ENERGY TRANSITION, ENERGY POLICY AND MACROECONOMIC PERFORMANCE IN NIGERIA: A COMPUTABLE GENERAL EQUILIBRIUM APPROACH

Eyitemi A. Fasanu, Christiana O. Hassan, Henry O. Okodua, Abiola Akande

Abstract

Nigeria is at a critical juncture in its energy transition journey, grappling with the dual imperatives of reducing carbon emissions while ensuring sustained macroeconomic stability. As a signatory to the Paris Agreement, the country has committed to ambitious emissions reduction targets—20% unconditionally and 47% conditionally. However, the macroeconomic consequences of these commitments remain an area of concern, particularly given Nigeria's heavy reliance on fossil fuels and the potential trade-offs between environmental sustainability and economic performance. This study employs a Computable General Equilibrium (CGE) model based on Nigeria's 2018 Social Accounting Matrix (SAM) to evaluate the macroeconomic implications of these emissions' reduction targets between 2018 and 2030. Two policy scenarios are analyzed, corresponding to the 20% and 47% emissions reduction strategies. The findings provide robust empirical evidence that while emissions reduction policies contribute to environmental sustainability, they impose significant economic costs, especially in the absence of foreign aid and technological support. Under the 20% emissions reduction scenario, Nigeria's real Gross Domestic Product (RGDP) is projected to decline by 0.05349% by 2030, whereas the 47% reduction scenario results in a sharper contraction of 0.06138%. Notably, the industrial sector emerges as the hardest hit, experiencing value-added losses of up to 2.4728%, despite being among the least energy- and emissions-intensive sectors. In contrast, the agriculture sector, which is less dependent on fossil fuels, exhibits relative resilience, with marginal growth recorded in select years under the 47% scenario. Furthermore, the study highlights a consistent decline in energy intensity across all sectors, with the service sector recording improvements of 0.57% and 0.89% under the 20% and 47% scenarios, respectively. A key novelty of this study lies in its comparative analysis with similar research conducted in other developing economies. Studies on South Africa's energy transition (Altman et al., 2021) reveal that ambitious decarbonization policies lead to short-term economic contractions, but long-term gains are attainable with adequate financial interventions and green technology investments. Similarly, research on Indonesia's low-carbon transition (Suroso & Pratiwi, 2022) suggests that while emissions reduction measures initially suppress industrial output, targeted fiscal incentives for green energy adoption mitigate these adverse effects. Unlike these cases, Nigeria's energy transition presents unique challenges due to its weaker institutional frameworks and limited access to external funding, making the projected economic costs more pronounced. Furthermore, very few studies have considered this phenomenon for the Nigerian economy, which means that the understanding of the practical and empirical transmission mechanism from the implementation of the ETP is very limited. This limitation restricts the ability to design policies that ensure a healthy trade-off between achieving environmental sustainability by 2030 and maintaining economic prosperity. This study, therefore, advances the literature by demonstrating that without foreign aid and strategic sectoral interventions, Nigeria's economic decline under stringent emissions targets could surpass those observed in comparable economies. Policy implications are significant. The study recommends that Nigerian policymakers prioritize international financial cooperation and foreign investment attraction to support the transition. Specific interventions, such as targeted subsidies for renewable energy adoption and incentives for energy efficiency in the industrial sector, are critical in alleviating economic costs. Furthermore, the establishment of a robust governance framework for managing foreign aid and climate finance is essential to ensure the sustainability of the Energy Transition Plan (ETP). By incorporating these strategies, Nigeria can navigate the trade-offs between emissions reduction and macroeconomic performance more effectively, thereby aligning with the Sustainable Development Goals (SDGs) of fostering economic growth while combating climate change. This research makes a novel contribution by quantitatively illustrating the economic costs of energy transition policies in Nigeria, while contextualizing these findings within broader global discourses. It underscores the urgency of integrating economic and environmental strategies to achieve a balanced and sustainable transition. Future research should explore dynamic policy simulations that incorporate technological innovations and external funding mechanisms to better inform Nigeria's pathway toward a resilient and low-carbon economy.

