependent on the importation of energy to meet domestic energy needs, and hence energy secured. Energy use is defined as the consumption of primary energy before transformation to other end-use fuels, usually equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport (Clark, Jorgenson & Kentor, 2010; IEA, 2020; Nathaniel, Barua, Hussain, & Adeleye, 2021). Countries with high net energy imports are not energy secure since they are energy import-dependent and vice versa.

An economic output and electricity consumption are basic indicators of its size and level of development. Most African countries produce electric power for domestic consumption. Yet, countries such as South Africa, Mozambique, Ghana, Morocco, Zambia, Zimbabwe, Ethiopia, Algeria, Ivory Coast, Egypt, Tunisia, etc., export power to neighbouring countries for foreign exchange. Expanding the domestic power generation and supply to meet the growing demand of the increasingly urbanized and industrialized economies requires careful consideration of the social, economic, and environmental costs comes that accompany such decisions. Such decisions continue to be a daunting task for developing economies. Power generation comes with different degrees of inefficiencies resulting in transmission and distribution losses hampering the security of supply. An electric power transmission and distribution loss is captured to reflect how countries could be energy insecure in terms of losses in power transmission and distribution. It includes losses in transmission between sources of supply and points of distribution and in the distribution to consumers, including pilferage (Lewis, 2015; Smith, 2004).

Energy production as a percentage of energy consumption is captured as an indicator to reflect how a country is able to meet its domestic energy demand given the amount of energy produced locally. A high ratio shows that the country is performing better in terms of domestic energy production that meet local energy demand compared to lower rates and vice versa.

Energy Equity is a dimension of the energy trilemma index under three broad categories energy access, affordability, and adaptability. The energy access category is measured with indicators such as access to clean and modern cooking fuel and access to electricity. The affordability category of energy equity includes indicators such as the pump price of diesel, the pump price of gasoline, the electricity tariff, and the cost of getting electricity.

Countries that have high populations with access to electricity and clean cooking fuels place a premium on the coverage and access of electricity to the citizenry through conscious investments in electricity infrastructure. Low access to electricity hampers the socioeconomic activities of communities as they are most likely not to untapped productive resources reflecting the extent of how impactful energy equity could drive economies (Dioha & Emodi, 2019).

The pump price of diesel and gasoline refers to the pump prices of the most widely sold grade of diesel and gasoline fuel converted from the local currency to U.S. dollars using the exchange rate in the Financial Times international monetary table for ease of international comparison (WB, 2020). It reflects the affordability dimension of energy to consumers. Consumers in a given country are likely to become energy unsecured when prices increase.

An indicator used to represent the energy quality category is the quality of the electricity supply, reflecting the reliability of the energy supply. The reliability of the power supply demonstrates the lack of interruptions and voltage fluctuations in the delivery of the energy service (Hensher, Shore & Train, 2014). This indicator is rated by the World Economic Forum Global Competitive Index from 1 to 7 for countries that have access to it. Lower ratings for a nation on power supply quality indicate the state is energy insecure.

Environmental sustainability concepts are in three broad categories: energy resource productivity, decarbonization, and emissions and pollution (WEC, 2020). Primary energy intensity measures the energy resource productivity category. Total primary energy intensity measures how much energy is required to generate one unit of GDP. Low energy intensity means less energy is used to generate output in a given economy (Templet, 1999; Wei, Zhou & Zhang, 2019). Hence, efficiency gains are derived from decreased energy intensity (Adom, 2015; Trotta, 2020; Wilson, Trieu & Bowen, 1994). Energy intensity, thus energy efficiency, plays a critical role in cutting the growth of world energy demand (Gielen, Boshell, Saygin, Bazilian, Wagner & Gorini, 2019; Koopmans & te Velde, 2001; Lange, Pohl & Santarius, 2020) and, therefore, the key to the transformation of global energy systems (Gielen, et al., 2019). Decreasing energy demand and focusing on energy efficiency is vital for countries to reduce GHG emissions to levels within the time frame set by the Paris Agreement (Bashir, Benjiang, Shahbaz, Shahzad & Vo, 2021; Herring, 2006; Creuheras, 2020).

The decarbonization category of the environmental sustainability dimension of the trilemma index adapted from the WEC (2020) includes variables such as low-carbon electricity generation and GHG emissions from primary energy consumption and use. Low-carbon electricity generation means avoiding fossil fuel power plants for electricity generation (Sims et al., 2003). Low-carbon electricity generation targets renewable power plants such as hydro power, wind power, solar power, geothermal energy, and bioenergy.

Therefore, the study captured low-carbon electricity generation as the share of renewable electricity to the total electricity generated by all plants for a given country annually. Seventy-three percent of greenhouse gas emissions in Africa emanate from the energy sector, with carbon dioxide being the most significant energy-related greenhouse gas (Africa Development Bank [AfDB], 2020). Methane (CH4) and nitrous oxide (N2O) emissions are only a tiny fraction of total energy-related emissions (2.1 % and 1.0 %, respectively) (AfDB, 2020). GHG is also included in the decarbonization category to capture the effect of the total GHG from energy on the environmental sustainability of energy systems.

Modern societies increasingly depend on reliable and secure electricity supplies that underpin economic growth and community prosperity (Amin, 2002; Asif & Muneer, 2007; Esen, 2016). Maintaining reliable and secure electricity services while rapidly decarbonizing power systems continues to be a crucial challenge for countries worldwide (Gottstein & Skillings, 2012; Staffell, Scamman, Abad, Balcombe, Dodds, Ekins & Ward, 2019). Governments in many countries are increasingly aware of the urgent need to integrate sustainability issues in the production and consumption of energy resources. Improved energy efficiency is often the most economical and readily available means of improving energy security and reducing greenhouse gas emissions (Bashir et al., 2021; Creuheras, 2020;).

Carbon dioxide intensity, CO_2 emissions per capita, and PM2.5 mean annual exposure are indicators used to measure the emissions and pollution category of environmental sustainability. CO_2 intensity is the ratio of carbon dioxide per unit of energy or the amount of carbon dioxide emitted due to using one unit of energy in production (Lin & Moubara, 2013; Ouyang & Lin 2015). Emission intensity is used as an indicator in this study to compare the environmental impact of energy resource exploitation in oil-producing African countries.

Anthropogenic carbon dioxide emissions result primarily from fossil fuel combustion and cement manufacturing (Bakhtyar, Kacemi, & Nawaz, 2017; Gregg, Andres, & Marland, 2008; Heede, 2014). In combustion, different fossil fuels release different amounts of carbon dioxide for the same level of energy use: oil releases about 50 percent more carbon dioxide than natural gas, and coal releases about twice as much (Robert, 2010). Cement manufacturing releases about half a metric ton of carbon dioxide for each metric ton of cement produced (WB, 2022). Data on carbon dioxide emission is sourced from the World Bank's World Development Indicators, which calculates and reports carbon dioxide emissions as elemental carbon. From the foregone discussion, it is not desirable for sustainability reasons for countries to increase carbon.

Particulate Matter (PM) 2.5 emission is one of the energy-related emissions from the combustion of Sulphur content fuels (Lee, Herage, He & Young, 2008; Yang, Chen, Wakeel, Hayat, Alsaedi & Ahmad, 2018), especially fossil fuels; hence, its inclusion as an indicator in the emissions and pollution category in the environmental sustainability dimension of the trilemma. It is measured as population-weighted exposure to ambient PM2.5 pollution (Aunan, Ma, Lund, & Wang, 2018; Ramacher & Karl, 2020; WB, 2022). It refers to a nation's population's average level of exposure to concentrations of suspended particles measuring less than 2.5 microns in aerodynamic diameter, which can penetrate deep into the respiratory tract, causing severe health damage (Blanchard, Tanenbaum, & Motallebi, 2011; WB, 2022). Exposure is calculated by

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weighting mean annual concentrations of PM2.5 by population in both urban and rural areas (Shen, Tao, Chen, Ciais, Güneralp, Ru & Zhao, 2017; WB, 2022)

Policy and institutions on environmental sustainability is a dependent variable included in the energy trilemma models. The variable is obtained from the Country Policy and Institutional Assessment (CPIA) database developed by the World Bank Group to capture the quality of a country’s policies and institutional arrangements, focusing on key elements that are within the country’s control rather than on outcomes of such as economic growth rates, that are influenced by events beyond the country’s control (World Bank, 2021). More specifically, the CPIA measures the extent to which a country’s policy and institutional framework supports sustainable growth and poverty reduction and, consequently, the effective use of development assistance (WB, 2014). This variable is likely to positively influence a country’s performance in keeping the balance between ensuring energy security and energy equity whiles reducing the impact of climate change.

Energy Poverty Model

The empirical model employed to analyse the relationship between petroleum rent, income, and energy poverty is adapted from Parker et al. (2006) and Khanna (2019).

$$\Delta CEPI_{it} = \theta_i\left[CEPI_{i,t-1} - \lambda`_i X_{i,t}\right] + \sum_{j=1}^{p-1} \xi_{ij} \Delta CEPI_{i,t-j} + \sum_{j=0}^{q-1} \beta`_{ij} \Delta X_{i,t-j} + \varphi_i + \varepsilon_{it} \tag{22}$$

where $(X`_{it})`$ is a vector of the explanatory variables such as GDP per capita, petroleum rent, squared term of the petroleum rent, and CEPI is the composite energy poverty index denoting the dependent variable. Following Nielsen

(2015), the squared term of the petroleum rent variable has been added to the equation with the intuition that lower small petroleum rent might not have significant effect on energy poverty reduction at the initial stages.

For the energy poverty model, the main variables of interest include CEPI, access to electricity, access to clean cooking fuel, primary energy supply per capita, GDP per capita, and petroleum rent. Establishing relationships between these variables is presented as:

$$\Delta CEPI_{it} = \alpha_0 + \alpha_1 CEPI_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 Petroleum\_Rent_{it-1} + \alpha_4 Petroleum\_Rent_{it-1}^2 + \beta_1 \sum_{i=0}^{m} \Delta CEPI_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGPDpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta Petroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Petroleum\_Rent_{it}^2 + \varepsilon_{it} \tag{23}$$

The CEPI is decomposed to show the effect of petroleum rent on the individual indicators that make up the energy poverty index, such as access to electricity, access to clean cooking fuel, and primary energy supply per capita. Estimates of three additional models to measure the effect of petroleum rent on the indicators as dependent variables follow the same model empirically specified in equations (24), (25), and (26):

$$\Delta AE_{it} = \alpha_0 + \alpha_1 AE_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 Petroleum\_Rent_{it-1} + \alpha_4 Petroleum\_Rent_{it-1}^2 + \beta_1 \sum_{i=0}^{m} \Delta AE_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGPDpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta Petroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Petroleum\_Rent_{it}^2 + \varepsilon_{it} \tag{24}$$

$$\Delta ACCF_{it} = \alpha_0 + \alpha_1 ACF_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 Petroleum\_Rent_{it-1} + \alpha_4 Petroleum\_Rent_{it-1}^2 + \beta_1 \sum_{i=0}^{m} \Delta ACF_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGPDpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta Petroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Petroleum\_Rent_{it}^2 + \varepsilon_{it} \tag{25}$$

$$\Delta PESpc_{it} = \alpha_0 + \alpha_1 PESpc_{it-1} + \alpha_2 lnGDPpc_{it-1} + \alpha_3 Petroleum\_Rent_{it-1} + \alpha_4 Petroleum\_Rent_{it-1}^2 + \beta_1 \sum_{i=0}^{m} \Delta PESpc_{it-1} + \beta_2 \sum_{i=0}^{n} \Delta lnGPDpc_{it} + \beta_3 \sum_{i=0}^{p} \Delta Petroleum\_Rent_{it} + \beta_4 \sum_{i=0}^{q} \Delta Petroleum\_Rent_{it}^2 + \varepsilon_{it} \quad (26)$$

where AE_{it}, ACF_{it} and $PESpc_{it}$ are the dependent variables in equations (24), (25), and (26) denoting energy poverty indicators such as access to energy, access to clean cooking fuel, and primary energy supply per capita, respectively.

By intuition, lower values of petroleum rent might deter energy poverty reduction until a threshold where the revenue is accumulated enough to allow for favourable foreign exchange and large investments into improving access to energy. For this reason, the study assumes that petroleum rent would be beneficial to energy poverty reduction at a certain threshold. Once petroleum rent surpasses this threshold, it will start to significantly reduce energy poverty. In order to check for the petroleum rent-energy poverty turning point, the study introduces a nonlinear relationship between petroleum rent and energy poverty and its dimensions. Intuitively, nonlinearity implies that the petroleum rent effect on energy poverty is conditioned by the level of petroleum rent. Hence, the specification of the quadratic terms in equations (23), (24), (25), and (26).

Equation (23) to (26) allows for testing the various forms of petroleum rent-energy poverty relationship. Thus, where $\alpha_3 < 0, \alpha_4 > 0$, it reveals that the relationship portrays a U-shaped curve; $\alpha_3 > 0, \alpha_4 < 0$ reveals an inverted U-shaped relationship; $\alpha_3 > 0, \alpha_4 > 0$ reveals a scenario that is a monotonically increasing linear relationship; $\alpha_3 < 0, \alpha_4 < 0$ reveals a monotonically linear relationship; and $\alpha_3 = 0, \alpha_4 = 0$ shows a level relationship (i.e., petroleum rent does not have a significant impact on energy poverty).

As in Afonso & Jalles (2013), Aswata, Nnyanzi & Bbale (2018), and Checherita-Westphal & Rother (2012), the thresholds are calculated only when both coefficients of petroleum rent and petroleum rent squared are statistically significant. Taking the first-order conditions, equations (23) to (26) turn out to be:

$$\frac{\partial CEPI_{it}}{\partial Petroleum\_Rent_{it}} = \alpha_3 + 2\alpha_4 Petroleum\_Rent_{it} \tag{27}$$

$$0 = \alpha_3 + 2\alpha_4 Petroleum\_Rent_{it}$$

Therefore, $Petroleum_{Rent_{it}}(threshold) = \frac{-\alpha_3}{2\alpha_4}$ (28)

Here, α_3 is the coefficient of the linear terms in the four models and α_4 denotes the coefficient of the significant quadratic terms in the four models.

Table 5 presents the apriori expectations of the explanatory variables used to analyse the relationship. In line with the energy ladder hypothesis, it is established that there exists a positive relationship between energy access and economic growth (Areski et al., 2017; Behmiri & Manso, 2013; Toole, 2015; Paunia, 2018; Srimarut & Sittisom, 2020).

As a result, the study envisages that increasing growth in income will cause a reduction in energy poverty and will have a positive effect on the indicators of energy poverty, such as access to electricity, access to clean cooking fuels, and primary energy supply per capita. Also, it is expected that an increase in petroleum rent will improve the dimensions of energy poverty and thus reduce energy poverty.

It is expected that the quadratic term will have a positive sign and thus assume a U-shaped quadratic graph. Implying that lower values of petroleum rent will reduce energy poverty up to a certain threshold and begin to rather increase energy poverty. The reverse is expected for the dimensions of energy poverty.

Table 5: Expected Signs of the Variables in the Energy Poverty Models

Variable	**Definition**	**Expected Sign**			
		EPI	**AE**	**ACF**	**PESpc**
$lnGDP_{pc}$	Log of GDP per Capita	-	+	+	+
$PetroleumRent$	Petroleum Rent	-	+	+	+
$Petroleum\_Rent\_Sq$	Square of Petroleum Rent	+	-	-	-

Note: EPI, AE, ACF, and PESpc represent the energy poverty index, access to electricity, access to clean and modern cooking fuel, and energy supply per capita, respectively.

Source: Author (2022)

Diagnostic Test

To determine the most appropriate estimator for the model, the Hausman test is conducted to decide between the MG, PMG, and DFE estimators. We employed the Hausman test to know whether there is a significant difference between PMG and MG. The null hypothesis of this test is that the difference between PMG and MG estimations is not significant. If the null is not rejected, then they are not significantly different; in this respect, we use the PMG estimator since it is efficient. The alternative hypothesis here is that there is a significant difference between PMG and MG. If the null hypothesis is rejected, there is a significant difference between the PMG and the MG.

Definition and Description of Energy Poverty Model Variables

Energy poverty is captured using an additive index called the Composite Energy Poverty Index (CEPI) measure. There exists a plethora of measures of energy poverty. Also, the principal component analysis was used to create the same index for the sake of robustness. In using the additive method, the study employed the methodology developed by Khanna et al. (2019) to measure energy poverty. The approach allows for the inclusion of essential parameters to represent accessibility, affordability, and availability which have not been captured by previous methods, such as the famous Multidimensional Energy Poverty Index (MEPI) used by Nussbaumer et al. (2012); Energy Poverty Index proposed by Mirza and Szirmai (2010); Total Energy Access Method by Practical Action (2013); and Energy Access Method by ADB, USAID & IEA (2011).

Accessibility indicators used to compute the energy poverty index are electricity access and access to modern cooking systems, including LP Gas, electricity, and biogas cooking stoves. The availability indicator is measured using countries' energy supply proxy by the total primary supply of energy per capita over time. Table 6 present the summary of definitions of variables used in constructing the energy poverty index.

A weighted average of the three indicators is constructed using weights assigned in Table 7 for accessibility, availability, and affordability. All these variables in the dataset are normalized to fall between 0 and 1 since, at levels, they have different measurement units. The min-max normalization method is adopted.

Table 6: Definition of Variables used in the Energy Poverty Index

No.	Indicator	Definition
1	Total Population with access to electricity (%)	Percentage of people with access to electricity.
2	Access to clean fuels and technologies for cooking (% of the population)	Percentage of people with access to clean cooking fuel.
3	Total primary supply of energy per capita	It is equal to indigenous production + net imports – distribution losses ± stock changes.

Source: Author (2022)

A normalized value of a variable (z_i) in a dataset is given in equation (29).

$$z_i = \frac{X_i - Min\ (X)}{Max(X) - Min(X)} \tag{29}$$

where X_i represents the ith value of the dataset, $Min\ (X)$ is the minimum value in the dataset of variable (X), and $Max\ (X)$ is the maximum value in the dataset of variable (X).

Table 7: Weight for the Measure of Energy Poverty

No.	Indicator	W_1	W_2	W_3
1	Total Population with access to electricity (%)	0.5	0.25	0.4
2	Access to clean fuels and technologies for cooking (% of population)	0.5	0.25	0.4
3	Total primary supply of energy per capita	0	0.25	0.2

Source: Adapted from Khanna et al. (2019)

The Weighted Average Energy Poverty Index is therefore constructed in equation (30) as;

$$WAEPI_{i,t} = \sum(W_1^* AE_{i,t} + W_2^* ACCF_{i,t} + W_3^* PESpc_{i,t}) \tag{30}$$

where, $AE_{i,t}$ represents access to electricity of country i at time t, $ACCF_{i,t}$ denotes access to modern fuel for cooking such as LP gas, electricity, and biogas, and $PESpc_{i,t}$ represents the total primary energy supplied by country i at year t. It must be noted that the sum of all the weight is unity. A country achieving a WAEPI of one implies that the country has fulfilled the people's energy needs in terms of accessibility, availability, and affordability. Finally, the composite energy index (CEPI) is computed by multiplying WAEPI by 100 as shown in equation (31).

$$CEPI_{i,t} = 100 \times WAEPI_{i,t} \tag{31}$$

The $CEPI_{i,t}$ measures the degree to which a country's energy is accessible, available, and affordable at a given time.

Energy Supply Security Model

Following Acemoglu et al. (2008) and Adeleye et al. (2017), the petroleum rent–energy security relationship is estimated with dependent variables being the dimensions of energy supply security such as energy import dependency, energy intensity, and domestic energy production rate. Three separate models are therefore estimated with the dimension of energy security as dependent variables to explain the effect of petroleum rent on energy supply security. For the purpose of this study, oil rent and gas rent are used as proxies for petroleum rent. The three empirical model specifications for the energy supply security are shown in equations (32), (33), and (34):

$$EID_{it} = \phi EID_{it-1} + \beta_1 GDP_{pc_{it}} + \beta_2 CO2_{it} + \beta_3 FF\_Consumption_{it} + \beta_4 RE\_Consumption_{it} + \beta_5 Oil\_Rent_{it} + \beta_6 Gas\_Rent_{it} + \beta_7 Oil\_Rent * GDP_{pc_{it}} + \beta_8 Gas\_Rent * GDP_{pc_{it}} + \varphi X'_{it} + \mu_i + \partial_t + \mathcal{E}_{it} \quad (32)$$

$$EI_{it} = \phi EI_{it-1} + \beta_1 GDP_{pc_{it}} + \beta_2 CO2_{it} + \beta_3 FF\_Consumption_{it} + \beta_4 RE\_Consumption_{it} + \beta_5 Oil\_Rent_{it} + \beta_6 Gas\_Rent_{it} + \beta_7 Oil\_Rent * GDP_{pc_{it}} + \beta_8 Gas\_Rent * GDP_{pc_{it}} + \varphi X'_{it} + \mu_i + \partial_t + \mathcal{E}_{it} \quad (33)$$

$$DEPR_{it} = \phi DEPR_{it-1} + \beta_1 GDP_{pc_{it}} + \beta_2 CO2_{it} + \beta_3 FF\_Consumption_{it} + \beta_4 RE\_Consumption_{it} + \beta_5 Oil\_Rent_{it} + \beta_6 Gas\_Rent_{it} + \beta_7 Oil\_Rent * GDP_{pc_{it}} + \beta_8 Gas\_Rent * GDP_{pc_{it}} + \varphi X'_{it} + \mu_i + \partial_t + \mathcal{E}_{it} \quad (34)$$

where EID, EI and $DEPR$ respectively represent the three measurements of energy supply security such as the energy import dependency, energy intensity, and domestic production rate of energy; EID_{it-1}, EI_{it-1} and $DEPR_{it-1}$ respectively represent the lag of the three measures of energy supply security, Oil_Rent and Gas_Rent are used as proxies for petroleum rent; $CO2_{it}$, $FF\_Consumption_{it}$, and $RE\_Consumption_{it}$ are control variables such as CO_2 emissions, fossil fuel consumption, and renewable energy consumption; μ is the unobserved country-specific fixed effects; ∂ is the time trend; ϕ, β, and φ are parameters; i is the number of cross-sections ($i = 1, \dots, N$); t is the number of time series ($t = 1, \dots, T$) and ε is the error term. The inclusion of the control variables is to determine whether the effect of petroleum rent and income on energy supply security still holds after considering the effect of CO_2 emission,

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domestic consumption of fossil fuel, and renewable energy on energy supply security.

In this model specification, the endogenous variable is the lag of energy import dependency rate, and others are treated as weakly exogenous (lag of oil rent, gas rent, and GDP per capita) and strictly exogenous (X'). The effect of petroleum rent through the moderating effect of GDP on energy security is represented by the interaction term between GDP and the variables used as proxies for petroleum rent (i.e., oil rent and gas rent).

Diagnostic Test

The study conducted two diagnostic tests. First, the instrument validity test is carried out using the Hansen (1982) J test and Sargan (1985) test for over-identifying restrictions with the null hypothesis that the instruments are valid. Where there is evidence to reject the null hypothesis implies the instruments are not valid. Second, the study test for the presence of autocorrelation/serial correlation of the error term. This test helps to establish whether differenced error term is first and second-order serially correlated. Hence, it tests the null hypothesis that the differenced error term is first and second-order serially correlated. Where the null hypothesis of no second-order serial correlation is not rejected provides evidence that the original error term is serially uncorrelated and the moment conditions are correctly specified. For the Sargan and Hansen test, it is expected the two null hypotheses are accepted.

