Cover

Analysis of the Relationship between Carbon Dioxide Emissions, Energy Supply from Fossil Fuel, Energy Consumption and GDP: Nigerian Case

나이지리아 이산화탄소 배출, 화석연료 에너지 공급, 에너지 소비 및 GDP 간의 관계 분석

August, 2023

Technology Management, Economics, and Policy Department,

International Energy Policy Program

College of Engineering

Al-Amin Habib Abba Jato

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이 논문을 공학석사 학위논문으로 제출함

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Title Page

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학위논문 원문제공 서비스에 대한 동의서

본인의 학위논문에 대하여 서울대학교가 아래와 같이 학위논문 제공하는 것에 동의합니다.

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Abstract

Analysis of the Relationship between Carbon Dioxide Emissions, Energy Supply from Fossil Fuel, Energy Consumption and GDP: Nigerian Case

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Human actions, like releasing greenhouse gases (GHGs) by burning fossil fuels, are the primary cause of global warming. Economic growth has had both positive and negative effects. Particularly, in developing countries like Nigeria, economic growth has sometimes led to climate change and increased greenhouse gas emissions. Previous studies pointed out that because resources are limited, it is crucial to find alternative options to fossil fuels in order to stop global warming from worsening. The power sector is the most significant source of CO2

pollution in Nigeria. Accordingly, about 80% of the country's energy comes from the “off-grid” or “decentralized” system, driven by gasoline and diesel. This causes significant environmental pollution, and so, we need to think about our future energy needs and how to stop pollution.

Through the lens of natural resources and environmental economics, this study looks at the links between economic growth, environmental pollution, and energy use. It also looks into the relationship between GDP and pollution, like CO2 emissions, and the relationship between economic expansion and energy use. In addition, it seeks to answer the question “What is the relationship and the causal direction between carbon dioxide emissions and energy supply/demand and economic growth?” and “What are the appropriate energy policies to attain the goal of greenhouse gas reduction in an economy mainly dependent on fossil fuel production and consumption?” To this end, this study uses Autoregressive Distributed Lag (ARDL) and a cointegration test on data from 1990 to 2020 to investigate how these relationships change over time. The International Energy Agency and the World Bank provided the study statistics on total energy use, energy supply from oil and gas, CO2 per person, and GDP per person.

The results of the ARDL short-run model reveal that CO2 emissions in the past added to CO2 levels today. This suggests that activities that hurt the environment in the past play a significant role in climate change today. Moreover, oil and gas energy supply affected CO2 emissions because more energy is used. Furthermore, the results of our

causality study show that using energy (especially oil and gas) makes a big difference in CO_2 pollution. However, GDP does not make a big difference in CO_2 pollution. Hence, the present study proposes changes to policies on energy and the environment, alternative energy, energy transition, decoupling, and green energy to simultaneously reduce CO_2 emissions and boost economic growth.

Indeed, long-term plans for sustainable growth and strong political will are needed to switch from fossil fuels to renewable energy. Building the infrastructure necessary for an economy based on renewable energy takes longer than one term of a government's administration. Thus, to keep the energy transition plan going, a strong legal framework that is safe from the vested interests of politicians is necessary. Additionally, people need to be committed to solving the short-term problems that arise during the shift to a low-carbon economy.

Keywords: CO2, ARDL, Short-run, Causality, Energy–environment–economic policies, Nigeria

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Introduction

1.1. Overview

Global warming is on the rise mainly due to anthropogenic (human) activities by way of the release of greenhouse gases (GHGs) into the environment, largely from burning fossil fuels (Esso & Keho, 2016).

The growth of the global economy has boosted people's standard of living in several ways. These include technological progress, longer life expectancy, higher incomes, and better educational opportunities, even if its at a slower pace. This growth also applies to most developing countries, including Nigeria. However, the increased economic growth has also resulted in certain negative outcomes, such as poverty in some nations, wealth inequality, environmental degradation, emissions, and global warming (Adebayo, 2020).

These resources are finite; they must be consumed in a more environmentally-friendly manner and conserved for further generation. More importantly, alternatives to fossil fuels, which emit GHGs, must be sought to stop the increase in global warming and its adverse effects on human existence and the environment.

The Intergovernmental Panel on Climate Change (IPCC) noted that global temperature had risen by 1.1– 1.5°C, above the 1850s levels

(Figure 1). It stated that if the temperatures rises 1.7–1.8°C over the benchmark, half of the population of the world will face life-threatening heat and humidity. Against this backdrop, the Paris Agreement was signed in 2015 by 194 countries pledging to commit to limit the rise of global temperature to 1.5°C (Erickson & Brase, 2019). This was in addition to earlier signed agreements such as the Kyoto, Montreal, and Copenhagen protocols of 1997, 1989, and 2009, respectively; theya re all geared towards a globalized approach and coordination in curtailing GHG emissions to combat climate change.

Noble and ideal as the above-stated approach and efforts may sound, the reality of practically applying GHG curtailment poses a huge challenge as more developing countries head towards industrialization. The emerging middle class will drive up the demand for energy consumption, which is still largely fossil fuel-dependent. Furthermore, a considerable portion of world population, especially in underdeveloped countries, are energy underserved and are making plans for access to power. Energy consumption per day differs from place to place, and with access to point, so does the proportion of GHG emissions. The daily per capita energy need is approximately50–100 gigajoules, an estimate in the USA. It is about 175 gigajoules per day in energy-efficient Japan and 300 gigajoules per day in the USA[1] (The colors of energy | shell global, n.d.), which reflects the global energy inequality.

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[1] 36 essays which share insights on how and what type of energy to be provided to a world with growing population

Figure 1. Graph showing a steady increase in global temperatures since record from the late 1800s

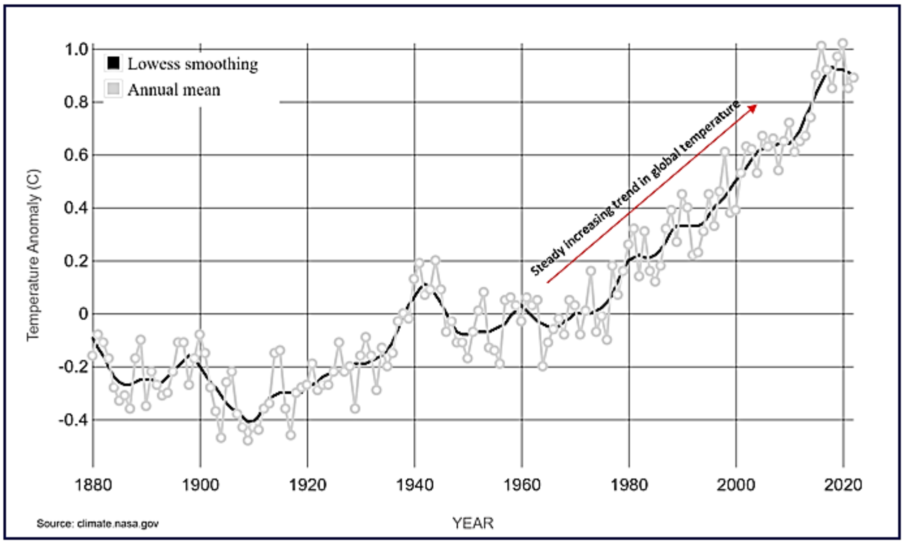


Figure 1 shows a steady increase in global temperatures since record-keeping started in the late 1800s. With the invention of steam engines during the first cycle of the industrial revolution from 1830 to 1840 in Britain, and later around the world, the demand for coal skyrocketed. Coal was needed to power the engines in factories for manufacturing products, locomotive steam engines on railroads and steamships used in transporting these manufactured goods all around the world. This significantly contributed to GHG emissions leading to global warming.[2]

CO2 has dominated in contributing to global warming of all the GHG in the past 20 years. It is prevalent in upcoming economies rich in

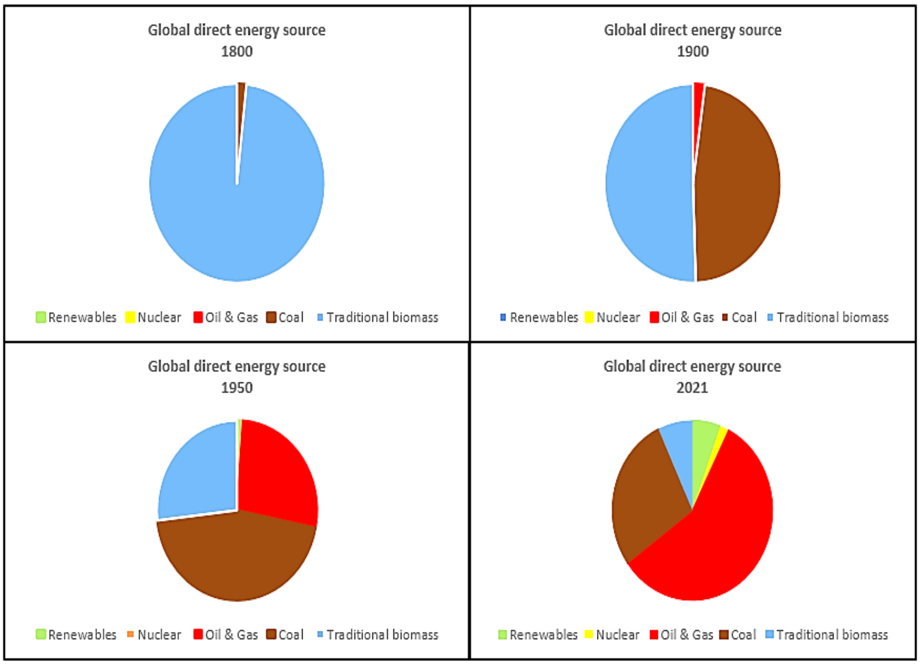
[2] Graph modified from NASA/GISS website

natural resources, with considerable geopolitical and economic peace uncertainties. Brazil, Russia, India, China, and South Africa (BRICS), together with Saudi Arabia, Israel, Ukraine, Turkey, and Venezuela, emitted about 1,730,115,4 kt of CO2 in 2014, increasing from241,029 kt in 1970, indicating a percentage increase of over 1,000%. Notably, BRICS[3] alone accounted for over 80% of the emissions (Adams et al., 2020). This monumental emission increase results from increased economic activity and growth, which comes with high energy demand and consumption. However, to combat global warming, our seemingly insatiable need for increased demand for energy (power consumption) should go side by side with the need to reduce GHG emissions associated with the increased energy demand (i.e., decarbonization).

The availability and sources of energy have evolved in the last few centuries from biomass to fossil fuel (solid, liquid, and gas), nuclear, and now to renewable energy (Figure 2). This energy mix is still varied, leading to a disproportionate emission of GHGs. For example, CO2 emissions in 2018 rose by 1.7% from the previous year (from 32.5 gtCO2e to 33.1 gtCO2e); while the emission reduced from 40% to 25% in developed countries, it increased from 27% to 42% in the BRICS nations (Menegaki, 2019). China alone is estimated to account for 30% of the global CO2 emissions and about 60% of the CO2 emissions by countries rich in resources (environmental performance index-epi).

[3] Five regional economies: The first four were initially grouped as "BRIC"

Figure 2. Energy transition graph of the world[4] (Our World in Data 2022)



To reduce global warming from GHG emissions, there must be a collective effort to decarbonize either by drastically reducing CO2 emissions or by carbon capture. To achieve this, a transition to cleaner energy is an option. Fossil fuel substitution with renewable energy is not a simple task. It will require nations to think about long-term sustainable

[4] The energy transition graph of the World shows a relatively historically slow energy transition relying mostly on one energy source at a time. The industrial revolution in the mid-19th century brought about a major shift from biomass to coal, with half of the Worlds energy coming from coal at the beginning of the 20th century. The energy mix is only a recent occurrence (hydro, oil, gas, nuclear, solar, and wind), but the transition it brought about happened rather quickly. For example, coal accounted for nearly two-thirds of the United Kingdom's power sources in 1990, but fell to a third by 2010 and was about 1% in 2020. Although transition had been historically slow, the emergence of the energy mix in renewable and improved technology are good motivators to ensure future transitions are faster (data taken from Our World in Data 2022).

developmental plans as against quick-win solutions to economic growth for political reasons with its attendant negative impacts on our shared environment. In other words, the transition towards decarbonization must be technological, economic, and political.

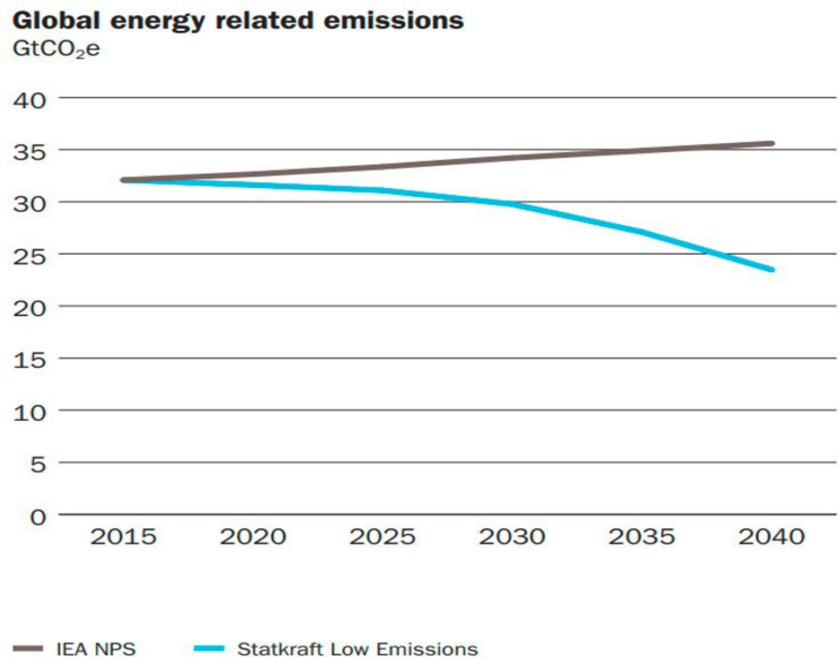
The technology required to implement a renewable energy economy is the long-to-build infrastructure type often outliving termed political administration. To guarantee continuity, governments should implement a robust legal framework to protect an ongoing energy transition plan from political interference. Moreover, there must be the political will to withstand the temporal setbacks during a period of creative destruction associated with adopting a low-carbon economy where an economic structure is renewed before progress can be achieved.

There are three major trending energy transition scenarios, each with a prediction of different assumptions:

1. The stat Kraft
2. The BP
3. The shell energy

The stat Kraft scenario (low emissions scenario 2022, n.d.) predicts that renewable energy will become cheaper than it is today and dominate the power sector with a 70% share (including 30% solar and 20% wind) by 2040, providing cleaner electricity to other sectors in the economy. This scenario further envisages a path to a completely renewable energy source for generating electricity if there is political will from policymakers to remove the issue of intermittency in renewables. This scenario predicts the possibility of attaining a 2°C reduction in temperature globally by 2040 due to a 30% drop in carbon emissions from adopting renewable energy.

Figure 3. StatKraft scenario 30% drop in carbon emission resulting from adopting renewable energy options



As global power plants retire (in 2017 alone, an excess of 25 GW), investment in renewable power plants can exceed that of fossil fuel, with these new plants being efficient enough to accommodate the projected 2.4% increase in annual energy demand, arising from the expected economic growth of developing countries and places with previously no access to electricity, till 2040. The transport sector will see an increased demand for electric cars as they become more efficient and strengthened by technology that will make battery manufacture cheaper with more mileage per charge and charging stations becoming more available, including battery swap options.

Meanwhile, the industrial sector will witness a change at a rate that is dependent on the type of industry. For example, while solar and wind can typically be sufficient for most manufacturing processes, sectors requiring high temperatures need carbon capture and storage options. The StatKraft scenario's success largely hinges on a balanced power system arising from the ability of the system swiftly changes when required in production and consumption, known as flexibility. Each country is expected to have its unique flexibility plan due to differences in climate conditions and different levels of starting points and progress of the transition to renewables.

The British Petroleum (BP) scenario is developed around evolving transition, predicting renewables accounting for 50% of energy supplies and GDP would have doubled by the 2040 threshold (BP, 2021). However, this share of renewable energy in the power sector depends on how fast the technology evolves and how fast old power plants are retired. The scenario gives a correlation between economic development and consumption of energy, justifying the need for further energy-growth nexus research as progress is made (BP-annual-report-and-form-20f-2019, n.d.). The industrial and building sectors are expected to take about

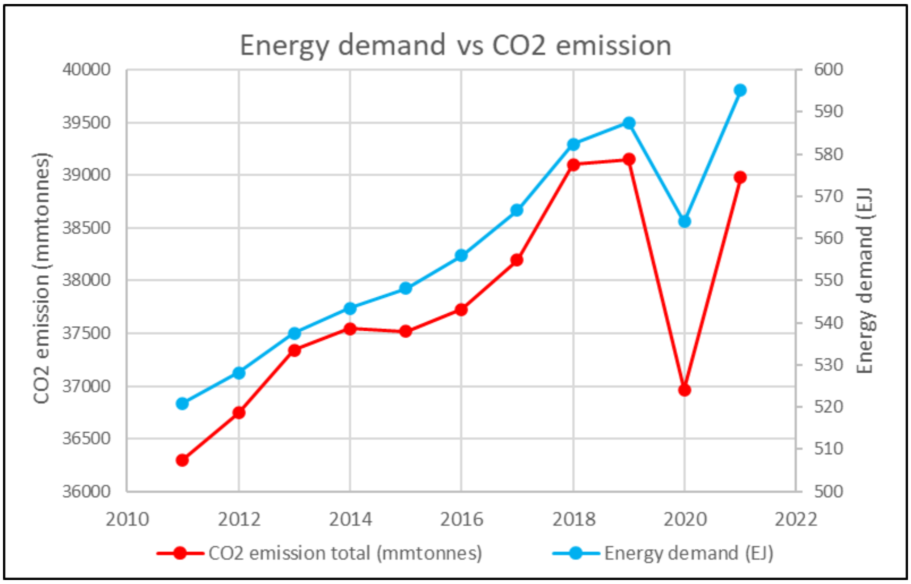
70% of the increased energy supply, while transport remains unchanged due to improved technology and mass transit schemes.

However, BP acknowledges the uncertainties in making predictions on renewables due to political delays in policies concerning transition and uncertainties in technology that will favor renewable energy development.

The shell scenario ties the demand for energy to income and prices depicting a typical energy ladder situation where people consume more power as they become wealthier. However, the energy ladder is, country-specific, as the effective cost of energy differs from country to country. The shell scenario has various scenario-based inputs (75 in total) since it is centered on population, technology, economic growth, people's choices, environmental pressure, and resource availability (Shell annual report, 2017). The shell scenario defines energy consumption when end-user demand for energy carriers increases rather than by energy sources. Shell predicts that the consumption of certain fuels by several countries will go up to 2060 beyond the 2040 target of zero carbon emissions due to significant growth in the economy of those countries.