Keywords: Climate Change, Computable General Equilibrium, Emission Reduction, Energy Transition, Macroeconomic Performance, Nigeria, Sustainable Development

1. Introduction

Climate change is a global phenomenon driven by local factors such as deforestation, agricultural activities, greenhouse gas emissions, energy production, and energy consumption. Although climate change is a global phenomenon, it is largely responsible for global warming, which has led to localized effects such as flooding, desertification, pollution, and other extreme events (Kumar et al., 2021). These effects are best managed at local levels, and this is why 194 countries, under the Paris Agreement, have a made a commitment to mitigate these effects through their Nationally Determined Contribution (NDC). An NDC is a climate action plan that each country submits under the Paris Agreement, outlining its efforts to reduce national greenhouse gas emissions and adapt to the impacts of climate change (Laudari et al., 2021). Key characteristics of the NDC include country specific agreements based on economic structure, adaptation measures, transparency, international cooperation, and emissions reduction targets.

NDCs include specific targets for reducing greenhouse gas emissions, which can be absolute reductions or relative to business-as-usual scenarios. Nigeria is one of the 194 countries that have made the climate change commitment, and one of the country's key strategies to reduce greenhouse gas emissions is the Energy Transition Plan (ETP). An energy transition plan is a comprehensive strategy designed to shift from a reliance on fossil fuels and non-renewable energy sources to a more sustainable energy system primarily based on renewable energy sources, such as solar, wind, and hydropower (Ramachandra, 2020). This plan aims to achieve several key objectives, including reducing greenhouse gas emissions, enhancing energy security, and promoting economic development through green technologies. Countries such as Sweden, Denmark and Finland have achieved over 50% of their electricity generation from renewable energy sources (Huterski et al., 2021).

The ETP is designed to ensure a reduction in greenhouse gas emissions through changes in the type of energy consumed. Renewable energy sources contain very low levels of greenhouse gases such as carbon dioxide (CO_2) and methane, hence the attention the energy type has received as a reliable transition fuel (Jeffry et al., 2021). However, renewable energy technologies are investment heavy, and developing countries like Nigeria may not be able to afford them, given the other challenges that the country faces. On this premise, the transition fuel under Nigeria's ETP is not renewable energy, but natural gas. Natural gas is a fossil fuel, in the category of coal and petroleum oil. However, it is the fossil fuel with the least greenhouse gas content, and is also an abundant resource in Nigeria. Additionally, the technologies that produce and consume energy from coal and petroleum oil can be modified to suit the production and consumption of natural gas, and these technologies are already available in Nigeria. These have potential to reduce the investment that is needed for transition (Williams et al., 2019).

Under the ETP, there are two emissions reduction strategies that the Nigerian government has committed to achieve. The first is the unconditional emissions reduction strategy. This strategy is aimed at ensuring a reduction in greenhouse gas emissions by 20%, by the year 2030. This strategy is called the unconditional emissions reduction strategy because it is achievable by the Nigerian government based on domestic resources alone, without any need for aid from the international community (Rivas et al., 2021). The second emissions reduction strategy is aimed at going further than a 20% reduction, to a 47% reduction, by the year 2030. However, this strategy is only possible based on aid and collaboration with developed countries, and development partners such as the World Bank. As at 2023, the share of electricity generated from renewable sources stood at about 21%, compared to Sweden's 69.16% (Khan et al., 2020).

It is important to state here that "greenhouse gas emissions" is an umbrella term for polluting gases such as (CO_2), Methane and Sulphur dioxide. The most emitted of all these gases both globally and in Nigeria is CO_2, which is responsible for up to 74% of global greenhouse gas emissions, and up to 90% of greenhouse gas emissions in Nigeria (Olivier et al., 2017). Based on this important note, this study is focusing on CO_2 as the greenhouse gas of interest. Greenhouse gas emissions, Carbon emissions and CO_2 are used interchangeably henceforth. Also, there is the need to emphasize that this study is focusing on energy consumption as the source of Carbon emissions in Nigeria.

Considering that the objective of the Paris Agreement is to reduce greenhouse gas emissions and subsequently, global warming effects, implementing the Energy Transition Plan (ETP) is expected to drive down the volume of Carbon emissions in Nigeria. This implies that implementing the ETP, through the unconditional and conditional emissions reduction targets is environmentally beneficial for the country, and the world (Okoh & Okpanachi, 2023). However, that something is environmentally sustainable, does not make it economically sustainable. This is why it is worthy of note that the concept of sustainability is a holistic one, which covers environmental, economic and social factors. For Nigeria, meeting up with the laudable Paris Agreement is environmentally sustainable, but economically damaging. This is what this study has been able to prove, using the Computable General Equilibrium Model framework.