Because of the nature of the dynamic model, the study expects that correlation is likely to be present at the lower level (AR (1)), but at the higher order, it is expected that there is no autocorrelation. Thus, the values of $AR(2) > 0.05$. Scholars are advised to be suspicious of the Hansen statistics in testing for the validity of over-identifying restrictions. If the p-values are above 0.9, scholars are advised to be respectively highly skeptical of the estimates and ignore it. Roodman (2009) advises the need not to take comfort in a Hansen test p-value below 0.1 and that higher p-values, such as 0.25, have potential troubles.

GMM is not advised for panels with a very long-time spans and that panel ARDL with PMG, MG, and DFE estimators are appropriate for such instances. Another challenge of GMM is that the results are biased if the number of instruments out-number the number of units in the panel. Literature is still not clear on the problem of how many are "too many" instruments. However, Monte Carlos simulation evidence suggests that reducing the number of over-identifying instruments in half can reduce the biases by 40%.

A priori Expectations

Table 8 presents the *apriori* expectation of the explanatory variables used in the energy security – petroleum rent model. Le and Nguyen (2019) revealed that energy supply security is enhanced by economic growth, and hence it is envisaged that GDP per capita will influence energy supply security positively.

As the income of a nation increases, they are in a better position to invest in ensuring energy supply security to expand the economy and hence the positive expected sign. Increased values of petroleum rent have a likelihood of improving the energy supply security situation of a country through investment in domestic energy production and building local capacities in terms of innovation and technologies towards reducing energy intensity (energy efficiency).

Table 8: Expected Signs of Variables in the Energy Security Models

Variable	**Definition**	**Expected Sign**		
		EID	**EI**	**DEPR**
GDP_{pc}	GDP per capita	+/-	-	+
Oil_Rent	Oil rent as percentage of GDP	+/-	+/-	+/-
Gas_{Rent}	Gas rent as percentage of GDP	+/-	+/-	+/-
$Oil\_Rent * GDP_{pc}$	Interaction of oil rent with GDP per capita	+/-	+/-	+/-
$Gas\_Rent * GDP_{pc}$	Interaction of gas rent with GDP per capita	+/-	+/-	+/-
$Fossil\ Fuel\ Consumption$	Share of fossil fuels in total final energy consumption	+/-	+	+/-
$Renewable\ Energy\ Consumption$	Share of renewable energy in total final energy consumption	+	+	+/-

Note: EID represent Energy Import Dependency, EI denotes Energy Intensity, and DEPR is Domestic Energy Production Rate
Source: Author (2022)

Fossil consumption is expected to either influence energy security positively or negatively, dependent on the economic conditions of the African continent. An increase in renewable energy consumption is expected to increase energy security. There is comparatively little or no limitation and negative consequences in its production and consumption as compared to non-renewable energy sources. Therefore, the effect of renewable energy and fossil fuel consumption is expected on energy supply security is expected to be positive.

Energy Supply Security Indicators

Energy supply security has evolved from several approaches of index construction methods: normalization (min/max - distance to a reference; standardization; etc.); weighting - equal weights; fuel/import share; Principal Component Analysis (PCA), Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA); Aggregation (additive aggregation, etc.). The measures reflect the concept of energy security that captures a multitude of definitions. Energy security data is categorised according to the sources of risk, the scope of the impacts, and the severity filters in the form of the speed, size, sustention, spread, singularity, and sureness of impacts. The selection of conceptual boundaries along these dimensions determines the outcome and the methodology of indexes (Winzer, 2012). Extant literature presents no unique and ideal indicator, and as such, the notion of energy supply security is highly context-dependent.

According to Narula and Reddy (2016), existing data on energy security indices have limited applicability for developing economies like Africa, where data availability is a big challenge. Instead, applying multiple indicators lead to a broader understanding (Kruyt et al., 2009). In developing countries, the study employs the approach developed by Erdal et al. (2015) to measure energy supply security using three indicators such as accessibility, availability, and affordability. It allows for the use of multidimensional indicators to measure energy security. Following Erdal et al. (2015) and Kruyt et al. (2009), the study assesses energy security on three critical indicators: energy import dependency ratio, energy intensity, and domestic energy production rate. The energy import dependency accounts for the accessibility dimension of energy by measuring the accessibility of energy in domestic economies.

The study uses the net energy import indicator as a measure of energy dependency. The IEA (2014) defined net energy dependency as the difference between energy usage and production, expressed in oil equivalents. A negative value indicates that the country is a net exporter. The term "energy use" refers to the use of primary energy prior to its transformation into end-use fuels. As presented in equation (35), it equals domestic production plus imports and stock changes minus exports and fuels supplied to ships and aircraft used in international transportation (IEA, 2014).

$$EID_{it} = Primary\ Energy\ use_{it} - Primary\ Energy\ Production_{it} \qquad (35)$$

Another dimension of energy supply security is energy intensity, defined as the total primary supply per unit of gross domestic product (Ramos-Martín, 2001; Pao & Tsai, 2011). A decline in energy intensity is often used as a proxy for efficiency improvement and leads to less energy consumed to produce more/same amount of goods and services (Duro, Alcántara & Padilla, 2010; Shahiduzzaman & Alam, 2013; Dong, Sun, Hochman & Li, 2018). Thus, reduced energy intensity accounts for increased efficiency and enhances ‘‘energy security’’ by decreasing the amount of imported energy. Energy intensity, presented in equation (36), therefore, handles issues of availability and affordability of energy specified as:

$$EI_{it} = \frac{Energy\ Use_{it}}{GDP_{it}} \qquad (36)$$

The third dimension of energy supply security well-thought-out is the domestic production rate of energy. It is an undeniable fact that energy availability increases when countries make progress in domestic energy production, causing those countries to be relatively energy-independent and consequently energy secure (Kruyt et al., 2009). The domestic energy production rate is measured as the ratio of domestic energy production to total energy consumption (Erdal, 2015) given in equation (37).

$$DPR_{it} = \frac{Total\ Energy\ Production_{it}}{Total\ Energy\ Consumption_{it}} \times 100 \qquad (37)$$

The min-max normalization method is adopted. A normalized value of a variable (z_i) in a dataset is given in equation (38).

$$z_i = \frac{X_i - \text{Min}\ (X)}{Max(X) - Min(X)} \qquad (38)$$

All the variables are also normalized using the min=max normalization approach, which defines a normalized value of a variable in a dataset as: $z_i = \frac{X_i - \text{Min}\ (X)}{Max(X) - Min(X)}$, where X_i denotes the variable in its raw form. The variables are normalized to overcome the main drawbacks of the previous energy supply security indices created.

Chapter Summary

This chapter discussed the research methods used for the study. It described the positivist philosophy underpinning the study, highlighted its various strengths and weaknesses, and provided a justification for the choice of the positivist philosophy. The chapter discusses the type of data used for the study and the procedures for sampling and data collection. The chapter also presented the theoretical frameworks and the empirical models used for the study and described the variables used for the empirical analysis in the study. Results of the empirical estimation of the effect of petroleum rent and income

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on energy trilemma, energy poverty, and energy supply security are covered in the following chapter.

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CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presents results and discussions as per the objectives of the thesis. First, the chapter discusses the effect of petroleum rent and income on energy trilemma index and how the decomposed dimensions are also affected by the petroleum rent and income. Second, the relationship between petroleum rent, income, and energy poverty in oil-producing African countries is presented and discussed. Lastly, empirical findings on how petroleum rent through the moderating effect of GDP per capita has influenced energy supply security in oil-producing African countries are presented and discussed.

Petroleum, Income and Energy Trilemma in Selected Oil-Producing African Countries

The section presents the empirical analysis of the effect of petroleum rent and GDP per capita on the energy trilemma index and its dimensions in oil-producing African countries. The influence of petroleum rent and income on the dimensions of the challenging triad, such as energy security, energy equity, and environmental sustainability, is also shown. The study first presents the trend analysis of the indices constructed for energy trilemma and its dimensions. The trend analysis is followed by descriptive statistics, a correlation matrix, some pre-estimation tests, and empirical results. The estimated results are presented and discussed, followed by the summary of the section.

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Trends in Energy Trilemma Index and its Dimensions

Among all the dimensions of the energy trilemma index, oil-producing African countries have performed considerably well in terms of energy equity over the years (see Figure 9). Thus, the problem of energy poverty in African oil-producing countries is not a matter of affordability but availability. The persistent performance over the years has been due to improvement in energy affordability in terms of a relatively affordable pump price of diesel, pump price of gasoline, and electricity tariffs. It can also be attributed to the progress nations have made from 2002 to 2020 in creating access to energy in terms of electricity expansion, and improving access to clean and modern cooking fuel like LPG.

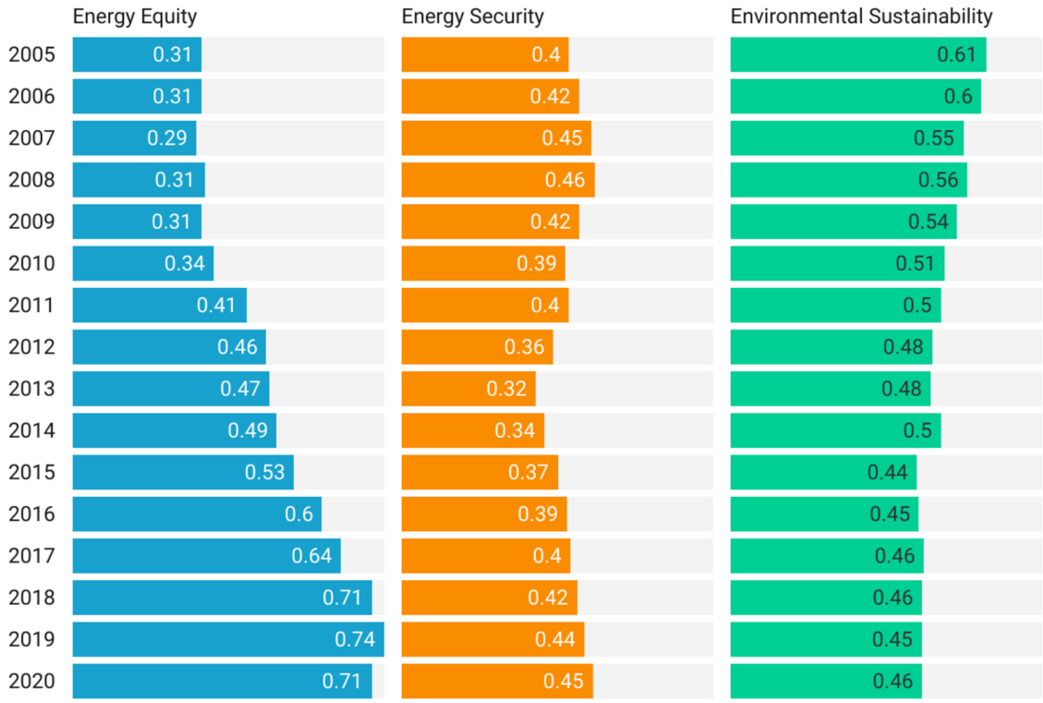

Figure 9: Energy Trilemma Index of Oil-producing African Countries 2020
Source: Author (2022)

Performance in environmental sustainability of energy systems has decayed over the years in oil-producing African countries, indicating that environmental issues have consistently been ignored making room for

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environmental degradation. As presented in Figure 10, the intensity of the blue colours in the maps from 2002 to 2020 portrays that progress is being made in the scores of the energy trilemma index with differential performance in the individual dimensions.

The energy trilemma scores, which range between 0 and 1, show the ability of a country to balance the quandary of ensuring energy security, making energy affordable, and at the same time achieving environmental sustainability of energy systems. Most countries did not have complete data for the computation of these indices. Cameroon overtook Ghana, which led in balancing the energy trilemma index in 2005 to become the best performer among the rest of the oil-producing African countries in 2020. The pie charts embedded show that Nigeria, which performed well in the environmental sustainability of energy systems and energy security dimensions, has improved on energy equity against the rest of the two dimensions as of 2020.

There has been considerable fluctuation in some countries for the Trilemma scores from 2002 to 2020. In Central and Middle Africa, Cameroon and Gabon are consistently increasing in ranking and achieving the average score in 2020 (see Figure 11). In West Africa, the trilemma performance by Cote d’Ivoire is not encouraging. The study could not find enough data on critical indicators for Nigeria to compute the trilemma index for Nigeria from 2002 to 2012. However, Nigeria’s performance from 2013 to 2020 is encouraging–reverting and hovering around the African average in the triple energy challenge.

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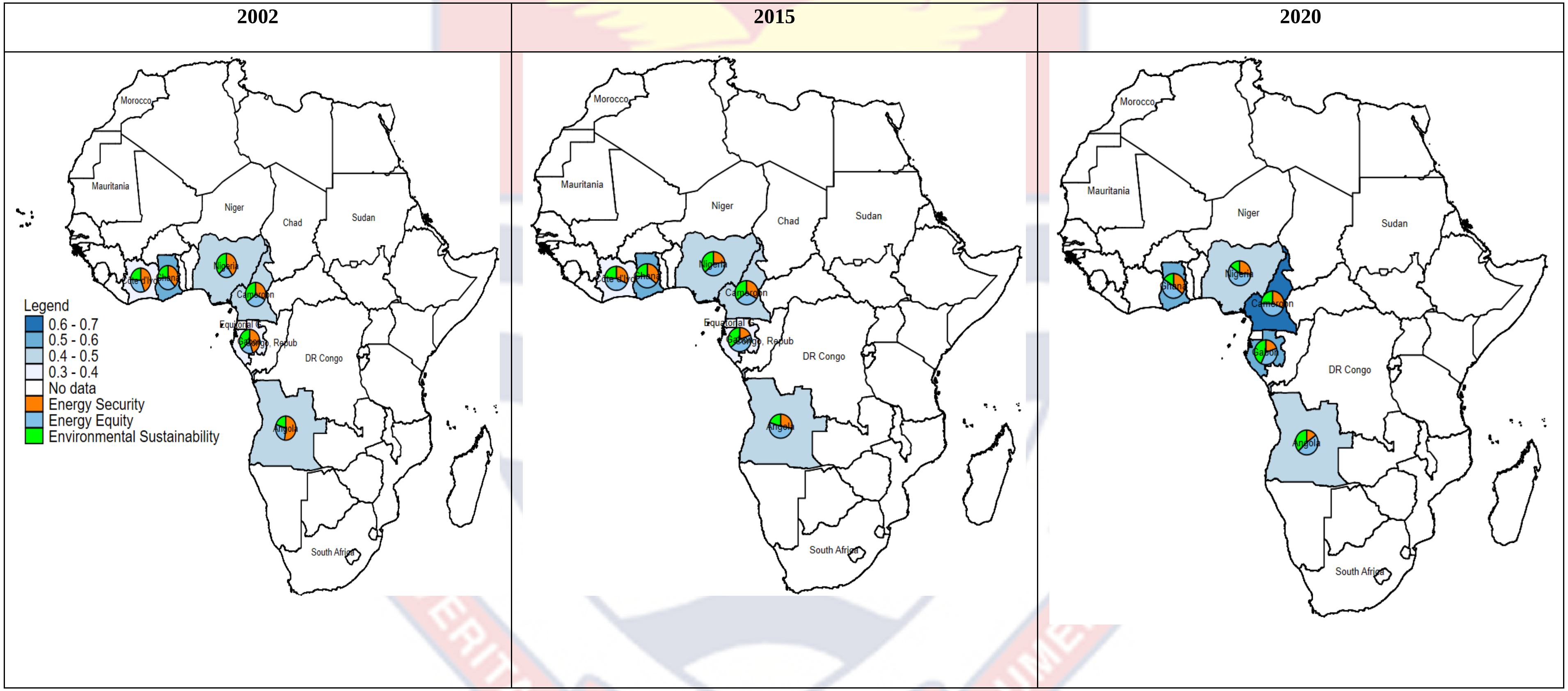


Figure 10: Energy Trilemma Index and Its Dimensions of Oil-Producing African Countries from 2002 to 2020
Source: Author, 2022

Ghana's performance has been good, scoring above the African average in dealing with the energy trilemma quandary (see Figure 11). Over the period under study, Ghana's performance in the trilemma also shows an increase from 40.1% in 2005 to 53.9% in 2020. The rise in Ghana's sustainable energy performance is more pronounced after the commercial production of petroleum (Aryeetey & Ackah, 2018) and maintained relatively slow changes between 2015 and 2020.

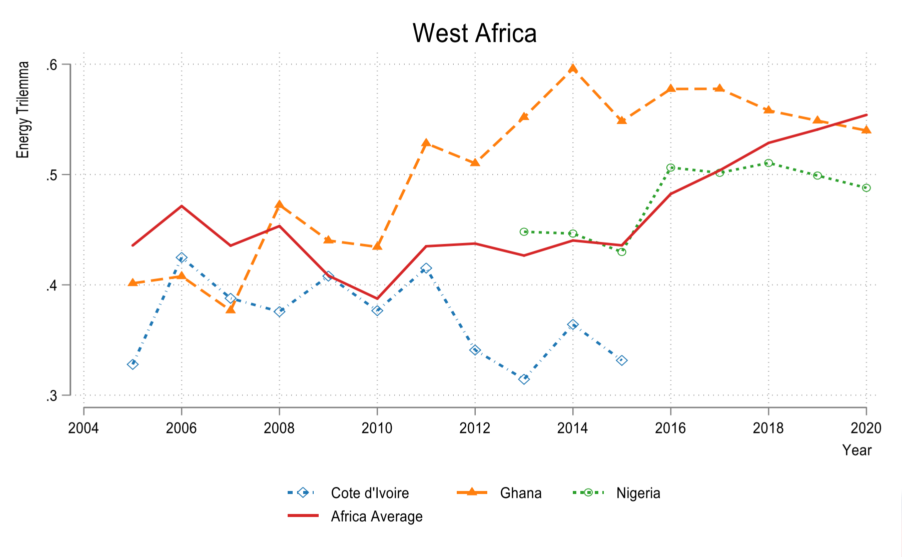


Figure 11: Energy Trilemma Index for Oil-producing West African Countries
Source: Author (2022)

The trend has shown that proper petroleum rent and natural resource endowment influence sustainable energy development. It is evident that Ghana and Cameroon are countries that have shown a considerable increase in energy security performance from 2013 to 2020 in their ability to meet current and future energy demands whiles withstanding and responding to system shocks.

In Central and Middle Africa, countries such as Gabon and the Democratic Republic of Congo performed below the African average in terms of energy security for the period 2013 to 2020. In West Africa, Nigeria and Cote d'Ivoire are low performers of indicators that constitute energy security.

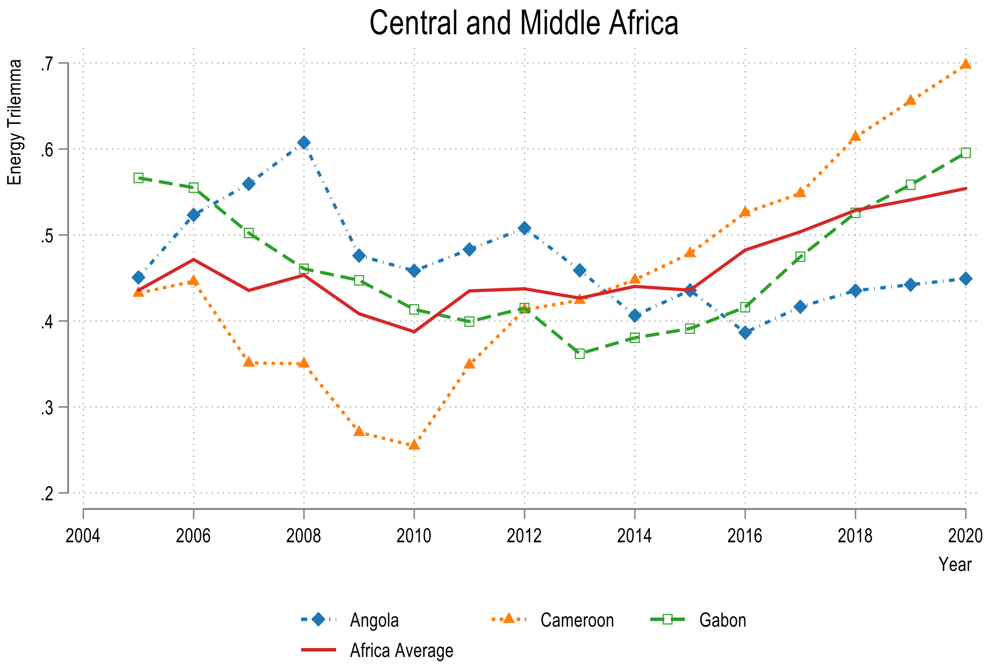
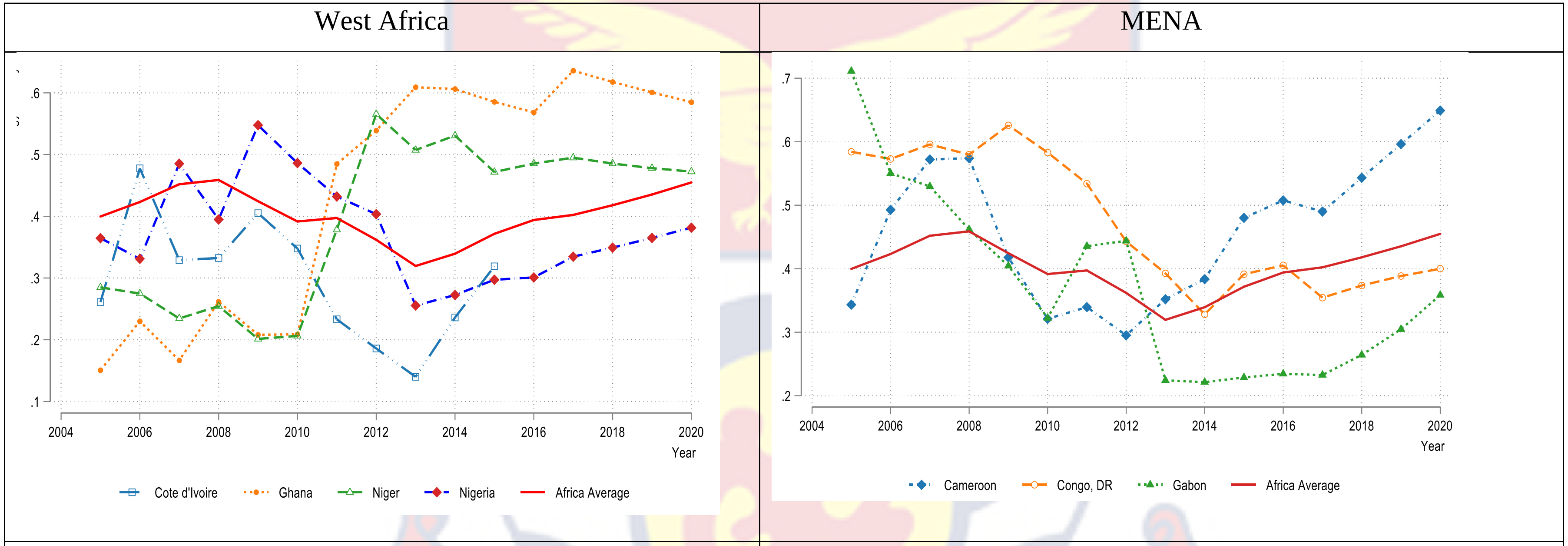


Figure 12: Energy Trilemma Index for Oil-producing Central Middle African Countries
Source: Author (2022)

It implies that these countries have low net energy import dependency levels, higher values of domestic energy consumption to production ratio, and high-power transmission and distribution losses. Net energy import dependency is considerably low and sometimes even negative (implying exporting the excess) in petroleum resource-rich countries.