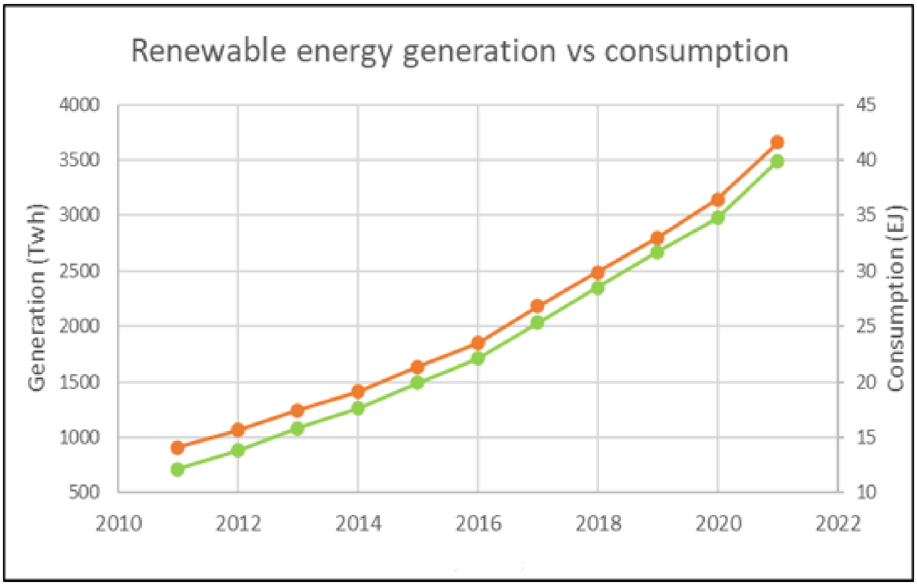
Globally, the demand for energy and emission in 2021 bounced back from its low values in 2020 due to the covid-19 pandemic. Energy demand increased by 5.8% from 564.91 EJ in 2020 to 595.15 EJ in 2021, representing the highest increase in history due to increased energy demand from emerging economies, with China alone expanding by ten EJ of the 13EJ taken up by emerging economies. CO2 emission from energy use, methane, industry, and flaring increased by 38.9 gtCO2e, representing a 5.7% increase in 2021 over 2020. Renewable energy consumption increased by 5.1 EJ in 2021 over 2020, representing 8.9%, with renewable energy generation increasing by 8.6% over the same period (Figure 4). Fossil fuel consumption remained largely unchanged, although it witnessed a 3% drop as a source of primary energy use in 2021 (82%) compared with the 85% it accounted for in 2016 (BP, 2021).

Figure 4. Graph showing direct trend energy demand/consumption from non-renewable and CO2 emission over a decade[5]*BP2021*



[5] This invariably indicates that if the world were to completely transition to renewables as a primary energy source, millions of tonnes of CO2 from emissions would be eliminated, thereby reducing global warming (Fig 4).

Figure 5. Shows the generation and consumption of energy from renewable sources[6]BP2021



[6] From Fig.5, Although generation increased with increased consumption as with fossil fuels, there is zero emission of CO2 into the atmosphere, affirming renewables as the only sustainable energy source for the environment (BP, 2021).

1.2. Background

Nigeria is a federal republic located in the West African sub-region. It covers an area of about 923,000 km2 from the arid Sahel savannah in the far north bordering Chad, Niger, and Cameroun republics, where the Sahara Desert is encroaching to the rain forest in the south that opens up to the Gulf of Guinea by the Atlantic Ocean. It is Africa's leading economy in Africa, with a GDP of 1.05 trillion USD as of 2021. It is the most populous country in Africa, with around 230 million people in 2021 (World bank, 2021).

Like other developing economies, Nigeria is experiencing rapid demand for energy due to its growing population and connecting to underserved areas. Adequate energy supply to meet demand is vital in facilitating economic development. The country's varied climatic conditions allow a mix of flexibility in renewable energy for low-carbon economic growth.

According to a report by the Ministry of Environment, the sector that emits the most CO2 is the energy sector, and based on a focus on the rate as of the time of the report, Nigeria may not meet its goal of NDC even by the year 2030 (climate transparency, 2020)

Nigeria has demonstrated its commitment towards decarbonization by committing to the global transition towards net zero carbon emission. The country is a signatory to the Paris Agreement and only recently revised its nationally determined contribution (NDC) to unconditionally reduce CO_2 emission by 20% by 2030, with an upward conditional reduction pledge from 45% to 47% reduction with adequate financial assistance, capacity building, and technology transfer and finally reach a zero-emission by the year 2060 (net zero targets | climate action tracker, 2021).

Nigeria launched an energy transition move in 2022 that is homegrown and aims at a net zero in 2060 via four critical sectors: oil and gas, the culinary industry, power, and transport (Nigeria energy transition plan, n.d.). The success of this natural gas is to be used as a short-term transition energy source from crude oil to a low-carbon economy that uses natural gas. Natural gas, over time, is expected to pass crude oil as a revenue source while providing cleaner energy, and eventually, a mix of renewables (solar, hydro, wind, biomass & hydrogen etc.) will become dominant in the energy sector. Nigeria is estimated, will require $410 billion to fully transition by 2060 and at least $10 billion at the initial stage.

Total electricity generated in Nigeria by the generating companies (Genco's) in 2019 stood at 33,448,633 MWh, with 32,799,114 MWh transmitted to the distribution companies (Discos). The consumption breakdown showed that the eleven Discos in Nigeria consumed 28,026,503 MWh. At the same time, 1,278,344 MWh and 1,048,807 MWh were transacted with Benin and Niger Republics, respectively, as cross-border supply transactions. This gives a total consumption sum of 30,353,654 MWh, with a loss of 2,445,490, representing a whopping 7.5% of the total energy supplied (NBS, 2020). Amid inefficient generation and distribution, a staggering 85 million persons don't access gridded electricity in Nigeria, representing 43% population, making Nigeria's energy access deficit the largest in the world (World Bank, 2021). World Bank's Ease of doing business 2020 report places Nigeria at 171 out of 190 countries with access to electricity.

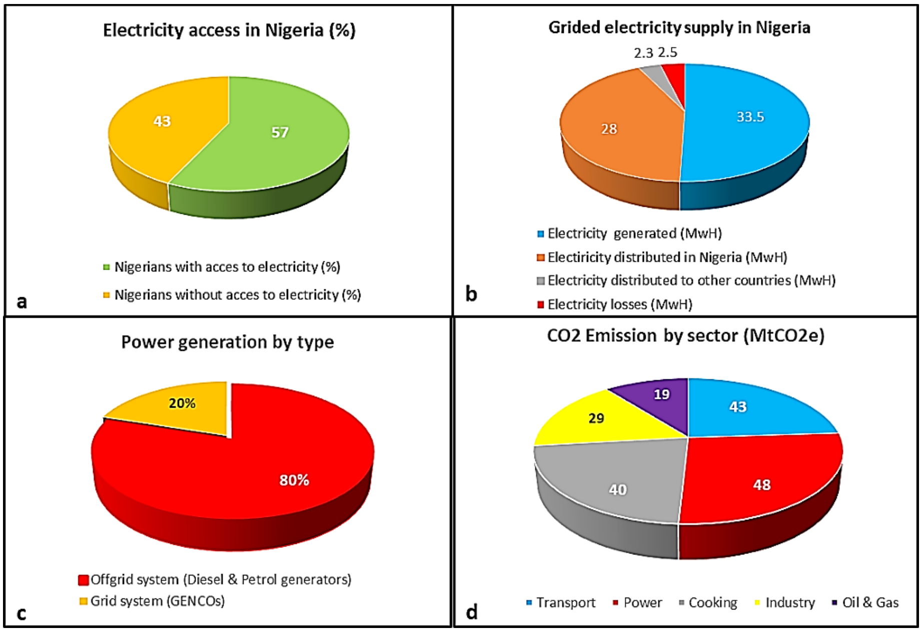
The power sector has the highest CO2 emission, with 48 mtCO2e in 2020 (Figure 4). Others include transportation (43 mtCO2e), cooking (40 mtCO2e), industry (29 mtCO2e), and oil & gas (19 mtCO2e) altogether accounting for about 65% of Nigeria's CO2 emission (Renewable energy roadmap: Nigeria, n.d.) In Nigeria, electricity supply is grouped into two; grid system (centralized) and off-grid (decentralized). The centralized system consists of a large-scale generation of electricity using majorly thermal (natural gas) and hydroelectricity (from dams) with an installed capacity to generate 13 GW of electricity daily.

However, the current daily generation hovers around 4.5 GW due to equipment failure from age, erratic gas supply (despite flaring natural gas), low water levels in dams due to climate change, and low power lines (national grid) capacities (Renewable energy roadmap: Nigeria, n.d.; Yetano Roche, 2023). This had, over the years, severely impacted the capacity of the centralized power system to provide adequate and uninterrupted power to Nigerians, thereby fueling the rise of the off-grid system, which is largely self-provided by individuals and corporations to power homes and businesses using petrol and diesel generators. It is estimated that as much as 15 GW to 30.5 GW of electricity is generated from the off-grid petrol and diesel-based system, accounting for about 80% of the operational energy capacity supply in the country (Tambari et al., 2020).

Nigeria is the leading importer of generators in Africa. It is estimated that 84% of city homes use fossil fuel generators and or solar power sources as a backup, while about 86% of corporations and businesses own/share a diesel-powered generator (Anjorin et al., 2020; Elinwa et al., 2021) & Irena 2023). Households and small and medium-scale enterprises spend as much as two orders of magnitude on fossil fuels generators than what they pay as electricity bills to the gridded system because of erratic supply in the gridded system (Fmiti, 2014) (Elinwa et al., 2021; renewable capacity statistics 2023, n.d.). This has far-reaching negative consequences on businesses, the economy, and the environment as the high costs of fueling and maintenance of captive generators and the attendant emissions significantly increase operational costs, translating to higher production costs and CO2 emissions. This poses a huge constraint for people and businesses and is estimated to result in an economic loss of about $26.2 billion annually, equating to about 2% of GDP. The problem with Nigerian electricity supply is policy and funding constraints.

However, significant progress has been made in the past ten years in policy shift toward open market private sector-driven electricity distribution to improve efficiency, thereby cutting down losses that will leave a carbon imprint on the environment. In 2021, the World Bank approved $500 million to support the country in providing mass metering through the electricity distribution companies (Discos), thereby improving access and expanding the distribution network. The lack of metering and incidental charges on electricity consumption has been a probe in Nigeria, making the exact consumption rate difficult to ascertain for national planning.

Figure 6. Showing Nigeria's electricity access, electricity supply, power generation, and CO2 emissions by sector[7]

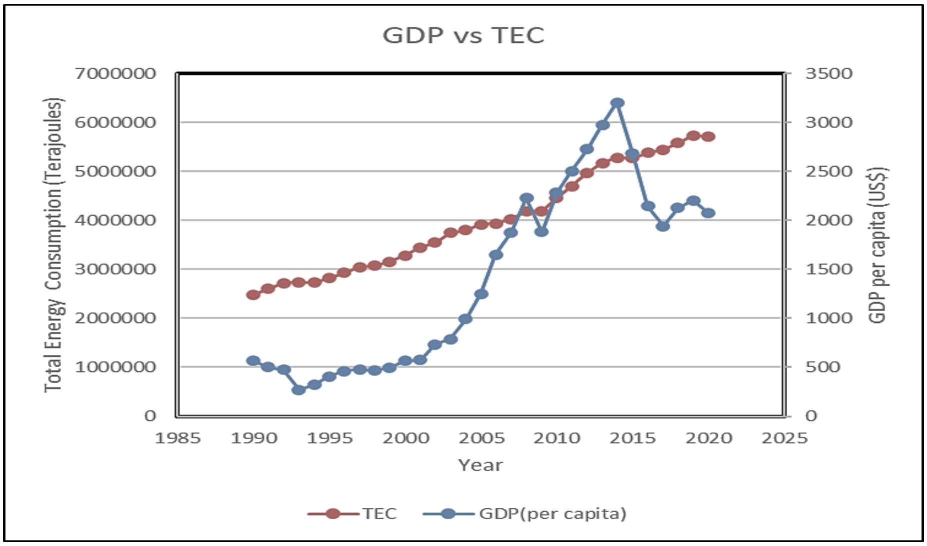


[7] Figure 6 (a): Chart showing that a whopping 43% of Nigerians are without access to electricity (World Bank, 2021) and are mostly the rural communities. Those who access electricity are also faced with erratic supply, with some studies suggesting an average supply of about 5-12 hours a day. (b) Chart showing the centralized gridded electricity supply and distribution that generates only 33.5% (4.5 GW) of its installed capacity (13 GW). The grid system in Nigeria is aged, cumbersome and largely inefficient. (c) Chart showing the heavy reliance of Nigeria on an off-grid system for power generation largely due to unreliable and aging centralized gridded system. However, this comes with its downside as the off-grid system is powered by diesel and petrol generators that emit CO2 and have high maintenance costs making them not economical compared to a centralized grid system and contributing to global warming by releasing CO2 into the atmosphere. However, the off-grid decentralized system currently dependent on fossil fuel, if replaced with renewable energy, will be an excellent sustainable and economical alternative, especially since Nigeria has the flexibility of varied, abundant sources of renewables. (d) Chart showing the leading CO2 emission source in 5 major sectors of the Nigerian economy with a combined emission of 179 MtCO2e in 2020. This represents over 65% of annual CO2 emissions in Nigeria, with the rest coming mostly from biofuels extensively used for heating and cooking in rural communities. These five critical sectors are the target of the Government's energy transition plan of achieving net zero by 2060. (*Renewable Capacity Statistics 2023*, n.d.; *Renewable Energy Roadmap: Nigeria*, n.d.; The World Bank, 2021)

A study of energy use, economic growth, and CO2 emission looking at 12 sub-Saharan African countries of Africa showed that long-term CO2 emissions correlated with energy use and economic growth have variations between nations (Esso & Keho, 2016). Granger causality studies found that economic expansion causes CO2 emissions in the near term in Nigeria as one of the countries of study (Figure 7). This suggests that economic growth cannot be achieved without impacting the environment.

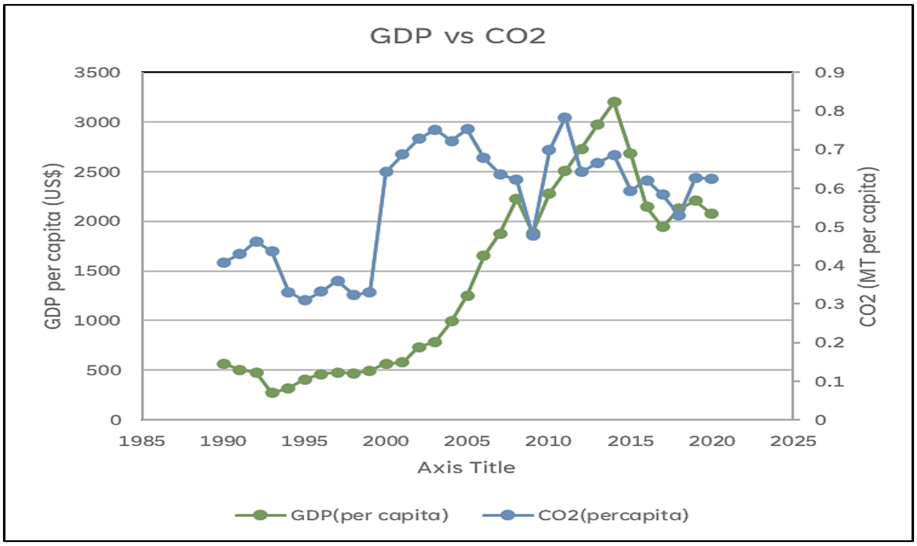
For Gabon, Nigeria, and Togo, there is proof that CO2 emissions lead to an increase in GDP in the other direction. Short-term results of Nigeria and long-term outcomes for Gabon and Congo, there have shown a causal link in both directions between economic expansion with carbon. The utilization of energy and economic development contribute to CO2 over time for Congo, South Africa, Benin, Cote d'Ivoire, Gabon, Nigeria, Ghana, Togo, and Senegal. The discovery of a one-way causality link between real GDP and pollution for Ghana, Senegal, Congo-democratic, and Benin shows these nations can implement CO2 emissions reduction measures without suffering short-term economic growth consequences.

Figure 7. Graph showing the direct trend between total energy consumption and GDP



Source: Authors work with data from (International Energy Agency, 2022b)

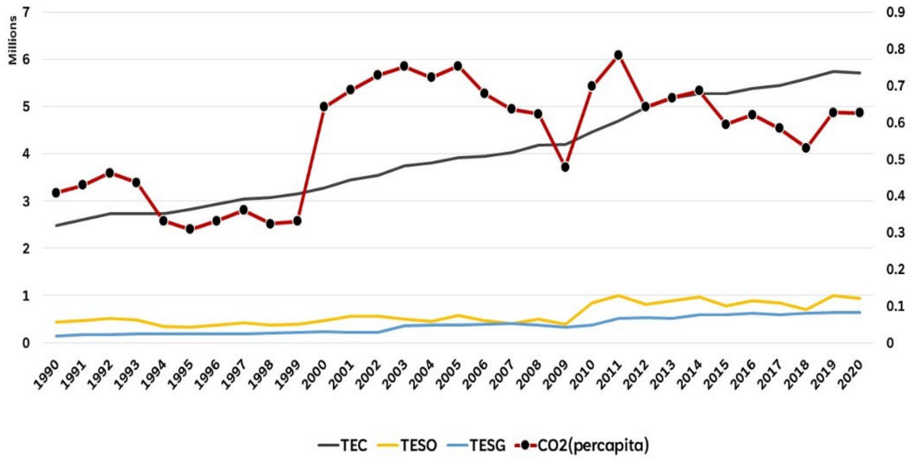
Figure 8. Graph showing the impact of GDP (per capita) increasing with CO2 increase[8]



Source: Authors work with data from (International Energy Agency, 2022b)

[8] *The increasing economic growth corresponds with a direct increase in CO2 emission, resulting in global warming. The result could be different if Nigeria replaces its fossil fuel source of energy with renewables*(A, 2022; IEA, 2022)

Figure 9. Showing the relationship between Nigeria's energy and CO2 per capita[9]



Source: Authors work with data from (International Energy Agency, 2022b)

As with other countries, the Energy transition in Nigeria comes with a huge investment opportunity for partners to choose from. A $23 billion investment opportunity has been identified across a portfolio of projects. The portfolio shows options along the entire value chain, involving projects and programs in production, transmission, and distribution (infrastructure renovation and distribution connections), meter addition, gas commercialization, clean cooking, e-mobility, healthcare, public buildings, and technical assistance. This is in addition

[9] *Nigeria's Total Energy Consumption (TEC), Total Energy Supply from Oil (TESO), Total Energy Supply from Gas (TESG), and CO2percapita for the period 1990 to 2020 data from*(A, 2022; IEA, 2022; International Energy Agency, 2022a). *The relationship clearly shows how energy consumption, with the rise in CO2 emissions, this would increase owing to the fact Nigeria is still growing both in population and economy. It is only proper to have alternative energy source that would cause a reversal or adopt technologies that would mitigate the carbon emissions produced.*

to $2 billion in guarantees and risk-reduction tools, $1 billion for generation, $300 million in transmission and distribution, $500 million for gas commercialization, $150 million for clean cooking, and $50 million for healthcare delivery (investing in Nigeria's energy transition, 2022; Nigeria energy transition plan, n.d.).