The general argument is that during the industrial revolution, the developed countries used fossil fuels to grow their economies, and are largely responsible for the global greenhouse gas emissions associated with large scale production and economic growth (Gokmenoglu & Sadeghieh, 2019). Now that there is a climate crisis, the developed countries are clamoring for developing countries and emerging economies, which are still on their growth trajectory, to move away from the consumption of the fuels that are cheaper for them to use for production, to the use of renewable energy, which is very expensive to invest in.

At this juncture, it is important to present a picture of the state of the Nigerian macroeconomy. Nigeria falls under the category of emerging lower-middle income economies. In 2019, Nigeria's GDP was about 410 US billion Dollars, while the GDP per capita was estimated to be up to 2,230 US dollars. Nigeria has the highest GDP per capita in Africa (World Development Indicators, 2019). As a result of COVID-19, Nigeria's GDP decreased by over 20% in 2020. According to the National Bureau of Statistics (NBS), the economy grew by 3.4% in 2021, opposed to the 1.92% contraction which was the case in 2020. Still according to NBS (2024), from 2012 to 2014, the economy experienced robust growth, peaking at 6.77% in Q4 2013. However, from 2015, GDP growth declined sharply due to the global oil price crash, leading to a recession in 2016, with the lowest growth at -2.34% in Q3 2016. The economy began a slow recovery in 2017, stabilizing around 2% growth from 2018 to 2019. The COVID-19 pandemic in 2020 caused another severe downturn, with a -6.10% drop in Q2 2020. Recovery started in late 2020 and continued through 2021, with a notable growth of 5.01% in Q2 2021. By 2023 and into 2024, growth rates fluctuated between 2.31% and 3.46%, indicating a steady but cautious recovery.

In addition to these macroeconomic events, Nigeria has also been experiencing a dynamic carbon emission landscape. In 2021, the country was responsible for 0.3% of global carbon emissions. Also, carbon emissions from combustion of fossil fuels increased by 128% between 2000 and 2021 (International Energy Agency, 2022). This conveniently placed Nigeria as the 4th highest emitter of carbon in Africa in 2022. It also contributed to Nigeria's ranking as 18th in carbon emission per capita, out of 54 African countries, in 2022. The largest source of carbon emissions was from oil in 2023, at 33%. This is followed by natural gas at about 25%, and coal at 27%.

This study seeks to investigate the relationship between carbon emissions reduction, energy transition, and macroeconomic performance in Nigeria. Specifically, the study aims to understand how energy regulatory framework can be used to adjust macroeconomic performance and mitigate the negative impacts of climate change in Nigeria. This implies that energy policy is a subset of climate change policy and can therefore be used as a tool to combat climate change (Baranzini, Van den Bergh, Carattini, Howarth, Padilla and Roca, 2017; Ji and Zhang, 2019). The study employed a computable general equilibrium (CGE) approach to analyze the economy- wide impacts of energy policy in Nigeria, taking into account the complex interdependencies between different sectors and markets. Therefore, the question comes up: how will macroeconomic performance be affected under different policy scenarios within the energy policy framework? The study examines the sectoral effects that ensue when energy policy is used to mitigate the effects of climate change.

2. Literature Review

Theoretical Review

This section provides a brief review of four relevant theories, including the theory underpinning this study, which is the Neoclassical Theory of General Equilibrium. The other three theories are the Environmental Kuznets' Curve, The Resource Curse Theory, and Game Theory. These theories were chosen because their precedence in explaining the impacts of energy dynamics on decision making and economies.

The Environmental Kuznets Curve (EKC) theory offers a framework to understand the relationship between economic development and environmental degradation. Initially, environmental quality deteriorates as economies grow and industrial activities intensify. However, as income levels increase, societies prioritize environmental quality, leading to the implementation of policies that mitigate pollution and eventually improve environmental conditions. Simon Kuznets, an economist, first introduced the concept of the Kuznets Curve in the 1950s, which was later adapted to environmental issues by researchers like Gene Grossman and Alan Krueger in the 1990s. The EKC assumes that economic growth, especially in its early stages, results in increased energy consumption and pollution. As societies become more affluent, they invest in cleaner technologies and adopt environmentally friendly policies, leading to a decline in pollution levels.