A very different equity story emerges from analyzing historical trends in performance. Reflecting success against SDG7 indicators, all oil-producing economies except Chad have remarkably improved in Equity since 2005. Looking at the indexed trends, many of these countries have improved their



West Africa

MENA

(a)

(b)

Figure 13: Trend in Energy Security Index of Oil-Producing African Countries

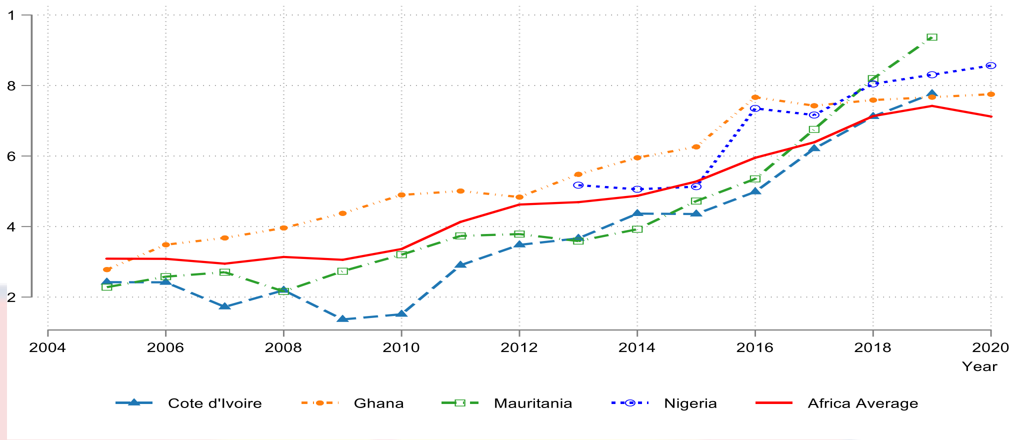
Source: Author (2022)

Equity performance by emerging from 30% to above 80% for the period 2005 to 2020 (see Figure 13 (a) and (b)).

Increased energy equity index implies that countries have high levels of electricity access, access to clean cooking fuels like LPG, and prices of energy services such as electricity and transport fuels like gasoline and diesel prices are kept relatively lower. Much Equity success can be explained by geography and population distribution factors. Cameroon, in Central and Middle Africa, emerged from low performance (12.86%) to become the highest in 2020 in terms of performance in energy equity (see Figure 14). Abundant domestic fuel reserves, albeit traditional hydrocarbons, explain the strong placing of countries such as Nigeria, Ghana, and Cameroon in the Equity top three. Revenues from crude oil and gas mean that road fuels tend to be sold in these countries at near production cost prices. All other things being equal, societal norms suggest that even these countries with significant oil production will tend to have similarly low-cost transport fuels with some of the lowest regional prices.

Hydrocarbon abundance affects power generation and subsequently causes cheap energy services such as low electricity tariffs. The benefit of abundant and low-cost energy is that it does support industrialisation, but to some level, it discourages energy efficiency if not well managed. Hydrocarbon-rich nations in petroleum production tend to have high emissions and energy intensities, reflected in their relatively poor performance on the Sustainability dimension, especially in Nigeria.

(a)



(b)

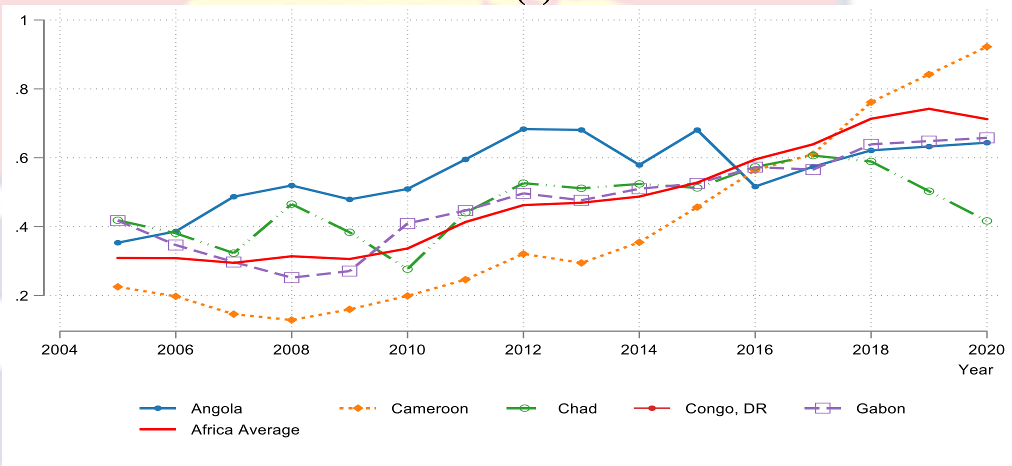
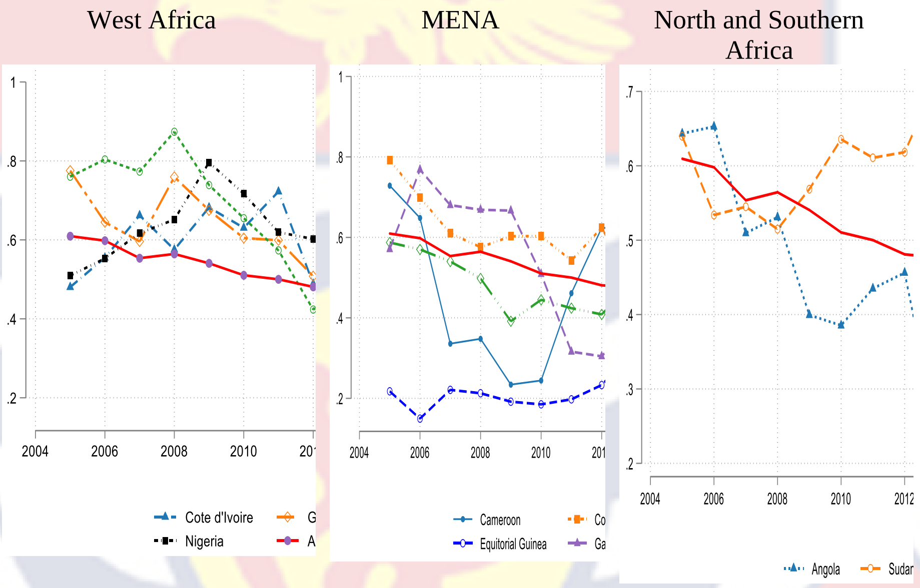


Figure 14: Trend in Energy Equity of Oil-producing African Countries
Source: Author (2022)

As shown in Figure 15, a downward trend is observed in the average performance of oil-producing economies in Africa on the environmental sustainability dimension of the energy trilemma index. The poor performance of these countries in the environmental sustainability of energy systems reflects their negligence in moving towards a low-carbon economy by increasing renewables in their energy mix, reducing greenhouse gas emissions, and improving air quality. In response to the Paris Agreement, Equatorial Guinea, Gabon, and the Republic of Congo are prominent performers in this dimension. All oil-producing West African countries have performed below the African average in the sustainability dimension.

In summary, the forgone discussions show that, on average, over the period for the study, oil-producing African economies have experienced a complex balance in addressing the challenging triad. It is worth noting that the future performance of the 2020-performing countries in the energy equity index will be closely linked with the success of their effort to diversify power generation and improve the long-term sustainability of their energy systems.


West Africa

MENA

North and Southern Africa

(a) (b) (c)

Figure 15: Trend in Environmental Sustainability of Energy Systems of Oil-producing African Countries
Source: Author (2022)

The future is bleak as oil-producing African countries are slowly responding to the energy transition agenda of shifting to lower carbon or carbon-free energy. Index rankings provide comparisons across countries on each of the three dimensions, while historical indexed scores provide insights into the performance trends of each country over time.

VERITAS NOBIS LUMEN

Descriptive Statistics

To analyse the relationship between petroleum rent, income, and energy trilemma index, the descriptive statistics of relevant variables used in the models are presented in Table 9. Relevant information on skewness and kurtoses supports the study to determine whether the regressors are normally distributed. Skewness measures the degree of asymmetry of the series. A normally skewed series is zero skewed and thus has a distribution that is symmetric around its mean.

Positive skewness has a long right tail indicating higher values above the sample average. Negative skewness indicates a long-left tail with lower values below the sample average. Kurtosis measures the peakness and flatness of the series. A leptokurtic series has a positive kurtosis (peaked-curve). Thus, it has higher values of that series above the sample average. The platykurtic series has a negative kurtosis (flatted-curve). It has lower values below the sample average. If the series is mesokurtic, it means it embodies a normal distribution with a kurtosis of three. A normally skewed series is zero skewed and thus has a distribution that is symmetric around its mean (Guo, Wang, Townend & He, 2019).

Over the sample period and across countries, the energy trilemma index averaged 0.46, ranging from 0.255 to as high as 0.698, with a standard deviation of 0.0861. The energy trilemma index mirrors a normal distribution since the skewness value is 0.205. A kurtosis value of almost three (2.903) suggests that the energy trilemma index series is mesokurtic (embodies a normal distribution).

Table 9: Descriptive Statistics

Variables	Mean	Std	Min	Max	Skewness	Kurtosis
Energy Trilemma (index from 0 to 1)	0.46	0.0861	0.255	0.698	0.205	2.903
Energy Security (index from 0 to 1)	0.402	0.139	0.0567	0.772	0.055	2.409
Energy Equity (index from 0 to 1)	0.495	0.193	0.129	1.055	0.245	2.694
Environmental Sustainability (index from 0 to 1)	0.503	0.169	0.148	0.88	-0.141	2.344
Petroleum Rent (% of GDP)	6.21	9.63	0.00	41.84	1.93	6.14
GDP per capita (1000 US$)	6.67	7.99	0.78	41.25	2.621	9.635
Policies & Inst. on Environmental Sustainability (index from 1 to 10)	2.956	0.543	2	4	0.176	2.325
Transparency, Accountability & corruption (index from 1 to 10)	2.547	0.57	1.5	4	0.432	3.173

Source: Author (2022)

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Though energy security, energy equity, and environmental sustainability indices resemble a normally distributed curve, they all exhibit platykurtic (flatted curve). They are positively skewed (long-right tail). Thus, there are higher values above the sample mean.

In relation to the key variables of interest, the petroleum rent averaged 6.21% over the sample period. Petroleum rent is found to be positively skewed, suggesting that high petroleum rent across oil-producing African countries is largely a recent phenomenon. It can be attributed to the new discoveries and production of hydrocarbons offshore Gulf of Guinea and onshore. As well the positive skewness portrays that recent hikes in petroleum rent can also be a result of expansion in global economic activity, culminating in an increase in the demand for crude oil for industrialization and transportation purposes and hence an increase in petroleum rent.

Over the sample period and across countries, GDP per capita (in billion) averaged US$ 6,665.00, varying between US$ 779.00 and US$ 41,249.00. The degree of variability is witnessed by the standard deviation depicting 7,987.00 deviations from its mean on average. The data for this variable is positively skewed, with the value of skewness standing at 2.621 and leptokurtic with excess kurtosis of 9.6635.

The leptokurtic characteristic observed suggests that the distribution of GDP per capita across countries and over time features heavy tails, whereas the former suggests that positive deviations from the mean tend to be more dispersed than negative deviations. Overall, positive skewness and excess kurtosis collectively result in a non-normal distribution.

Countries' rating of policies and institutions on environmental sustainability is measured as a flow variable from 1 to 10 ratings. It takes on a value of 2.96 on average across countries and over time. Assessing the extent to which environmental policies foster the protection and sustainable use of natural resources and the management of pollution, the rating varies dramatically in the sample of country and years, ranging from a value as low as 2 to 4. The rating also deviates from the mean by 0.54, as indicated by the standard deviation. Slight positive skewness of 0.176 and large excess kurtosis (48.2372) lead to the rejection of no normality in the rating variable.

Over the sample period and across countries, the transparency accountability and corruption rating averaged 2.547, ranging from 1.5 to as high as 4 with a deviation of 0.57. It mirrors a normal distribution since the skewness value is 0.432. The kurtosis value of 3.173 is almost three, suggesting that the series is mesokurtic (i.e., embodies a normal distribution).

Correlation Analysis

Pearson correlation coefficients among the variables are presented in Table 10. The correlation analysis sought to investigate the existence of an exact or perfect relationship among the regressors. A correlation statistic of 0.8 and above between the explanatory variables is evidence of a linear relationship between the variables (Schober, Boer, & Schwarte, 2018). In this case, such regressors are not supposed to be included in the same model to avoid multicollinearity. It is shown that all the regressors do not show any exact dependence.

Table 10: Coefficients of Correlation

Variables	ETI	ESI	EEI	EnvSI	PR	GDP	PIES	TAC
ETI	1							
ESI	0.4569	1						
EEI	0.5287	0.3422	1					
EnvSI	0.2284	-0.2877	-0.4376	1				
PR	0.243	-0.0048	0.3224	-0.1405	1			
GDP	0.2128	0.1911	0.4709	-0.3982	0.4476	1		
PIES	0.3137	0.3593	0.3928	-0.0374	-0.2637	-0.2758	1	
TAC	0.1651	0.0174	0.2991	0.0515	-0.229	-0.1443	0.3191	1

Note: ETI, ESI, EEI, EnvSI, PR, GDP, PIES, and TAC, respectively, represent Energy Trilemma, Energy Security, Energy Equity, Environmental Sustainability, Petroleum Rent (% of GDP), GDP per capita (US$), Policies & Inst. on Environmental Sustainability and Transparency, Accountability & corruption (indices).
Source: Author (2022)

Heterogeneity and Cross-sectional Dependence

The heterogeneity test using Pesaran and Yamagata (2008) and (Blomquist and Westerlund, 2013) is presented in Table 11. Evidence proved that there exist homogenous coefficient estimates across the sample since the study failed to reject the null hypothesis of homogeneous slope coefficients at 5% level of significance.

In addition to demonstrating homogeneity across sections, the study used the Breusch and Pagan (1980) Lagrange multiplier (LM) test to determine cross-sectional independence. The results presented in Table 12 of the LM test show that the null hypothesis of cross-sectional independence cannot be rejected since the p-values are above the 5% level. Therefore, it can be concluded that there is no cross-sectional dependence in the analysed panel data.

Table 11: Pesaran and Yamagata (2008) Slope Homogeneity Tests

Test	Energy Trilemma		Environmental Sustainability		Energy Security		Energy Equity	
	Statistics	α	Statistics	α	Statistics	α	Statistics	α
$\tilde{\Delta}$	-0.158	0.875	3.251	0.115	3.507	0.301	3.997	0.091
$\tilde{\Delta}_{adj}$	-0.219	0.826	4.206	0.119	4.682	0.181	5.329	0.106
Δ_{HAC}	-0.925	0.355	6.889	0.201	1.783	0.099	0.526	0.599
$(\Delta_{HAC})_{adj}$	-1.287	0.198	8.913	0.199	2.380	0.109	0.702	0.483

Note: $\tilde{\Delta}$ test and $\tilde{\Delta}_{adj}$ test denote the slope homogeneity tests proposed by Pesaran and Yamagata (2008).

Source: Author (2023)

Table 12: Breusch-pagan Test Cross-sectional Dependence

Test	Energy Poverty		Energy Access		Clean Cooking Fuel		Primary Energy Supply	
	$\chi^2(36)$	α	χ^2	α	$\chi^2(36)$	α	χ^2	α
CD_{LM}	511	0.189	320.021	0.223	315.612	0.419	311.214	0.211

Note: χ^2 denotes chi-squared and α is the level of significance.
Source: (Author, 2023)

The study can go ahead and estimate the first-generation panel unit root test since the panel data is homogenous in slope coefficients and cross-sectionally independent.

Panel-Unit-Root Test

The study employed several first-generation unit root tests due to their differences in assumptions, strengths, and weaknesses underlying their specification. The unit root tests conducted include the Im, Pesaran, and Shin W-stat test (IPS) and Levin, Lin & Chu test (LLC). The IPS assumes that the slopes are heterogeneous, whiles the LLC assumes homogenous slopes. As shown in Table 13, we discovered that the variables' levels of integration are varied. While some series are integrated of order 0 (I (0)), others are integrated of order 1 (I (1)).

Instead of using the static or panel cointegration test, the study proceeds to apply the panel-ARDL technique (Pesaran, 1997; Pesaran et al., 1999, 2001; Phillips & Perron, 1988) because there are mixed levels of integration among the series (Asteriou & Monastiriotis, 2004). The panel-ARDL approach is distinguished for its variety of benefits and makes possible the estimation of various variables with various orders of stationarity. Additionally, the panel-ARDL estimators enable us to estimate the error correction coefficient as well as both short-run and long-run relationships.

Table 13: First Generation Panel-Unit Root Test

Variable	**Levels**		**First difference**		**Level of Integration**
	IPS	**LLC**	**IPS**	**LLC**	
Energy Trilemma Index	-0.336		-3.616***		I (1)
lnGDPpc	0.541	-2.109**	-2.167**	-1.419*	I (0)
lnPetroleumRent	-1.692**	-5.453***	-4.469***	-3.602***	I (0)
Policy_Env_Sustainabilit	1.362	0.495	-3.810***	-4.001***	

Note: ***, ** and * denotes significance at the 1%, 5%, and 10% respectively, scale. - Levin, Lin & Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS). - Values in parentheses are p-values.
Source: Author's Computation (2022)

Test for cointegration is not conducted since it can be inferred from the ARDL model. Cointegration is determined by the statistical significance of the long-run coefficients and the error correction term. Using the PMG, GM, and DFE, one may deduce cointegration from the statistical significance of the long-run coefficients and the error term in the panel ARDL model.

Effect of Petroleum Rent and Income on the Energy Trilemma

The goal of the Index is to provide insights into a country's relative energy performance with regard to Energy Security, Energy Equity, and Environmental Sustainability of energy systems. In doing so, the Index highlights a country's challenges in balancing the dimensions of the energy trilemma and opportunities for improvements in meeting energy goals now and in the future as provided by the SDGs, African Union Agenda 2063, and respective national sustainability policies. The drivers of the Index will inform policy-makers, energy leaders, and the investment and financial sector in making critical decisions with respect to sustainable energy development and petroleum resource management.

The study makes an attempt to establish if long-run improvement in energy trilemma can be fostered by petroleum rent and income in 8 oil-producing African countries. Table 14 presents the results of panel ARDL/PMG models for the energy trilemma index as dependent variables with petroleum rent and income as well as countries' ratings in policies and institutions on environmental sustainability and corruption, transparency, and accountability as independent variables.

Table 14: PMG-ARDL Estimation of Effect of Petroleum Rent and Income on Energy Trilemma Index

Variables	Coefficients	Standard errors
Long-run		
$lnGDP_{pc}$	-0.178*	(0.107)
$lnPetroleum\_Rent$	0.001	(0.011)
$Policy\_Env\_Sust$	-0.023***	(0.008)
$Corruption\_Account$	-0.002	(0.021)
Short-run		
ECT	-0.762***	(0.293)
$lnGDP_{pc}D1.$	0.424	(0.447)
$lnPetroleumRentD1.$	0.025*	(0.013)
$Policy\_Env\_SustD1.$	-0.017	(0.019)
$Corruption\_AccountD1.$	0.017	(0.044)
Constant	1.539***	(0.562)
Observations	57	

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Author (2022)

The results of the model provide both short-run and long-run effects of petroleum rent on improving sustainable energy (i.e., energy trilemma index – keeping the balance between environmental sustainability, energy security, and energy equity). The PMG estimates are appropriate over DFE and MG models (see Appendix C) by checking for the statistical appropriateness of the respective estimators using the Hausman test.

The results of the Hausman test show that the null hypothesis of consistency and efficiency of the PMG cannot be rejected relative to the benchmark DFE and MG estimator. The PMG is found to be consistent. Hence, we conclude that the PMG is the preferred model specification in the context of the relationship between petroleum rent, income and the energy trilemma index (sustainable energy performance) in oil-producing African countries.

Testing the null hypothesis that the PMG estimator is efficient and consistent shows that the p-value of the Chi-square (2.97) is 0.8 for MG and

DFE, greater than 0.05, meaning the null hypothesis cannot be rejected, implying that PMG is a more efficient estimator than MG and DFE.

Results of the ARDL/PMG estimates show that the short-run (SR) error correction (ECT) term is -0.762 and significant at a 5% level. It implies that deviations from long-run equilibrium in the model are corrected at 76.2% adjustment speed, and thus, there is a long-run cointegration. GDP per capita and environmental sustainability policies are found to have a significant negative effect in explaining variations in the energy trilemma index of oil-producing African countries in the long run. It is also found that petroleum rent does not significantly influences sustainable energy performance positively in the short run.

Increasing petroleum rent by 1% is associated with an increase in the energy trilemma index by 0.0003% (i.e., 0.025/100) in the short run. The long-run effect of petroleum rent on the energy trilemma is positive but not significant. An increase in GDP per capita by 1% adversely affects the performance of oil-producing African countries on keeping a balance between ensuring environmental sustainability, making energy secured, and ensuring energy equity by 0.002% (i.e., 0.178/100) in the long run. With regards to how countries' ratings in terms of their performance in policies and institutions on environmental sustainability affect energy trilemma, we also found a significant adverse relationship. An increase in a country's rating on environmental sustainability rating by one point is associated with a decrease in energy trilemma by 0.023 points. It implies that oil-producing African economies are not strengthening and establishing the institutions and policies in environmental sustainability enough to drive sustainable energy performance.

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The significant short-run effect of petroleum rent on the energy trilemma index implies petroleum rent is spent on goods and services, which has an immediate effect. These goods and services, including reducing prices and tariffs through tariffs and resorting to cheap deals in power generation through expensive power plants from independent power producers, have an immediate effect on improving energy equity and increasing the trilemma index. In the long run, petroleum rent’s effect on the energy trilemma index is positive but weak, confirming the fact that more capital investments are not being made to improve sustainable energy development in oil-producing African countries.

Effect of Petroleum Rent and Income on Dimensions of Energy Trilemma Index

The study investigated, in separate models, the effect of petroleum rent and income on the dimensions of energy trilemma, such as energy security, energy equity, and environmental sustainability of energy systems. In the environmental sustainability model, the Hausman tests suggest that the PMG estimates are appropriate over DFE and MG models (Appendix A). The decision was arrived at by checking for the statistical appropriateness of the respective estimators using the Hausman test.

The environmental sustainability of energy systems as a dimension of the energy trilemma index represents the transition of a country’s energy systems towards mitigating and avoiding potential environmental harm and climate change impacts. The dimension focuses on productivity and efficiency of generation, transmission and distribution, decarbonisation, and air quality. It is revealed that petroleum rent and GDP per capita have a significant positive effect on environmental sustainability in energy systems. This finding is in line with Bekun et al. (2019), who found that it is desirable for the exploration of natural resources to trigger economic growth directly and subsequently spur increased CO_2 emissions. However, countries' ratings on corruption, transparency, and accountability have a significant negative influence on environmental sustainability.

To elaborate, an increase in petroleum rent by 1% is associated with an increase in the energy sustainability index, on average, by 0.0027 points (i.e., 0.265/100) in the long run. Thus, the finding shows that petroleum rent has a significant positive effect on environmental sustainability, which opposes the study by Ulucak, Danish and Ozcan (2020) in OECD nations, Hassan et al. (2021) for Pakistan, Tufail et al. (2021) for developed nations, Khan et al. (2021) for the United States, Dagar et al. (2021) for the 38 OECD countries. Arslan et al. (2022) have a similar direct relationship between natural resource rent and environmental sustainability in China. The result of the current study is also partly in line with the findings by Baloch et al., 2020 who found that natural resources mitigate CO_2 emission in Russia but contributes to pollution in South Africa. The current direct relationship portrays that oil-producing African economies are able to translate rich oil resources into mitigating and avoiding potential environmental harm and climate change impacts.