World Bank had earlier in June 2020 approved a Power Sector Recovery Program (PSRP) to ensure Discos invest in rehabilitating power lines and equipment and electric meters are installed for transparent billing. Financing based on performance and loss reduction will also be provided as an incentive to improve the quality of service to Discos through the Nigeria Distribution Sector Recovery Program.

Recently (March 2023), the government of Nigeria signed into law an act that further liberalizes electricity distribution, allowing individual states (prefectures) to license, generate, transmit, and distribute electricity. This is widely welcomed as it will bring about competition and efficiency but, more importantly, improved access using a mix of abundant renewables in Nigeria's multi climates. All these are geared towards efficiently increasing access to electricity to Nigerians with low carbon emissions while the country transits to renewables with a net zero target in 2060.

With the above background, it is vital to carry out empirical analysis to see if the effect of the use of fossil fuels and economic expansion contribute to deterioration with recent data sets and find out ways to see if new policies can be implemented or improved from previous ones.

1.3. Motivation for the research

The energy sector is crucial to Nigeria's economy since the country is the continent's largest oil and gas producer. The GDP per capita in 2021 (in current USD) is 2,065.7, and annual GDP growth is 3.6%, a significant increase from 2020's figure of -1.8% due to the economic slowdown brought on by the Covid-19 epidemic (GDP growth (annual %) - Nigeria | data, n.d.).

With most of its emissions coming from the oil and gas sector, Nigeria significantly contributes to global warming. Energy consumption in the country has been rising due to growing populations, more urbanization, and increased industrialization, which is expected to continue. Therefore, it is crucial to understand the connection between Nigeria's economic growth, oil and gas supply, energy consumption, and CO2 emissions and to discover ways to lower emissions without compromising energy security or economic growth.

The issue of greenhouse gas emissions (GHG) and methane emissions is important in Nigeria and especially in the upstream oil and gas sector, of which the Nigerian upstream petroleum regulator commission is the sole regulator, as it concerns the exploration and exploitation of oil and gas as mandated by the petroleum industry act 2021 and upstream petroleum environmental regulation 2022 part 11 sub 116 to 119 exclusively speaks about the greenhouse gas (GHG) emissions (CO2 has been the main component) management which spans from the control of emissions to monitoring and even making sure oil and gas producers have net-zero targets. This part may be my primary motivation regarding this research as it affects and would contribute directly to my organization and its mandate in line with extant laws and regulations.

1.4. Problem statement

According to a report by the Ministry of Environment, the sector that emits the most CO2 is the energy sector. Based on a focus on the rate as of the time of the report, Nigeria may not meet its goal of NDC even by the year 2030 (climate transparency, 2020).

The power sector has the highest CO2 emission, with 48 mtCO2e in 2020 (figure 4). Others include transportation (43 mtCO2e), cooking (40 mtCO2e), industry (29 mtCO2e), and oil & gas (19 mtCO2e), altogether accounting for about 65% of Nigeria's CO2 emission (renewable energy roadmap: Nigeria, n.d.).

Electricity supply is grouped into two; grid system (centralized) and off-grid (decentralized).

The centralized system consists of a large-scale generation of electricity using majorly thermal (natural gas) and hydroelectricity (from dams) with an installed capacity to generate 13 GW of electricity daily. However, the current daily generation hovers around 4.5 GW due to equipment failure from age, erratic gas supply (despite flaring natural gas), low water levels in dams due to climate change, and old power lines (national grid) capacities (Renewable energy roadmap: Nigeria, n.d.; Yetano Roche, 2023).

The off-grid system, largely self-provided by individuals and corporations, power homes and businesses using petrol and diesel generators. It is estimated that as much as 15gw to 30.5gw of electricity is generated from the off-grid petrol and diesel-based system, accounting for about 80% of the operational energy capacity supply in the country (Tambari et al., 2020).

All these have led to the problem statement of "**identify effective strategies that can be implemented to reduce CO2 emissions resulting from energy demand and supply from fossil fuels as it applies to Nigeria.**"

1.5. Research questions

Q1. What is the relationship and the causal direction between carbon dioxide emissions, energy supply/demand, and economic growth?

Q2. What are the appropriate energy policies to attain the goal of greenhouse gas reduction in an economy mainly dependent on fossil fuel production and consumption?

1.6. Research objective

Essentially, the primary research objective is to investigate the relationship and causal direction between CO2 emissions and key macroeconomic variables, specifically GDP growth and energy consumption.

Literature review

1.7. Literature review

The study of environment, energy and economic development is gaining more attention in recent years due to the concerns about climate change. The rate of growth in the economy is a major factor in energy requirements. Consuming energy, especially by burning fossil fuels, contributes to the pollution effect of climate change and is particularly common in developing economies. Future energy demands and supply, as well as pollution control measures to maintain environmental quality, can only be estimated with the help of growth predictions. (Jorgenson & Wilcoxen, n.d.). The popular belief is that while natural resource and environmental economics are closely connected, its different fields. In general, economic and policy challenges are environmental and related to resources. However, from a theoretical standpoint, a substantial intrusion between two disciplines offers an engaging paper for modelling the interrelationships the environment, energy and economic growth show. This link appears dynamic because detrimental effects are observable despite resource use producing immediate economic advantages(Esso & Keho, 2016).

GHG, particularly CO2 (carbon dioxide), is believed to drive global warming primarily. Several nations signed the Kyoto protocol and pledged to reduce emissions to avert global warming and its repercussions. The 26th session of the un[10] (Cop26) was held, marking the significance of cutting greenhouse effects to battle global climate. Nigeria announced a commitment to achieve net zero emissions in 2060. This necessitates identifying CO2 emission sources(Gupte et al., 2021).

The research on the link of economic growth and environmental pollutants (such as SO2, CO2 and NOx, etc.) Focuses primarily on three aspects (Zhang & Cheng, 2009).

The first aspect of the study examines the connection between environmental contaminants and economic expansion, which is popular in most works of literature (Chen & Huang, 2013; Farhani & Ozturk, 2015; Halicioglu, 2009; Saraç & Yağlikara, 2017; Stern, 1998). This connection is closely connected to the environmental Kuznets curve ("EKC") theory, which implies a reverse-u relationship of ecological deterioration and income growth. The EKC hypothesis suggests that environmental degrading would increase with a country's per capita income during the initial stage of the economy. Still, it will decrease as per capita income rises after that. Grossmann and Krueger produced the first empirical research to establish the EKC hypothesis in 1991 (Grossman & Krueger, 1991). Since then, several studies have examined the correlation between economic growth and environmental pollutants (Grossman & Krueger, 1991).

[10] United Nations conference on climate change tagged COP26

Secondly, the literature review examines the link between energy (input) and production (output). This connection asserts that economic growth and production may be determined together due to the strong link in economic expansion and energy use (Halicioglu, 2009).

Kraft (Kraft & Kraft, 1978) utilized yearly data from the united states from 1947 to 1974 and discovered a causal connection in only one way between national income and energy (Kraft & Kraft 1978).

Following this analysis (Kraft & Kraft, 1978), several empirical investigations were conducted on the correlation between GDP and consumption of energy (Kraft & Kraft, 1978).

Kraft & Kraft (1978) explored the causative linkages energy use and real income/total employment and found presence of one-way Granger that flows from GNP to energy. The idea that energy conservation might be a workable strategy without having a negative impact on national GDP is intriguing.

According to (Akarca & Long, 1979), energy use has a negative Granger effect on total employment. Implies that when energy-saving policies are implemented, overall employment will increase. Although it may be disputed, the empirical analysis was clear about it, the majority of data for energy conservation programs and several researches support the neutrality hypothesis conservation of energy has a lack of effect on economic activities (Akarca & Long, 1979; Yu & Hwang, 1984) (The causal relationship between energy and GNP: an international comparison on Jstor, n.d.) and other researchers have not discovered any causal links (Granger, 1969a) between actual GNP and energy consumption. Although energy consumption is neutral regarding employment (The causal relationship between energy and GNP: an international comparison on Jstor, n.d.), short-run causation of energy consumption may be shown to influence income.

In (Yu & Hwang 1984), researchers utilized Sims' work to examine the link between GDP and energy use in United States of America 1947 and 1979. (Kuersteiner, 2010) a test for causation between two variables and found no evidence of it. Also, in 1992, (Yu & Jin 1992a) have not discovered any connection between long-term energy use and income (Yu & Jin, 1992b), "The relationship between energy consumption and GDP in the United Kingdom, France, Germany, Italy, Canada, and Japan" from 1952 to 1982 was explored. In Japan, they identified bidirectional causation amongst energy and growth, unidirectional causation between how energy is utilized and GDP in Canada, and one-way directional causation in economy to energy consumption for Germany and Italy.

The third characteristic of the study of links between economic expansion and environmental emissions resulted from a combination of the two prior approaches, which examine the application of the correlations. This research examines all dynamic connections between economic expansion, environmental pollution, and energy usage.

(Acaravci & Ozturk, 2010). (Moomaw & Unruh, 1997) investigated the link between CO_2 emissions and income in developed nations from 1950 to 1992. According to the investigations, there is a reverse-u pattern, and their threshold levels occurred between 1970 and 1980. Liu (Li & Liu, 2005)used panel data analysis to evaluate OECD member countries (24) and economic development, carbon emissions, energy consumption, concluding "EKC" presence based on carbon dioxide emissions (Li & Liu, 2005).

The broad literature above and the three scenarios of studies, i.e. linkage in environmental pollutants and economic growth, have given literature backing as to the aspect of the studies, which can be seen in the lights of environmental pollutants, economic evolution, and energy utilization as a base to see how various nations are adhering to the EKC or other economic theories. This research combines and adopts the third scenario. Empirically we see the effecting cause of microeconomic variables or energy and economy on CO_2 emissions as is seen in (Act et al., 2022) results indicate that carbon emissions rise as per capita wage increases, supporting the notion of monotonically rising connection between CO_2 per capita and income per capita, as well as the oil and power consumption models. According to the gas consumption model, the long-term and short-term income elasticity of carbon emissions is negative (-). This study suggests that if the Saudi-Arabian economy shifts from oil and uses gas, a rise in per capita income would cut CO_2 (carbon emissions).

In a Nigerian case seen from 1970 to 2010 by (Chindo et al., 2015), according to empirical findings, a long-term link of energy use, CO2 emission, with GDP, C02 emissions have been demonstrated to have a considerable positive influence on GDP in the short and long term, suggesting that increasing C02 emissions aid GDP growth. In contrast, energy use substantially negatively impacts GDP in the short term.

The Granger causality test reveals the unidirectional relationship between GDP and carbon emissions. These were the findings in the studies done by (khan et al., 2018) for the case of China.

A case of Tunisia, 1971–2012 long-run connection is examined using Autoregressive and Error Correction Methods (ECM). Additionally, Tunisian instance demonstrates monotonic correlation which is positive between economy and emissions. An indication data doesn't align with the Environmental Kuznets curve theory (Farhani & Ozturk, 2015).

Another study by (Adams et al., 2020) using this analysis covers the period 1996-2017 for ten resource-rich nations, including Brazil, China, India, Israel, Russia, Saudi Arabia, South Africa, Turkey, Ukraine, and Venezuela, using the autoregressive distributed lag model.

In the study (Bildirici & Kayikçi, 2013), oil output and economic growth are empirically demonstrated to be cointegrated. Positive bidirectional causality is present for oil output and economic enlargement, in both near and future, which bolsters case for policies that encourage investment in energy infrastructure. This study examines the correlation between oil production and GDP of major crude-exporting nations, Eurasia, including Azerbaijan, Kazakhstan, the Russian Federation, and Turkmenistan, from 1993 to 2010. The possibility of this analysis has shown the possible usage of production and supply data for empirical study, which this research partly adopts.

A study by (Ang, 2007) shows a somewhat dynamic relationship between CO2, energy, and output in the case of France; the same cointegration was used and later, a vector correction model to examine the long run. Short-run results show one-way cause and effect from energy consumption growth and output growth.

Ferda Halicioglu (Halicioglu, 2009) conducted an analysis of "CO2, energy consumption income, and foreign trade in Turkey", an empirical investigation and to see the dynamic causal relationship, and the bound testing procedure was used, which is best practice for an ARDL model and concluded that foreign trade and energy consumption contributed the most to CO2 emissions.

The uniqueness of the bound test approach to cointegration which was used in place of the other cointegration is mainly developed to have a novel way to assessing the presence of a level connection between a dependent variable and a group of regressors when it is unclear if the regressors are trend- or first-difference. The method was developed

(Pesaran et al., 2001a), which details have been elaborated in the methodology.

A causal relationship was investigated using panel cointegration analysis in three North African countries, after which a Granger-causality was done to know the direction. The data year was 1980-2021, and findings demonstrate that the short-term panel result shows causation in one way from the economy's growth to consumed energy; unidirectional causality exists for ratio of energy use to CO2 emissions, confirming the EKC proposition. The author also stated that these studies regarding environment, energy, and economy could be done in a single country and in a combination of a group of companies which is what he did in this case.(Kais et al., 2015) used the panel cointegration technique which was developed by (Baltagi et al., 2001; Pedroni, 2000). This was done so because the method seems to be improved unlike the conventional co-integration analysis applied on a single country series.

Taking a good look at the appropriate methodology as regards the research pathway as stated by (kais et al., 2015), the environment, energy growth nexus can be studied in two ways which are either country-specific or single country, but as panel cointegration was used for (Kais et al., 2015) which was developed by (Pedroni, 2000) a more suitable cointegration was developed by (Pesaran et al., 2001b) which was best for the use in smaller countries and data, data as low as 30 number observation was used in the a study (Menegaki, 2019) . (Menegaki, 2019) further elaborated how most of the methodology was not explained in detail especially when it comes to the ARDL model itself of which this research would follow all procedures and explain without any truncation in the methodology and interpretation to get the optimum desired result of policy implications. Furthermore (Shrestha & Bhatta, 2018a) in his writing said one of the most challenging problem economist faces is selection of appropriate methodology while working on time series data, as it is commonly known from years of time series analysis that time series data possess specific properties such as trends and structural breaks as well as other like serial correlation and heteroskedastic which proper diagnosis have to be done to know how well the model is specified or has the goodness of fit for proper policy implementation (Anscombe & Tukey, 1963).

A study done to determine the short- and long-term link of environmental deterioration resulting from carbon dioxide (CO2) emissions and energy utilization, GDP, and urbanization in Vise grad region (V4) nations. The analysis included data from 1996 through 2020. ARDL bound test and ARDL and ECM models were used to identify the directions and strength of dependency in the field of methodology in some v4 nations (Czech Republic, Poland, Slovakia, and Hungary) (Myszczyszyn, Janus Supron̈, BłażEJ, 2022).

Finally, we look at the study done by (Esso & Keho, 2016); both long-run to short-run causality in 12 sub-Saharan countries were investigated as regards CO2 and GDP adopted (Menegaki, 2019) and also did a Granger causality test and a mixed result was obtained. Nigeria was one of the 12 countries investigated, unlike the study done by (Chindo et al., 2015), who just did the analysis for Nigeria alone. Both the studies from the two studies show that's economic activities and consumption of energy contribute to CO2. In contrast, the short-run showed that CO2 affected GDP, which goes against the EKC; however, its shows environmental policies such as energy conservation policies.

This study will take the literature review and apply an autoregressive distributed lag and bound test for cointegration (Chindo et al., 2015; Menegaki, 2019; Pesaran, 2008; Pesaran et al., 2001b; Shrestha & Bhatta, 2018a) and later apply Granger causality (Dumitrescu & Hurling, 2012; Engle & Granger, 2015a; Granger, 1969a; Kuersteiner, 2010) to see how the variables selected will be interpreted with their relationship with CO2, a major addition to this study is the addition of the variables of energy supply from oil and energy supply from gas, these variables will give additional insight as to the interplay of the high consumption of fossil fuel majorly for energy in the use of portable generators and other sectors(Anjorin et al., 2020; Elinwa et al., 2021) that are not captured by the consumption data. The extensive literature review has shown that gas and oil production have been used as variables (Bildirici & Kayikçi, 2013; Chrulski & Laciak, 2021). By proxy, it implies the usage of oil and gas supply. The analysis will be conducted as mentioned in the methodology as we adopt the above literature and draw a conclusion and policy implication.

Methodology and data

1.8. Data

The analysis utilizes yearly time series data from 1990 to 2020. Total energy consumption (terajoules), total energy supply from oil (terajoules), total energy supply from gas (terajoules), CO_2 per capita (metric tons per capita), which was taken from the International Energy Agency (IEA) and GDP per capita current used was taken from World Banks WDI. Availability of data determined the time frame for the analysis. All variables were transformed into natural logs. The short forms of the variables as used in the study are thus; total energy consumption (logtec), total energy supply from oil (logteso), total energy supply from gas (logtesg), CO_2 per capita (logCO2percapita) and GDP per capita (logGDPpercapita).

It is well to note that this is the first combination of these variables used for such analysis.