While the EKC suggests that environmental degradation will decline with economic growth, Nigeria has not yet reached this stage, making the theory crucial for future planning. The EKC is advantageous in highlighting the dynamic relationship between economic development, energy policy, and environmental quality. It underscores the potential for economic growth to be compatible with environmental sustainability in the long term. However, the theory is criticized for oversimplifying the complex interactions between economic development and environmental degradation, neglecting factors such as technological progress, institutional quality, and social norms. Studies, like those by Grossman and Krueger (1995), have provided empirical evidence supporting the EKC hypothesis, showing an inverted U-shaped relationship between income levels and pollution. Research such as that by Li and Lin (2015) has also demonstrated the role of carbon taxation in mitigating emissions while minimizing economic impacts, aligning with the EKC theory's insights.

The Resource Curse Theory, also known as the "paradox of plenty" or "Dutch disease," explores the negative economic and social outcomes that often accompany natural resource abundance. Coined by Richard Auty in 1993, this theory highlights how resource-rich countries, despite their wealth, often experience slower economic growth and development. Notable contributors like Jeffrey Sachs, Paul Collier, and Terry Lynn Karl have expanded on this theory, emphasizing challenges such as rent-seeking behavior, lack of economic diversification, and vulnerability to commodity price fluctuations. These issues can lead to economic instability and hinder sustainable development.

The theory assumes that overreliance on natural resources can result in economic underperformance, often due to the crowding out of other sectors and the "Dutch disease" effect, where resource booms cause currency appreciation, making non-resource sectors less competitive. Additionally, weak institutions and governance exacerbate these challenges, leading to ineffective resource management and potential political instability. While the theory is valuable for highlighting the pitfalls of resource dependence, it has been criticized for oversimplifying the varied experiences of resource-rich countries. Studies like those by Ross (1999) and Van Der Ploeg (2011) provide empirical support for the theory, illustrating the economic difficulties faced by resource-rich countries like Nigeria and emphasizing the importance of diversification and prudent fiscal policies.

Game Theory, developed by scholars such as John Nash, John von Neumann, and Oskar Morgenstern, is a powerful analytical tool for understanding strategic decision-making in the energy sector. It examines how different stakeholders, including policymakers, energy producers, and consumers, interact and make decisions to maximize their interests. The theory assumes rational actors, perfect information, and the consideration of others' responses in decision-making processes. Game theory provides a framework to analyze the complexities of energy policy, including pricing, investment decisions, and regulatory challenges.

Despite its strengths, game theory has limitations, such as the assumptions of perfect rationality and information, which may not always hold in real-world scenarios. Moreover, the static nature of many game theory models may not fully capture the dynamic aspects of energy markets. Empirical studies, like those by Azad (2016) and Wright-Maley and Joshi (2016), use game theory to analyze the strategic behavior of stakeholders in the energy market, providing insights into the impacts of policy interventions on market outcomes and macroeconomic performance.

The Neoclassical Theory of General Equilibrium, as developed by economists such as Léon Walras, Kenneth Arrow, and Gérard Debreu, provides a robust and comprehensive framework for analyzing the implications of the green transition in Africa. This theory is particularly well-suited to underpin this study because it offers a clear and structured approach to understanding how energy policies impact macroeconomic variables, including GDP, employment, and overall economic welfare. By assuming perfect competition, rational behavior, and efficient resource allocation, the Neoclassical Theory of General Equilibrium facilitates a nuanced analysis of how shifts in energy policy, particularly toward greener technologies, can lead to optimal outcomes for African economies.

In the context of Africa's green transition, this theory effectively explains how market mechanisms can be harnessed to balance the economic benefits of sustainable energy practices with environmental goals. It underscores the potential for efficient markets to drive investments in renewable energy, reduce dependence on fossil fuels, and spur economic growth through increased energy security and job creation. The assumption of rational actors making utility or profit-maximizing decisions is particularly relevant, as it reflects the motivations of various stakeholders—governments, businesses, and consumers—in pursuing sustainable energy transitions.

While the theory's assumptions, such as perfect competition and complete information, may not fully capture the complexities of real-world markets, it remains a valuable tool for projecting the broad economic impacts of green policies. The limitations, such as its traditional focus on static equilibrium and potential underestimation of market imperfections, can be mitigated by integrating dynamic models and considering policy interventions that address these imperfections. Despite these challenges, the Neoclassical Theory of General Equilibrium is uniquely positioned to provide a clear framework for policymakers in Africa, helping to navigate the complexities of the green transition and its macroeconomic repercussions.

By applying this theory, the study can offer actionable insights into how African economies can achieve sustainable growth through energy transitions. It highlights the importance of aligning market incentives with environmental goals, ensuring that the green transition is not only environmentally beneficial but also economically viable. As such, the Neoclassical Theory of General Equilibrium is the most appropriate choice to underpin this study, offering a rigorous foundation to explore what the green transition means for Africa and how it can be harnessed for long-term economic prosperity.