In Table 15, it is shown that increasing GDP per capita by 1% is associated with increased environmental sustainability of energy systems by 0.0087 points (i.e., 0.866/1000). Increasing petroleum rent has a direct effect on GDP. As a result, the per capita income of oil-producing economies is found to improve the environmental sustainability index but with greater magnitude. An

Table 15: Panel ARDL Estimation of Petroleum Rent and Dimensions of Energy Trilemma Index

Variables	**Environmental Sustainability**	**Energy Security**	**Energy Equity**
Lon-run			
$lnGDP_{pc}$	0.866***	-0.186***	0.488***
	(0.187)	(0.027)	(0.071)
$lnPetroleumRent$	0.265***	0.021***	0.124***
	(0.058)	(0.003)	(0.022)
$Policy\_Env\_Sust$	-0.127	-0.037***	-0.137***
	(0.099)	(0.008)	(0.041)
$Corruption\_Account$	-0.254**	-0.005	-0.008
	(0.102)	(0.032)	(0.110)
Short-run			
ECT	-0.207**	-0.559***	-0.303*
	(0.103)	(0.210)	(0.236)
$lnGDP_{pc}D1.$	0.365	0.725	-0.418
	(0.670)	(0.808)	(0.580)
$lnPetroleumRentD1.$	-0.008	0.001	-0.012
	(0.013)	(0.015)	(0.018)
$Policy\_Env\_SustD1.$	-0.057	-0.026	0.012
	(0.042)	(0.029)	(0.031)
$Corruption\_AccountD1.$	0.054	0.046	-0.001
	(0.058)	(0.057)	(0.026)
Constant	-4.254**	2.756***	-3.752
	(2.165)	(1.045)	(2.852)
Observations	139	114	89

Standard errors in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$
Source: Author's Computation

increase in corruption by a point result in a decrease in the environmental sustainability dimension of the trilemma, on average, by 0.254 points, in the long run, ceteris paribus.

Oil-producing African economies have failed to translate their progress in the rating on transparency, accountability, and corruption in the public sector into improving the environmental sustainability of energy systems. Thus, corruption is detrimental to sustainable energy development in oil-producing countries in Africa. The ratings measure the extent to which the executive can be held accountable for its use of funds. It also expresses the results of the actions of the electorate, the legislature, and the judiciary in the use of resources. The direction of influence of the corruption variable shows that the rating is not supporting oil-producing economies in Africa in terms of mitigating and avoiding environmental consequences in the production and utilisation of energy.

The ensuing discussions begin with the energy security model. We found in the energy security model that the PMG estimates are preferred over the DFE and MG models. The choice of PMG is arrived at by checking for the statistical appropriateness of the respective estimators using the Hausman test (see appendix C).

The energy security dimension of the energy trilemma reflects how countries have progressed on indicators such as net energy imports, the ratio of energy consumption to GDP, the ratio of energy production to consumption, and electric power transmission and distribution losses. The results show that the effect of petroleum rent has a significant positive effect on energy security in the long run, whereas income per capita and institutional quality are revealed to have a significant adverse effect on energy security in the long run. One percent increase in petroleum rent results in an increase in energy security, on average, by 0.0002 points in the long run and vice versa. Petroleum rent is therefore playing an instrumental role in improving energy security in oil-producing African economies.

Thus, these countries' capacity to be reliable, meet current and future energy demand, and withstand and bounce back swiftly from system shocks with minimal disruption to supplies is being improved through increases in petroleum rent. Improvement in per capita income by 1%, on average, is found to decrease energy supply security in the long run. Similarly, an increase in country's performance on policies and institutions on environmental sustainability by 1 point reduces energy supply security by 0.037 points. The income per capita and environmental sustainability policies are not positively supporting oil-producing African economies in ensuring energy supply security.

It is imperative to also relate petroleum rent and relevant variables to a country's ability to provide universal access to reliable, affordable, and abundant energy for domestic and commercial use. Petroleum rent and income have a significant positive effect on energy equity, whereas environmental sustainability policies and institutions' ratings have an adverse effect on energy equity.

As presented earlier in Table 15, a rise in petroleum rent by 1% leads to an increase in energy equity by 0.0012 points, on average, in the long-run, ceteris paribus. Most oil-producing countries are in a better position to invest petroleum rent into improving access to electricity, access to clean cooking fuels, generating cheap power, thereby making electricity tariffs affordable, creating a domestic gas market, thereby making the price of LPG affordable and refining crude oil locally to sell diesel and gasoline at affordable prices. These, in effect, guarantee the positive relationship between petroleum rent and energy equity. A rise in income by 1% increases energy equity by 0.0049 points, on average, in the long run. It corroborates with the energy ladder hypothesis. A rise in the environmental sustainability policies and institutions results in a decrease in energy equity by 0.137 points. It implies policies targeting environmental sustainability are not being able to improve energy equity in oil-producing African countries.

Discussions

Petroleum rent is found to have a significant positive effect on the energy trilemma index and its dimensions, such as environmental sustainability, energy security, and energy equity, in the long run. Increasing Petroleum rent and GDP per capita are found to significantly increase energy security through import dependency, whereas carbon dioxide emissions decrease energy security.

The study proffers setting up an African energy system to deal with the new paradigm in the energy management landscape as a blueprint for securing the energy future of the continent. The study applied the panel-ARDL model by choosing between PMG, MG, and DFE based on the Hausman Test for consistent efficiency of estimators. The model to analyse the effect of petroleum rent on sustainable energy production and consumption reveals a positive and significant relationship. Petroleum rent is revealed to have a positive and significant effect on the energy trilemma and its dimensions as a measure of sustainable energy performance in oil-producing African countries in the short run. Indeed, petroleum rent sets a good source of funding that can support oil-producing African countries in managing and improving sustainable energy performance.

A negative long-run effect of income per capita on the energy trilemma index reflects the fact that GDP per capita limits countries' performance in balancing the energy trilemma index. Thus, income is a hindrance to sustainable energy development. Most countries, especially hydrocarbon-rich African economies, are yet to begin responding to concerns of climate change and hence, environmental suitability. Just like China has kept to the use of coal and is among the high emitters of CO_2, oil-producing African countries are also most likely to rely on petroleum, thereby delaying the transition and subsequently contributing to the non-attainment of the targets set in the Paris Agreement.

As explained by previous scholars using the EKC hypothesis, income (GDP per capita) is found to have adverse effect on sustainable energy performance (i.e., energy trilemma index). Contrarily, environmental sustainability and energy equity dimensions of the energy trilemma index are found to be influenced by income positively. Increasing income per capita of countries has a significant effect on the energy security dimension in the short run but an insignificant positive effect on energy security in the long run.

The country’s rating in oil-producing African countries in terms of policies on environmental sustainability is found to significantly influence the energy trilemma index negatively in the long run. In the short run, except for petroleum rent, none of the variables were significant in explaining variations in energy trilemma. An increase in petroleum rent by 1% results in an increase in the energy trilemma index 0.0002%.

Summary

The results obtained in this study clearly show that its purpose was achieved as the result of the study revealed that petroleum rent and income have

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a differential effect on the energy trilemma, its dimensions, and indicators. The study has provided evidence that petroleum rent presents a big opportunity for oil-producing African countries in terms of solving problems with the dimensions of the energy trilemma index. Petroleum rent and income are found to have a differential effect on the dimension of the energy trilemma index depending on whether it is short-run or long-run.

Petroleum Rent, Income and Energy Poverty

Extant literature on energy poverty has dwelled so much on cross-sectional data with a focus on microeconomic analysis, leaving some gaps in cross-country and regional-level analysis over time. There have not been studies examining the role of petroleum rent in reducing energy poverty in oil-producing African countries. This current study fills this gap in the literature and adds to knowledge in petroleum and energy economic analysis in Africa and elsewhere. The study constructed a panel data set for a macro analysis using the panel ARDL approach. In this regard, the section presents results and discussions on the effect of petroleum rent on energy poverty in oil-producing African economies. The study establishes the effect of rent and GDP on energy poverty indicators and the composite index. The section first presents a trend analysis of the energy poverty index constructed using an additive index, descriptive statistics of the variables of interest to the study, a correlation matrix, and then the empirical results.

Energy Poverty Index of Oil-producing African Countries

The energy poverty index is constructed from three indicators: access to electricity, clean cooking fuels and energy supply per capita. Figure 16 shows

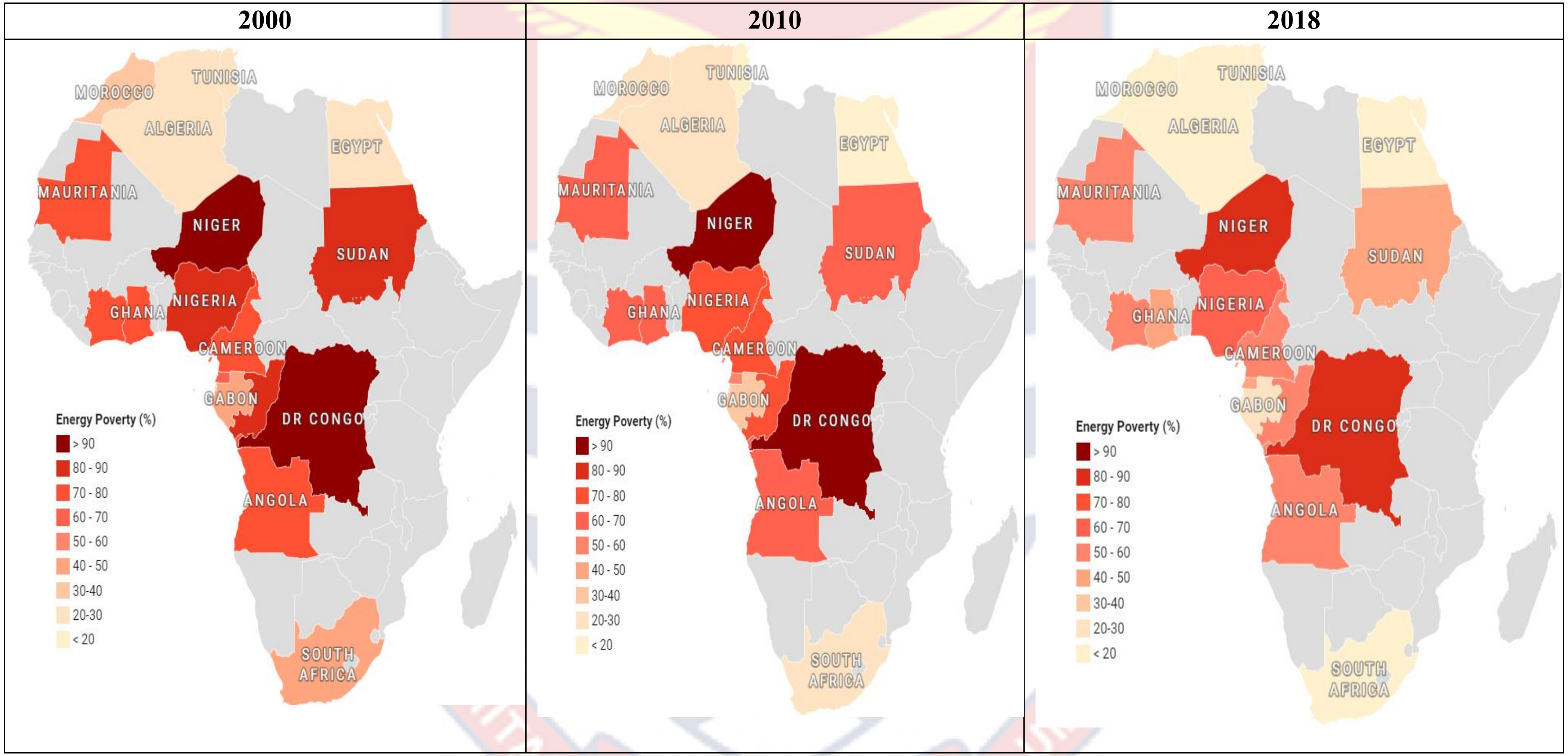

Figure 16: Energy Poverty Index in Oil-Producing African Countries from 2000 to 2018

Source: Author (2022)

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that energy poverty has decreased over the years. Energy poverty levels shown by the intensity of the colour have faded from 2000 to 2018, indicating a reduction in energy poverty over time. Mauritania and South Africa look less intense in colour over the years depicting that these countries are becoming less energy poor. Niger and the Republic of Congo are triple burdened in energy poverty with very low access to electricity, low access to clean cooking fuels and low energy supply per capita.

There is a wide gap in energy poverty indices in Oil-producing African countries. This creates doubts about the relevance of how petroleum wealth translates into improving energy access in oil-producing African countries. It is important to establish the effect of petroleum rent on access to energy. The impression these maps present is that just enjoying rent from exploration of petroleum resources in a country does not guarantee that energy access is improved. Reasons for this gap can be attributed to differences in economic rent from petroleum resources, economic growth, and strategic resource management policies.

Specifically, North African oil-producing countries do better in energy poverty than their counterpart, oil-producing economies in Africa (see Table 16). The first four countries with the lowest energy poverty index are in North Africa. Tunisia is the best-performing oil-producing African country which has consistently reduced energy poverty from as low as 93.3% in 2000 to 10.4% in 2018. It is followed by the Arab Republic of Egypt, Morocco, and Algeria, with an energy poverty performance of 10.7%, 11.2%, and 13%, respectively, in 2018.

Table 16: Tend in Energy Poverty and its Indicators in Oil-producing African Countries

	2000				2008				2018			
Country/Sub-region	**ACCF**	**EA**	**PESpc**	**EP**	**ACCF**	**EA**	**PESpc**	**EP**	**ACCF**	**EA**	**PESpc**	**EP**
Central Africa												
Cameroon	9.9	41	14	79.5	15.9	50.5	11.0	70.3	23.0	62.7	11.0	54.9
Congo, Dem. Rep.	3.6	6.7	2.5	95.8	3.7	11.5	1.9	91.1	21.2	19.0	1.8	84.0
Congo, Rep.	10	21.3	200.0	87.5	15.7	38.1	130.0	75.5	20.2	68.5	150.0	53.8
Equatorial Guinea	23.0	70.8	550.0	62.5	28.8	67.4	1100.0	52.2	6.6	67.0	440.0	49.7
Gabon	58.7	73.6	560	47.1	71.1	82.7	360.0	36.2	62.5	93.0	210.0	24.4
Northern Africa												
Algeria	86.5	97.6	2.6	25.1	92.1	98.6	2.1	21.6	100	100	11	13.0
Egypt, Arab Rep.	83.3	97.7	37	27.6	94.6	99.8	48.0	16.3	100	100	39	10.7
Morocco	89.7	69.7	0.4	36.3	94.9	85.3	0.5	23.0	100	100	1.7	11.2
Sudan	14.2	23	13	85.1	25.4	38.9	27.0	68.9	47.1	59.8	5.1	47.8
Tunisia	93.3	94.8	25	23.5	97.9	99.4	28.0	15.8	99.6	99.8	12.0	10.4

Table 16 (continued)

	2000				2008				2018			
Country/Sub-region	**ACCF**	**EC**	**PESpc**	**EP**	**ACCF**	**EA**	**PESpc**	**EP**	**ACCF**	**EA**	**PESpc**	**EP**
Southern Africa												
South Africa	56.4	71.8	110.0	48.4	73.4	81.9	120.0	29.0	89.6	91.2	100.0	19.6
Angola	37.3	14.9	99.0	79.1	42.6	31.3	190.0	66.4	100	43.3	120	53.3
West Africa												
Cote d'Ivoire	18.4	47.6	5.6	71.7	18.6	55.8	10.0	67.7	32.9	67.0	7.2	55.8
Ghana	5.9	43.7	4.3	78.9	12.1	60.5	3.1	68.8	67.3	82.4	15.0	47.3
Mauritania	29.0	22.8	0.1	79.3	37.8	30	8.5	69.5	0.6	44.5	0.9	54.0
Niger	1.0	6.5	0.3	96.9	1.4	11.7	0.2	92.7	11.7	17.6	1.4	82.4
Nigeria	0.8	42.9	42.0	81.5	2.0	50.3	40.0	75.1	31.0	56.5	30.0	65.0

Note: ACCF, EA, PESpc, and EP, respectively, represent Access to Clean Cooking Fuel, Electricity Access, Primary Energy Supply per capita, and Energy Poverty.
Source: Author (2022)

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The tremendous improvement in energy poverty scores of oil-producing countries reflects their high performance in access to electricity, access to clean and modern cooking fuels, and per capita supply. Democratic Republic of Congo, Niger, and Nigeria are the least-performing countries in the energy poverty index, with 84%, 82.4%, and 65%, respectively.

As Africa’s biggest economy with a GDP of US$ 432.3 and the biggest hydrocarbon-rich nation, Nigeria still has 65% of its population being energy poor. Only 56.5% of the Nigerian population has access to electricity, and 31% have access to clean cooking fuel. It can be inferred from the map that Nigeria's abysmal performance sets doubts about whether petroleum resource development in Nigeria plays a significant role in reducing energy poverty.

One of the emerging petroleum economies in Africa, Ghana, is doing quite well compared to the giant economy in Africa, Nigeria. The energy poverty index in Ghana reduced from 78.9% in 2000 to 47.3% in 2018. The reduction can be attributed to improved access to electricity (82.4%) and access to clean cooking fuels (67.3%).

Among the regions, the North African countries, especially Tunisia, Egypt, and Morocco, performed tremendously in reducing energy poverty, whiles Central African and West African countries performed poorly. In West Africa, as of 2018, the majority (82%) of the population was still energy poor. In Central Africa, the Democratic Republic of Congo still has a majority (84%) of the population being energy poor.

Descriptive Statistics

This section provides a description of the data on the key variables used in the models to examine the effect of petroleum rent and income on energy poverty and its indicators. A summary of the descriptive statistics of the variables is shown in Table 17. A panel dataset is constructed from 17 oil-producing African countries obtained for the period 2000 to 2018 to examine the effect of petroleum rent and income on energy poverty. The standard deviation of energy poverty and its indicators are large enough to explore variations in the data.

Table 17: Descriptive Statistics of Variables

Variable	Unit of Measurement	Obs.	Mean	Std. Dev.	Min	Max
Energy Poverty	Indices	323	0.539	0.255	0.104	0.969
Electricity Access	%		59.57	29.01	6.000	100
Access to Clean Cooking Fuel	%		43.32	35.01	0.840	99.24
Primary Energy Supply per capita	Indices		0.099	0.200	0.000	1.00
GDPpc	US$		3,031.55	3,535.72	153.59	22,942.60
Petroleum_Rent	% of GDP		6.094	9.354	0.000	41.839
Crude_Oil_Price	US$		63.79	29.02	23.12	111.57

Source: Author (2022)

Over the period, the energy poverty index in oil-producing African countries averages 53.9%, with a range of 10.4% and 96.9%. It implies that 46.1% of people in oil-producing African countries are energy poor. Over the period, there has been high inequality in access to electricity among oil-producing African economies. Some countries have 100% of their population with access to electricity, while others have as low as 6% of the population with access to electricity. The standard deviation of 29% provides enough variances among the countries over the years to explore the data to establish attributes of such variations.

The mean values obtained are good measures of central tendency, given that they all lie midway between the maximum and minimum values. Over the years, in oil-producing African countries, per capita GDP averaged US$ 3,031.55, ranging from US$ 153.59 to US$ 22,942.60, with a standard deviation of US$ 3,535.72. It implies that, even with the wealth of petroleum in some countries in Africa, some countries producing petroleum are still below the benchmark of US$ 1,000.00 to move out from a low-income economy as set by the World Bank.

The descriptive statistic also shows that oil rent in oil-producing African countries over the period averaged 6.09% of GDP, ranging from no rent to 41.84%, with a standard deviation of 9.35%. The zero percent of oil rent depicts periods when petroleum exploration is economically not viable in Africa in some countries listed in this study. During the period of zero rent, revenue from petroleum resource extraction was not beyond what could be considered a reasonable return on investment. Oil-producing African countries enjoyed a maximum oil rent of 41.89%, far above the current oil rent enjoyed by the oil giant nations such as the United States, Russia, Canada and the Republic of Saudi Arabia.

Crude oil prices averaged US$ 63.90 over the period and traded as high as US$ 111.57 and as low as US$ 23.12, with a very high standard deviation of US$ 29.02, depicting its volatility. In corroboration with stylized facts in petroleum economics, trend analysis presented earlier in the foregone section shows that crude oil price is highly correlated with petroleum rent. Petroleum

Economists have proven that world crude oil prices and oil rent are highly correlated (Fuinhas, Marques & Couto, 2015). As a result, multicollinearity is likely to disturb the energy poverty model if oil rent and crude oil price are included in the model at the same time.

Correlation Analysis

The correlation matrix in Table 18 is presented to investigate the existence of an exact or perfect relationship among the regressors. The correlation matrix shows no perfect correlation between the independent variables such as petroleum rent and GDP per capita, the energy poverty index and its indicator. Thus, the regressors are not linearly dependent on one another. It suffices to state that the models to examine the effect of petroleum rent and GDP per capita on energy poverty and its indicators will not suffer from multicollinearity.

Table 18: Correlation Matrix

Variables	**Abbr.**	**EP**	**EA**	**ACCF**	**PESpc**	**GDPpc**	**PR**
Energy Poverty	EP	1					
Electricity Access	EA	-0.9433	1				
Access to Clean Cooking Fuel	ACCF	-0.9451	0.8115	1			
Primary Energy Supply per capita	PESpc	-0.4346	0.4826	0.4102	1		
GDPpc	GDPpc	-0.7487	0.7385	0.6811	0.761	1	
Petroleum_Rent	PR	0.1368	0.023	-0.2879	0.0102	0.0224	1

Source: Author's Computation, 2022

The high correlation between the energy poverty index and the indicators (i.e., access to electricity, access to clean cooking fuels, access to electricity, access to clean cooking fuels, and energy supply per capita) used in constructing the index is expected.

Heterogeneity and Cross-sectional Dependence

Table 19 shows that there is enough evidence to conclude that there is slope homogeneity in the panel. The study failed to reject the null hypothesis at a 5% level of significance. Given that homogeneity exists across sample countries for the analysed variables, the homogenous panel estimation technique is applied in which the parameters do not vary across countries. Thus, all slope coefficients are identical across cross-sectional units.

Table 19: Pesaran and Yamagata (2008) Slope Homogeneity Tests

Test	**Energy Poverty**		**Energy Access**		**Clean Cooking Fuel**		**Primary Energy Supply**	
	Statistics	**α**	**Statistics**	**α**	**Statistics**	**α**	**Statistics**	**α**
$\tilde{\Delta}$	0.835	0.404	-0.777	0.437	0.706	0.480	0.836	0.403
$\tilde{\Delta}_{adj}$	1.023	0.306	-0.914	0.361	0.831	0.406	1.024	0.306
Δ_{HAC}	-0.404	0.686	0.030	0.976	-0.075	0.940	-0.063	0.950
$(\Delta_{HAC})_{adj}$	-0.495	0.621	0.035	0.972	-0.088	0.930	-0.077	0.939

Note: $\tilde{\Delta}$ test and $\tilde{\Delta}_{adj}$ test denote the slope homogeneity tests proposed by Pesaran and Yamagata (2008).

Source: Author (2023)

Aside from establishing the presence of slope homogeneity across sections, the study employed the Lagrange multiplier (LM) test for cross-sectional independence, developed by Breusch and Pagan (1980). The results presented in Table 20 show that there is cross-section independence. Given the p-value, the study failed to reject the null hypothesis of independent cross-sections against the alternative hypothesis of dependent cross-sections for the analysed panel dataset.

Therefore, the study employs the first-generation tests for panel unit roots since the first-generation tests assumed cross-sectional independence and homogeneity. Meeting the conditions of cross-sectional independence and homogeneity will produce efficient and accurate estimates by applying the first-generation test instead of the second and third-generation tests.