Figure 10. CO2 emissions of Nigeria for the year analyzed

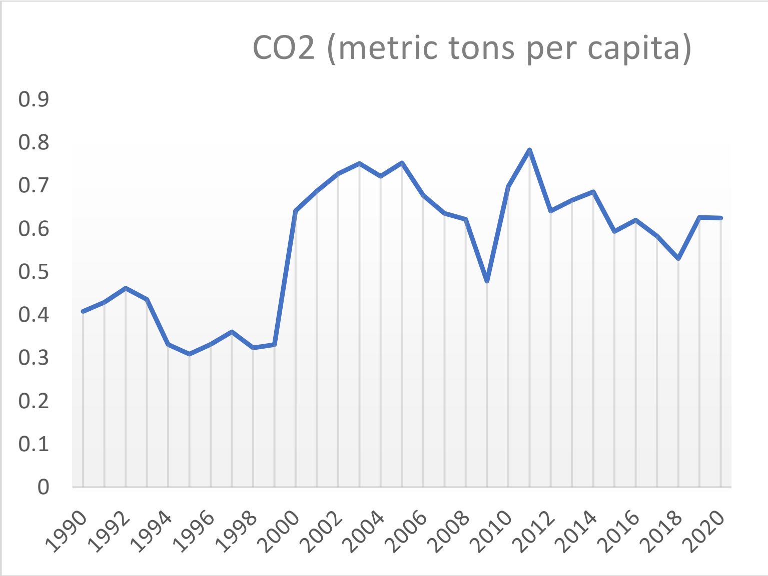


Figure 11. GDP of Nigeria for the year analyzed

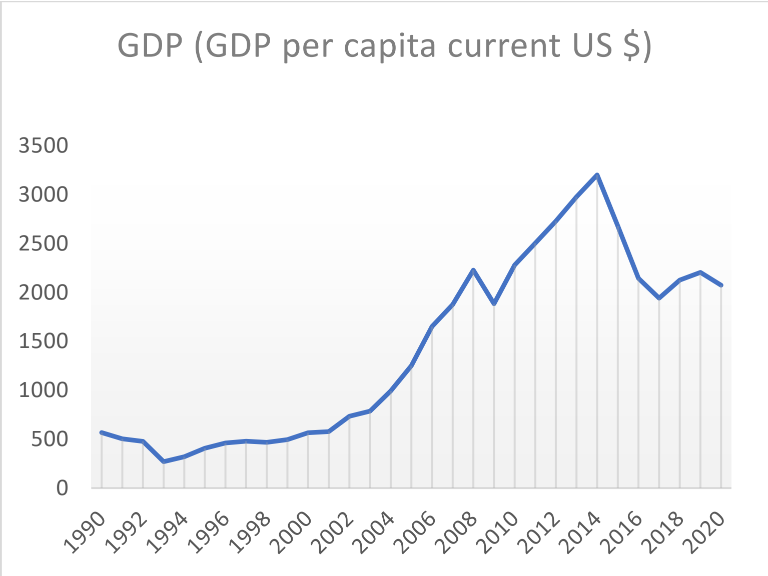


Figure 12. Total energy consumption of Nigeria

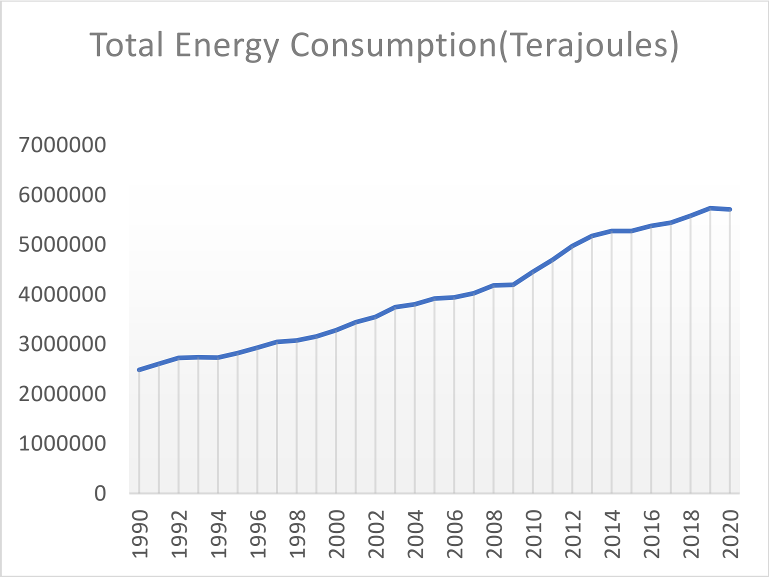


Figure 13. Total energy supply oil of Nigeria

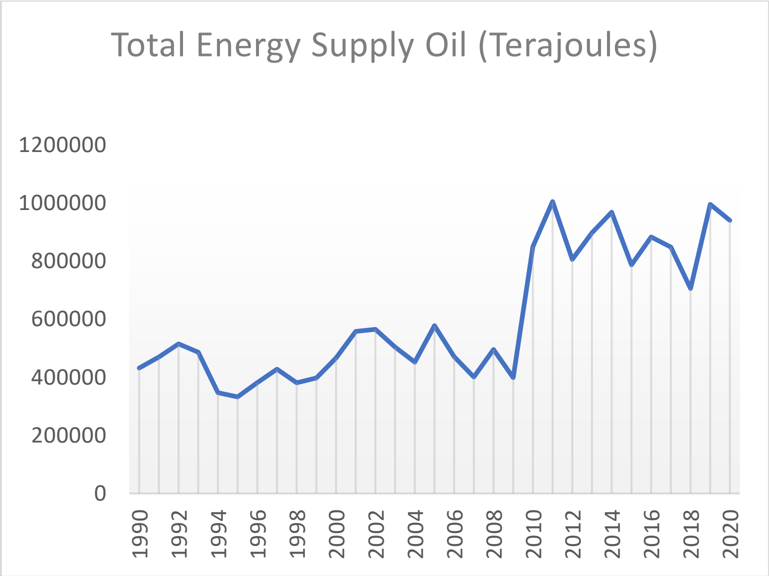
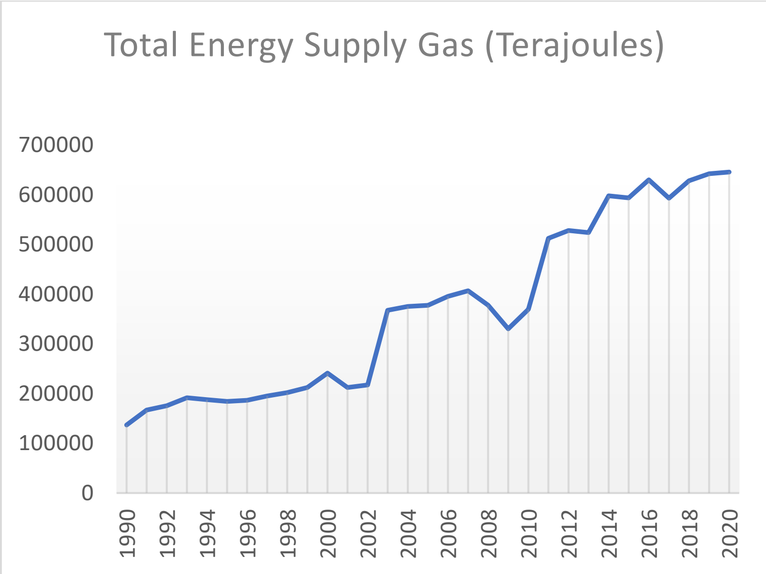


Figure 14. Total energy supply gas of Nigeria 1990-2020



Definition of Variables

CO_2 emissions (metric tons per capita):

"Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring" as stated by IEA(A, 2022; IEA, 2022; International Energy Agency, 2022b).

GDP per capita (current US$)

"GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars”. as stated by World Bank(The World Bank, 2021)

Total final consumption by source (TFC) in Terajoule

“The sum of the consumption in the end-use sectors and for non-energy use. Energy used for transformation processes and for own use of the energy producing industries is excluded. Final consumption reflects for the most part deliveries to consumers (see note on stock changes). Backflows from the petrochemical industry are not included in final consumption (see from other sources under supply and petrochemical plants in transformation). Note that international aviation bunkers and international marine bunkers are not included in final consumption except for the world total, where they are reported as world aviation bunkers and world marine bunkers in transport” as defined by IEA(A, 2022; IEA, 2022).

Total energy supply by source in (TJ) Terajoule

“Total energy supply (TES) is made up of production + imports -exports -international marine bunkers -international aviation bunkers ±stock changes. Note, exports, bunkers and stock changes incorporate the algebraic sign directly in the number. For World, TES is defined as production + imports -exports ±stock changes. Note, exports, bunkers and stock changes incorporate the algebraic sign directly in the number” as defined by IEA(A, 2022; IEA, 2022).

1.9. Methodology

Autoregressive distributed lag and bounds test for cointegration, established by (Pesaran et al., 2001a)and further developed by (Pesaran, 2008). It is considered one of the most versatile econometric tools for analyzing energy-growth connection, especially in a study framework is changed by regime transitions and shocks which alter energy use outline or how other model components vary over time. The unique advantage of the ARDL method is it can also be used for a relatively small sample. The data set of twenty-eight years was used by (Narayan & Smyth, 2005). The fact that various components might have different lags also adds to the appeal of the ARDL technique and demonstrates how adaptable it is.

ARDL only needs a single equation form, and the technique is simple to grasp and apply for analysis (Bayer & Hanck, 2013; Rahman & Kashem, 2017). Other methods call for a set of equations.

According to (Halicioglu, 2007)and (Haug, 2002), the lag method is more trustworthy for small samples than the (Johansen, 1991)' cointegration methodology. The approach also has two additional advantages. These include the ability hypotheses evaluation based on the predicted coefficients in the long run, which was not possible with the

Engle-Granger (Engle & Granger, 2015b), and simultaneous calculation of short- and long-term results.

Before our analysis, we need to specify our model based on the variable selection.

Autoregressive distributed lag (ARDL) the model includes lagged values of dependent variable and present and lagged values of the regressors as explanatory variables.

The generalized ARDL (P, Q) model is specified as follows:

$$Y_t = \gamma_{0j} + \sum_{i=1}^{p} \delta_j Y_{t-1} + \sum_{i=0}^{q} \acute{\beta}_J X_{t-1} + \varepsilon_{it} \quad (1)$$

Y_t = dependent variable (this can be a vector if you take each variable as dependent variable)

P = lag value of the dependent variable

Q = lag value of the independent variable

δ_j ,$\acute{\beta}_J$ = coefficients

$$LPCO_{2_t} = \beta_0 + \beta_1\, Lgdpt + \beta_2\, Ltec_t + \beta_3\, Lteso_t + \beta_4\, Ltesg_t + \mu_i \quad (2)$$

The unconditional linear correction model (ulcm) for estimate to conduct f-bound testing $\Delta LCO_{2_t} = \beta_0 + \sum_{i=1}^{q} \beta_{1i}\, \Delta LCO_{2t-i} + \sum_{i=1}^{p_1} \beta_{2i}\, \Delta Lgdp_{t-i} \sum_{i=1}^{p_2} \beta_{3i}\, \Delta\, Ltec + \sum_{i=1}^{p_3} \beta_{i4}\, \Delta lteso_{t-i} +$

$\sum_{i=1}^{p_4} \beta_{5i}\, \Delta\, Ltesg_{t-i} + \delta_0 LCO_{2t-1} + \delta_1 Lgdp_{t-1} + \delta_2 Ltec_{t-1} +$

$\delta_3 Lteso_{t-1} + \delta_4 Ltesg_{t-1} + \mu_t$ (3)

Δ: the first differential operator; β_0: drift components; μ_t: the usual white noise residuals.

$\beta_1 - \beta_6$: the error correction dynamics.

Coefficients $\delta_0 - \delta_5$: the long-term connection between the analyzed variables.

The null proposition in Wald-f statistics indicates the lack of long-run co-integration

$(H_0 = \delta_0 = \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0)$ (4)

Against $(H_a = \delta_0 \neq \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0)$. (5)

Equation (3) also has a long-run error correction model; however, the short-run model alone can be analyzed if there is no cointegration in the analysis outcome.

The short-run relationship amongst studied variables if there is no cointegration is in equation (6) $\Delta LCO_{2_t} = \beta_0 +$

$\sum_{i=1}^{n_1} \beta_{1i}\, \Delta LCO_{2t-i} + \sum_{i=1}^{n_2} \beta_{2i}\, \Delta Lgdp_{t-i} + \sum_{i=1}^{n_3} \beta_{3i}\, \Delta\, Ltec +$

$\sum_{i=1}^{n_4} \beta_{i4}\, \Delta \mathrm{l}teso_{t-i} + \sum_{i=1}^{n_5} \beta_{5i}\, \Delta\, Ltesg_{t-i} + \mu_t$ (6)

The long-run relationship when there is cointegration leads to the ECM (error correction model) $\Delta LCO_{2_t} = \beta_0 + \sum_{i=1}^{n_1} \beta_{1i}\, \Delta LCO_{2t-i} + \sum_{i=1}^{n_2} \beta_{2i}\, \Delta Lgdp_{t-i} + \sum_{i=1}^{n_3} \beta_{3i}\, \Delta\, Ltec + \sum_{i=1}^{n_4} \beta_{i4}\, \Delta lteso_{t-i} + \sum_{i=1}^{n_5} \beta_{5i}\, \Delta\, Ltesg_{t-i} + \eta_1 ECT_{t-1} + \mu_t$ (7)

$\eta = \left(1 - \sum_{i=1}^{n_3} \beta_{1i}\right)$, adjustment speed of parameter with a negative sign

$ECT = (\Delta LCO_{2t-i} - \boldsymbol{\theta X}_t)$, an error correction term

$\boldsymbol{\theta} = \frac{\sum_{i=1}^{n_3} \beta_{1i}}{\alpha}$, is the long-run parameter

Finally, the causality test further embosses the model's relationship, which will take the following equations. However, it should also be noted that when there is no cointegration, the causality would only be done in the short run ARDL.

To see the direction and interplay between the dependent variable and independent variables

$$\begin{bmatrix} \Delta L(CO_2)_t \\ \Delta Lgdp_t \\ \Delta Ltec_t \\ \Delta Lteso_t \\ \Delta Ltesg \end{bmatrix} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \\ \alpha_4 \\ \alpha_5 \end{bmatrix} + \begin{bmatrix} \beta_{11,1} & \beta_{12,1} & \beta_{13,1} & \beta_{14,1} & \beta_{15,1} \\ \beta_{21,1} & \beta_{22,1} & \beta_{23,1} & \beta_{24,1} & \beta_{25,1} \\ \beta_{31,1} & \beta_{32,1} & \beta_{33,1} & \beta_{34,1} & \beta_{35,1} \\ \beta_{41,1} & \beta_{42,1} & \beta_{43,1} & \beta_{44,1} & \beta_{45,1} \\ \beta_{51,1} & \beta_{52,1} & \beta_{53,1} & \beta_{54,1} & \beta_{55,1} \end{bmatrix} \times \begin{bmatrix} \Delta L(CO_2)_t \\ \Delta Lgdp_t \\ \Delta Ltec_t \\ \Delta Lteso_t \\ \Delta Ltesg \end{bmatrix} +$$

$$\sum_{i=1}^{p-1}\begin{bmatrix}\delta_{11,i} & \delta_{12,i} & \delta_{13,i} & \delta_{14,i} & \delta_{15,i}\\ \delta_{21,i} & \delta_{22,i} & \delta_{23,i} & \delta_{24,i} & \delta_{25,i}\\ \delta_{31,i} & \delta_{32,i} & \delta_{33,i} & \delta_{34,i} & \delta_{35,i}\\ \delta_{41,i} & \delta_{42,i} & \delta_{43,i} & \delta_{44,i} & \delta_{45,i}\\ \delta_{51,i} & \delta_{52,i} & \delta_{53,i} & \delta_{54,i} & \delta_{55,i}\end{bmatrix}\begin{bmatrix}\Delta L(CO_2)_t\\ \Delta Lgdp_t\\ \Delta Ltec_t\\ \Delta Lteso_t\\ \Delta Ltesg\end{bmatrix}+\begin{bmatrix}\eta_1\\ \eta_2\\ \eta_3\\ \eta_4\\ \eta_5\end{bmatrix}(ECT_{t-1})+$$

$$\begin{bmatrix}\mu_{1t}\\ \mu_{2t}\\ \mu_{3t}\\ \mu_{4t}\\ \mu_{5t}\end{bmatrix} \qquad (8)$$

Δ: first differential operator;

α: intercept;

Matrices of β and δ: the long and short-run constants, respectively.

μ_t: error terms, which are independent and normally distributed, and i denotes the maximum lag length of the analyzed variable.

The ecmt – if variables are not co-integrated, then will be eliminated from the model.

Above equations is as adopted and modified from (Oryani et al., 2021)

1.10. Unit root test

False regressive steps (high r-squared and a low Durbin Watson statistic indicating autocorrelation in residuals being some of the side effects) are possible when the series with unit roots are not properly and adequately recognized, and this renders information obtained from the series useless for policy making. Most modelling techniques utilized in time series analysis focus predominantly on the stationarity of the data. Even though the unique advantage of the ARDL model is that it can be used even if the series of data are I (0) or I (1), except I (2), a good starting point for every analysis would be to find out if series are stationary. The initial step is to examine the properties of the series graphically, confirming it statistically. Graphs are the most rudimentary method for estimating the stationarity of a series. However, statistical analyses are necessary for making a final determination. The stationarity of a given series can be determined through unit root tests (Shrestha & Bhatta, 2018a).

The most widely used stationarity test methods are the “Augmented Dickey-Fuller (ADF) test and Phillips-perron”(Menegaki, 2019), among others. Each of these tests has advantages and disadvantages and different powers; however, the choice was made after several literature reviews—also, the uniqueness of the model used is flexible enough to use both stationary and non-stationary data.

1.10.1. Augmented dickey -fuller test (ADF)

A widely used method for testing unit root. The following equations are the general and conventional Dickey fuller test equations.

$$Yt = a + bt + uy_{t\_1} + e_t \quad (9)$$

The above equation is estimated eq. (9)

$$\triangle yt = (u\text{-}1)y_{t\_1} + a + bt + e_t \quad (10)$$

The null hypothesis that u = 1 is tested in the augmented dickey-fuller (ADF) test. We cannot rule out the possibility of a unit root if we are unable to rule out the null hypothesis. This test is one of the most common and widely used in most publications done for carbon emissions studies and energy growth nexus papers; however, it is also proper to know that this is not the only test that would be conducted for confirmation of results and to make for certainty all conditions are fulfilled for chosen model.

1.10.2. Phillip-Perron

The Phillip-Perron is widely used in the analysis of unit root tests. It is considered as

$$s_{\mathrm{nw}}^2 = T^{-1} \sum_{t=1}^{T} u_t^2 + 2T^{-1} \sum_{t=1}^{k} w_t \sum_{t=r+1}^{T} u_t u_{t-r} \quad (11)$$

Wτ=1_τ/(k+1) = weight function. The effects of serial correlation and heteroskedasticity are modeled with nonparametric variance estimators. The Phillips-perron test is likened to the augmented Dickey-Fuller (ADF), mostly based on first-order auto-regression.