Empirical Review

Emissions Reduction and Energy Transition

Kabeyi and Olanrewaju (2022) conducted a comprehensive review of energy transition strategies, proposing a detailed roadmap for achieving a sustainable energy transition aimed at ensuring sustainable electricity generation and supply. This roadmap is aligned with the commitments of the Paris Agreement, which seeks to reduce greenhouse gas emissions and limit the global average temperature rise to 1.5°C above pre-industrial levels. The study emphasizes that while sustainable development traditionally relies on social, economic, and environmental pillars, energy sustainability requires a more nuanced analysis. They suggest a five-dimensional approach encompassing environmental, economic, social, technical, and institutional/political sustainability to accurately assess resource sustainability.

The study underscores the importance of various technologies in facilitating the energy transition. These include conventional mitigation technologies, negative emissions technologies that capture and sequester carbon emissions, and innovative technologies designed to alter the global atmospheric radiative energy budget, thereby stabilizing and reducing global average temperatures. A sustainable electricity system, according to Kabeyi and Olanrewaju, necessitates a combination of facilitating technologies, supportive policies, strategic frameworks, and essential infrastructure such as smart grids. Additionally, they advocate for models incorporating an appropriate mix of both renewable and low-carbon energy sources to achieve long-term sustainability in electricity generation.

Gershon, Asafo, Nyarko-Asomanim, and Koranteng (2024) focused their study on the interconnections between Sustainable Development Goals (SDGs) 7, 8, and 13, which pertain to affordable and clean energy, decent work and economic growth, and climate action, respectively. Their investigation centered on the interactive effects of energy consumption and economic growth on carbon emissions across seventeen selected African countries. Utilizing static panel estimation techniques and annual data from 2000 to 2017, their analysis revealed that increased energy consumption positively impacts economic growth while negatively impacting carbon emissions.

The findings from Gershon et al. (2024) indicate that economic growth, driven by the energy transition in Africa, helps mitigate the negative environmental effects of increased energy consumption. This suggests that the transition to renewable energy sources is playing a crucial role in moderating the adverse effects of rising energy consumption and economic growth on the environment. Specifically, their results highlight that while energy consumption is directly proportional to economic growth, it also contributes to a reduction in carbon emissions when coupled with a shift towards renewable energy sources. This leads to a proposed modification of the energy intensity theory for sub-Saharan Africa: carbon emissions are directly proportional to the amount of fossil fuel energy consumed per unit of output.

Emissions Reduction and Macroeconomic Indicators

Ezenwa, Nwatu, and Gershon (2021) delve into the intricate relationship between economic growth, renewable energy consumption, and CO_2 emissions in Nigeria. The study employs the Johansen co-integration technique to test for long-term relationships and applies the Vector Error Correction Model (VECM) to analyze annual data from 1990 to 2015. Their findings reveal a bi- directional causality between renewable energy consumption (REC) and economic growth (GDP), indicating that REC positively influences GDP in both the short and long term. Conversely, GDP has a negative short-term effect on REC. The historical decomposition of shocks highlights that renewable energy shocks had predominantly negative implications for GDP between 1990 and 2007, a period marked by inefficient renewable technologies. However, from 2009 to 2015, there was a persistent and positive influence of REC on economic growth, attributed to the increased use of more affordable and efficient renewable technologies. The variance decomposition analysis forecasts a rise in renewable energy technology use over the next five years, but also predicts an increase in CO_2 emissions due to continued reliance on fossil fuel energy resources.

In a related context, Prawoto and Basuki (2020) explore the impact of trade value, investment, rupiah-to-dollar exchange rates, industrial added value, oil consumption, and CO_2 emissions on Indonesia's economic growth. Utilizing data from 1986 to 2018 and employing the Error Correction Model (ECM), their study reveals that trade value, investment, exchange rates, and industrial added value significantly influence economic growth both in the short and long term. However, oil consumption and CO_2 emissions only show a significant impact in the long term. The findings suggest that CO_2 emissions drive economic growth, necessitating a shift in Indonesia's economic development strategy towards more environmentally sustainable practices to ensure that future generations can benefit from natural resources without causing environmental degradation.