Table 20: Breusch-pagan Test Cross-sectional Dependence

Test	Energy Poverty		Energy Access		Clean Cooking Fuel		Primary Energy Supply	
	$\chi^2(36)$	α	χ^2	α	$\chi^2(36)$	α	χ^2	α
CD_{LM}	128	0.244	107.404	0.121	252.928	0.989	256.442	0.103

Note: χ^2 denotes chi-squared and α is the level of significance.
Source: (Author, 2023)

Panel Unit-Root Test

The study employed two different first-generation panel unit root tests; Pedroni, Im, Pesaran and Shin, Breitung and Levin Lin Chu, (1995) tests in order to determine the order of integration between all the series considered in establishing the relationships. These unit roots tests were employed due to their different assumptions proving their strengths and weaknesses. The IPS assumes that the slopes are heterogeneous, whiles the LLC assumes homogenous slopes. Noting that the order of integration of variables must not exceed I (1) when applying the ARDL model (Pesaran and Smith, 1995; Pesaran, 1997; Pesaran et al., 1999), we introduced these tests to make sure that no series exceeds the integration of order I (1) as shown in Table 21. The unit root tests show that variables of interest have non-stationary and stationary characteristics.

It is found that the variables have a mixture of levels of integration. Some are integrated of order zero, while others are integrated of order one. Thus, they are I (0) and I (1).

Among the six variables, two variables such as GDP per capita and petroleum rent, are stationary at levels using the LLC test, while one variable (i.e., GDP per capita) is stationary at levels using the IPS test. After first differencing, five variables are also stationary. Due to the existence of mixed levels of integration among series which do not exceed I (1), we proceed to apply the Panel ARDL approach (Phillips & Perron, 1988; Pesaran, 1997; Pesaran, Shin & Smith, 1999, 2001) rather than traditional static or panel cointegration test (Asteriou & Monastiriotis, 2004) to establish the long-run relationship in the series.

Table 21: Panel Unit Root Test Results

Variable	**Levels**		**First difference**		**Level of Integration**
	IPS	**LLC**	**IPS**	**LLC**	
Energy Poverty	2.688	-1.255	-5.149***	-4.690***	I (1)
Electricity Access	2.100	-0.792	-7.844***	-7.514***	I (1)
Access to Clean Cooking Fuel	3.085	-1.117	-3.816***	-3.709***	I (1)
Primary Energy Supply per Capita	1.756	-0.297	-4.972***	-5.196***	I (1)
lnGDPpc	-1.963**	-4.272***			I (0)
Petroleum_Rent	-1.224	-2.708**	-5.897***		I (0)

Remark: *** denotes significance at the 1%, scale. - Levin, Lin & Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS). - Values in parentheses are p-values.
Source: Author's Computation, 2022

Panel ARDL approach is characterised by several advantages, among which include its advantage of estimating different variables with different orders of stationarity. On top of that, these estimators allow us to estimate both short-run and long-run relationships along with the error correction coefficient.

Test for Panel-Cointegration

Notwithstanding the potential of ARDL in establishing long-run relationships among the variables, for the sake of robustness checks, we conducted panel cointegration tests using Kao (1999), Pedroni (2004) and Westerlund (2005). The test is conducted for all the variables in the energy poverty model and the models with the indicators that were used to construct the energy poverty index. It is intended to check for the possible existence of a long-run relationship.

The panel cointegration test requires the use of an appropriate functional form for the model. Overall, the Kao, Pedroni, and Westerlund test results (see Appendix D to G) show that the null hypothesis of no cointegration in the panel is rejected. Statistical inference is straightforward because all the test statistics are normally distributed (i.e., N (0, 1)).

With most of the test statistics rejecting the null hypothesis of no cointegration in Appendix D to G, showing a p-value lower than 0.05, the study concludes that a cointegrating relationship exists between the variables used in all the models. The results provide enough evidence that the application of the panel-ARDL yields desired results since long-run relationships have been proven by the cointegration tests.

Effect of Petroleum Rent and Income on Energy Poverty

Can long-run improvement in energy poverty reduction be fostered by the effect of petroleum rent in oil-producing African countries? The section establishes this relationship by assessing the effect of petroleum rent and GDP per capita on energy poverty. Further, EPI is disaggregated to observe the effect of petroleum rent on the indicators used to compute the energy poverty index, including access to electricity, clean cooking fuel, and primary energy supply per capita. In establishing these relationships, the choice of an appropriate ARDL estimator is important. Based on the results of the Hausman tests (see Appendix H), the DFE estimator is found to be preferred for the energy poverty model.

The results of the Hausman tests show that we cannot reject the null hypothesis of consistency and efficiency of the DFE relative to the benchmark MG and PMG estimator. The PMG is found to be inconsistent. Hence, we conclude that the DFE is the preferred model specification in the context of the relationship between petroleum rent, income and energy poverty in oil-producing African countries. Testing the null hypothesis that the PMG estimator is efficient and consistent, we found that the Chi-square p-value (0.326) from the Hausman test is greater than 0.05, implying that the null hypothesis (H_0) cannot be rejected. Hence PMG is a more efficient estimator than MG and DFE (see Appendix H for the other estimates).

Table 22 presents the results of the DFE/ARDL models for energy poverty. The ARDL/DFE estimates indicate that the short-run error correction (ECT) term is -0.130 and significant at a 5% level. It implies that any deviation from the long-run equilibrium is corrected at 13% adjustment speed, and thus, there is a long-run cointegration. It is also found that GDP per capita, petroleum rent, and petroleum rent squared are significant in explaining variations in energy poverty of oil-producing African countries.

Table 22: DFE-ARDL Estimates of Effect of Petroleum Rent on Energy Poverty

Variables	Coefficients	Standard Errors
Long-run		
$lnGDPpc$	-0.176***	(0.028)
$Petroleum\_Rent$	0.022***	(0.008)
$Petroleum\_Rent\_Sq$	-0.0003***	(0.000)
Short-run		
ECT	-0.130***	(0.032)
$lnGDP_{pc}D1.$	0.017*	(0.010)
$Petroleum\_Rent\_D1.$	-0.002**	(0.001)
$Petroleum\_Rent\_Sq\_D1.$	0.000	(0.000)
Constant	0.224***	(0.058)
N	162	

Remark: ***, ** and * refers to importance at the 1%, 5%, and 10% scales respectively. Values in parentheses are p-values. N represent number of observations.
Source: Author (2022)

An increase in GDP per capita by 1% is revealed to decrease energy poverty by 0.002% (i.e., 0.176/100 = 0.002) in the long run, ceteris paribus. In the short run, the magnitude of the influence of GDP per capita on energy poverty is positive. A 1% increase in GDP per capita significantly increases energy poverty by 0.0002% (i.e., 0.017/100) in the short run. In terms of the net effect of petroleum rent on energy poverty, the study found that an increase in petroleum rent by one percentage point results in an increase in energy poverty by 0.018% in the long run, as shown in Appendix K. In the short-run, increasing petroleum rent by 1% decreases energy poverty by 0.003%.

The significance of the quadratic term in the long-run presupposes that the relationship is non-linear. The coefficient of the squared term tells both the direction and steepness of the curvature. A positive value indicates the curvature is upwards, while a negative value indicates that the curvature is downwards. The negative and significant quadratic term suggests that the relationship between petroleum rent and energy poverty is non-linear, suggesting that for low values of petroleum rent, energy poverty increases but for high values, the relationship becomes declines in the long run.

The change of sign from a significantly positive to negative on the associated coefficients of the unsquared and squared petroleum rent variables, respectively, affords the conclusion of an inverted U-shaped curve. Threshold analysis presented in Appendix L shows that the petroleum rent effect is expectedly negative on energy poverty at a threshold of about 36.67% of GDP, below which the effect is positive. Thus, petroleum rents of oil-producing countries in Africa begin to be beneficial to energy poverty reduction when petroleum rent reaches 36.7% of GDP, ceteris paribus.

Indeed, higher petroleum rent is proven to have a direct effect on reducing energy poverty in oil-producing African countries. Unfavourable costs of exploration and reduced prices of crude oil, which affect petroleum rent, have a high tendency to affect the ability of oil-producing African economies to translate their oil wealth into removing their population of energy poverty.

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Effect of Petroleum Rent and Income on Energy Poverty Dimensions

Access to Electricity

In the case of assessing the effect of petroleum rent and income on electricity access, the DFE estimator is again preferred under the null hypothesis that the differences in coefficients are not systematic. The probability value of chi-square, 0.35 for the DFE versus PMG test, is less than 0.05 (see Appendix H). Therefore, the null hypothesis that differences in coefficient are not consistent is rejected in favour of the alternative. Hence, the DFE estimator is preferred over PMG. Likewise, the probability value of chi-square is 0.00 for the Hausman test between MG and DFE, more than 0.05. Therefore, the null hypothesis that differences in coefficient are not consistent is rejected. Because the probability value is more than 0.05, we cannot reject the null hypothesis and conclude that differences in coefficients are not systematic, and hence DFE is a better estimator. Since DFE has become the better option over MG and PMG, there is no need to compare MG and PMG.

The significant and negative error correction term shows significant cointegration among the variables in the panel ARDL/DFE model. The negative sign implies that the results meet the a priori expectation that the error correction term can be one but not lower than negative two (-2). Any deviations from the long-run equilibrium are corrected at the 32.9% adjustment speed. The pooled mean group, which is not preferred, assumes that the long-run coefficients are the same for all the groups that make up the panel.

All the regressors, such as GDP per capita, petroleum rent, and petroleum rent squared, are found to significantly influence access to electricity in oil-producing African countries during the period 2000 to 2018 (see Table

23) both in the short-run and long-run. As the per capita income of countries increase by 1%, access to electricity decreases by 0.044% (i.e., -4.391/100) in the short run but increases by 0.14% per annum (i.e., 14.118/100) in the long run. Likewise, the positive quadratic term, in the long run, implies that the shape of the petroleum rent – energy access model is U-shaped. Thus, as more petroleum rent is earned annually, electricity access decreases up to a point and begins to rise.

Table 23: DFE-ARDL Estimation of Effect of Petroleum Rent on Energy Poverty Dimension

Variables	**Access to Electricity**	**Modern Cooking Fuel Access**	**Energy Supply Per Capita**
Long-run			
$lnGDPpc$	14.118***	12.866***	0.719*
	(1.896)	(2.623)	(0.399)
$Petroleum\_Rent$	-1.785***	-1.014	-0.025
	(0.517)	(0.636)	(0.103)
$Petroleum\_Rent\_Sq$	0.022***	0.012	0.000
	(0.007)	(0.009)	(0.001)
Short-run			
ECT	-0.329***	-0.023***	-0.226***
	(0.058)	(0.005)	(0.049)
$lnGDPpcD1.$	-4.391**	-0.446***	0.304
	(1.736)	(0.155)	(0.229)
$Petroleum\_RentD1.$	0.403**	0.022	0.034
	(0.176)	(0.015)	(0.024)
$Petroleum\_Rent\_SqD1.$	-0.004*	-0.000	-0.000
	(0.002)	(0.000)	(0.000)
Constant	-14.018***	-0.389	0.043
	(5.166)	(0.420)	(0.638)

Remark: ***, ** and * refers to importance at the 1%, 5%, and 10% scales respectively. Values in parentheses are p-values.
Source: Author's Computation, 2022

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The net effect analysis presented in Appendix L shows that petroleum rent decreases electricity access by 1.51%. Lower values of petroleum rent decrease energy access, whereas higher values increase energy access in the long run. The petroleum rent-effect is expectedly negative until a threshold of about 40.57% of GDP, after that, it begins to be beneficial to electricity access. In the short run, the opposite is the case. The quadratic term bears a negative sign implying that the relationship between petroleum and access to electricity in the short run has an inverted U-shape. Lower values of petroleum rent increase access to electricity.

The net effect analysis in Appendix S shows that, an increase in petroleum rent by 1% will result in an increase in electricity access by 0.35% in the short-run, ceteris paribus. At a threshold of 50.38% of petroleum rent, electricity access begins to decline. The concentration of petroleum wealth at the initial stages of extraction on other sub-sectors of the economy rather than energy investment can be detrimental to increasing energy access in oil-producing countries in Africa. Where enough investments are not being made in the sector, increasing population will deteriorate the percentage of people with access to energy and hence the adverse effect of lower petroleum rent on energy access.

Access to Modern Cooking Fuels

As part of the decomposition of the energy poverty index to establish the effect of petroleum rent on the indicators of energy poverty in oil-producing African countries, the panel ARDL results for access to modern cooking fuel is presented in Table 23. Based on the results of the Hausman test for the choice between PMG, MG, and DFE presented in Appendix H, we found that the dynamic fixed effect estimator is appropriate for the model, and hence the discussion focuses on the DFE estimators.

The null hypothesis test of homogeneity through a Hausman-type test compares the mean group, pooled mean group, and dynamic fixed effect estimators for the models. Thus, there was evidence that the model supports the dynamic fixed effect estimator. The short-run (SR) error correction (ECT) term is -0.023 and significant at the 5% level. It implies that any deviation from the long-run equilibrium is corrected at 2.3% adjustment speed, and thus, there is a long-run cointegration. The DFE estimator under the null hypothesis is preferred since the chi-square of the Hausman test 0.35 and 0.00 revealed a probability value above 0.05 level of significance, respectively, in comparing the DFE with PMG and MG.

The study found only GDP per capita significantly influences access to clean cooking fuel in both the short and long run. An increase in per capita income by 1% results in an increase in access to clean cooking fuels by 0.004% and 0.13%, respectively, in the short run and long run. The effect of per capita income on access to clean cooking fuel is greater in the long run than in the short run. This finding corroborates the energy ladder hypothesis (Toole, 2015; Paunio, 2018), which states that as incomes increase, people (countries) turn to the use of modern sources of energy. As the income of a country (individual) increases, they turn to buy modern cooking fuels instead of the rudimentary sources of cooking fuel like biomass.

The effect of petroleum rent on access to clean cooking fuels is insignificant in the short and long run. This reflects the fact that most oil-producing economies invest petroleum revenue into providing goods and services related to energy services which have short-term direct impacts on improving access to cooking fuels rather than capital expenditures that have long-term impacts.

Energy Supply Per Capita

In the panel ARDL model with energy supply per capita as the dependent variable, the DFE estimator is again found to be the appropriate estimator since, for both the MG and DFE, the p-value of the chi-squares were more than 0.5 granting evidence for rejecting the null hypothesis that differences in coefficients are not systematic. The ARDL/DFE estimates in Table 23 show that only GDP per capita has a significant long-run effect on the primary energy supply per capita. The influence of petroleum rent, although positive, is found to be weak.

One percent increase in GDP per capita is associated with an increase in the energy supply per capita by 0.719% in the long run. Oil-producing African countries are more likely to improve energy supply per capita when per capita incomes increase. It implies that, as countries' income increases, the amount of energy available for consumption increases in the long run and vice versa. The error correction term has a significant negative sign, implying that the model converges to a long-run relationship at an adjustment speed of 26.6%.

Discussions

The ECTs, measuring the speed of adjustment, lie within acceptable limits (-1 to 0) and are all statistically significant at the 1% level. The coefficients on the ECT also meet the *a priori* expectation of being negative. For the energy poverty model, electricity access, access to clean cooking fuel, and energy supply per capita, the coefficient of -0.242, -0.329, -0.023 and -0.226, respectively, shows that 24.2%, 32.9%, 2.3% and 22.6% of deviations from previous periods will be corrected in the next period in the respective models.

The effect of petroleum rent and income per capita was positive and negative, respectively, in the long run. The negative quadratic term, in the long run, means that lower values of petroleum rent increase energy poverty at the initial stage and begin to decrease energy poverty with high petroleum rent. Therefore, realising high petroleum rent is an incentive to improve energy poverty reduction in oil-producing African countries. Conversely, petroleum rent and per capita income are revealed to have a positive and negative significant effect on electricity access in the long run. In the short-run, the reverse is true.

In sub-Saharan Africa, improving energy access is a key agenda on political manifestos and campaigns, but the fact remains that energy poverty levels are undesirably high. Politicians promise to increase rural electrification via energy investments to curtail interruptions in power supply and distribution of gas cylinders. Investing petroleum revenue and income (GDP) to reduce energy poverty by increasing access to electricity, access to modern cooking fuels, and energy supply per capita is a sure way to build a solid foundation for economic transformation and development.

The adverse effect of income per capita on access to clean cooking fuels implies that oil-producing African economies have not yet prioritized access to clean cooking fuels but have been heavily dependent on rudimentary energy sources such as biomass for cooking. Meanwhile, Africa’s access levels are low compared to the developed countries. As a result, income per capita has an adverse effect on access to clean cooking fuel.

Energy policy towards utilisation of petroleum rent should focus on improving energy infrastructure and improving power generation towards easing access to electricity, access to modern cooking fuels like LPG, and increasing energy availability (improving energy supply per capita) (Adams et al., 2016). Governments of most oil-producing African countries primarily focus on utilizing petroleum revenue in building infrastructures such as roads, health, and education infrastructure and fund agricultural programmes to the detriment of investing in energy infrastructure to improve energy poverty.

Summary

Goal 7 of the SDGs requires that modern energy should be acceptable and, at the same time, accessible, affordable, and reliable for all. Petroleum resource development in oil-producing countries presents a better chance for these countries to improve in energy poverty. When extracted at a viable economic condition in African oil-producing countries, the wealth of petroleum resources needs to be translated into energy poverty reduction through the indicators that make up the index.

Petroleum Rent, Income, and Energy Supply Security

The section presents the empirical analysis regarding objective three, which seeks to examine the effect of petroleum rent and income per capita on energy supply security in oil-producing African countries. The energy supply security is divided into energy import dependency rate, energy intensity (energy efficiency), and domestic energy production rate. The section first presents the descriptive statistics of the study, the correlation matrix, and then the empirical results. The estimated results are presented and discussed, followed by the summary of the section.

Descriptive Statistics

This section deals with descriptive statistics of all the variables and indicators (dependent and independent variables as well as the control variables) used in the research to investigate the effect of petroleum rent on energy supply security. We present the central tendency and degree of variability of the variables. The average values specify values of the mean of the indicators employed in the whole model. The standard deviation captures the distribution of data around the average value. The standard deviation also specifies how near the data is to the mean value. The highest and smallest values measure the spread of the data. The wider the range of values, the higher the variability in the variable, and the lower the range of values, the lower the level of variability in the variable. The values of the mean, maximum, minimum, and standard deviation as well as the skewness and kurtosis of the variables, are shown.

Taking a cursory look at the summary statistics in Table 24, the panel data is robustly balanced with 129 observations. Energy import dependency represents net energy import with a reduced dependency of an economy signaling better energy supply security. Energy import dependency refers to the proportion of energy that an economy must import to meet excess demand over supply (US EIA, 2020). A negative dependency rate indicates a net exporter of energy, while a dependency rate in excess of 100% indicates that energy products have been stocked.

Table 24: Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max	Skew.	Kurt.
Energy Import Dependency (billion Koe)	129	-149.263	253.295	-944.893	90.941	-1.647	4.842
Energy Intensity (Koe)	129	6.324	4.562	2.861	24.318	2.698	9.935
Domestic Energy Production Rate (%)	129	366.374	426.288	2.295	1937.425	1.626	5.029
Energy Consumption (billion Koe)	129	0.951	1.497	0.015	5.655	2.123	6.473
GDP per capita (US$)	129	3,173.336	2,323.577	381.455	14,619.751	1.495	6.665
Carbon dioxide emission (thousand kt)	129	65.469	106	0.820	447.980	2.425	8.265
Fossil Fuel Consumption (billion Koe)	129	52.226	33.485	0	99.978	.255	1.487
Renewable Energy Consumption (billion Koe)	129	47.86	33.778	.069	97.172	-.187	1.422
Oil Rent (% of GDP)	129	15.285	17.377	0	63.28	1.128	3.102
Gas rent (% of GDP)	129	0.675	0.972	0	3.749	1.642	4.935

Source: Author (2022)

Energy net import in oil-producing African countries is negative, implying that, on average, oil-producing African economies produce energy in excess of the domestic demand. An average of 149.26 billion kilograms of oil equivalence is produced annually as a surplus to feed the international market. Implying that oil-producing economies consume less than the energy produced and export the surplus for foreign exchange. Unfortunately, the good performance in net energy import in Africa may not yield desired goals since the computation of this indicator is on primary energy instead of the energy refined to end-user fuels. Over the period under study, oil-producing African countries experienced a shortfall in production by 90.941 billion Koe, during which their maximum energy export peaked at 944.89 billion Koe. Reduced energy intensity is favourable for energy efficiency, which reduces the burden of increasing supply to meet growing domestic demand.

In oil-producing African countries, on average, use 6.324 Koe of energy to produce US$ 1 of GDP. Lower energy intensity indicates that less energy is used to produce one unit of output, and hence such a country is said to be energy efficient. Energy intensity was as high as 24.318 Koe/US$ and low as 2.861 Koe/US$. Just as energy intensity measures energy efficiency, it also depicts a country's level of energy affordability. High energy intensities indicate a high price or cost of converting energy into national output (GDP) and vice versa.

Another dimension of energy supply security considered is the energy self-sufficiency rate measured as the domestic energy production rate. A rate of over 100% indicates a national production surplus in relation to domestic demand and, therefore, net exports. We found that, on average, the domestic energy production rate of oil producers in Africa averaged 366.37%, with a range of 2.3% and 1937.4%. High domestic energy production is anticipated to be high to meet increasing demand in emerging economies.

The average GDP per capita of US$ 3,173.34 for oil producers in Africa shows that they fall in the Lower Middle-income groupings based on the World Bank’s classification of countries' income levels. The income per capita range indicates a large income inequality gap with some countries experiencing low incomes US$ 381.46, with others even falling in the high-income class (US$ 14,619.75) classification by World Bank. The contribution of petroleum rent to economic growth has been established, so it is very likely that petroleum rent will either affect energy supply security directly or be moderated by economic expansion through growth in GDP per capita.

Oil-producing African countries realize about 20 times of rent from crude oil than Gas. For the period under study, oil producers in Africa enjoyed an annual oil rent of 15.29% of GDP, which peaked at 63.28% of GDP. That of gas rent is too low, perhaps due to low industrial use of gas in these countries and hence a likely gas flaring during the period under study. Only in recent times that African oil-producing countries begun to initiate strategies towards creating local gas markets and linking up with international markets for natural gas to increase its demand instead of the previous practice of gas flaring. As to whether the rent from petroleum is being translated into improving the energy supply security situation or not is what this current study sought to establish.

Energy consumption in oil-producing African countries represents 6.2% of the energy consumed in the United States alone in 2020 (IEA, 2021). The energy consumption in Africa is tilted towards fossil fuels. The oil producers in Africa consume about 4.37% of fossil fuel more than renewable energy. The

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anthropogenic carbon dioxide emission, mainly from fossil fuel production and use and cement manufacturing by oil producers in Africa, averaged 65.5 thousand kt. The maximum CO_2 emission of 448 thousand kt in these oil-producing economies is far below recent emissions by China, the US, and Europe of 10,707 thousand kt, 4,817 thousand kt, and 2,729 kt, respectively.

From the forgone discussions, it is clear that oil producers who are net exporters consume less energy produced and do better in terms of carbon dioxide emission compared to the developed countries such as US, China, Russia Federation, and Europe. They are mostly lower middle-income countries though characterised by high-income disparities.

Correlation Analysis

The study uses the correlation matrix to understand the degrees of associations among the variables in the model. This is particularly important to establish an early warning signal of the possible presence of multicollinearity among regressors. A correlation of 0.8 and above is considered as having a perfect relationship and therefore calls for a drop of one of such regressors (see Table 25). The correlation matrix illustrates a direct or positive correlation between the indicators of energy supply security and oil rent, gas rent, and GDP per capita, as well as some control variables. This may be due to the different computational dynamics used by the different data sources. No presence of multicollinearity is detected since there is no evidence of a perfect relationship between the regressors.