The null hypothesis and its alternative determine unit root testing method employed in the energy-growth nexus field, how small samples are handled, and whether the sample is assumed to be homogenous or heterogenous (Solarin & Shahbaz, 2013a). It is possible to combine the use of unit root tests with those of stationary tests, depending on which hypothesis is most appropriate and practical for the supplied data (Menegaki, 2019).

1.11. Optimal lag selection

The ARDL developed by(Pesaran, 2008; Pesaran et al., 2001b) necessitates an appropriate latency extent in variables to eliminate any "serial correlation" as stated in (Pesaran et al., 2001c). This length was determined by taking the first difference in the version of ARDL with conditional error correction. The Akaike information criterion for determination of the utmost latency, which is also referred to as the lag. To get reliable and unbiased results, an appropriate lag order is necessary. for the analysis to be carried out (Khan et al., 2018). The lag of variable is calculated with the help of the Akaike information criterion (AIC) for which this analysis is based. The statistics are applied to the ARDL model; the lowest value is AIC or BIC (Schwarz information criterion). The AIC and BIC indices can be computed for any estimator, as no *p*-value is computed.

Mathematically the AIC can be shown as.

$$AIC = \ln\left(\frac{RSS}{n-k}\right) + \frac{2}{n}k \tag{12}$$

RSS is Residual Sum Square regressions, n size of sample and k parameters. AIC and BIC are not utilized to evaluate the model in the sense of evaluating hypotheses but rather for model selection. Given a data set, a researcher computes the AIC or BIC for each model under consideration. The model with the lowest index is chosen next for the analysis. (Maydeu-Olivares & García-Forero, 2010) After this has been determined, the ARDL model.

1.12. Bound test for co-integration and ARDL model (short-run model)

The relationship between the variables x and y is misleading when we do not have stationary time series. However, even if the two variables are not stationary, the combination may be linearly. A circumstance where one variable is stationary while the other is not, yet adding them together linearly remains linear (Pesaran, 2008).

The economic relevance of cointegration stems from the notion of cointegrated economic impact in the long run connection. The cointegration relationship does not directly create information on the variables' short-run equilibrium, but it can help to shape the information in the short run. This happens as a result of the error correction model paradigm (Menegaki, 2019).

Under the null hypothesis that there aren't any cointegration of variables under study, asymptotic distribution of the joint f-statistic, on which the limits testing process is based, is non-standard. The alternative hypothesis is tested against the null h0: there is no cointegration detected.

The hypothesis;

Null hypothesis (h0): series are not co-integration.

Alternative hypothesis (h1): series are co-integrated.

H0: $a_1 = a_2 = a_n = 0$ (13)

$$H1: a_1 \neq a_2 \neq a_n \neq 0 \quad (14)$$

The bounds test has the benefit of being used whether sequence equal to I (0) or I (1) (Narayan & Smyth, 2005).

1.13. Causality test

When cointegration is absent, a basic Granger-causality can be done. On stable data, the var should be stated. Multiple explanations exist for why cointegration cannot be established. This could be due to the absence of a correlation between the factors evaluated or the omission of specific variables. Some tests can be done to ascertain the presence of omitted variables in the model despite the fact that there may be no cointegration. A model can also be holistic, and several diagnostic tests can be done as it is the path taken in this research (Farhani & Ozturk, 2015; Marvell, 2021; Menegaki, 2019).

In 1978, the Granger causality test was run for the first time. The united states were chosen as the test country, and the years 1947–1974 were used as the testing period. Then they tested to find out what caused the link between total energy consumption and gross national product (GNP). After that, there was a lot of research on the cause-and-effect relationship between economic performance (i.e., the growth of gross domestic product, or GDP) and total energy consumption to give policymakers advice (Erol, 1987).

The Granger test incorporates an estimate of regression. Since this study also analyzes the one-to-one causal relationship between carbon dioxide emissions and macroeconomic factors, it is evident that such a relationship exists. The appropriate specification of the model (whether Autoregressive Distributed Lag , Vector Autoregressive, or Vector Error Correction Model is dependent on unit-roots in variables and the fact that the variables are co-integrated. If the variables are not co-integrated, then a var model and a pairwise causality test are employed to determine causation (Cosmas et al., 2019).

1.14. Diagnostics and fitness of model

Various tests were conducted to see the good fit of the model. Below are the different tests that would be conducted based on literature to ensure the model is accurate.

Breusch-Godfrey and Durbin Watson's test for serial correlation or autocorrelation was conducted.

White's test and Lm-test decomposition by Cameron & Trivedi is employed to determine whether a regression model is heteroskedastic.

Ramsey reset test was conducted to ensure the model's fitness was accurately described, with no omitted variables.

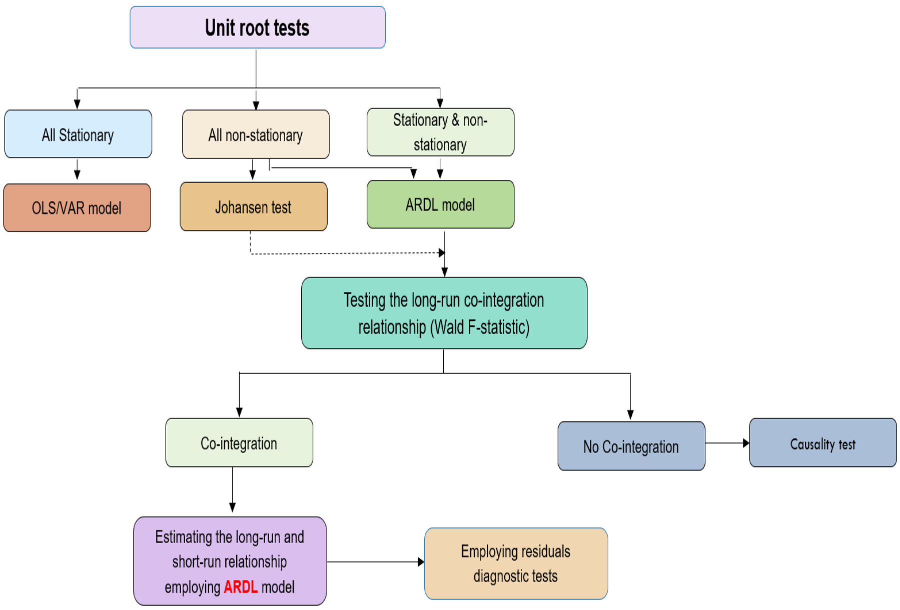
Cu-sum and Cu-sumsq

They investigate consistency in the model. A plot is displayed based on the computation at specific thresholds to see if it will surpass the model break point. The model is stable if the plot is within the 5% critical value. Deviation of the plot slightly from the critical value bands but in a transient manner, i.e., it returns to the bands as mentioned earlier; we consider this model to be stable. This is a crucial stage in analysis, because it's used to foretell whether or not a relationship will remain stable over time. (Anscombe & Tukey, 1963; Brown et al., 1975).

Empirical analysis and results

The selection of variables is made based on the research questions and research objectives, the analytical framework was adopted from (Shrestha & Bhatta 2018a), and it is shown below;

Figure 15. Analytic framework



Auto-regressive distributed lag model as adopted from (Shrestha & Bhatta, 2018a)(Menegaki, 2019) (Oryani et al., 2021) *and as modified by the author.*

Detailed analysis was conducted using Stata/SE 17.0 software provided by Seoul national university, which consists of the full package that enables the above analytical framework.

As shown above, the analysis would commence with the unit root test after variable selections.

1.15. Descriptive statistics

Table 1. Descriptive statistics of variables

Variable	Obs	Mean	StdDev	Min	Max	Var	Skew	Kurtosis
LogCO2perc~a	31	-0.61	0.29	-1.17	-0.24	0.08	-0.67	2.01
LogGDPpercapita	31	6.98	0.78	5.59	8.07	0.61	-0.17	1.46
Logtec	31	15.1	0.26	14.7	15.5	0.07	-0.01	1.66
Logteso	31	13.2	0.35	12.7	13.8	0.12	0.31	1.66
Logtesg	31	12.6	0.50	11.8	13.3	0.25	-0.05	1.52

Descriptive statistics of variables used for analysis showing mean, median, standard deviation, minimum, maximum, variance, skewness and kurtosis. Author's compilation adopting (Kais et al., 2015)

The above table of descriptive statistics shows some insight as regards the data used and some descriptions like the mean, which is the average value of the variables, and the standard deviation, which shows the dispersion of the data as regards its highest and lowest value. Logtec has the lowest value, and logGDPpercapita has the highest value. The skewness indicates the symmetry of the variable distribution where zero (0) is symmetric around the mean. For positive values, it means the balance is right-tailed, and for negative values it means its left tailed as regards the variables, we can see that all but the variable logteso have a positive value which indicates it is long right-tailed, and all others are long left tailed.

1.16. Unit root test results

The unit root analysis said to be initial stage of the ARDL analysis. It provides information on the level in terms of integrating each variable, to fulfill the ARDL models' bounds test postulate, each variable should be I (0) or I (1) (Myszczyszyn & Suproń, 2022). "Augmented Dickey–Fuller" (ADF) with "Phillips Perron" (pp) tests were applied confirming integration order. ADF and PP tests show series of order *I* (1), shown in table below.

Table 2. Unit root tests (Adf) (p-p))

		Non-	**stationary**		**First**	**difference I(1)**
Variables	Adf	Adf lags (1)	P-p test	P-p test lags (1)	Adf lags (1)	P-p test lags (1)
LogCO2percapita	-1.74	-1.71	-1.77	-1.78	-4.4	-5.3
	(.40)	(.42)	(0.39)	(.38)	(.00) ***	(.00) ***
LogGDPpercapita	-0.59	-0.90	-0.71	-0.65	-2.94	-4.21
	(.87)	(.78)	(.84)	(.85)	(.04) **	(.00) ***
Logtec	-1.03	-.69	-2.98	-0.98	-3.27	-4.05
	(.74)	(.84)	(0.76)	(0.76)	(0.01) **	(0.00) ***
Logteso	-1.46	-1.05	-1.31	-1.37	-5.02	-6.44
	(0.5)	(0.7)	(0.62)	(0.5)	(0.0) ***	(0.00) ***

		Non-stationary			First difference I(1)	
Logtesg	-1.13	-0.77	-1.11	-1.13	-5.23	-5.45
	(0.6)	(0.8)	(0.70)	(0.6)	(0.00)***	(0.00)***

The significance of the coefficients is indicated in the tables where ***, ** and * denotes 1%, 5% and 10% significance level, respectively, parenthesis denote the p-value for each test. (Cosmas et al., 2019)

The test performed with the ADF and the PP i.e. (Augmented Dickey Fuller and Phillip-Perron) test adopting(Raihan & Tuspekova, 2022), the ADF test thought to be better because it is used so often and by so many researchers. By adding the lagged difference term of the dependent variable, the ADF test changes the df test to account for possible correlations in the error terms. For the pp test, the autocorrelation in the error term is also considered, and its asymptotic distribution is the same as that of the ADF test statistic. Conversely, ADF often used because it is easy to use (Nkoro & Uko, 2016).

The hypothesis here is;

Null hypothesis (h0): the time series has a unit root, which implies non-stationarity.

Alternative hypothesis (h1): the time series does not have a unit root, which implies stationarity.

We reject null h0 and accept alternate hypothesis h1, and same goes for the Phillip-Perron test for stationarity. The next procedure is to see if the first difference of the variables is stationary or non-stationary still following (Menegaki, 2019). In this regard, we accept null theory of non-stationary at the first difference for all the variables and reject the alternate proposition of stationary for variables at first difference.

Null hypothesis (h0): the time series has a unit root at first difference, which implies non-stationarity.

Alternative hypothesis (h1): the time series does not have a unit root at first difference, which implies stationarity.

The table above shows all the unit root tests. The p-value indicates various levels of significance. The variables are non-stationary at I (0) (level), but are at level I (1) stationary i.e. first difference. This should prompt to perform the cointegrations test. Before carrying out the bound test for cointegration, the optimal lag selection is required for proper model selection based on the computation to be done, as explained in the methodology part.

1.17. Optimal lag selection

Optimal lag selection was made to find the appropriate use in the ARDL model. The table below shows the optimal lag for the various variables and different criteria. The Akaike information criterion (AIC) statistics used to determine which model is the best match out of a collection of estimates (Maydeu-Olivares & García-Forero, 2010).

Table 3. Optimal lag selection for variables

LogCO2percapita

Lag	Ll	Lr	Df	P	Fpe	AIC	Hqic	SBIC
0	-5.78				0.09	0.50	0.51	0.55
1	9.07	29.7*	1	0.00	0.03*	-0.52*	-0.49*	-0.42*
2	9.17	0.19	1	0.65	0.03	-0.45	-0.41	-0.31
3	9.39	0.44	1	0.50	0.03	-0.39	-0.34	-0.20
4	10.28	1.79	1	0.1	0.03	-0.39	-0.32	-0.15

LogGDPpercapita

Lag	Ll	Lr	Df	P	Fpe	AIC	Hqic	SBIC
0	-29.81				0.57	2.282	2.29	2.33
1	19.39	98.4*	1	0.00	0.01*	-1.28*	-1.26*	-1.19*
2	20.07	1.34	1	0.24	0.01	-1.26	-1.22	-1.12
3	20.09	.045	1	0.83	0.01	-1.19	-1.13	-1.00
4	20.13	0.07	1	0.78	0.01	-1.12	-1.04	-0.88

Logtec

Lag	Ll	Lr	Df	P	Fpe	AIC	Hqic	SBIC
0	0.76				0.05	0.01	.031	.065
1	70.04	138*	1	0.0	0.00*	-5.04*	-5.01*	-4.94*
2	70.82	1.56	1	0.21	0.00	-5.02	-4.98	-4.87
3	70.82	0.00	1	0.93	0.00	-4.95	-4.89	-4.75
4	71.61	1.58	1	0.20	0.00	-4.93	-4.86	-4.69

Logteso

Lag	Ll	Lr	Df	P	Fpe	AIC	Hqic	SBIC
0	-11.19				0.14	0.90	0.91	0.95
1	3.29	28.9*	1	0.0	.053*	-0.09*	-0.06*	0.00*
2	3.48	.3866	1	0.53	.0565	-0.03	0.00	0.10
3	4.086	1.19	1	0.27	.058	-0.00	0.05	0.18
4	4.293	.414	1	0.5	.0619	0.05	0.12	0.29

Logtesg

Lag	Ll	Lr	Df	P	Fpe	AIC	Hqic	SBIC
0	-16.8				0.21	1.31	1.33	1.36
1	17.66	68.9	1	0.0	0.01*	-1.16*	-1.13*	-1.06*
2	17.66	.002	1	0.95	0.01	-1.08	-1.04	-0.94
3	19.64	3.95*	1	0.04	0.01	-1.15	-1.10	-0.96
4	19.65	0.03	1	0.86	0.01	-1.08	-1.01	-0.84

*represents the criterion for selecting the lag order. Lr, Fpe, AIC, Sc, and Hq represent the sequentially modified Lr test statistic, Final Prediction Error (FPE), Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan–Quinan (HQ) information criterion, respectively. Authors compilation adopting (Nasrullah et al., 2021).

The optimal lag selection was made based on the Akaike information criterion having the least value, and this lag is then used to determine the lag used for the ARDL model. The selection of lag one implies it will give the best result during the analysis of the ARDL bound test (Nasrullah et al., 2021).

1.18. Bound test for co-integration results

It is unnecessary whether the sequences were I (0) or I (1) to draw a solid conclusion about co-integration when estimated f-statistic exceeds the upper analytical boundaries. Irrespective of analytical sequences been I (0) or I (1), null of no-cointegration is unaccepted. Alternatively, Consequently, we accept the null hypothesis not considering the series is I (0) or I (1) t-statistic is lower than the L0 (lower critical value). Test-statistic is inconclusive once range is inside the L0 (Lower) and the L1 (Upper bounds).

The hypothesis is;

Null hypothesis (h0): series is not co-integration.

Alternative hypothesis (h1): the series are co-integrated.

H0: $a_1 = a_2 = a_n = 0$

H1: $a_1 \neq a_2 \neq a_n \neq 0$

Table 4. The ARDL bound test for co-integration

	Optimal lag	**F-statistics**	**Observation**	**Remarks**
LogCO2percapita= f(logGDPpercapita logtec logteso logtesg)	(1, 0, 0, 1, 1)	0.661	30	No cointegration
	Critical value			
Significant level	L(0)	L(1)		
10%	3.74	5.06		
5%	2.86	4.01		
2.5%	3.25	4.49		
1%	2.45	3.52		

Table of bound test for cointegration authors compilation based on (Pesaran et al., 2001a) *l (0) stands for the lower bound and l (1) stands for the upper bound.*

The results as obtained imply that there is no co-integration. Which means we can’t reject the null hypothesis.

If two or more series are themselves non-stationary, but a linear combination of them is stationary, then the series is said to be cointegrated. However, in the case of the above results, it can be implied that they are not cointegrated, and the linear combination remains non-stationary.

The research can proceed by using straightforward Granger causality (unrestricted var) if cointegration is not proved. The absence of cointegration is due to a number of factors. This can be due to missing variables or a gap in the relationships between the examined variables. However, diagnostics might disprove this, and even if a long-run link is absent from the data, it does not necessarily follow that there are no short-run relationships either. The ARDL analysis will proceed from here, and necessary inferences will be made (Shrestha & Bhatta, 2018).

1.19. Short-run ARDL model

The implication of a no-cointegration will lead to only the short run ARDL model been interpreted.

Table 5. Short-run estimation of parameters from ARDL models (1990 to 2020)

Variable	Coefficient	Standard error	T-statistic	P-value	T-statistics(lag)	P-value (lag)
Constant	-3.57	4.79	-0.75	0.46		
LogCO2percapita_1	(0.89)	(0.12)	-	-	7.66	0.00***
LogGDPpercapita	-0.07	0.09	-0.78	0.44	-	-
Logtec	0.33	0.56	0.59	0.56	-	-
Logteso_1	0.52 (-0.58)	0.146 (0.14)	3.60	0.00***	-4.09	0.00***
Logtesg_1	0.38 (-0.40)	0.25 (0.22)	1.55	0.14	-1.80	0.09*
No of obs = 30	Prob>f =0.0000	R-squared= 0.878	Adj r-squared=0.83			

***, ** and * show 1,5 and 10% significance of p-value; values in parentheses are for lag value. Authors compilation based on (Yeboah Asuamah, 2016). _1= one-period lag.

The prob>f value for the model is well below the 5% significant level, which shows that the model as a whole is very significant with a value of 0.000. Or it can be said that the model is jointly significant.

The r-squared and adjusted r-squared with values of 0.88 and 0.84, respectively, show that the variance in the dependent variable is 88% and 84%, explained by the independent variables in the model, and this percentage shows the model's goodness of fit.