Furthermore, Afolayan, Okodua, Oaikhenan, and Matthew (2020) investigate the combined effects of carbon emissions and health investment on economic development in Nigeria by integrating ecological economics with the endogenous growth model. Using annual time series data from 1980 to 2017, the bounds testing approach of the autoregressive distributed lag (ARDL) framework confirms the existence of co-integration among the variables. Long-term estimates indicate that a 1% increase in government health investments enhances economic development (measured by GDP per capita) by 0.008%, while a 1% increase in CO_2 levels reduces GDP per capita by 0.1%. Interestingly, the study finds no causal link between fossil fuel consumption (FFC) and CO_2 emissions, contradicting previous studies. However, it identifies unidirectional causality from health outcomes (proxied by life expectancy) to CO_2 emissions, and from CO_2 emissions to electricity consumption (ELCON). Additionally, increased energy consumption (both FFC and ELCON) directly influences GDP per capita.

The diverse methodological approaches and contexts of these studies underscore the complex interplay between renewable energy, economic growth, and environmental impact. Ezenwa, Nwatu, and Gershon's (2021) research highlights the evolving role of renewable energy in Nigeria's economic landscape, demonstrating both its potential benefits and challenges. Prawoto and Basuki (2020) emphasize the multifaceted drivers of economic growth in Indonesia, while also pointing to the need for more sustainable development strategies. Afolayan et al. (2020) bring to light the critical interconnections between health investments, carbon emissions, and economic development in Nigeria, suggesting that comprehensive policies addressing both environmental and health factors are essential for sustainable economic growth. These studies collectively contribute to a deeper understanding of how renewable energy consumption and policy interventions can shape economic outcomes in different regional contexts.

Energy Transition and Macroeconomic Indicators

Rajendran, Krishnaswamy, and Subramaniam (2023) present a comprehensive conceptual framework that explores the macroeconomic factors associated with the energy transition in G7 countries and addresses the challenges related to achieving Sustainable Development Goal (SDG) 7, which focuses on renewable energy sources (RES). The study recognizes the well- established link between energy, economic growth, and CO_2 emissions, and reviews authentic databases and a broad spectrum of literature concerning macroeconomic indicators of energy transition. This review helps in identifying current research gaps. To address these gaps, the authors conceptualize a framework that integrates macroeconomic factors related to RES, drawing on supporting theories from existing literature. The framework aligns with the multi-level perspective transition theory of socio-technological innovation and the Triple Bottom Line concepts, which emphasize sustainability across social, economic, and environmental dimensions. Additionally, the study offers global policy recommendations and decision-making solutions from a management perspective, addressing analytical challenges associated with the energy transition.

Großmann and Lutz (2020) investigate the macroeconomic effects of Germany's energy transition in a study commissioned by the German Federal Ministry for Economic Affairs and Energy. The research, conducted by Prognos/EWI/GWS, aims to analyze the impact of Germany's energy transition on the economy, energy system, and emissions. The study employs the PANTA RHEI model, which reflects historical developments up to 2013 and projects future developments up to 2020 based on the Energy Reference Forecast. The model includes both economic and environmental modules, with the economic core comprising input-output tables, national accounts, and the labor market, while the environmental module incorporates IEA’s energy balances and prices. The results indicate that investments in renewable energy and energy efficiency positively affect GDP and employment. However, the EEG surcharge leads to higher electricity prices for most consumers, except those in electricity-intensive industries.

Liu et al. (2019) seek to enhance the understanding of the macroeconomic effects of autonomous improvements in energy efficiency. Using a global computable general equilibrium model, the study projects that energy efficiency improvements, following historical trends until 2040, will increase global GDP by 1.3% from 2015 to 2040 without adversely affecting any region. The model includes regions such as the USA, European Union, Japan, Russia, China, India, and Brazil, and considers energy efficiency improvements across all economic activities except energy production. However, the study also finds that economy-wide rebound effects on energy use, varying between 55 to 78% across regions by 2040, necessitate aligning energy efficiency policies with renewable and climate targets to manage these rebound effects and their impact on emissions.

Nieto et al. (2020) assess the macroeconomic impacts of different scenarios within the ER2050 strategy, focusing on the absolute decoupling of GDP growth from energy use. This paper introduces a novel modeling approach based on Post-Keynesian Economics, which emphasizes demand-led economic growth, and Ecological Economics, which considers biophysical constraints such as energy availability. The study uses the Economy module of the Integrated Assessment Model MEDEAS-Europe, which combines System Dynamics with Input-Output analysis. It evaluates the ER2050 targets under various scenarios related to primary income distribution, foreign trade, labor productivity, industrial policy, and working time reduction. The findings suggest that achieving the ER2050 targets could potentially halt GDP growth and employment creation due to energy scarcity, despite significant gains in energy efficiency.