Table 25: Correlation Matrix

Variables	Energy Import Dependency	Energy Self-sufficiency	Energy Efficiency	LnGDPpc	$LnCO_2$	FF Consumption	RE Consumption	Oil Rent	Gas Rent
Energy Import Dependency	1.000								
Energy Self-sufficiency	-0.716	1.000							
Energy Efficiency	0.132	-0.037	1.000						
LnGDPpc	-0.343	-0.201	-0.430	1.000					
$LnCO_2$	0.085	-0.381	-0.160	0.596	1.000				
FF Consumption	0.235	-0.387	-0.432	0.553	0.449	1.000			
RE Consumption	-0.268	0.282	0.425	-0.557	-0.647	-0.542	1.000		
Oil Rent	-0.462	0.002	-0.144	0.287	0.495	0.192	-0.146	1.000	
Gas Rent	-0.029	-0.045	-0.254	0.501	0.256	0.500	-0.481	0.375	1.000

Source: Authors' Computations

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Choice of Appropriate Model (Difference versus System GMM)

The study uses three separate models to examine the effect of petroleum rent and income on energy supply security. The three dimensions of energy supply security, such as energy import dependency, energy efficiency, and domestic energy production rate, are the dependent variables for the three separate models estimated.

For all these models, the study made choices on the appropriate model specification that fit the data for the period considered. The two-system GMM estimator was found appropriate for all the models.

The decision on the appropriate estimator of the GMM model is presented in Table 26. Based on the decision criteria provided earlier in the methodology, we found that, for the first two models with energy import dependency and energy production rate as dependent variables, the difference GMM estimate of the lagged dependent variable (ϕ) are well above the upper bound represented by the estimate of the pooled OLS. It implies that the difference GMM estimates are upwards biased; hence, the two-step system GMM estimate is preferred.

With regards to the model for the energy intensity, the study observed no significant efficiency and consistency gains in using system GMM compared to the difference GMM since the estimate of the lagged dependent variable of the difference GMM estimate is well above the pooled OLS (upper bound). Difference GMM estimate is said to be inefficient where the dependent variable is persistent. In this regard, we go ahead to interpret only the system GMM.

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Both the one-step and two-step GMM estimators follow the standard asymptotic and are asymptotically normal.

Table 26: Deciding between System and Difference GMM Estimators

Estimators	**Coefficients of lagged dependent variables**		
	Energy Import Dependency Rate	**Domestic Energy Production Rate**	**Energy Intensity**
Pooled OLS (upper bound)	0.877	0.843	0.975
Fixed Effects (lower bound)	0.792	0.744	0.165
One-step Difference GMM	0.928	0.897	0.423
Two-step Difference GMM	0.944	0.905	0.399
One-step System GMM	1.01	0.991	0.521
Two-step System GMM	0.97	0.966	0.47
Conclusion	Difference GMM estimator of ϕ > upper bound and hence system GMM is preferred	Difference GMM estimator of ϕ < upper bound and > lower bound and hence difference GMM is preferred	Difference GMM estimator of ϕ > upper bound and hence system GMM is preferred

Source: Author (2022)

The asymptotic variance is typically lower for the two-step GMM estimator. The coefficients of the lagged dependent variable are found to be the same for both one-step and two-step system GMM (Hwang & Sun, 2018). This confirms the claim by Arellano and Bond (1991) that there are very modest efficiency gains from the two-step, even in the presence of heteroscedasticity. The two-step GMM is deemed to be more robust than the one-step GMM. The

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two-step is more robust to heteroscedasticity and autocorrelation (Roodman, 2009).

The consistency of the system-GMM estimator is assessed by two specific tests. The Hansen test of over-identifying restrictions for the overall validity of the instruments and the second test examines the null hypothesis that the error term is not serially correlated. Failure to reject both null hypotheses give support to the model (Arellano & Bond, 1991; Arellano & Bover, 1995; Blundell & Bond, 1998; Osabuohien, Efobi & Gitau, 2015). This study reports p-values of Arellano-Bond AR (1) and AR (2) tests as contained in the respective models presented in Table 27. It is found that none of the three models suffers from both first and second-order serial autocorrelation since the AR (2) is not significant even at 10% level.

The significance of AR (2) implies that some lags of the dependent variable used as instruments (i.e., endogenous) might be bad instruments. Both the Hansen and Sargan test are found to be insignificant, and hence we can conclude that the instrumental variables are valid. In other words, all the instrumental variables and the endogenous variables are justified because of the insignificance of the Hansen test, which falls between probability values of 0.10 - 0.30, as proposed by Roodman (2009). This was observed for all three models that explained energy supply security.

Effect of Petroleum Rent and Income on Energy Import Dependency

The estimates of the two-step system GMM for the relationship between petroleum rent and income on the import dependency dimension of energy supply security have shown that oil rent, through the moderating effect of income, decreases energy import dependency (see Table 27). In all, six models are presented, with the first model in column [1] having only the control variables. In columns [2] to [6], the variables of interest are introduced systematically to observe how they become significant predictors of energy supply security.

Models in columns [4] to [6] captured moderating effect of GDP per capita on the effect of oil rent and gas rent on energy import dependency. The results in column [6] show that the effect of petroleum rent on energy import dependency through the moderating effect of GDP per capita is significant and negative. The effect of gas rent through the moderating effect of GDP per capita is negative but insignificant. However, the individual effect of oil rent and GDP per capita increases energy import dependency but is insignificant.

The marginal effect analysis in Appendix M shows that through the moderating effect of GDP per capita, an increase in oil rent by 1% results in an increase in energy import dependency by 6.61% in the short run, ceteris paribus. Given oil rent, an increase in GDP per capita by 1% leads to an increase in energy import dependency by 174.98% in the short run (see Appendix M). The coefficient of the gas rent and the interaction term of gas rent and GDP per capita are not significant, and therefore their marginal effects are not computed.

The study found that across all model specifications, the past energy import dependency levels are a strong predictor of its current level. This denotes that energy supply security represented by energy import dependency tends to be somewhat path-dependent, suggesting that a country’s energy import

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Table 27: Estimates System GMM for Energy Import Dependency Model

	[1]	[2]	[3]	[4]	[5]	[6]
L.EIDR	1.09***	1.078***	1.074***	1.071***	0.96***	0.97***
	(0.053)	(0.07)	(0.033)	(0.075)	(0.026)	(0.126)
$lnGDPpc$	5117.091***	4097.438**	4674.037***	3050.24**	1431.609	2626.962
	(1464.455)	(1897.699)	(1083.178)	(2562.087)	(1115.827)	(4552.068)
CO_2	-0.015**	-0.01	-0.008	-0.013	0.000	0.001
	(0.007)	(0.005)	(0.005)	(0.007)	(0.003)	(0.013)
$FF\_consumption$	-270.312	-261.614*	-313.194**	-155.317	153.922	800.061
	(185.02)	(144.589)	(152.646)	(168.613)	(357.683)	(1997.235)
$RE\_consumption$	-182.623	-163.42	-188.514	-119.906	186.808	831.575
	(178.186)	(149.929)	(140.692)	(145.396)	(360.05)	(2029.243)
Oil_Rent	--	1.254**	--	6.143***	--	9.781***
		(0.558)		(2.344)		(3.794)
Gas_Rent	--	--	2113.462	--	1723.111	3837.837
			(1339.901)		(1559.486)	(2645.222)
$Oil\_Rent * GDP$	--	--	--	-0.001*	--	-0.001**
				(0.001)		(0.001)
$Gas\_Rent * GDP$	--	--	--	--	-0.001	-0.001
					(0.001)	(0.001)
Constant	-11417.67	-6985.975	-7697.739	-5993.014	-27683.761	-101838.52
	(21403.188)	(21308.828)	(14165.226)	(22428.516)	(41489.789)	(232294.89)
No. of Obs.	128	128	128	128	128	128
Groups/Instruments	16/13	16/14	16/14	16/16	16/17	16/17
Wald Chi2 / p-value	1795.1	1306	2286.92	1204.09	1633.50	1761.73
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR (1) (p-value)	0.105	0.110	0.101	0.107	0.097	0.082
AR (2) (p-value)	0.295	0.278	0.278	0.268	0.267	0.203
Sargan test (p-value)	0.055	0.025	0.024	0.000	0.000	0.004
Hansen test (p-value)	0.269	0.233	0.254	0.258	0.543	0229

Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

dependency level in the present year has a strong influence in determining her level of dependency in the following year.

There is an apparent deterioration in energy supply insecurity for countries that produce fossil fuels with the individual effect of oil rent and GDP per capita. As shown in columns [2], [4], and [6], the effect of oil rent on energy import dependency is significant and positive.

Another interaction term (i.e., gas rent and GDP per capita) is negative but statistically not significant. The negative sign implies that national income has an equalising effect on energy insecurity if resources are well managed, and thus GDP per capita has a moderating effect on the relationship between gas rent and energy insecurity. The lone related study in the literature by Mayer (2022) does not establish a significant relationship between oil rent and energy security. Most oil-producing African countries lack oil refineries and gas processing plants, and in some instances, they are inadequate.

They, therefore, resort to the exportation of petroleum and export them at their raw state to earn foreign exchange to import refined oil at high prices. Consequently, increasing oil rent in oil-producing Africa countries does not make these countries secure in energy supply. Rising demand for imported refined petroleum and other energy services accounts for the adverse relationship between oil rent and energy import dependency rate in emerging oil-economies.

The tendency of oil-producing African economies to use foreign earnings from crude oil and natural gas exports to import refined petroleum is high. This can be attributed to why the study observed a positive and significant

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relationship between oil rent and energy import dependency. The effect of gas rent is positive but insignificant. The importation of refined energy products by these oil producers in Africa has serious implications on the exchange rate and, thus, the strength of the local currency. According to Okoro et al. (2017), the increasing demand for refined energy products mostly imported strains local currencies and also comes as a huge cost to importing countries. Theses reliance on the importation of refined energy products reduces importing country's capacity to be energy supply secured.

Hence, GDP per capita has a great tendency to increase energy dependency in oil-producing countries in Africa by making them more vulnerable to dependence instead of putting in measures to avoid the importation of energy to reduce their insecurity. As the incomes of countries improve, energy consumption increases. Given a fixed domestic energy supply, the government will consequently rely on importation to meet the local deficit. Once domestic production cannot meet local energy consumption, the country is more likely to resort to the importation of energy to deal with the deficit situation.

Given that income per capita and petroleum rent positively affect the energy import dependency dimension of energy supply security, it implies that oil-producing African countries turn to importing more energy (mostly refined energy) when petroleum rent and income per capita increase. Importing refined energy with petroleum rent could have been channeled into building refineries and processing plants to add value to the crude for both domestic consumption and export, thereby reducing the risk of becoming energy supply insecure. Though the zero-carbon agenda is widely and radically pushed with different levels of targets, oil-producing African countries could use the shorter period as a window of opportunity to set up oil refineries and gas processing plants to add value to their petroleum. Ghana, together with other emerging oil economies, must hasten the establishment of the Petroleum hub to immediately tap the benefits before the full energy transition makes petroleum less useful, if not redundant.

Variables such as carbon dioxide emissions, fossil fuel consumption and renewable energy consumption were controlled for in the model. This is so done because of their high likelihood of predicting energy supply security. An increase in fossil fuel consumption is found to enhance energy security by reducing energy import dependency in oil-producing economies in Africa, as shown in columns [2] and [3].

Before the introduction of the variables of interest into the model, carbon dioxide emission has a negative relationship with energy import dependency and was significant at 5% level, as shown in column [1] of Table 27. An increase in carbon dioxide emissions by one kiloton is associated with a decrease in energy dependency rate by 0.015%. Most energy imported into oil-producing countries is refined petroleum products (Akwesi et al., 2017). Being energy import-dependent means importing refined petroleum that may increase carbon dioxide emissions. Nonetheless, oil-producing countries are becoming increasingly careful with the impact of greenhouse gases per the Paris Agreement. As a result, an increase in carbon dioxide emission decreases energy import dependency, making the country less energy insecure.

Effect of Petroleum Rent and Income on Energy Self-sufficiency

The comparatively increasing demand for petroleum and its related product has increased petroleum resource exploitation. Continuous exploitation has resulted in the intense depletion of non-renewable energy reserves. As a consequence, energy supply security in low technological-capacitated nations is threatened. This has resulted from their inability to tap alternative energy sources to increase domestic energy production to deliver energy services to consumers at affordable prices. The strategic role of petroleum rent should be relevant in the trajectory of how oil-producers in Africa have improved in being self-sufficient in energy supply domestically. The study examines the effect of oil rent and income on the domestic energy production rate in oil-producing African countries.

In the context of this study and in line with contemporary energy sector discussions, energy self-sufficiency proxy by domestic production rate of energy is measured as the ratio of domestic energy production to total energy consumption. Table 28 presents the two-step system GMM estimates on the relationship between petroleum rent and GDP per capita and domestic production rate of energy. We control for variables such as fossil fuel consumption, renewable energy consumption, and carbon dioxide emission.

The study found that the past domestic energy production rate is a strong predictor of its current level across all models specified. This denotes that the trend in domestic energy production rate is somewhat path-dependent, which suggests that a country’s domestic energy production rate in the present year strongly influences its production rate in the following year. All the models do not suffer from second-order serial correlation, and the instruments are also valid since the Hansen test statistic is not significant even at 1% level.

With a focus on the model [6] in Table 28, the marginal effect analysis presented in Appendix L(a) for the effect of oil rent and gas rent on domestic energy production rate through the moderating effect of GDP per capita. The marginal effects show that, given GDP per capita, an increase in oil rent by 1% will result in a corresponding increase in domestic energy production rate by 3.07%, in the short run, ceteris paribus (see Appendix N).

Conversely, the effect of GDP per capita through the moderating effect of oil rent on the domestic energy production rate is 0.005% for an increase in GDP per capita by 1%, ceteris paribus (see Appendix N). For the case of gas rent, we observed that both gas rent at levels and the interaction term with GDP per capita have no significant effect on the domestic energy production rate. The negative relationship presupposes that oil-producing economies in Africa are unable to translate the oil rent into increasing local energy production that meets domestic consumption. Hence, countries' increase in oil rent is associated with decreasing share of domestic energy production to domestic energy consumption.

However, the effect of oil rent on domestic energy security measured by the domestic energy production rate is found to be moderated by GDP per capita. The statistical significance of the interaction term, which is negative, means that: i) the negative effect of oil rent on the rate of domestic energy production is stronger at lower levels of GDP per capita; ii) the positive effect of GDP per capita on the rate of domestic energy production is stronger at

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Table 28: Estimates of Two-step System GMM for Energy Self-sufficiency Model

	[1]	[2]	[3]	[4]	[5]	[6]
L.DEPR	1.002***	1.009***	1.002***	1.034***	0.976***	0.984***
	(0.092)	(0.101)	(0.090)	(0.112)	(0.045)	(0.111)
$lnGDPpc$	8.739	14.35	7.631	9.468	10.265*	10.05*
	(43.979)	(39.147)	(44.7)	(45.078)	(28.295)	(33.395)
$lnCO_2$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$FF\_consumption$	0.536	0.816	0.55	0.894	0.457	0.102
	(0.81)	(1.104)	(0.896)	(1.068)	(0.902)	(1.086)
$RE\_consumption$	0.194	0.459	0.094	0.651	0.201	0.164
	(0.71)	(0.832)	(0.775)	(1.061)	(0.849)	(0.97)
Oil_Rent	--	-0.01	--	-0.057	--	-0.103**
		(0.012)		(0.06)		(0.047)
Gas_Rent	--	--	-14.056	--	-14.375	-39.956
			(13.666)		(21.484)	(27.927)
$Oil\_Rent * GDP$	--	--	--	0.000	--	0.001**
				(0.000)		(0.000)
$Gas\_Rent * GDP$	--	--	--	--	0.000	0.000
					(0.000)	(0.000)
Constant	-129.43	-192.111	-105.749	-175.541	-120.413	-90.118
	(328.406)	(296.702)	(336.638)	(336.829)	(240.834)	(260.723)
No. of Obs.	129	129	129	129	129	129
Groups/Instruments	17/13	17/14	17/14	17/16	17/17	17/17
Wald Chi2 / p-value	2859	4068.09	3453.12	2864.88	3326.65	3598.51
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR (1) (p value)	0.061	0.062	0.061	0.060	0.058	0.053
AR (2) (p value)	0.108	0.110	0.103	0.108	0.109	0.107
Sargan test (p value)	0.200	0.201	0.189	0.182	0.153	0.168
Hansen test (p value)	0.125	0.161	0.150	0.153	0.163	0.192

Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

smaller levels of oil rent. The interaction term means that the marginal effect of oil rent will differ at different levels of GDP per capita. None of the control variables, including natural gas rent, were significant in predicting the rate of domestic energy production.

The adverse effect of petroleum rent on the domestic energy production dimension of energy supply security implies that as governments of these countries are busy spending petroleum rent on solving infrastructural deficits other than investing in the energy sub-sector, the rate of increasing domestic consumption is far outweighing the rate of increase in domestic energy production. The imbalance puts those countries at risk of energy supply security. Increasing a country's domestic energy production rate will not only support in dealing with energy security problems but also earn them some foreign exchange, thereby strengthening their currency and presenting a favourable macroeconomic environment.

Effect of Petroleum Rent and Income on Energy Efficiency

Reduced energy intensity accounts for the increase in energy efficiency (Dong et al. (2018), which enhances energy supply security. It is important to note that the IEA has cautioned that the use of energy intensity as a measure of energy efficiency does not include climate indicators (IEA, 2021). Climate change is not the focus of this study, but to establish the relationship between petroleum rent on energy supply security. An energy intensity level is the ratio between energy use and gross domestic product measured at purchasing power parity (Martinez et al. (2019). Energy intensity is an indication of how much energy is used to produce one unit of economic output. A lower ratio indicates that less energy is used to produce one unit of output.

Model [6], the preferred results of the energy efficiency model presented in Table 29, show that oil rent, gas rent and GDP per capita reduce energy intensity and thus make them more energy supply secure. There is, however, no significant relationship between energy intensity and the interaction terms of petroleum rent and GDP per capita. Introducing oil and gas rent into the model in column [6] makes the effect of petroleum variables insignificant. Again, the interaction terms of the petroleum rent variables and the GDP per capita are insignificant, as shown in columns [4], [5], and [6]. In column [4], it is shown that an increase in oil rent by one percentage point results in a decrease in energy intensity by 0.001 points. Column [5] also shows that an increase in natural gas rent by one percentage point reduces energy intensity by 0.649 points. This implies that natural gas rent affects energy intensity more than oil rent.

Robustness Checks

Robustness checks are done in two forms. Firstly, since the system-GMM is fragile to arbitrary lag limits, we test for the use of 2 lags (see Appendix P, R, and T, respectively, for the three models of energy supply security). Our results are significantly different from those of Tables 27, 28, and 29. The notable difference is that, across all specifications, the petroleum rent variables and income and the interaction terms reduced the level of significance, and the models also suffer from second-order autocorrelation with a statistically significant AR (2).

The second form of robustness is using another measure of petroleum rent, namely gas rent (% of GDP), instead of oil rent by several studies (Mayer, 2022). Thus, it is expected that more gas rent will enhance energy supply security either through the moderating effect of GDP or not, ceteris paribus. The

Table 29: Estimates of Two-step System GMM for Energy Intensity Model

	[1]	[2]	[3]	[4]	[5]	[6]
L.EIDR	0.564***	0.558**	0.568**	0.566***	0.585**	0.47*
	(0.218)	(0.221)	(0.223)	(0.216)	(0.236)	(0.271)
$lnGDPpc$	-0.968	-0.798	-0.955	-0.687*	-1.03*	-1.074
	(0.685)	(0.641)	(0.719)	(0.61)	(0.609)	(0.942)
$lnCO_2$	0.000**	0.000**	0.000*	0.001*	0.000**	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$FF\_consumption$	-0.018	-0.016	-0.018	-0.017	-0.013	-0.012
	(0.02)	(0.02)	(0.022)	(0.02)	(0.016)	(0.02)
$RE\_consumption$	0.00	0.006	0.001	0.01	0.011	0.016
	(0.027)	(0.027)	(0.03)	(0.025)	(0.025)	(0.036)
Oil_Rent	--	0.000	--	-0.001*	--	0.000
		(0.000)		(0.000)		(0.000)
Gas_Rent	--	--	-0.013	--	-0.649*	-0.707
			(0.149)		(0.421)	(0.601)
$Oil\_Rent * GDP$	--	--	--	0.000	--	0.000
				(0.000)		(0.000)
$Gas\_Rent * GDP$	--	--	--	--	0.000	0.000
					(0.000)	(0.000)
Constant	10.574	8.998	10.516	7.989	10.014*	10.512
	(7.454)	(6.928)	(7.939)	(6.596)	(5.873)	(8.929)
No. of Obs.	129	129	129	129	129	129
Groups/Instruments	17/13	17/14	17/14	17/16	17/17	17/17
Wald Chi2 / p-value	1102.38	12601.16	1706.11	1236.1	15662.95	5520.57
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR (1) (p value)	0.209	0.207	0.213	0.208	0.199	0.220
AR (2) (p value)	0.732	0.757	0.730	0.719	0.799	0.870
Sargan test (p value)	0.094	0.081	0.103	0.013	0.042	0.062
Hansen test (p value)	0.239	0.241	0.195	0.312	0.322	0.284

Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

results are displayed in Appendices 4, 5, and 6, respectively, for the three models of energy supply security. The results show that the energy supply insecurity situation is persistent in oil-producing African countries, evident across all model specifications. The oil rent variable is positive and significant for all the models except for the [4]. This corroborates with the priori expectations. However, the results of the specification tests show that the models are well specified and therefore mean that the results of this study are robust and can be relied upon for useful inference.

Summary

The study applied the panel-GMM model by using either difference or system GMM considering the decision criteria proposed by Bond et al. (2007). Regarding energy import dependency as a measure of energy supply insecurity, oil-producing countries are less vulnerable to becoming energy insecure, with an average negative energy dependency rate of 149.26%. The significant interaction effect of oil rent and GDP per capita on energy import dependency is obvious. The study found that oil-producing economies produce an average of 266.37% more than they consume annually. Domestically producing enough energy to meet local needs also presents a good indicator of energy supply security.

The study revealed that the domestic energy production rate is enhanced through the combined effect of oil rent and GDP per capita. GDP per capita is found to be relevant in moderating the effect of oil rent and natural gas rent on energy intensity. In conclusion, petroleum rent plays an important role in dealing with the energy supply security situation for African countries to avert possible consequences that have befallen Europe due to the Russia-Ukraine War.

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CHAPTER FIVE

SUMMARY, CONCLUSION, AND POLICY RECOMMENDATIONS

Introduction

This chapter presents the summary, conclusions, and recommendations of the study. The summary displays the overall outcome of the study in light of a brief overview of the problem statement, the research objectives, the methodology, and the results. Conclusions are hinged on major findings and research objectives of the study. Besides, recommendations were suggested to relevant bodies.

Summary

The Ukraine-Russia War in 2022 and the 1970s oil crises raised concerns about energy security. Coupled with this, the global call per the Paris Agreement on climate change has heightened interest by researchers and policymakers to drift attention to identifying how to minimize GHG emissions whiles reducing energy poverty and ensuring energy supply security. It has brought about a complex issue for developing economies, especially emerging oil-producing countries. Developing economies extracting petroleum are eager to tap the rich resources for rent to bridge the energy poverty gap and ensure energy supply security that has long been a hindrance to economic transformation. Petroleum extraction in petroleum-rich nations through petroleum rent guarantees additional funding to the national budget and contributes to GDP.