The interpretation of the ARDL model, which is also the short-run model, can be done as follows: a percentage change in the one-period lag of logCO2percapita will lead to an increase by 0.89% increase in the current logCO2percapita at 1% significance level based on the p-value which shows that it is highly significant. The implication is that the previous activities that led to CO2 emissions may still have their effect felt, which is associated with climate change.

The logGDPpercapita has no significance in the model, and thus no interpretation can be given. The same goes for logtec, which has no significance regarding p-value on the level and lag values.

Logteso, which represents the total energy supply from oil, is significant in both present and lag periods, and this can be interpreted as a percentage change in logteso will result in an increase in CO_2 by 0.58%, the increase is significant at 1% significance level with a p-value of 0.002 and a t-statistics of 3.60. In contrast, a percentage change in one period lag of logteso will decrease CO_2 (considering the negative sign of the coefficient) by 0.58%, taking all things equal.

The logtesg is significant at its lagged value and implies that a percentage change in the one-period lag will lead to a decrease in CO_2 emissions by 0.40% at a 10% significant level as indicated by the p-value and an absolute t-statistics of 1.8 considering all things normal (ceteris paribus).

1.20. Causality test

The cointegration suggests that there must be causation in some direction; nevertheless, it does not reveal the direction of causality; hence, extra causality analysis is necessary. Examining and determining the direction of causation may be accomplished through various methods. The vecm (vector error correction model) approach, a limited variant of unconstrained var, applicable after variables are integrated at I (1). But as the case may be, the no cointegration has led to the use of the var and pairwise causality, as stated by (Menegaki, 2019).

This model relies on the dependent variable's own lagged values and the lagged values of the independent variables. However, error correction term is not considered since no cointegration only implies the short run can be analyzed. The causality test that was conducted, as detailed in (Menegaki, 2019), was the pair-wise causality test which is also a form Granger causality test. It is frequently preferable to do many tests to determine the link between prior results, even though the methodologies may vary. When cointegration is not established, the pairwise solution is used to investigate causation (Menegaki & Tugcu, 2016a).

Table 6. Granger pairwise causality

Obs: 30

Variables	LogCO2perc~a	LogGDPpercapita	Logtec	Logteso	Logtesg	All
LogCO2perc~a	-	0.79	0.00	0.03	0.01	0.031
LogGDPpercapita	0.02	-	0.17	0.00	0.97	0.0
Logtec	0.52	0.06	-	0.21	0.01	0.038
Logteso	0.36	0.10	0.01	-	0.01	0.001
Logtesg	0.21	0.38	0.00	0.33	-	0.00

*Authors compilation, *** ** and * signify 1%, 5% and 10% significance level*(Engle & Granger, 2015c; Granger, 1969b)

The results of the pair-wise causality shown above and all the necessary significance level show that among all the variables, GDP does not have any relationship with CO2, which goes against the EKC hypothesis, as also stated by (Chen & Huang, 2013). However, when considering the variables all together, it shows a very significance relationship at the 5% significance level with a 0.031 significance as the p-value, which indicates that CO_2 is affected or has a relationship with all variables(Chen & Huang, 2013; Menegaki & Tugcu, 2016a) in the combined model. However, it should be noted this effect is in the short term as the long term can't be established from the outcome of no cointegration.

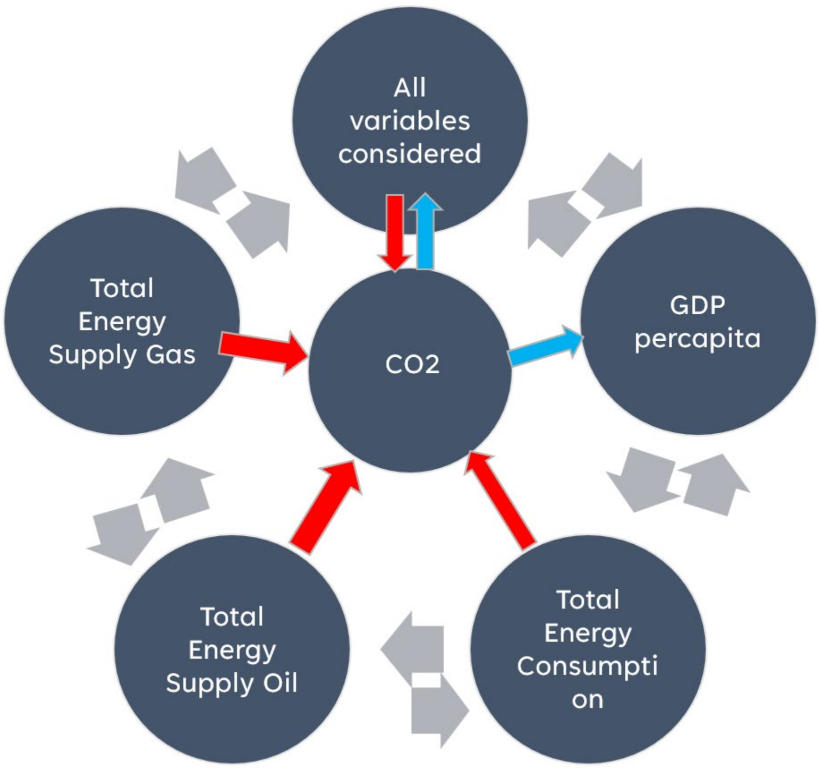


Figure 16. Causality direction and relationship between CO2 and other variables. Authors compilation following (Oryani et al., 2021) (Chontanawat, 2020)

The figure above shows the relationship between the variables and causal direction. It can be seen that considering all variables together in the model, the interaction between CO2, GDP, Tec, Teso and Tesg have a bidirectional causality with a significance level of 0.031% at the 5% significance level. This can also be related to the early stage of the EKC. A proposed correlation amongst numerous measures of environmental deterioration and per capita income according to “EKC”. In the early phases of economic growth, environmental concerns are given minimal importance, leading to increased environmental deterioration as a country becomes wealthier. However, the trend reverses at a certain level of per capita income: as economic growth continues, a society's interaction with the environment improves, and environmental degradation levels decline. (Stern, 1998). All other variables of Tec, Teso, and Tesg contribute to CO2 emissions except GDP which has an inverse relationship, and that is also against the EKC hypothesis as seen in the case of (Act et al., 2022; Chen & Huang, 2013)

The negative but significant relationship of both teso and Tesg can only imply that although it may contribute to the emissions, it’s not as high as other sources of fuels like biomass(A, 2022). (Act et al., 2022) also mentioned the less resultant effect of gas on emission compared to oil and also recommended the use of gas as a source fuel in electricity production.

The results have implications for policymakers on environmental policies, energy conservation policies, energy efficiency policies, and greenhouse gas (GHG) emission reduction policies.

The table below shows the summary of the logCO2 variable in relation to all other variables, as explained above.

Table 7. Granger causality test result logCO2percapita

Equation	**Excluded**	**Granger causality**	**Prob > chi**	**Remarks**
LogCO2percapita	Log GDP percapita	Not detected	0.79	GDP per capita does not Granger cause CO2 emissions per capita.
LogCO2percapita	Logtec	Detected	0.006***	Total energy consumption Granger cause CO2 emissions per capita.
LogCO2percapita	Logteso	Detected	0.033**	Energy supply from oil Granger cause CO2 emissions per capita.

LogCO2percapita	Logtesg	Detected	0.01***	Energy supply from gas Grangers causes CO2 emissions per capita.
LogCO2percapita	All	Detected	0.031**	All factors considered the Granger causality effect on CO2 emissions per capita.

*Authors compilation based on literature, significance of the coefficients is indicated in the tables where ***, ** and * denotes 1%, 5% and 10% significance level, respectively.*(Cetintaş & Murat Sarikaya, 2015)

Diagnostics

1.21. Diagnostics for analysis

The test for stability is undertaken using “the cumulative sum of recursive residuals (cu sum) and the cumulative sum of squares of recursive residuals (cu sum sq)” as done by (Oryani et al., 2021) to assess the model's fit. The Breusch- Godfrey serial correlation and Durbin Watson test were conducted for autocorrelation. White's test and Im-test decomposition by Cameron & Trivedi is employed to determine whether a regression model is heteroskedastic. Ramsey test is done in verification of model been accurately described, with no omitted variables. The following are analyzed and presented with statistical results, as described below.

1.21.1. Diagnostics for autocorrelation

Initially, diagnostics are performed on the ARDL model as a singular equation, followed by the Durbin-Watson and Breusch-Godfrey serial correlation Lm-tests. The two results are shown below, along with a concise explanation of their outcomes from the literature.

Durbin-Watson; this is a simple test for autocorrelation in the residuals of a regression analysis. The test statistic ranges from 0 to 4, with a score around 2 indicating the lack of autocorrelation. Greater than two indicates negative autocorrelation, while less than two indicates positive autocorrelation.

Table 8. Test for autocorrelation

Test	Test statistic	P-value
Durbin-Watson	1.9652	_
Breusch-Godfrey Lm test (lag 1)	0.012	0.914

The Breusch-Godfrey Lm test is used to check because it can handle more complex model structures, which may either be lagged or have high order or possibility of correlation.

From the above, both Durbin-Watson and Breusch-Godfery tests have the under-listed hypothesis;

H0= no serial correlation

H1= there is a serial correlation

The null hypothesis is accepted and the alternative hypothesis is rejected. This also shows that the model has a degree of acceptability, and more tests would be conducted to diagnose the model further.

1.21.2. Diagnostic for heteroskedasticity

Two tests are used to assess if a regression model is heteroskedastic, which occurs when the variability of the error terms varies across all levels of the independent variables.

White's test: this statistical test determines whether or not the heteroskedasticity in a regression analysis is constant (the null hypothesis, h0) and whether or not it is not (the alternative hypothesis, ha). The chi-square statistic, in this case, has 29 degrees of freedom and is 30.00 observations. The probability is 0.4140. Based on this test, Since this p-value is more than the threshold for statistical significance 0.05, the homoskedasticity null hypothesis cannot be rejected.

Hypothesis;

H0: homoskedasticity

H1: unrestricted heteroskedasticity

Lm-test decomposition by Cameron & Trivedi: the test separates the heteroskedasticity, skewness, and kurtosis portions of the score test for model misspecification. These tests have p-values over 0.05, indicating insufficient evidence to disprove the "null hypotheses" of no heteroskedasticity, absence of skewness, also normal kurtosis.

Hypothesis;

H0: homoskedasticity

H1: unrestricted heteroskedasticity

The results are shown in the table below

Table 9. Test for heteroskedasticity

Test	Source	Test statistic	P-value
White's test	Heteroskedasticity	30.00	0.41
Cameron & Trivedi's Lm test	Heteroskedasticity	30.00	0.41
	Skewness	6.24	0.51
	Kurtosis	1.25	0.26
	Total	37.50	0.44

Authors compilation following (Farhani & Ozturk, 2015)

The model residuals exhibit no homoskedasticity, skewness, or non-normal kurtosis symptoms. These results suggest that the residuals in our model are homoscedastic and well-specified based on these assumptions.

1.21.3. The Ramsey reset test

This test is for missing model variables. The test's null hypothesis (H0) is that the model is accurately described with no omitted variables.

The p-value of 0.1266 is larger than 0.05; hence the H0 (null) hypothesis is not ruled out. This indicates that the model accurately stated since there are no missing variables or improper functional forms based on the results of this test. (Marvell, 2021)

Table 10. Ramsey rest test

Test	Null hypothesis	F-statistic	P-value	Conclusion
Ramsey reset	The model has no omitted variables	2.16	0.1266	Fail to reject H0. The model appears to be correctly specified, with no evidence of omitted variables or incorrect functional forms.

Authors compilation

1.21.4. The cumulative sum of recursive residuals (cu sum) and the cumulative sum of squares of recursive residuals (cu sum sq).

These diagnostics helps in checking stability based on coefficient across the model. It has the hypothesis as follows;

H0 = no structural break

H1 = There is a structural break

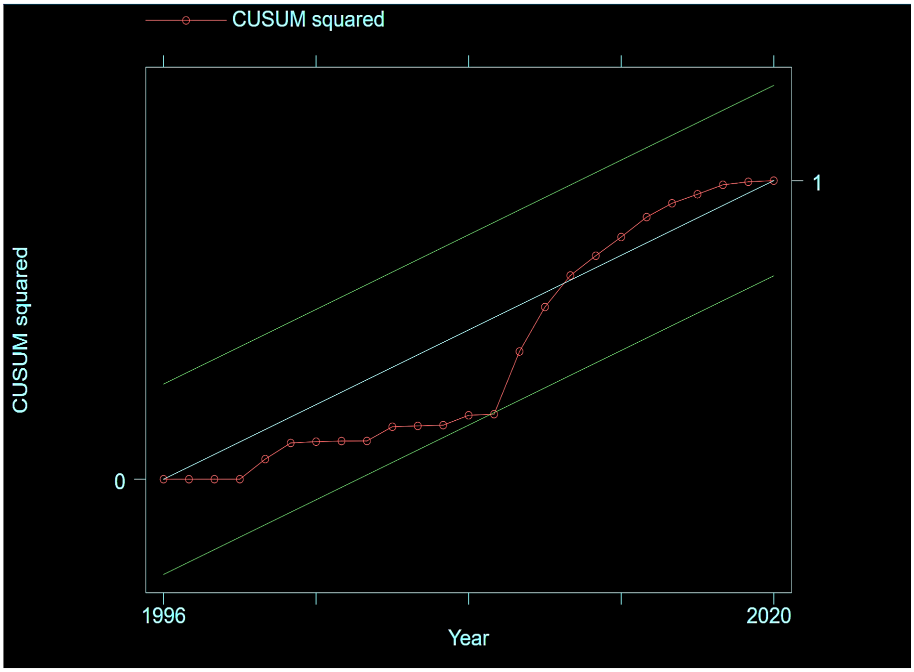
The table below shows H0 (null hypothesis) was accepted at 1% significant showing to a large extent how there are little or no structural breaks based on the interpretation of the 5% and 10% critical level

Table 11. Test for cumulative sum of recursive residual

Test type	**Test statistics**	**Critical value (1%)**	**Critical value (5%)**	**Critical value (10%)**
Recursive	1.0057	1.1430	0.9479	0.8499

Authors compilation

Figure 17. Cumulative-sum of squares of recursive residuals (cu-sum sq) plot



The “cu-sum sq” numbers are within the crucial limits. This indicates that every coefficient is steady. Since a result, the selected model (i.e., CO2) may be utilized to comprehend the pronouncement-creation of policy, as influence in unstable fluctuations in the regression coefficients of descriptive variables in the CO2 emanation model resolve not remain significantly affected by the amount of CO2 releases (Farhani & Ozturk, 2015; halicioglu, 2009).

Policy Implications and Conclusions

1.22. Key findings

The analysis was conducted with the main aim of investigating and finding out the link between the dependent variable carbon dioxide emission per capita and the independent variables of GDP per capita, total energy consumption, total energy supply from oil and total energy supply from gas. Based on the research question and objective and looking critically at the literature, the methodology of autoregressive distributed lag (ARDL) was selected and also considering the sample sizes as a guide (Act et al., 2022; Pesaran, 2008; Pesaran et al., 2001b).

The Key findings regarding the various analysis are stated below, even though it has already been highlighted in detail above based on each procedure carried out in the empirical analysis.

Unit root analysis is the initial phase in ARDL analysis. Each variable value must be I (0) or I (1) for the limits test postulate of ARDL models to be met(Myszczyszyn & Suproń, 2022). To examine the sequence of integration, “Augmented dickey–fuller test and Phillips Perron test” used (Menegaki & Tugcu, 2016b). The tests demonstrate that variables integrated in the order I (1). This gives the strongest reason to use the ARDL model(Myszczyszyn & Suproń, 2022).

Optimal lag for the ARDL model was performed. Akaike information criterion (AIC) is utilized as statistics of excellent fit from a collection of estimated models (Maydeu-Olivares & García-Forero, 2010).

Bound test for cointegration conducted regardless of series been I (0) or I (1), null of no-cointegration was accepted; reason is if t-statistic value is below L0 (lower critical value), the null (H0) is not rejected (Menegaki, 2019). The series was not cointegrated for this analysis. Therefore, only the short-run ARDL model may be executed and understood as the analytical framework guidance. Numerous reasons can account for the lack of cointegration. This may result from missing variables or a gap in the analyzed connections between variables. However, diagnostics may contradict this, and even if a long-term relationship is absent from the data, it does not necessarily follow that there are no short-term ties (Shrestha & Bhatta, 2018a).

The implication of a no-cointegration implies only the short-run ARDL model interpreted based on the model study. The following results were drawn.

1. The p-value indicates that a percentage change in the one-period lag of logCO2percapita will result in a 0.89 per cent rise in the present logCO2percapita at the 1 per cent significance level, which is highly significant. This implies that the effects of prior CO2

emission-causing actions may still be felt, and this is related to the current climate change.

2. The logGDPpercapita has no meaning in the model and hence cannot be interpreted. The same holds for logtec, which does not affect the p-value for level and lag values.

3. Logteso, which represents the total energy supply from oil, is significant in both the present and lag period, and this can be interpreted as a percentage change in logteso will result in a 0.58 per cent increase in CO2, the increase is significant at 1 per cent significance level with a p-value of 0.002 and a t-statistic of 3.60, whereas a percentage change in logteso on the lag period will result in a 0.58 per cent decrease in CO2 (considering the negative sign on the coefficient)

4. The logtesg is significant at its lagged value, indicating that a percentage change in the one-period lag will result in a 0.40 per cent decrease in CO2 emissions at a 10 per cent significant level, as indicated by the p-value and an absolute t-statistic of 1.8, assuming that all other factors are normal (ceteris paribus).

The presence of no cointegration leads us to do a var and causality. Cointegration suggests that there must be causation in some direction; nevertheless, it does not reveal the direction of causality; hence, extra causality analysis is necessary. Examining and determining the direction of causation may be accomplished through various methods. No cointegration has led to using the var and pairwise causality, as stated by (Menegaki, 2019). The causality test that was conducted, as detailed in (Menegaki, 2019), was the pair-wise causality test which is also a form Granger causality test. It is frequently preferable to do many tests to determine the link between prior results, despite the fact that the methodologies may vary. When cointegration is not established, pairwise is used to investigate causation (Menegaki, 2019; Menegaki & Tugcu, 2016a).