Stylized Facts on the Nigerian Economy

2.4.1 Trend Analysis of Key Variables

This section explains the trends in macroeconomic, energy and environment related variables. The macroeconomic variables include real gross domestic product and value added from the four main sectors of the Nigerian economy. Energy and environment related variables include emissions intensity and energy intensity.

According to Figure 2.1, the Residential sector consistently stands out as the highest energy consumer over this period. Its energy consumption began at 616,795 TJ in 2000 and steadily increased, reaching a peak of 1,039,263 TJ in 2022. This upward trend is largely due to the rapid urbanization and increased access to electricity in urban and rural areas, driven by government initiatives like the National Electrification Project and improvements in grid infrastructure. Additionally, the proliferation of electrical appliances and air conditioning systems in households has significantly boosted residential energy demand.

The Transport sector follows as the second highest energy consumer, showcasing a consistent upward trend. Starting at 309,475 TJ in 2000, its consumption rose to 864,836 TJ in 2022. This increase reflects the sector's expanding role in the economy, particularly due to the rise in vehicular use as a result of economic growth and increased disposable income, which led to more private vehicle ownership. Furthermore, the deregulation of the downstream oil sector in 2003 and subsequent increases in fuel availability spurred higher consumption rates. The significant jump in energy consumption from 2011 onwards can be attributed to the liberalization policies that encouraged the importation of fuel-efficient vehicles and the development of road infrastructure, making road transport more viable and accessible.

The Industrial sector displayed notable fluctuations in energy consumption throughout the 22-year period. It reached its peak in 2012 with 478,112 TJ, primarily due to the government's National Industrial Revolution Plan (NIRP) launched in 2011, which boosted manufacturing activities. However, this was followed by a decline and subsequent stabilization around 320,000 TJ, as a result of the economic recession in 2014-2016 and challenges such as inconsistent power supply and high operating costs, which forced many industries to downscale or shut down operations.

The Commercial sector showed a more stable and moderate consumption pattern compared to other sectors. It began at 67,479 TJ in 2000 and gradually increased to a maximum of 149,090 TJ in 2012. This steady growth is linked to the expansion of the services sector and increased commercial activities, particularly in urban centers like Lagos and Abuja, which saw a surge in business operations, retail markets, and financial services during this period. Additionally, the increase in small and medium enterprises (SMEs) supported by favorable business policies and access to finance played a role in this gradual rise in energy demand.

On the other end of the spectrum, the agriculture sector consumed the least energy throughout the period, starting at just 260 TJ in 2000 and peaking at 476 TJ in 2006. The minimal energy use in this sector can be attributed to the low level of mechanization and reliance on manual labor, coupled with limited access to modern irrigation and processing equipment. Despite various agricultural initiatives like the Agricultural Transformation Agenda (ATA) launched in 2011, which aimed to boost mechanization and productivity, the sector remained predominantly subsistence-based, leading to its relatively low energy consumption.