Previous studies on the subject essentially considered just the effect of petroleum rent on economic growth as a whole. Some of them have concentrated on the oil curse hypothesis, with most studies applying cross-sectional methods. This study, therefore, uses a panel-ARDL and panel-GMM approach to examine the effect of petroleum rent and income on energy trilemma in oil-producing African countries. For objective one, the data span from 2002 to 2020 from 13 oil-producing African countries. For the second objective, the study could only get data for 9 countries for the period 2000 to 2018. The last objective used a micro panel of 19 countries for 15 years (2006 to 2020). The study specifically explores how petroleum rent and income account for performance in the energy trilemma index over the period under study in oil-producing countries in Africa.

The results of the ARDL/PMG estimates for the energy trilemma model show that petroleum rent has a significant positive effect on the energy trilemma index in the short but positively insignificant effect on the energy trilemma index in the long run. Income is revealed to have a significant negative effect on energy trilemma in the long run, whereas in the short run, the effect is positive but insignificant. On measuring the extent of the effect of countries' ratings on policies and institutions and transparency, accountability, and corruption on the energy trilemma index, the study found a negative significant and weak effect on energy trilemma, respectively, in the long run. In the short run, environmental sustainability and corruption variable have negative and positive effect weak effects, respectively, on the energy trilemma index.

The panel ARDL/PMG estimates for the environmental sustainability dimension of the energy trilemma index show that petroleum rent has a weak positive effect on the performance of oil-producing African countries in terms of the environmental sustainability dimension in the long run. In contrast, in the short run, the effect is negative. The income per capita is found to have a significant and weak positive effect on environmental sustainability, respectively, in the long and short run.

For the energy security dimension of the energy trilemma model, the PMG estimates were preferred, and the results indicated that petroleum rent has a significant effect on energy security in the long run, whereas, in the short run, the positive effect is insignificant. Conversely, against the a priori expectation, income per capita is found to have a significant negative long-run effect on energy security, whereas, in the short run, it turns out to have a positive effect. Higher ratings of countries in terms of policies and institutions turn to be antagonistic to energy security. In the long run, increased rating reduces energy security. The study also found a significant positive effect of petroleum rent and income per capita on energy equity in the long run, whereas, in the short run, the effect is weak and negative.

The study developed four models with energy poverty and its indicators as dependent variables to examine the effect of petroleum rent and income on energy poverty. The study employed annual data of oil-producing African countries on variables such as access to electricity, access to clean cooking fuels, primary energy supply, oil rent and GDP per capita constant 2017. In constructing an index for the country's performance in energy poverty, the study used access to electricity, access to clean cooking fuels, and per capita energy supply. A panel-ARDL model was applied to address objectives one and two. The study conducted a slope homogeneity test and cross-sectional dependency test to establish that the first-generation unit root test is required. A first-generation panel unit root test was conducted using Levin, Lin & Chu test (LLC), and Im, Pesaran, and Shin W-stat test (IPS), while a panel cointegration test was conducted using Kao, Pedroni, and Westerlund test. The test results revealed that the variables involved in our estimations to address objectives one and two were both 1(1) and I (0). In assessing objectives one and two, the study did not find any variable that is integrated of order two, which might violate the application of panel-ARDL.

The results of the panel-cointegration test revealed a cointegrating relationship, with most of the test statistics rejecting the null hypothesis of no cointegration. Therefore, Panel-ARDL estimation was justified per the existence of long-run cointegration among variables and for all four separate models estimated in addressing objectives one and two. Significant error correction term also confirms the existence of the long-run relationship.

The study used the Hausman test to decide on the choice of PMG, MG, and DFE estimators for the models. For the first objective, results of the Hausman test show that the study cannot reject the null hypothesis of consistency and efficiency of the PMG relative to the benchmark DFE and MG estimator; hence the PMG estimates are preferred for all the models for objective one. In the case of objective two, the test showed the appropriateness of using DFE for the panel-ARDL.

To examine the effect of petroleum rent and income on the energy trilemma, we constructed the energy trilemma index by adopting the approach used by the World Energy Council in 2019. The trilemma index has three dimensions, namely, energy equity, energy security, and environmental sustainability of energy systems, based on 16 indicators. The study used a time span of 2002 to 2020 for 13 countries for the four models. Results for all the models have significant error correction terms, implying the presents of a long-run relationship in the series and justifying why a panel cointegration test is not conducted.

Results of the panel-ADRL/DFE estimates for the effect of petroleum rent on energy trilemma indicate that petroleum rent and income, respectively, have a positive and negative effect on the performance of energy trilemma in oil-producing African countries in the long-run. The performance in the environmental sustainability dimension of the energy trilemma is enhanced with increases in petroleum rent and income in the long-run. Countries are able to make energy accessible and affordable (energy equity) when petroleum rent and income per capita increase in the long run.

The results of the panel-ARDL/DFE estimates on the effect of petroleum rent and income on energy poverty show that petroleum rent has a significant positive effect on energy poverty in the long run but a significant negative effect on energy poverty in the short run. The income per capita is found to have a significant positive effect on energy poverty but a negative effect in the long run. The study found a positive and significant quadratic term for petroleum rent, implying that the relationship between energy poverty and petroleum rent is exponential. For high values of petroleum rent, the relationship between petroleum rent and energy poverty is negative, whereas for low values of petroleum rent, the relationship is positive. In the long run, petroleum rent positively influences energy poverty in Africa. Thus, petroleum rent in oil-producing African countries fails to translate into reducing energy poverty. GDP per capita and the price of crude oil negatively affect energy poverty in the long run in Africa. As income increases, people can afford to consume energy and hence, improvement in energy poverty reduction. In the short run, GDP per capita does not translate into energy poverty reduction in Africa.

The composite energy poverty index is decomposed to estimate the effect of petroleum rent and income on access to electricity, access to clean cooking fuel, and energy supply per capita. Panel-ARDL/DFE estimates show that petroleum rent has a significant short-run effect on access to electricity, whereas, in the long run, the effect is negative. Per capita income significantly increases access to electricity in the long run, whereas, in the short run, per capita income has a significant negative effect on access to electricity. Similarly, in the long run, income per capita is found to have a significantly positive effect on access to clean cooking fuel and energy supply per capita. In the short run, the effect of income per capita on access to clean cooking fuel and per capita energy supply is significantly negative and weakly positive, respectively. The effect of petroleum rent in the short run is weak and positive, whereas, in the long run, it is weak and negative.

For objective three, the study examined the effect of petroleum rent and per capita income on energy security based on three dimensions: energy import dependency, energy intensity, and domestic energy production rate. Due to inadequate data, panel data was constructed for the period 2006 to 2020 using nineteen oil-producing countries, making 285 observations. It justified the choice of panel-GMM since the number of groups is less than the time dimension (Bond et al., 2001). The study found that the difference GMM estimate of the lagged dependent variable is well above the upper bound represented by the estimate of the pooled OLS, implying that the difference

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GMM estimates are upward bias, and hence the system GMM estimate is preferred.

Results of one-step system GMM estimates show that petroleum rent and income per capita directly affect energy import dependency in African hydrocarbon-rich countries. The Difference GMM estimates are preferred for the domestic energy production model. Estimates of the difference GMM reveal that income per capita positively affects the domestic energy production rate in the long run.

Following the above, the study provides the following insights. Firstly, the study found that petroleum rent and income significantly aid in reducing energy poverty in oil-producing African countries both in the long and short run. Contrary to the evidence, petroleum rent significantly decreases access to electricity in the long run. However, higher values of petroleum rent increase access to electricity. A counterfactual analysis shows that petroleum rent and income in oil-producing African countries have a positive long-run effect on increasing the country’s performance on sustainable energy management.

Key Findings

This study's major findings were that the effect of petroleum rent and income of oil-producing African countries on the energy trilemma index, its dimensions, and indicators is positive. The following are the specific findings of the study:

1. The energy trilemma index is increased by 0.0003 points for an increase in petroleum rent by 1% in the short run, whereas in the log-run, income is found to decrease energy trilemma by 0.002 points for an increase in income by 1%.

2. Petroleum rent and GDP per capita are found to increase performance in the environmental sustainability of energy systems by 0.003% and 0.009%, respectively, in the long run.
3. An increase in petroleum rent and income by 1% leads to an increase in energy equity by 0.0012 points and 0.0049 points, respectively, in the long run, ceteris paribus.
4. An increase in petroleum rent by 1% results in an increase in energy poverty by 0.018% in the long run, whereas in the short run, increasing petroleum rent by 1% leads to a decrease in energy poverty by 0.003%.
5. Petroleum rent of oil-producing African economies begins to be beneficial to energy poverty reduction when petroleum rent reaches 36.7% of GDP.
6. Economic rent has a net effect of decreasing electricity access by 1.51% in the long run.
7. The petroleum rent effect is negative until a threshold of about 40.57% of GDP begins to be beneficial to electricity access in the long run.
8. In the short run, electricity access increases by 0.35% for a unit increase in petroleum rent. At a threshold of 50.38% of petroleum rent, electricity access declines in the short run.
9. An increase in oil rent and income per capita by 1% results in an increase in energy import dependency by 6.14% and 30.5%, respectively, in the short run, ceteris paribus. Thus, ESS is hampered.
10. An increase in oil rent and income per capita by 1% enhances a country’s performance in ensuring ESS through a decrease in energy intensity by 0.001 points and 0.007 points, respectively.

Conclusion

This research aimed to assess the effect of petroleum rent and income on energy trilemma in oil-producing African countries. Based on a quantitative analysis of panel data of some selected oil-producing African countries, it can be concluded that petroleum rent and income play a critical role in improving the environmental sustainability of energy systems whiles reducing energy poverty and ensuring energy security. The results indicate that oil-producing producing African countries should put more effort into exploring more oil reserves and increase efforts in the exploration and production of petroleum at minimum cost to achieve a considerable return on investments.

Specifically on the dimensions of energy trilemma, petroleum rent and income per capita supports countries in making energy systems environmentally sustainable. Regarding the energy equity dimension of the energy trilemma index, the study concludes that petroleum rent and income per capita contributed to countries' improvements in energy equity. The increased petroleum rent and income per capita in oil-producing African countries account for low prices of gasoline and diesel and electricity tariffs, as well as increased access to electricity and modern cooking fuels.

Concerning energy poverty, the study concludes that petroleum rent and income are congenial to energy poverty reduction. In the short run, petroleum rent and income reduce energy poverty in oil-producing African countries. Analyses of the effect of the explanatory variables on the individual indicators have shown that petroleum rent has a net effect of decreasing electricity access in the long run. The petroleum rent effect is negative until a threshold of about 40.57% of GDP; after that, it benefits electricity access in the long run. In the short-run, electricity access increases to an increase in petroleum rent. At a threshold of 50.38% of petroleum rent, electricity access declines in the short run.

Based on the energy supply security dimension of energy import dependency, we conclude that petroleum rent and income per capita make oil-producing African countries more energy import-dependent, thereby making them more energy insure. Most of these countries spend huge sums of monies on imported refund fuels instead of refining them in their own countries for domestic consumption and export. The study also concludes that oil rent and income per capita enhance countries' performance in ensuring energy supply security by reducing energy intensity.

Recommendations

Based on the study results and conclusions drawn, the following policy recommendations are made based on the objectives.

Energy Trilemma

1. Based on the inertia performance in the environmental sustainability dimension of the energy trilemma index from 2012, the study recommends that governments of oil-producing African countries step up measures to decarbonize transportation, petroleum production, and power generation. Thus, governments must ensure drastic reductions in emissions, pollution, and energy intensity amidst the current fossil fuel-dominant energy mix.
2. The study recommends that governments of oil-producing African countries should put measures towards increasing petroleum rent since it is evident that rent from petroleum extraction improves the energy trilemma.

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3. Based on the fact that petroleum rent and income per capita support improving performance in the environmental sustainability of energy systems, the study recommends that governments of oil-producing African countries be encouraged to add more effects in petroleum extraction and drive optimal revenues from there.
4. Governments are encouraged to improve domestic energy production to reduce energy supply insecurity.
5. Oil-producing African countries are encouraged to invest petroleum revenue into renewable energy projects and sustainable development initiatives.

Energy Poverty

1. Based on the indicators used in constructing the energy poverty index and the trends observed, the study recommends that governments of oil-producing African countries, especially Niger Democratic Republic of Congo, Republic of Congo, Mauritania, Angola, Cote d'Ivoire, and Cameroon, who have more than half of the population with energy population, should consider improving access to electricity, access to clean and modern cooking fuels and primary energy supply per capita through revenue from petroleum.
2. The study recommends that oil-producing countries in Africa should exert efforts to increase petroleum rent and income per capita to achieve a greater reduction in energy poverty.
3. Since petroleum rent and income are found to improve access to electricity and access to modern and clean cooking fuel, the study recommends that governments of oil-producing African countries strengthen efforts in

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increasing rents and investing them in the energy infrastructure that will improve energy access.

Energy Security

1. Increasing GDP per capita and petroleum rent should not elude oil-producing African countries from being energy import dependent. The government of these countries should ensure that GDP per capita and petroleum rent translates into reducing energy dependency.
2. Oil-producing countries in Africa should consider channeling petroleum rent into building refineries, gas processing plants, and renewable energy technologies for domestic consumption in the medium term to avoid being dependent on refined energy imports that make them energy supply insecure.
3. Since oil rent and gas rent reduces energy intensity, the study recommends efforts made towards increasing oil and gas rent to reduce energy supply insecurity.

Suggestions for Future Research

Future studies should consider a general equilibrium analysis for specific oil-producing economies and assess the effect of petroleum rent on various economic sectors, especially by augmenting energy to capital, labour, and technology in the Cobb Douglas production function. The suggestion would provide a clear and specific understanding of the extent to which petroleum rent and income can influence the energy trilemma index. The approach will go a long way to give specific recommendations explicitly directed to the country.

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APPENDICES

A: Panel ARDL Estimation of Petroleum Rent and Energy Trilemma Index

Variables	Energy Trilemma			Environmental Sustainability		
	MG	**PMG**	**DFE**	**MG**	**PMG**	**DFE**
$lnGDP_{pc}$	0.474	-0.178*	-0.003	-5.987	0.866***	-0.207
	(0.573)	(0.107)	(0.665)	(5.401)	(0.187)	(0.270)
$lnPetroleumRent$	0.084***	0.001	-0.127	0.593	0.265***	0.119
	(0.022)	(0.011)	(0.140)	(0.586)	(0.058)	(0.087)
$Policy\_Env\_Sust$	0.054	-0.023***	0.373	0.044	-0.127	0.209
	(0.035)	(0.008)	(0.271)	(0.093)	(0.099)	(0.154)
$Corruption\_Account$	-0.095	-0.002	0.017	-1.700	-0.254**	0.011
	(0.059)	(0.021)	(0.235)	(1.689)	(0.102)	(0.215)
ECT	-1.207***	-0.762***	-0.159	-0.873***	-0.207**	-0.170***
	(0.269)	(0.293)	(0.111)	(0.219)	(0.103)	(0.060)
$lnGDP_{pc}D1.$	-0.119	0.424	0.015	0.145	0.365	-0.428***
	(0.603)	(0.447)	(0.206)	(0.783)	(0.670)	(0.154)
$lnPetroleumRentD1.$	-0.057	0.025*	0.043***	-0.013	-0.008	0.017
	(0.048)	(0.013)	(0.014)	(0.042)	(0.013)	(0.014)
$Policy\_Env\_SustD1.$	-0.056	-0.017	-0.011	-0.084	-0.057	-0.021
	(0.080)	(0.019)	(0.032)	(0.068)	(0.042)	(0.035)
$Corruption\_AccountD1.$	0.106**	0.017	-0.014	0.070	0.054	-0.033
	(0.043)	(0.044)	(0.043)	(0.079)	(0.058)	(0.049)
Constant	-4.321	1.539***	0.013	19.985	-4.254**	0.723
	(5.887)	(0.562)	(0.905)	(13.001)	(2.165)	(1.287)
Observations	57	57		139	139	

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Author (2022).

B: Panel ARDL Estimation of Petroleum Rent and Dimensions of Energy Trilemma Index

Variables	**Energy Security**			**Energy Equity**		
	MG	**PMG**	**DFE**	**MG**	**PMG**	**DFE**
$lnGDP_{pc}$	0.391	-0.186***	-0.424**	-0.556	0.488***	0.992***
	(0.460)	(0.027)	(0.204)	(1.911)	(0.071)	(0.331)
$lnPetroleumRent$	0.049	0.021***	-0.115	0.568	0.124***	-0.208
	(0.041)	(0.003)	(0.088)	(0.452)	(0.022)	(0.140)
$Policy\_Env\_Sust$	-0.076	-0.037***	0.249*	-0.666	-0.137***	0.314
	(0.429)	(0.008)	(0.146)	(0.626)	(0.041)	(0.210)
$Corruption\_Account$	-0.178	-0.005	-0.046	-0.896	-0.008	-0.276
	(0.145)	(0.032)	(0.163)	(0.897)	(0.110)	(0.245)
ECT	-0.217	-0.559***	-0.274***	-0.606**	-0.303	-0.186**
	(0.484)	(0.210)	(0.075)	(0.280)	(0.236)	(0.091)
$lnGDP_{pc}D1.$	0.931	0.725	0.590***	-0.830	-0.418	-0.006
	(0.954)	(0.808)	(0.188)	(0.884)	(0.580)	(0.199)
$lnPetroleumRentD1.$	0.108	0.001	0.041**	0.015	-0.012	0.034**
	(0.114)	(0.015)	(0.018)	(0.027)	(0.018)	(0.015)
$Policy\_Env\_SustD1.$	-0.013	-0.026	-0.027	-0.017	0.012	-0.015
	(0.062)	(0.029)	(0.037)	(0.022)	(0.031)	(0.035)
$Corruption\_AccountD1.$	-0.113	0.046	0.027	-0.003	-0.001	0.044
	(0.175)	(0.057)	(0.056)	(0.063)	(0.026)	(0.046)
Constant	9.058	2.756***	2.948**	-25.915	-3.752	-4.174*
	(19.952)	(1.045)	(1.224)	(16.559)	(2.852)	(2.173)
Observations	114	114	114	89	89	89

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Author (2022)

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C: Hausman Test for appropriateness of ARDL model (PMG, MG & DFE)

Test	**Statistic/p-value**	**Decision**
Energy Trilemma model		
MG vs PMG	$Chi^2_{(4)} = 2.97$ p-value = 0.5635	The PMG estimator, under the null hypothesis is preferred
DFE vs PMG	$Chi^2_{(4)} = 0.80$ p-value = 0.9384	The PMG estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{(4)} = 0.01$ p-value = 1.000	The MG estimator, under the null hypothesis is preferred
Environmental Sustainability		
PMG vs MG	$Chi^2_{(4)} = 21.78$ p-value = 0.0002	The PMG estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{()} = 0.00$ p-value = 1.0000	The MG estimator, under the null hypothesis is preferred
PMG vs DFE	$Chi^2_{(4)} = 0.01$ p-value = 1.000	The PMG estimator, under the null hypothesis is preferred
Energy Security		
MG vs PMG	$Chi^2_{(4)} = 0.53$ p-value = 0.9703	The PMG estimator, under the null hypothesis is preferred
DFE vs PMG	$Chi^2_{(3)} = 0.58$ p-value = 0.9651	The PMG estimator, under the null hypothesis is preferred

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C (continued)

Test	**Statistic/p-value**	**Decision**
DFE vs MG	$\text{Chi}^2_{(3)} = 0.00$	The MG estimator, under the null
	p-value = 1.0000	hypothesis is preferred
Energy Equity		
MG vs PMG	$\text{Chi}^2_{(4)} = 1.73$	The PMG estimator, under the null
	p-value = 0.7860	hypothesis is preferred
PMG vs DFE	$\text{Chi}^2_{(4)} = 0.01$	The PMG estimator, under the null
	p-value = 1.0000	hypothesis is preferred
MG vs DFE	$\text{Chi}^2_{(4)} = 0.01$	The MG estimator, under the null
	p-value = 1.000	hypothesis is preferred

H_0 : difference in coefficients not systematic
Source: Author (2022)

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D: Panel Co-integration Test – Energy Poverty Model

Cointegration Test	Test Statistic	Statistic	Decision
Pedroni			
	Modified Phillips-Perron t	2.4999***	Reject H_o
	Phillips-Perron t	0.2901	Do not reject H_o
	ADF t	2.4310***	Reject H_o
Kao			
	Modified DF t	1.5418*	Reject H_o
	DF t	2.5810***	Reject H_o
	ADF t	2.9908***	Reject H_o
Westerlund			
	Variance ratio	2.2306**	Reject H_o

H_0: No cointegration. ***, ** and * refer to the level of significance at the 1%, 5%, and 10% scales respectively.
Source: Author (2022)

Appendix E: Co-integration Test – Electricity Access Model

Cointegration Test	Test Statistic	Statistic	Decision
Pedroni			
	Modified Phillips-Perron t	1.3457*	Reject H_o
	Phillips-Perron t	-2.3442***	Reject H_o
	ADF t	-0.6115	Do not reject H_o
Kao			
	Modified DF t	1.5136*	Reject H_o
	DF t	2.2601**	Reject H_o
	ADF t	3.6688***	Reject H_o
Westerlund			
	Variance ratio	0.7676	Do not reject H_o

H_0: No cointegration. ***, ** and * refer to the level of significance at the 1%, 5%, and 10% scales respectively.
Source: Author (2022)

F: Co-integration Test – Access to Clean Cooking Fuel Model

Cointegration Test	Test Statistic	Statistic	Decision
Pedroni			
	Modified Phillips-Perron t	2.8470***	Reject H_o
	Phillips-Perron t	1.8400**	Reject H_o
	ADF t	4.8464***	Reject H_o
Kao			
	Modified DF t	1.6783**	Reject H_o
	DF t	1.8467**	Reject H_o
	ADF t	1.6579**	Reject H_o
Westerlund			
	Variance ratio	2.5559***	Reject H_o

H_0: No cointegration. ***, ** and * refer to the level of significance at the 1%, 5%, and 10% scales respectively.
Source: Author (2022)

G: Co-integration Test – Access to Energy Supply per Capita

Cointegration Test	Test Statistic	Statistic	Decision
Pedroni			
	Modified Phillips-Perron t	1.8192**	Reject H_o
	Phillips-Perron t	-1.7370**	Reject H_o
	ADF t	1.1198	Reject H_o
Kao			
	Modified DF t	1.5176*	Reject H_o
	DF t	0.6727	Do no reject H_o
	ADF t	1.6579**	Reject H_o
Westerlund			
	Variance ratio	0.9188	Do no reject H_o

H_0: No cointegration. ***, ** and * refer to the level of significance at the 1%, 5%, and 10% scales respectively.
Source: Author (2022)

H: Hausman Test for appropriateness of ARDL model (PMG, MG & DFE)

Test	Statistic/p-value	Decision
Energy Poverty model		
PMG vs DFE	$Chi^2_{(3)} = 0.01$ p-value = 0.9998	The DFE estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{(3)} = 0.00$ p-value = 1.0000	The DFE estimator, under the null hypothesis is preferred
MG vs PMG	$Chi^2_{(3)} = 3.16$ p-value = 0.3063	The PMG estimator, under the null hypothesis is preferred
Electricity Access		
DFE vs PMG	$Chi^2_{(3)} = 18.46$ p-value = 0.0004	The PMG estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{(3)} = 2.14$ p-value = 0.5445	The DFE estimator, under the null hypothesis is preferred
MG vs PMG	$Chi^2_{(3)} = 1.76$ p-value = 0.6237	The PMG estimator, under the null hypothesis is preferred
Access to modern cooking fuel model		
PMG vs DFE	$Chi^2_{(3)} = 0.35$ p-value = 0.9508	The DFE estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{(3)} = 0.00$ p-value = 1.0000	The DFE estimator, under the null hypothesis is preferred
MG vs PMG	$Chi^2_{(3)} = 2.13$ p-value = 0.5469	The PMG estimator, under the null hypothesis is preferred

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H (Continued)

Test	Statistic/p-value	Decision
Primary energy supply per capita model		
PMG vs DFE	$Chi^2_{(3)} = 0.01$ p-value = 0.9997	The DFE estimator, under the null hypothesis is preferred
MG vs DFE	$Chi^2_{(3)} = 0.01$ p-value = 0.9995	The DFE estimator, under the null hypothesis is preferred
MG vs PMG	$Chi^2_{(3)} = 4.67$ p-value = 0.1975	The PMG estimator, under the null hypothesis is preferred

H_0 : difference in coefficients not systematic
Source: Author (2022)

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I: Panel ARDL Estimation of the Effect of Petroleum Rent on Energy Poverty

Variables	**Energy Poverty**			**Access to Electricity**		
	PMG	**MG**	**DFE**	**PMG**	**MG**	**DFE**
Long-run						
$lnGDPpc$	-0.098***	-0.177***	-0.176***	8.726***	15.387***	14.118***
	(0.008)	(0.047)	(0.028)	(0.854)	(4.024)	(1.896)
$Petroleum\_Rent$	0.016	0.833	0.022***	-0.479***	-50.603	-1.785***
	(0.029)	(0.656)	(0.008)	(0.112)	(38.808)	(0.517)
$Petroleum\_Rent\_Sq$	-0.024	-9.783	-0.0002***	0.006***	361.449	0.022***
	(0.016)	(9.297)	(0.000)	(0.001)	(326.408)	(0.007)
Short-run						
ECT	-0.134	-0.242***	-0.130***	-0.445***	-0.632***	-0.329***
	(0.082)	(0.092)	(0.032)	(0.144)	(0.119)	(0.058)
$lnGDP_{pc}D1.$	0.037**	0.059***	0.017*	-9.595***	-11.230***	-4.391**
	(0.015)	(0.020)	(0.010)	(2.316)	(2.671)	(1.736)
$Petroleum\_Rent\_D1$	-0.347	-0.375	-0.002**	40.796	30.318	0.403**
	(0.248)	(0.309)	(0.001)	(31.051)	(23.219)	(0.176)
$Petroleum\_Rent\_Sq$	6.960	7.404	0.000	-1,074.361	-756.573	-0.004*
	(6.809)	(7.310)	(0.000)	(1,057.569)	(741.410)	(0.002)
Constant	0.168	0.360**	0.224***	-3.831	-27.399**	-14.018***
	(0.121)	(0.151)	(0.058)	(4.349)	(12.069)	(5.166)
Observations	162	162	162	162	162	162

Remark: ***, ** and * refers to importance at the 1%, 5%, and 10% scales respectively. Values in parentheses are p-values.