1. The relationship between the variables and causal direction indicates that, when all variables are considered together in the model, the interaction between CO2, GDP, tec, teso, and tesg have a bidirectional causality with a significance level of 0.031 per cent at the 5 per cent significance level; this can also be linked to the early stage of an Environmental Kuznets curve also for short EKC. Environmental Kuznets curve (EKC) is a proposed correlation between numerous measures of environmental deterioration and in the early stages of economic expansion, environmental concerns are given little weight, resulting in an acceleration of environmental degradation as a nation gets wealthy. At a certain level of per capita income, however, the pattern reverses: as the economic expansion continues, a society's connection with the environment improves, and levels of environmental degradation drop (stern, 1998, 2004).
2. Except for GDP, all other variables of Tec, teso, and Tesg contribute to CO2 emissions. This is also contrary to the EKC theory which clearly shows that GDP is a key contributor to CO2 especially

in a developing economy like Nigeria's, as illustrated in the case of Tesg (Act et al., 2022; Chen & Huang, 2013).

3. The negative but substantial association between teso and Tesg may only suggest that while it may contribute to emissions, it is not as important as other fuel sources, such as biomass (A, 2022). (Act et al., 2022) also discussed the lesser influence of gas on emissions compared to oil and recommended using gas as a fuel source in power production.

Finally, for all the above to have been deemed suitable for policy implications and suggestions, diagnostics were performed based on literature (Menegaki, 2019; Menegaki & Tugcu, 2016; Shrestha & Bhatta, 2018a)on the ARDL model, and all tests showed that the model passed all the test and can be used for policy implication as shown in the various test;

1. Durbin-Watson and Breusch-Godfrey serial correlation Lm tests.
2. White's test, which is a statistical test, determines whether or not the heteroskedasticity in a regression analysis is constant (the null hypothesis, h0) and whether or not it is not (the alternative hypothesis, H1).
3. Im-test decomposition by Cameron & Trivedi is a test that separates the heteroskedasticity, skewness, and kurtosis portions of

the score test for model misspecification; this was also done to see model stability, and the model is stable.

4. The Ramsey test for missing model variables. The null hypothesis (h0) is the model has accurately been described, with no omitted variables, and the model had no omitted variables as tested.

5. The cu-sum-sq numbers are within the crucial limits. This indicates that every coefficient is steady. As a result, the selected model (i.e., CO2 release) may be utilized to comprehend the implications of policy, as influence of unstable changes in the regression coefficients of descriptive variables in the CO2 model not significantly exaggerated by the amount of CO2 productions.

In summary, the major findings are, variables were stationary at the first difference, which satisfies the use of the ARDL methodology, subsequently after an appropriate lag selection using the Akaike information criterion (AIC), the optimal lag was used to carry out the cointegration test using the Pesaran Shim bound test (Pesaran et al., 2001c) , the cointegration test came out with a no cointegration results which lead us to carry out the ARDL analysis and interpreted the short-run model. Since there is no cointegration, a long run or error correction model can't be applied. Results show CO2 in lag values contributed to CO2 in the present, which means or can be implied that previous environmental degrading activities [11] are responsible for the present

[11] Environmental degrading activities include the burning of fossil fuels for industrialization and land use. However, the amount of CO2 is mostly from fossil fuels.

climate change phenomena, which is a result of carbon emissions due to industrialization that involved heavy use of fossil fuels(Treut et al., 2007). The variables logtesg and logteso which are the supply of oil and gas energy showed an effect on CO2 in the lagged and present but more in the present, and this is due to the increase in energy consumption, as seen in figures 13 and 14.

The causality shows that all considered together variables had bi-directional reason and relation with CO2. Economic expansion and energy use, mainly driven by energy supply, are the main causals for carbon emission and aligns with the environmental Kuznets curve. The inverse causality of CO2 contributing to GDP shows how it goes against the EKC, the EKC hypothesis shows that GDP contributes to CO2 and not the other way around (Act et al., 2022; Farhani & Ozturk, 2015). The causality of both energy supply from oil and gas are unidirectional, contributing to CO2 emissions but negatively.

Finally, a diagnostic to ascertain the goodness of model fitness and found out the various test conducted and the plot of the cu-sum-sq all show the model can be used for policy (Farhani & Ozturk, 2015; Halicioglu, 2009; Shrestha & Bhatta, 2018b)

1.23. Policy implication

The analysis and findings can be directed towards some policies and policy directions, as interpreted from the results, it can be implied both in the context of adoption of existing policies from similar countries that have worked or from developing countries considering the peculiarities of Nigeria, it is also necessary to note that some existing policies need to be modified with existing realities so as to have its full effects have been felt and implemented without hitches. The findings have consequences for those who create environmental policies, such as those aimed at reducing greenhouse gas (GHG) [12] emissions and conserving energy.

An initial start by looking at the overall implication of the autoregressive distributive lag (ARDL) outcome. The no cointegration led to only the ARDL short-run model, which later causality was done to find out the direction and link with CO2 as the dependent variable.

From the analysis, the results of reverse or inverse causality seen from CO2 to GDP, it can be inferred that any policy done with the intention of reducing CO2 emissions will clearly affect GDP growth which is economic growth. This is not surprising as most often seen that

[12] According to the world metrological organization, the major components of GHG are carbon dioxide, methane, nitrous oxide, and hydrochlorofluorocarbons, among others. NB Carbon dioxide makes the highest percentage.

developing countries or low-income countries, due to industrialization and use of non-clean fuel sources, have higher emissions and partly also due to the non-strict emission policies as regards manufacturing process (Gurtu et al., 2019, 2022); hence any policy made in regards to reduction of CO2 will directly affect economic growth (Gurtu et al., 2022). Government is advised or recommendations would be implementing environmental policies that will not affect economic growth (GDP). This can be in the form of alternate energy policies, such as establishing energy conservation techniques, lowering energy intensity, enhancing energy efficiency, and expanding renewable energy sources. This results in lower emissions and better economic growth development. This can be achieved by encouraging import of green technologies for dropping carbon production, specifically targeting disparity between cities and the countryside, particularly about the amount of power required. The area of energy disparity can be seen by the contribution of emissions from biomass and coal for cooking and, to a large extent, the supply of gridded electricity, which often leads to the use of portable power generators that contribute to emissions (Tambari et al., 2020).

The unidirectional causality of gas and oil supply to CO2 can be used also in the recommendation of policies in line with renewable energy policies, carbon pricing mechanisms and energy efficiency policies. It's well known that Nigeria has a huge renewable energy potential(renewable energy roadmap: Nigeria, n.d.) and utilizing that will lead to less fossil fuel consumption. When it comes to energy efficiency policies, adaptation of existing policies to help in greenhouse gas emissions reduction, among this it can said looking at the high number of used vehicles that are imported into the country can have age limits which in turn would help in higher emission volumes, also it's best to change the use of gasoline generators and use gas-powered generators which may have cleaner effect than petrol generators. This can also be related to energy transition policy, in which one cleaner energy is utilized instead of the other less clean one. Since gasoline is widely consumed, it is believed that a shift to natural gas would lead to less emissions and better efficiency. A gas utilization policy would be appropriate. The petroleum industry bill, which was a result of several policies and acted like the Nigerian oil and gas policy which was implemented by the oil and gas sector reform implementation committee (OGIC) in 2004, in addition to other existing laws and act, have holistically looked at the enhanced usage of gas in the upstream sector to meet up with the energy demand and also environmental aspect in the Nigerian energy landscape. The petroleum industry act (2021), passed on the 21st August 2021, has some key regulations that will foster policies that may be made towards utilizing gas as a transition fuel in Nigeria. These include the gas flare and venting (prevention of waste and pollution) regulations which have the objective of reducing flaring and venting of gas and fugitive methane emissions, mostly at oil and gas production facilities and also to enhance the energy transition plan of the government by utilizing the flared gas to generation of power or use in manufacturing sectors. The petroleum industry act also has the upstream environmental regulation, which in part-11 exclusively spoke about greenhouse gas emissions and how volumes from operators are to be reported for the necessary guidance on ways of mitigations in line with international best practices which entails adoption of best policies to have a holistic approach (Act, 2022; v.a.r.barao et al., 2022).

Other ways of encouraging the implementation of the policies stated above as regards Nigeria, especially when it comes to renewable energy policies, is the removal of subsidies from gasoline. Nigeria spent $10 billion in subsidies in 2022(Reuters, 2023). Despite efforts to modify them and accumulating proof of their positive effects on the environment and the economy, fossil fuel subsidies continue to exist around the world. Numerous nations, including Germany, Nigeria, Canada, Indonesia, Mexico, and the United Arab Emirates, have made efforts to eliminate the subsidies given to fossil fuels at least partially (Van Asselt, 2018). The advantages of reform are obvious: eliminating subsidies for fossil fuels would enable governments to save significantly on costs and might have considerable environmental advantages. For instance, abolishing fossil fuel subsidies in 37 (mostly developing, major polluting) nations between 2013 and 2020 would, according to one estimate, cut global greenhouse gas emissions by 8% by the year 2050 (Burniaux & Chateau, 2014). These subsidy cuts should not be seen only in terms of emissions. According to reports, a country like Nigeria would free up $10 billion for investment in either less polluting energy sources or renewable energies.

Therefore, diversifying the economy in areas that may be less energy-intensive, adopting technologies in the production process, adopting renewable energy sources, mitigation and alternate energy source with utilizations of carbon capture and reducing the uncertainties must prioritize designing the inclusive economic-environment national energy policy that will be beneficial and ensure the achievement of the goal to reduce CO2 emissions.

1.24. Conclusion

This study uses an autoregressive distributive lag model (ARDL) and Granger causality to analyze the causal link among energy consumption, economic growth, energy supply from oil, and energy supply from gas with the effect on CO2 emission in Nigeria over the period 1990 to 2020. The bound test for cointegration came out with a no cointegration which led to the only interpretation of short-run ARDL and causality.

The causal interplay of variables and causal direction indicates that, when all variables are considered together in the model, the interaction between CO2, GDP, Tec, Teso, and Tesg have a bidirectional causality, with a significance level of 0.031% at the 5% significance level. This can also be linked to the early stage of the environmental Kuznets curve (EKC) (Stern, 1998).

Except for GDP, all other variables of tec, teso, and tesg contribute to CO2 emissions. This is also contrary to the EKC theory, as illustrated in the case of tesg (Act et al., 2022; Chen & Huang, 2013)

The negative but substantial association between teso and tesg may only suggest that while it may contribute to emissions, it is not as crucial as other fuel sources, such as biomass (A, 2022). Act et al. (2022) suggested the lesser influence of gas on emissions than oil and recommended using gas as a fuel source in power production.

The aforementioned study led to the suggestion of some policy implications. Most of these policies are related to the environmen, alternate energy (e.g., energy transition policies), economy decoupling, and renewable energy, with the main aim being the reduction of CO2 emissions and simultaneous economic growth.

It is not easy to replace fossil fuels with renewable energy, and doing so will need nations to consider long-term sustainable development plans for economic growth, which negatively influence the environment. In other words, the change must be technological, economic, and political to properly achieve decarbonization. The infrastructure needed to create a renewable energy economy takes a long time to build and frequently outlasts political administration. Therefore, a robust legal framework should be established to ensure the continuity of and safeguard an ongoing energy transition strategy from political intervention. Before progress is made, there must be the political will to overcome the short-term setbacks during the creative destruction associated with adopting a low-carbon economy. During this time, the economic structure must be renewed (Yetano Roche, 2023).

Nigeria must increase the overall energy efficiency of its economy through technical, behavioral, and other approaches in addition to supporting cleaner energy sources. A reliable electrical supply is crucial in Nigeria, where the widespread use of gasoline generators undermines efforts to lower CO2 emissions. It is essential to invest a significant amount of money in enhancing the electrical infrastructure and mandating the relevant agencies to place mechanisms for the smooth utilization of the vast gas reserves for energy generation, as they are cleaner than coal or liquid fuels.

1.25. Limitations and future research

Limitations:

The analysis is based on historical data from 1990-2020, it is possible that it does not consider current changes in policy or technological developments that impact the amount of energy consumed and CO_2 emissions.

The ARDL model and Granger causality offer an overall perspective on the relationship between causes and effects but do not consider micro-level impacts or industry-specific variances.

The research is limited in its relevance to other nations since it is narrowly focused on Nigeria, which has a unique political, economic, and environmental setting.

Future research:

Research on how recent shifts in policy and technological developments have affected the correlation between CO_2 emissions, the amount of energy used, and the amount of energy supplied by oil and gas.

To better understand the micro-level causation and impacts at play in various sectors, such as transportation, manufacturing, and residential real estate, sector-specific research should be carried out.

Comparative studies can be carried out to get a deeper comprehension of the dynamics governing energy supply and CO_2

emissions, with the research expanded to include additional oil-producing nations located on the African continent.

Further investigation into the potential for gas to serve as a cleaner alternative fuel, considering not only CO2 emissions but also the environmental effects of various energy sources across their whole life cycles.

References

Acaravci, A., & Ozturk, I. (2010). On the relationship between energy consumption, CO2 emissions and economic growth in Europe. *Energy*, *35*(12), 5412–5420. https://doi.org/10.1016/J.ENERGY.2010.07.009

Act, P. R. (2022). Federal republic of Nigeria official gazette. *Federal Government of Nigeria, Lagos*, *500*(17), 31.

Act, P. R., Algarini, A., Alkhathlan, K., Javid, M., Belucio, M., Santiago, R., Fuinhas, J. A., Braun, L., Antunes, J., Burnett, J. W., Bergstrom, J. C., Wetzstein, M. E., Caseiro, A., Gehrke, B., Rücker, G., Leimbach, D., Kaiser, J. W., Chindo, S., Abdulrahim, A., … Zhou, C. (2022). Energy consumption, carbon emissions and economic growth in Saudi Arabia: An aggregate and disaggregate analysis. *Energies*, *15*(3), 315–322. https://doi.org/10.1016/j.scitotenv.2015.10.027

Adams, S., Adedoyin, F., Olaniran, E., & Bekun, F. V. (2020). Energy consumption, economic policy uncertainty and carbon emissions; causality evidence from resource rich economies. *Economic Analysis and Policy*, *68*, 179–190. https://doi.org/10.1016/J.EAP.2020.09.012

Adebayo, T. S. (2020). Revisiting the EKC hypothesis in an emerging market: an application of ARDL-based bounds and wavelet coherence approaches. *SN Applied Sciences*, *2*(12), 1–15. https://doi.org/10.1007/S42452-020-03705-Y/TABLES/8

A, I. E. (2022). *World Energy Statistics and Balances - Data product - IEA*. https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

Akarca, A. T., & Long, T. V. (1979). Energy and employment: a time-series analysis of the causal relationship. *Resources and Energy*, *2*(2–3), 151–162. https://doi.org/10.1016/0165-0572(79)90027-6

Ang, J. B. (2007). CO2 emissions, energy consumption, and output in France. *Energy Policy*, *35*(10), 4772–4778. https://doi.org/10.1016/j.enpol.2007.03.032

Anjorin, F. O., A. Abashi, S., Masok, F. B., & Essen, I. M. (2020). Comparative Assessment of Some Emitted Pollutants' Concentrations from Selected Fossil Fuel-fired Generators. *Journal of Atmospheric Pollution*, *8*(1), 1–12. https://doi.org/10.12691/JAP-8-1-1

Anscombe, F. J., & Tukey, J. W. (1963). The Examination and Analysis of Residuals. *Technometrics*, *5*(2), 141–160. https://doi.org/10.1080/00401706.1963.10490071

Baltagi, B. H., Fomby, T. B., & Carter Hill, R. (Eds.). (2001). *Nonstationary Panels, Panel Cointegration, and Dynamic Panels*. *15*. https://doi.org/10.1016/S0731-9053(2001)15

Bayer, C., & Hanck, C. (2013). Combining non-cointegration tests. *Journal of Time Series Analysis*, *34*(1), 83–95. https://doi.org/10.1111/J.1467-9892.2012.00814.X

Bildirici, M. E., & Kayikçi, F. (2013). Effects of oil production on economic growth in Eurasian countries: Panel ARDL approach. *Energy*, *49*(1), 156–161. https://doi.org/10.1016/J.ENERGY.2012.10.047

BP. (2021). Statistical Review of World Energy globally consistent data on world energy markets and authoritative publications in the field of energy. *BP Energy Outlook*, *70*, 72.

bp-annual-report-and-form-20f-2019. (n.d.).

Brown, R. L., Durbin, J., & Evans, J. M. (1975). Techniques for Testing the Constancy of Regression Relationships Over Time. *Journal of the Royal Statistical Society: Series B (Methodological)*, *37*(2), 149–163. https://doi.org/10.1111/J.2517-6161.1975.TB01532.X

Burniaux, J. M., & Chateau, J. (2014). Greenhouse gases mitigation potential and economic efficiency of phasing-out fossil fuel subsidies. *International Economics*, *140*, 71–88. https://doi.org/10.1016/J.INTECO.2014.05.002

Çetintaş, H., & Murat SARIKAYA, ve. (2015). Co 2 Emissions, Energy Consumption and Economic Growth in the Usa and the United Kingdom: Ardl Approach. *Cilt*, *16*, 173–194.

Chen, J.-H., & Huang, Y.-F. (2013). The Study of the Relationship between Carbon Dioxide (CO 2) Emission and Economic Growth. *Journal of International and Global Economic Studies*, *6*(2), 45–61.

Chindo, S., Abdulrahim, A., Waziri, S. I., Huong, W. M., & Ahmad, A. A. (2015). Energy consumption, CO2 emissions and GDP in Nigeria. *GeoJournal*, *80*(3), 315–322. https://doi.org/10.1007/S10708-014-9558-6

Chrulski, T., & Łaciak, M. (2021). Analysis of natural gas consumption interdependence for polish industrial consumers on the basis of an econometric model. *Energies*, *14*(22). https://doi.org/10.3390/en14227649

Climate Transparency. (2020). *Climate Transparency Report | 2020 Nigeria 2*. *May*, 1–20. https://www.climate-transparency.org/wp-content/uploads/2021/01/Nigeria-CT-2020.pdf

Cosmas, N. C., Chitedze, I., & Mourad, K. A. (2019). An econometric analysis of the macroeconomic determinants of carbon dioxide emissions in Nigeria. *Science of The Total Environment*, *675*, 313–324. https://doi.org/10.1016/J.SCITOTENV.2019.04.188

Dumitrescu, E. I., & Hurlin, C. (2012). Testing for Granger non-causality in heterogeneous panels. *Economic Modelling*, *29*(4), 1450–1460. https://doi.org/10.1016/J.ECONMOD.2012.02.014

Elinwa, U. K., Ogbeba, J. E., & Agboola, O. P. (2021). Cleaner energy in Nigeria residential housing. *Results in Engineering*, *9*, 100103. https://doi.org/10.1016/J.RINENG.2020.100103

Engle, R. F., & Granger, C. W. J. (2015a). Co-integration and error correction: Representation, estimation, and testing. *Applied Econometrics*, *39*(3), 107–135. https://doi.org/10.2307/1913236

Engle, R. F., & Granger, C. W. J. (2015b). Co-integration and error correction: Representation, estimation, and testing. *Applied Econometrics*, *39*(3), 107–135. https://doi.org/10.2307/1913236

Engle, R. F., & Granger, C. W. J. (2015c). Co-integration and error correction: Representation, estimation, and testing. *Applied Econometrics*, *39*(3), 107–135. https://doi.org/10.2307/1913236

Erickson, L. E., & Brase, G. (2019). Paris Agreement on Climate Change. *Reducing Greenhouse Gas Emissions and Improving Air Quality*, 11–22. https://doi.org/10.1201/9781351116589-2

Erol, U. (1987). *ON THE CAUSAL RELATIONSHIP BETWEEN ENERGY AND INCOME FOR INDUSTRIALIZED COUNTRIES Author (s): and Eden S . H . Yu Source : The Journal of Energy and Development , Autumn , 1987 , Vol . 13 , No . 1 Published by : International Research Center for Energy*. *13*(1), 113–122.

Esso, L. J., & Keho, Y. (2016). Energy consumption, economic growth and carbon emissions: Cointegration and causality evidence from selected African countries. *Energy*, *114*, 492–497. https://doi.org/10.1016/J.ENERGY.2016.08.010

Farhani, S., & Ozturk, I. (2015). Causal relationship between CO2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. *Environmental Science and Pollution Research*, *22*(20), 15663–15676. https://doi.org/10.1007/s11356-015-4767-1

GDP growth (annual %) - Nigeria | Data. (n.d.). Retrieved March 31, 2023, from https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=NG

Granger, C. W. J. (1969a). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, *37*(3), 424. https://doi.org/10.2307/1912791

Granger, C. W. J. (1969b). Investigating Causal Relations by Econometric Models and Cross-spectral Methods. *Econometrica*, *37*(3), 424. https://doi.org/10.2307/1912791

Grossman, G. M., & Krueger, A. B. (1991). *Environmental Impacts of a North American Free Trade Agreement*. https://doi.org/10.3386/W3914

Gupte, E., Ram, A., Power, E., Transition, E., Gas, N., & Transition, E. (2021). *COP26 : Nigeria vows to reach net-zero by 2060 but stresses role of gas Demonization of gas*. https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/110321-cop26-nigeria-vows-to-reach-net-zero-by-2060-but-stresses-role-of-gas

Gurtu, A., Saxena, R., & Sah, N. B. (2019). Offshoring Decisions: A Comprehensive and Conceptual Framework. *Operations and Supply Chain Management: An International Journal*, *12*(3), 118–128. https://doi.org/10.31387/OSCM0380236

Gurtu, A., Vyas, V., & Gurtu, A. (2022). Emissions Reduction Policies and Their Effects on Economy. *Journal of Risk and Financial Management 2022, Vol. 15, Page 404*, *15*(9), 404. https://doi.org/10.3390/JRFM15090404

Halicioglu, F. (2007). Residential electricity demand dynamics in Turkey. *Energy Economics*, *29*(2), 199–210. https://doi.org/10.1016/J.ENECO.2006.11.007

Halicioglu, F. (2009). An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, *37*(3), 1156–1164. https://doi.org/10.1016/j.enpol.2008.11.012

Haug, A. A. (2002). Temporal aggregation and the power of cointegration tests: A Monte Carlo study. *Oxford Bulletin of Economics and Statistics*, *64*(4), 399–412. https://doi.org/10.1111/1468-0084.00025

IEA, I. E. A. (2022). *World Energy Outlook 2022 Sumário executivo*. 1–524. www.iea.org/t&c/%0Awww.iea.org/weo

International Energy Agency. (2022a). Electricity Information - Data product - IEA. *Electricity Information*. https://www.iea.org/data-and-statistics/data-product/electricity-information

International Energy Agency. (2022b). *Energy Statistics Data Browser – Data Tools - IEA*. Online. https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser?country=WORLD&fuel=Energy supply&indicator=ElecGenByFuel.

INVESTING IN NIGERIA ' S ENERGY TRANSITION. (2022). *March*.

Johansen, S. (1991). Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models. *Econometrica*, *59*(6), 1551. https://doi.org/10.2307/2938278

Jorgenson, D. W., & Wilcoxen, P. J. (n.d.). *ENERGY, THE ENVIRONMENT, AND ECONOMIC GROWTH*.

Kais, S., Mounir, &, Mbarek, B., & Mbarek, M. Ben. (2015). Dynamic relationship between CO2 emissions, energy consumption and economic growth in three North African countries. *Http://Dx.Doi.Org/10.1080/14786451.2015.1102910*, *36*(9), 840–854. https://doi.org/10.1080/14786451.2015.1102910

Khan, Z., Khan, Z., Ahmad, M., Rahman, Z., Hengyi, H., & Khan, S. (2018). Carbon emissions, energy use, gross domestic product and total population in China. *Ekonomia i Środowisko*, *2*(2), 32–44.

Kraft, J., & Kraft, A. (1978). On the Relationship Between Energy On the Relationship Between Energy and GNP. *Journal of Energy and Development*, *3*(2), 401–403.

Kuersteiner, G. M. (2010). Granger-Sims causality. *Macroeconometrics and Time Series Analysis*, 119–134. https://doi.org/10.1057/9780230280830_14

Li, X., & Liu, X. (2005). Foreign Direct Investment and economic growth: An increasingly endogenous relationship. *World Development*, *33*(3), 393–407. https://doi.org/10.1016/j.worlddev.2004.11.001

Low emissions scenario 2022. (n.d.). Retrieved June 16, 2023, from https://www.statkraft.com/lowemissions/

Marvell, T. B. (2021). *A NEW TEST FOR REVERSE CAUSATION AND OMITTED VARIABLE BIAS IN REGRESSIONS: USING EXTREME COLLINEARITY BIAS*. 1–33.

Maydeu-Olivares, A., & García-Forero, C. (2010). Goodness-of-Fit Testing. *International Encyclopedia of Education, Third Edition*, 190–196. https://doi.org/10.1016/B978-0-08-044894-7.01333-6

Menegaki, A. N. (2019). The ARDL method in the energy-growth nexus field; best implementation strategies. *Economies*, *7*(4), 1–16. https://doi.org/10.3390/economies7040105

Menegaki, A. N., & Tugcu, C. T. (2016a). Rethinking the energy-growth nexus: Proposing an index of sustainable economic welfare for Sub-Saharan Africa. *Energy Research & Social Science*, *17*, 147–159. https://doi.org/10.1016/J.ERSS.2016.04.009

Menegaki, A. N., & Tugcu, C. T. (2016b). Rethinking the energy-growth nexus: Proposing an index of sustainable economic welfare for Sub-Saharan Africa. *Energy Research & Social Science*, *17*, 147–159. https://doi.org/10.1016/J.ERSS.2016.04.009

Moomaw, W. R., & Unruh, G. C. (1997). Are environmental Kuznets curves misleading us? The case of CO2 emissions. *Environment and Development Economics*, *2*(4), 451–463. https://doi.org/10.1017/S1355770X97000247

Myszczyszyn, J., & Suproń, B. (2022). Relationship among Economic Growth, Energy Consumption, CO2 Emission, and Urbanization: An Econometric Perspective Analysis. *Energies*, *15*(24). https://doi.org/10.3390/en15249647

Narayan, P. K., & Smyth, R. (2005). Electricity consumption, employment and real income in Australia evidence from multivariate Granger causality tests. *Energy Policy*, *33*(9), 1109–1116. https://doi.org/10.1016/J.ENPOL.2003.11.010

Nasrullah, M., Rizwanullah, M., Yu, X., Jo, H., Sohail, M. T., & Liang, L. (2021). Autoregressive distributed lag (ARDL) approach to study the impact of climate change and other factors on rice production in South Korea. *Journal of Water and Climate Change*, *12*(6), 2256–2270. https://doi.org/10.2166/WCC.2021.030

NBS. (2020). Power Sector Report: Energy Generated and Sent Out and Consumed and Load Allocation. *National Bureau of Statistics / Nigerian Electricity Regulatory Commission*, *July*, 1–85.

Net zero targets | Climate Action Tracker. (2021). Climate Action Tracker. https://climateactiontracker.org/countries/south-africa/net-zero-targets/

Nigeria Energy Transition Plan. (n.d.). Retrieved June 9, 2023, from https://energytransition.gov.ng/

Nkoro, E., & Uko, A. K. (2016). Autoregressive Distributed Lag (ARDL) cointegration technique: application and interpretation. *Journal of Statistical and Econometric Methods*, *5*(4), 63–91.

Oryani, B., Koo, Y., Rezania, S., Shafiee, A., Khan, M. K., & Mahdavian, S. M. (2021). The role of electricity mix and transportation sector in designing a green-growth strategy in Iran. *Energy*, *233*, 121178. https://doi.org/10.1016/J.ENERGY.2021.121178

Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels. *Advances in Econometrics*, *15*, 93–130. https://doi.org/10.1016/S0731-9053(00)15004-2/FULL/PDF

Pesaran, M. H. (2008). An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis. In *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium* (Issue February). https://doi.org/10.1017/ccol0521633230.011

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001a). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/JAE.616

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001b). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/JAE.616

Pesaran, M. H., Shin, Y., & Smith, R. J. (2001c). Bounds testing approaches to the analysis of level relationships. *Journal of Applied Econometrics*, *16*(3), 289–326. https://doi.org/10.1002/JAE.616

Rahman, M. M., & Kashem, M. A. (2017). Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. *Energy Policy*, *110*, 600–608. https://doi.org/10.1016/J.ENPOL.2017.09.006

Raihan, A., & Tuspekova, A. (2022). Toward a sustainable environment: Nexus between economic growth, renewable energy use, forested area, and carbon emissions in Malaysia. *Resources, Conservation and Recycling Advances*, *15*(June), 200096. https://doi.org/10.1016/j.rcradv.2022.200096

Renewable capacity statistics 2023. (n.d.). Retrieved June 11, 2023, from https://www.irena.org/Publications/2023/Mar/Renewable-capacity-statistics-2023

Renewable Energy Roadmap: Nigeria. (n.d.). Retrieved June 11, 2023, from https://www.irena.org/Publications/2023/Jan/Renewable-Energy-Roadmap-Nigeria

Reuters. (2023). *Nigeria's NNPC spent $10 billion on fuel subsidy in 2022*. https://www.reuters.com/business/energy/nigerias-nnpc-spent-10-billion-fuel-subsidy-2022-2023-01-20/

Saraç, Ş., & Yağlikara, A. (2017). Environmental Kuznets Curve: The Evidence from BSEC Countries. *Ege Akademik Bakış Dergisi*, *17*(2), 255–264. https://doi.org/10.21121/eab.2017225203

Shell Annual Report. (2017). *Shell Annual Report 2017 - Home*. https://reports.shell.com/annual-report/2017/

Shrestha, M. B., & Bhatta, G. R. (2018a). Selecting appropriate methodological framework for time series data analysis. *The Journal of Finance and Data Science*, *4*(2), 71–89. https://doi.org/10.1016/J.JFDS.2017.11.001

Shrestha, M. B., & Bhatta, G. R. (2018b). Selecting appropriate methodological framework for time series data analysis. *The Journal of Finance and Data Science*, *4*(2), 71–89. https://doi.org/10.1016/J.JFDS.2017.11.001

Solarin, S. A., & Shahbaz, M. (2013). Trivariate causality between economic growth, urbanisation and electricity consumption in Angola: Cointegration and causality analysis. *Energy Policy*, *60*, 876–884. https://doi.org/10.1016/j.enpol.2013.05.058

Stern, D. I. (1998). Progress on the environmental Kuznets curve? *Environment and Development Economics*, *3*(2), 173–196. https://doi.org/10.1017/S1355770X98000102

Stern, D. I. (2004). Environmental Kuznets Curve. *Encyclopedia of Energy*, 517–525. https://doi.org/10.1016/B0-12-176480-X/00454-X

Tambari, I. T., Dioha, M. O., & Failler, P. (2020). Renewable energy scenarios for sustainable electricity supply in Nigeria. *Energy and Climate Change*, *1*, 100017. https://doi.org/10.1016/J.EGYCC.2020.100017

THE CAUSAL RELATIONSHIP BETWEEN ENERGY AND GNP: AN INTERNATIONAL COMPARISON on JSTOR. (n.d.). Retrieved June 11, 2023, from https://www.jstor.org/stable/24807818

The colours of energy | Shell Global. (n.d.). Retrieved June 13, 2023, from https://www.shell.com/energy-and-innovation/the-energy-future/colours.html

The World Bank. (2021). *GDP growth (annual %) - Nigeria | Data*. GDP Growth (Annual %) - Nigeria | Data. https://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG?locations=NG

Treut, L., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, a, Peterson, T., Prather, M., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., & Tignor, M. (2007). Historical Overview of Climate Change Science. *Earth*, *Chapter 1*(October), 93–127. https://doi.org/10.1016/j.soilbio.2010.04.001

van Asselt, H. (2018). The Politics of Fossil Fuel Subsidies and their Reform. In *The Politics of Fossil Fuel Subsidies and their Reform*. https://doi.org/10.1017/9781108241946

V.A.R.Barao, R.C.Coata, J.A.Shibli, M.Bertolini, & J.G.S.Souza. (2022). No 主観的健康感を中心とした在宅高齢者における健康関連指標に関する共分散構造分析Title. *Braz Dent J.*, *33*(1), 1–12.

Yeboah Asuamah, S. (2016). *Modelling financial development and electricity consumption nexus for Ghana*.

Yetano Roche, M. (2023). Built for net-zero: analysis of long-term greenhouse gas emission pathways for the Nigerian cement sector. *Journal of Cleaner Production*, *383*, 135446. https://doi.org/10.1016/J.JCLEPRO.2022.135446

Yu, E. S. H., & Hwang, B. K. (1984). The relationship between energy and GNP: Further results. *Energy Economics*, *6*(3), 186–190. https://doi.org/10.1016/0140-9883(84)90015-X

Yu, E. S. H., & Jin, J. C. (1992a). Cointegration tests of energy consumption, income, and employment. *Resources and Energy*, *14*(3), 259–266. https://doi.org/10.1016/0165-0572(92)90010-E

Yu, E. S. H., & Jin, J. C. (1992b). Cointegration tests of energy consumption, income, and employment. *Resources and Energy*, *14*(3), 259–266. https://doi.org/10.1016/0165-0572(92)90010-E

Zhang, X. P., & Cheng, X. M. (2009). Energy consumption, carbon emissions, and economic growth in China. *Ecological Economics*, *68*(10), 2706–2712. https://doi.org/10.1016/J.ECOLECON.2009.05.011

국문 요약

나이지리아 이산화탄소 배출, 화석연료 에너지 공급, 에너지 소비 및 GDP 간의 관계 분석

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인간 활동으로 인한 온실가스(GHG)의 배출, 특히 화석연료의 연소로 인한 배출이 지구 온난화의 주된 원인이 되고 있다. 경제 성장은 그로 인한 이익과 더불어 부작용도 존재한다. 특히 나이지리아와 같은 개발도상국에서는 경제 성장이 때때로 기후 변화와 더 많은 온실가스 배출을 초래하기도 한다. 이전의 연구들은 자원은 유한하기에 화석연료를 대체할 수 있는 방안을 모색하는 것이 지구 온난화를 막기 위해 중요하다고 지적했 왔다. 나이지리아에서는 전력 부문이 CO2 오염의 가장 큰 원인이 되고 있다. 이 나라의 에너지 중 약 80%는 가솔린과 디젤로 구동되는 "독립형" 또는 "분산형" 시스템에서 나온다. 이처럼 화석연료를 많이 사용함으로써 환경이 크게 오염되고 있으며, 따라서 우리는

미래의 에너지 수요와 환경 오염을 막을 수 있는 방법에 대해 생각해 봐야 한다.

이 연구는 자원·환경경제학의 관점에서 경제 성장, 환경 오염, 에너지 사용의 상호관계를 살펴보고자 한다. 경제 성장과 CO2 배출과 같은 환경 오염 사이의 관계, 그리고 경제 성장과 에너지 사용 사이의 관계를 고찰한다. 또한 "이산화탄소 배출과 에너지 공급·수요, 경제 성장의 상관관계와 인과관계는 무엇인가?"와 "화석연료 생산과 소비에 주로 의존하는 경제에서 온실가스 감축 목표를 달성하기 위한 적절한 에너지 정책은 무엇인가?"라는 연구 질문에 대한 해답을 찾고자 한다. 이러한 연구 목적을 위해 1990 년부터 2020 년까지의 데이터를 사용하여 자기회귀분포시차(Autoregressive Distributed Lag; ARDL)와 공적분 테스트(cointegration test)를 사용하여 이러한 관계가 시간에 따라 어떻게 변화하는지 살펴보았다. 국제에너지기구(IEA)와 세계은행이 제공한 총 에너지 사용량, 석유와 가스 에너지 공급량, 1 인당 CO2 배출량, 1 인당 GDP 통계를 사용하였다.

ARDL 단기 모델의 결과는 과거의 CO2 배출이 오늘날의 CO2 수준을 증가 시켰다는 것을 보여준다. 이는 과거에 환경을 해친 활동이 오늘날의 기후 변화에 큰 영향을 미친다는 것을 시사한다. 또한 석유와 가스 에너지의 공급으로 더 많은 에너지가 사용되었고 오늘날의 CO2 배출에 영향을 미친다. 인과관계 연구의 결과에 따르면 에너지 사용, 특히 석유와 가스 사용은 CO2 오염에 큰 영향을 미치나, GDP 는 큰 영향을 미치지 않는다. 따라서 이 연구는 에너지와 환경 정책, 대체 에너지

정책, 에너지 전환 정책, 탈동조화 정책, 녹색 에너지 정책을 통하여 CO2 배출을 줄이고 동시에 경제 성장을 촉진할 것을 제안한다.

화석연료에서 재생 에너지로 전환하기 위해서는 지속 가능한 성장을 위한 장기 계획과 강력한 정치적 의지가 필요하다. 재생 에너지 기반 경제에 필요한 인프라를 구축하는 데는 종종 한 정부 행정 기간보다 더 오래 걸린다. 따라서 에너지 전환 계획을 유지하기 위해서는 강력한 법적 틀이 마련되어 정치인들이 이를 저해하지 못하도록 해야 한다. 또한 사람들은 저탄소 경제로의 전환 과정에서 발생하는 단기 문제들을 해결하기 위해 헌신해야 한다.

주요어: 이산화탄소(CO2), 자기회귀분포시차(ARDL), 단기모델, 인과관계, 에너지-환경-경제 정책, 나이지리아

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Appendix

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