J: Panel ARDL Estimation of Effect of Petroleum Revenue on Modern Cooking Fuel and Energy Supply per Capita

Variables	**Modern Cooking Fuel Access**			**Energy Supply Per Capita**		
	PMG	**MG**	**DFE**	**PMG**	**MG**	**DFE**
Long-run						
$lnGDPpc$	-1.361***	-0.716	12.87***	1.241***	0.054	0.719*
	(0.386)	(3.373)	(2.623)	(0.431)	(0.542)	(0.399)
$Petroleum\_Rent$	0.071***	-28.875	-1.014	-0.067	-15.635	-0.025
	(0.023)	(20.071)	(0.636)	(0.066)	(18.058)	(0.103)
$Petroleum\_Rev\_Sq$	-0.001***	400.245	0.012	0.001	367.286	0.000
	(0.000)	(386.110)	(0.009)	(0.001)	(365.188)	(0.001)
Short-run						
ECT	0.000	-0.048	-0.023***	-0.082**	-0.562***	-0.226***
	(0.020)	(0.033)	(0.005)	(0.040)	(0.114)	(0.049)
$lnGDPpcD1.$	-0.131	-0.272**	-0.446***	-0.463	-0.457	0.304
	(0.145)	(0.125)	(0.155)	(0.352)	(0.363)	(0.229)
$Petroleum\_RentD1.$	-0.293	1.503	0.022	-3.434	2.076	0.034
	(0.307)	(1.709)	(0.015)	(7.090)	(1.920)	(0.024)
$Petroleum\_Rent\_SqD1.$	4.870	-36.053	-0.000	110.321	-48.620	-0.000
	(4.863)	(36.253)	(0.000)	(113.913)	(48.913)	(0.000)
Constant	2.539*	2.423	-0.389	-0.403*	0.517	0.043
	(1.344)	(1.764)	(0.420)	(0.245)	(1.947)	(0.638)

Remark: ***, ** and * refers to importance at the 1%, 5%, and 10% scales respectively. Values in parentheses are p-values.

K: Net effect of petroleum rent on energy poverty and its indicators

Energy Poverty

$$\frac{dEPI}{dPetroleum\_Rent} = 0.022 - 2(0.0003)Petroleum\_Rent$$

At average petroleum rent of 6.094% in oil-producing countries in Africa, the net effect of petroleum rent on energy poverty is 0.018% in the long-run and -0.003% in the short run.

Access to Electricity

$$\frac{dEPI}{dPetroleum\_Rent} = -1.785 + 2(0.022)Petroleum\_Rent$$

At average petroleum rent of 6.094% in oil-producing countries in Africa, the net effect of petroleum rent on Access to Electricity is -1.517%.

Access to Clean Cooking Fuels

$$\frac{dEPI}{dPetroleum\_Rent} = -1.014 + 2(0.012)Petroleum\_Rent$$

At average petroleum rent of 6.094% in oil-producing countries in Africa, the net effect of petroleum rent on Access to clean cooking fuels is -0.868%.

Energy Supply Per Capita

$$\frac{dEPI}{dPetroleum\_Rent} = -0.025 + 2(0.0001)Petroleum\_Rent$$

At average petroleum rent of 6.094% in oil-producing countries in Africa, the net effect of petroleum rent on energy supply per capita is -0.024%.

L: Threshold level of Petroleum Rent on energy poverty and its indicators

(a) *Energy Poverty Index*

The quadratic econometric equation shown in equation (13) is estimated through panel-ARDL and shown as follows:

$$EPI = 0.022Petroleum\_Rent - 0.0003 \times Petroleum\_Rent^2$$

$$\frac{dEPI}{dPetroleum\_Rent} = 0.022 - 2(0.0003)Petroleum\_Rent = 0$$

$\frac{d^2EPI}{dPetroleum\_Rent^2} = -0.0006$, which is < 0, and hence maximum.

Since it is established that the petroleum rent – energy poverty relationship is quadratic and an inverted U-shaped, the threshold level of petroleum rent can be determined by solving from equation (13) estimated in Table 22 as follows:

$$0.022 - 2(0.0003)Petroleum\_Rent = 0$$

$$Petroleum\_Rent(threshold) = \frac{0.022}{0.0006} = 36.67$$

(b) *Access to Electricity*

The quadratic econometric equation shown in equation (14) is estimated through panel-ARDL and shown as follows:

$$EPI = -1.785Petroleum\_Rent + 0.022Petroleum\_Rent^2$$

$$\frac{dEPI}{dPetroleum\_Rent} = -1.785 + 0.044Petroleum\_Rent = 0$$

$\frac{d^2EPI}{dPetroleum\_Rent^2} = 0.044$, which is < 0, and hence minimum.

Since it is established that the petroleum rent – electricity access relationship is quadratic and an inverted U-shaped, the threshold level of petroleum rent can be determined by solving from equation (14) estimated and presented in Table 23 as follows:

$Petroleum\_Rent(Threshold)_{LR} = \frac{1.785}{0.044} = 40.57\%$ for the long-run.

The short-run threshold level is:

$$Petroleum\_Rent(Threshold)_{SR} = \frac{0.403}{0.008} = 50.38\%$$

M: Marginal Effect Analysis – Energy Import Dependency

a: GDP per capita as a moderator

Effect of oil rent on energy import dependency through the moderating effect of GDP per capita is calculated by taking the first differential of the model in column [6] of Table 27. The partial differential with respect to petroleum rent is:

$$\frac{\partial EID_{it}}{\partial Oil\_Rent_{it}} = 9.781 - 0.001 GDPpc_{it}$$

It can be recalled that the GDP per capita averaged US$ 3,173.34.

$$\frac{\partial EID_{it}}{\partial Oil\_Rent_{it}} = 9.781 - 0.001(3{,}173.34)$$

Therefore, the marginal effect of petroleum rent is 6.61.

b: Oil rent as a moderator

Effect of GDP per capita on energy import dependency through the moderating effect of oil rent is calculated by taking the first differential of the model in column [6] of Table 27. The partial differential with respect to petroleum rent is:

$$\frac{\partial EID_{it}}{\partial GDP_{it}} = \frac{2626}{GDP_{it}} - 0.001(Oil\_Rent_{it})$$

It can be recalled that the oil rent averaged 15.285% of GDP and GDP per capita averaged US$ 3,173.34.

$$\frac{\partial EID_{it}}{\partial Oil\_Rent_{it}} = \frac{2626}{3{,}173.34} - 0.001(15.285)$$

Therefore, the marginal effect of GDP per capita given oil rent is 174.98%.

N: Marginal Effect Analysis – Energy Self Sufficiency

(a) *GDP per capita as a moderator*

Effect of oil rent on energy import dependency through the moderating effect of GDP per capita is calculated by taking the first differential of the model in column [6] of Table 27. The partial differential with respect to petroleum rent is:

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$$\frac{\partial DEPR_{it}}{\partial Oil\_Rent_{it}} = -0.103 - 0.001GDPpc_{it}$$

It can be recalled that the GDP per capita averaged US$ 3,173.34.

$$\frac{\partial EID_{it}}{\partial Oil\_Rent_{it}} = -0.103 + 0.001(3{,}173.34)$$

Therefore, the marginal effect of petroleum rent is 3.07.

(b) *Oil rent as a moderator*

Effect of GDP per capita on energy import dependency through the moderating effect of oil rent is calculated by taking the first differential of the model in column [6] of 27. The partial differential with respect to petroleum rent is:

$$\frac{\partial EID_{it}}{\partial GDP_{it}} = \frac{10.05}{GDP_{it}} + 0.0001(Oil\_Rent_{it})$$

It can be recalled that the oil rent averaged 15.285% of GDP and GDP per capita averaged US$ 3,173.34.

$$\frac{\partial EID_{it}}{\partial Oil\_Rent_{it}} = \frac{10.05}{3{,}173.34} + 0.0001(15.285)$$

Therefore, the marginal effect of GDP per capita given oil rent is 0.005%.

O: Estimates of Pooled OLS, FE, Difference GMM and System GMM for Energy Import Dependency Model

	Pooled OLS	Fixed Effects	One-step Diff GMM	Two-step Diff GMM	One-step System GMM	Two-step System GMM
L.EIDR	0.877***	0.792***	0.928***	0.944***	1.01***	0.97***
	(0.053)	(0.09)	(0.083)	(0.092)	(0.096)	(0.126)
$lnGDPpc$	-2680.111	-11121.005	-11640.742*	-13198.255*	1174.009	2626.962
	(1831.945)	(9249.235)	(7058.341)	(7673.794)	(3417.167)	(4552.068)
CO_2	0.001	0.122	0.098	0.034	-0.005	0.001
	(0.003)	(0.112)	(0.099)	(0.066)	(0.006)	(0.013)
$FF\_consumption$	74.08	461.067	332.796	256.435	-130.344	800.061
	(136.557)	(410.043)	(309.772)	(419.63)	(216.337)	(1997.235)
$RE\_consumption$	-2.195	-126.896	-97.95	-105.092	-123.054	831.575
	(137.99)	(343.948)	(317.108)	(449.157)	(176.421)	(2029.243)
Oil_Rent	7.734**	13.701	17.727	15.051	12.528***	9.781***
	(3.114)	(17.596)	(17.576)	(19.091)	(3.222)	(3.794)
Gas_Rent	3539.876***	6395.652**	5991.695***	4279.944*	4893.615***	3837.837
	(1093.036)	(2348.115)	(1766.51)	(2411.242)	(1835.72)	(2645.222)
$Oil\_Rent * GDPpc$	0.000***	0.000	0.000	0.000	0.000***	0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Gas\_Rent * GDPpc$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	16170.18	54549.326	--	--	4912.811	-101838.52
	(19342.841)	(64089.506)			(21938.707)	(232294.89)
No. of Obs.	128	128	112	112	128	128
Groups/Instruments			16/15	16/15	16/17	16/17
Wald Chi2 / p-value					3312.37	1761.73
			--	--	(0.000)	(0.000)
GMM instrument lag			1	1	1	1
AR(1) (p value)			0.029	0.059	0.074	0.082
AR(2) (p value)			0.118	0.134	0.278	0.203
Sargan test (p value)			0.040	0.040	0.004	0.004
Hansen test (p value)			0.252	0.252	0229	0229

Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Source: Author, 2022

P: Estimates Two-Step System GMM for Energy Import Dependency Model with Lag two

	[1]	[2]	[3]	[4]	[5]	[6]
L.EIDR_2	1.125***	1.041***	0.78***	0.754***	0.809***	0.652***
	(0.253)	(0.262)	(0.044)	(0.066)	(0.037)	(0.072)
$lnGDPpc$	10782.021	6269.143	-2381.978	-2542.592	-1501.172	-7266.833**
	(9766.526)	(7838.477)	(2033.343)	(2149.419)	(2037.648)	(3365.272)
$lnCO_2$	-0.02	-0.011	0.003	0.003	0.004	0.007
	(0.017)	(0.012)	(0.007)	(0.006)	(0.01)	(0.007)
$FF\_consumption$	-441.014	-390.609	87.541	172.953	-25.923	203.661
	(520.162)	(382.654)	(254.269)	(278.099)	(309.928)	(297.608)
$RE\_consumption$	-212.697	-234.99	46.268	114.472	-37.794	30.937
	(626.388)	(301.759)	(246.015)	(254.668)	(303.714)	(256.226)
Oil_Rent	--	1.587	--	-1.24	--	10.038**
		(1.964)		(4.938)		(4.733)
Gas_Rent	--	--	176.875	--	2295.044	4772.281**
			(1037.924)		(2303.078)	(2029.444)
$Oil\_Rent * GDPpc$	--	--	--	0.000	--	0.000***
				(0.000)		(0.000)
$Gas\_Rent * GDPpc$	--	--	--	--	0.000	0.000
					(0.000)	(0.000)
Constant	-41459.986	-12381.303	10559.498	4011.055	13628.522	40805.406
	(115923.43)	(51353.576)	(26313.175)	(23739.763)	(27561.489)	(25777.578)
No. of Obs.	112	112	112	112	112	112
Groups/Instruments	16/12	16/13	16/13	16/15	16/16	16/16
Wald Chi2 / p-value	378.47	814.26	389.81	593.21	1755.56	896.72
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR(1) (p-value)	0.465	0.446	0.506	0.450	0.681	0.876
AR(2) (p-value)	0.064	0.070	0.050	0.063	0.040	0.094
Sargan test (p-value)	0.027	0.009	0.022	0.000	0.000	0.007
Hansen test (p-value)	0.448	0.421	0.623	0.495	0.495	0.357

Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Author, 2022

Q: Estimates of Pooled OLS, FE, Difference GMM and System GMM for Energy Self-sufficiency Model

	Pooled OLS	**Fixed Effects**	**One-step Diff GMM**	**Two-step Diff GMM**	**One-step System GMM**	**Two-step System GMM**
L.DEPR	0.843***	0.744***	0.897***	0.905***	0.991***	0.966***
	(0.044)	(0.088)	(0.079)	(0.086)	(0.105)	(0.111)
$lnGDPpc$	36.83**	125.584	135.455*	185.364	15.735	13.967
	(17.948)	(101.789)	(76.177)	(114.916)	(36.478)	(34.738)
$lnCO_2$	-6.724	-17.354	43.382	13.126	6.448	-12.828
	(11.101)	(92.776)	(49.002)	(73.836)	(19.539)	(15.673)
$FF\_consumption$	-1.328**	-3.878	-3.553	-3.919	0.266	-0.061
	(0.556)	(5.331)	(3.408)	(5.766)	(0.875)	(0.801)
$RE\_consumption$	-0.525	5.843	6.608**	3.294	0.569	-0.232
	(0.534)	(3.828)	(2.9)	(3.642)	(1.054)	(0.925)
Oil_Rent	-0.07**	-0.164	-0.211	-0.165	-0.108*	-0.088*
	(0.034)	(0.206)	(0.197)	(0.21)	(0.06)	(0.048)
Gas_Rent	-41.94***	-46.051*	-39.595**	-27.032	-33.421	-42.631**
	(13.35)	(25.926)	(15.996)	(20.472)	(27.392)	(21.717)
$Oil\_Rent * GDPpc$	0.000***	0.000	0.000	0.000	0.000**	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Gas\_Rent * GDPpc$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-99.496	-793.396	--	--	-237.314	39.463
	(138.058)	(986.264)			(275.421)	(280.504)
No. of Obs.	129	129	112	112	129	129
Groups/Instruments			16/15	16/15	17/17	17/17
Wald Chi2 / p-value					2765.27	1844.50
			--	--	(0.000)	(0.000)
GMM instrument lag			1		1	1
AR(1) (p-value)			0.023	0.052	0.062	0.056
AR(2) (p-value)			0.034	0.045	0.089	0.069
Sargan test (p-value)			0.115	0.115	0.168	0.168
Hansen test (p-value)			0.167	0.167	0.376	0.376

Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Author, 2022

R: Estimates of Two-step System GMM for Energy Self-sufficiency Model

	[1]	[2]	[3]	[4]	[5]	[6]
L.DEPR_2	1.018***	1.045***	1.017***	1.063***	1.004***	1.014***
	(0.104)	(0.113)	(0.096)	(0.12)	(0.071)	(0.089)
$lnGDPpc$	-31.44	-26.252	-34.681	-7.56	-27.082	-20.19
	(61.225)	(63.94)	(59.186)	(76.991)	(52.586)	(57.804)
$lnCO_2$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$FF\_consumption$	2.678	2.852	3.706	4.028	7.612*	3.386
	(4.335)	(4.345)	(4.226)	(5.63)	(4.478)	(3.713)
$RE\_consumption$	1.671	1.518	2.152	3.027	5.99	2.612
	(3.742)	(3.873)	(3.485)	(4.794)	(3.84)	(3.308)
Oil_Rent	--	-0.018	--	-0.067	--	-0.117***
		(.012)0		(0.075)		(0.044)
Gas_Rent	--	--	-25.411*	--	-15.546	-38.309
			(13.472)		(36.296)	(24.897)
$Oil\_Rent * GDPpc$	--	--	--	0.000	--	0.000***
				(0.000)		(0.000)
$Gas\_Rent * GDPpc$	--	--	--	--	0.000	0.000
					(0.000)	(0.000)
Constant	-35.673	-67.306	-63.032	-363.248	-531.775	-173.615
	(539.339)	(584.748)	(509.862)	(569.599)	(551.888)	(509.973)
No. of Obs.	112	112	112	112	112	112
Groups/Instruments	16/12	16/13	16/13	16/15	16/16	16/16
Wald Chi2 / p-value	1437.8	3378.25	4989.57	503.92	1230.76	1673.74
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR(1) (p-value)	0.302	0.252	0.305	0.234	0.274	0.306
AR(2) (p-value)	0.042	0.039	0.039	0.038	0.035	0.039
Sargan test (p value)	0.302	0.416	0.297	0.117	0.152	0.305
Hansen test (p value)	0.357	0.376	0.435	0.253	0.184	0.465

Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Author, 2022

S: Estimates of Pooled OLS, Fixed Effect, Difference GMM and System GMM for Energy Efficiency Model

	Pooled OLS	Fixed Effects	One-step Diff GMM	Two-step Diff GMM	One-step System GMM	Two-step System GMM
L.EIDR	0.975***	0.165	0.423***	0.399**	0.521**	0.47*
	(0.03)	(0.12)	(0.144)	(0.18)	(0.26)	(0.271)
$lnGDPpc$	-.072	-1.644	-1.543*	-1.684***	-1.102	-1.074
	(0.182)	(1.018)	(0.878)	(0.644)	(0.793)	(0.942)
$lnCO_2$	0.000	0.000	0.000	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$FF\_consumption$	0.000	0.042	0.042	0.046	-0.022	-0.012
	(0.006)	(0.06)	(0.056)	(0.055)	(0.02)	(0.02)
$RE\_consumption$	0.002	0.078	0.074	0.075*	0.017	0.016
	(0.006)	(0.056)	(0.046)	(0.042)	(0.027)	(0.036)
Oil_Rent	0.000	0.000	0.000	0.000	-0.001	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Gas_Rent	0.256	0.336	0.143	0.373	0.801*	0.707
	(0.275)	(0.466)	(0.512)	(0.329)	(0.454)	(0.601)
$Oil\_Rent * GDPpc$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$Gas\_Rent * GDPpc$	0.000	0.000	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	0.539	12.132*			11.035	10.512
	(1.703)	(5.786)			(7.623)	(8.929)
No. of Obs.	129	129	112	112	129	129
Groups/Instruments			16/15	16/15	17/17	17/17
Wald Chi2 / p-value					8899.74	5520.57
			--	--	(0.000)	(0.000)
GMM instrument lag			1	1	1	1
AR(1) (p-value)			0.117	0.176	0.066	0.220
AR(2) (p-value)			0.929	0.901	0.776	0.870
Sargan test (p-value)			0.002	0.002	0.062	0.062
Hansen test (p-value)			0.403	0.403	0.284	0.284

Robust standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Author, 2022

T: Estimates of Two-step System GMM for Energy Efficiency Model

	[1]	[2]	[3]	[4]	[5]	[6]
L.DEPR_2	0.658***	0.659***	0.642***	0.687***	0.632***	0.579***
	(0.095)	(0.1)	(0.097)	(0.161)	(0.085)	(0.129)
$lnGDPpc$	-0.617	-0.513	-0.656	-0.432	-0.726**	-0.729
	(0.565)	(0.537)	(0.541)	(0.522)	(0.368)	(0.45)
$lnCO_2$	0.000**	0.000**	0.000**	0.000	0.000***	0.000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
$FF\_consumption$	-0.012	-0.014	-0.018	-0.012	-0.013	-0.014
	(0.062)	(0.062)	(0.056)	(0.118)	(0.05)	(0.071)
$RE\_consumption$	0.009	0.007	0.005	0.012	0.014	0.016
	(0.062)	(0.059)	(0.054)	(0.103)	(0.052)	(0.061)
Oil_Rent	--	0.000	--	-0.001	--	0.000
		(0.000)		(0.001)		(0.001)
Gas_Rent	--	--	0.095	--	0.699***	0.599***
			(0.147)		(0.188)	(0.232)
$Oil\_Rent * GDPpc$	--	--	--	0.000	--	0.000
				(0.000)		(0.000)
$Gas\_Rent * GDPpc$	--	--	--	--	0.000***	0.000**
					(0.000)	(0.000)
Constant	6.374	5.857	7.209	5.023	6.965	7.271
	(9.571)	(9.048)	(8.816)	(14.007)	(6.367)	(8.332)
No. of Obs.	112	112	112	112	112	112
Groups/Instruments	16/12	16/13	16/13	16/15	16/16	16/16
Wald Chi2 / p-value	1437.8	3378.25	4989.57	503.92	1230.76	1673.74
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
GMM instrument lag	1	1	1	1	1	1
AR(1) (p-value)	0.302	0.252	0.305	0.234	0.274	0.306
AR(2) (p-value)	0.042	0.039	0.039	0.038	0.035	0.039
Sargan test (p-value)	0.302	0.416	0.297	0.117	0.152	0.305
Hansen test (p-value)	0.357	0.376	0.435	0.253	0.184	0.465

Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Source: Author, 2022

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