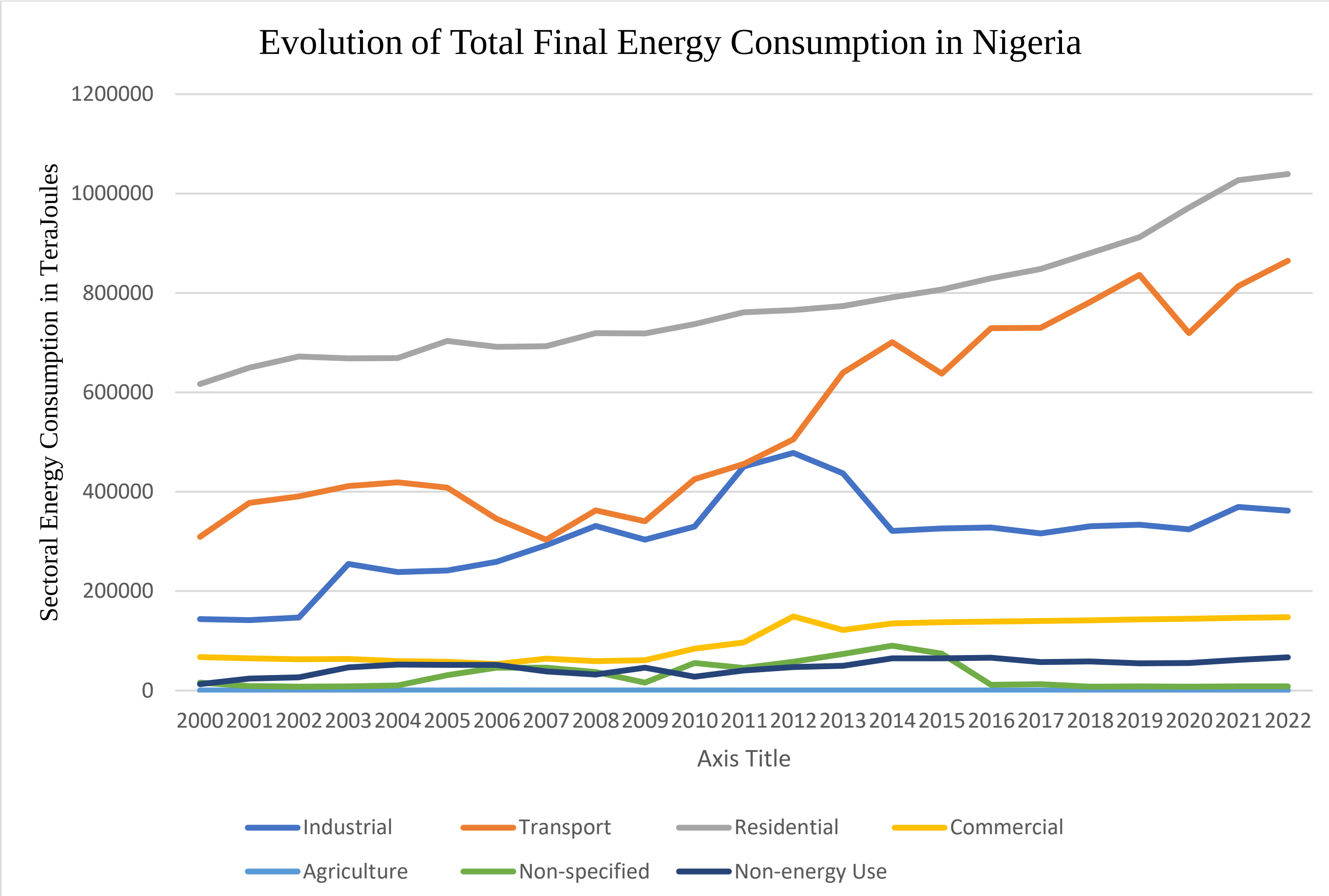


Figure 2.1: Sectoral Evolution of Total Final Energy Consumption in Nigeria between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

From 2000 to 2022, Nigeria's CO_2 emissions from fuel combustion have shown a notable upward trend from Figure 2.2. This reflects the country's growing energy consumption and industrial activities. The average annual emissions over this period were approximately 72.21 million metric tons (MT), with a maximum emission level of 100.389 MT recorded in 2022 and a minimum of 44.331 MT in 2000.

The early 2000s saw relatively moderate emissions, with levels hovering between 44 and 57 MT. This period was characterized by moderate industrial growth and limited energy infrastructure. A significant dip occurred in 2009 when emissions dropped to 46.869 MT, reflecting the global economic downturn's impact on industrial activities and energy demand in Nigeria.

However, from 2010 onwards, there was a marked increase in CO_2 emissions, with a steep rise observed between 2011 and 2014. Emissions escalated from 69.502 MT in 2011 to 95.988 MT in 2014, driven by rapid economic growth, increased industrial output, and a surge in vehicular use. This period coincided with increased fossil fuel consumption, particularly in the transport and industrial sectors, which are major contributors to CO_2 emissions.

The peak in 2022, with emissions reaching 100.389 MT, underscores the continued reliance on fossil fuels for energy generation and transportation, despite global efforts to curb emissions. This peak value also places Nigeria in a significant position regionally and globally. According to the International Energy

Agency (IEA) 2022 ranking, Nigeria ranked 4th in CO2 emissions from fuel consumption at the regional level and 38th globally, with its emissions volume standing at 100.389 MT.

In comparison to global and regional averages in 2022, Nigeria's CO2 emissions are substantial. The global average CO2 emissions for fuel combustion were around 4,000 MT, and for the African region, it was approximately 750 MT. This indicates that while Nigeria's emissions are lower compared to global powerhouses, they are significant within the African context, reflecting its status as a major energy consumer and economic leader in the region.

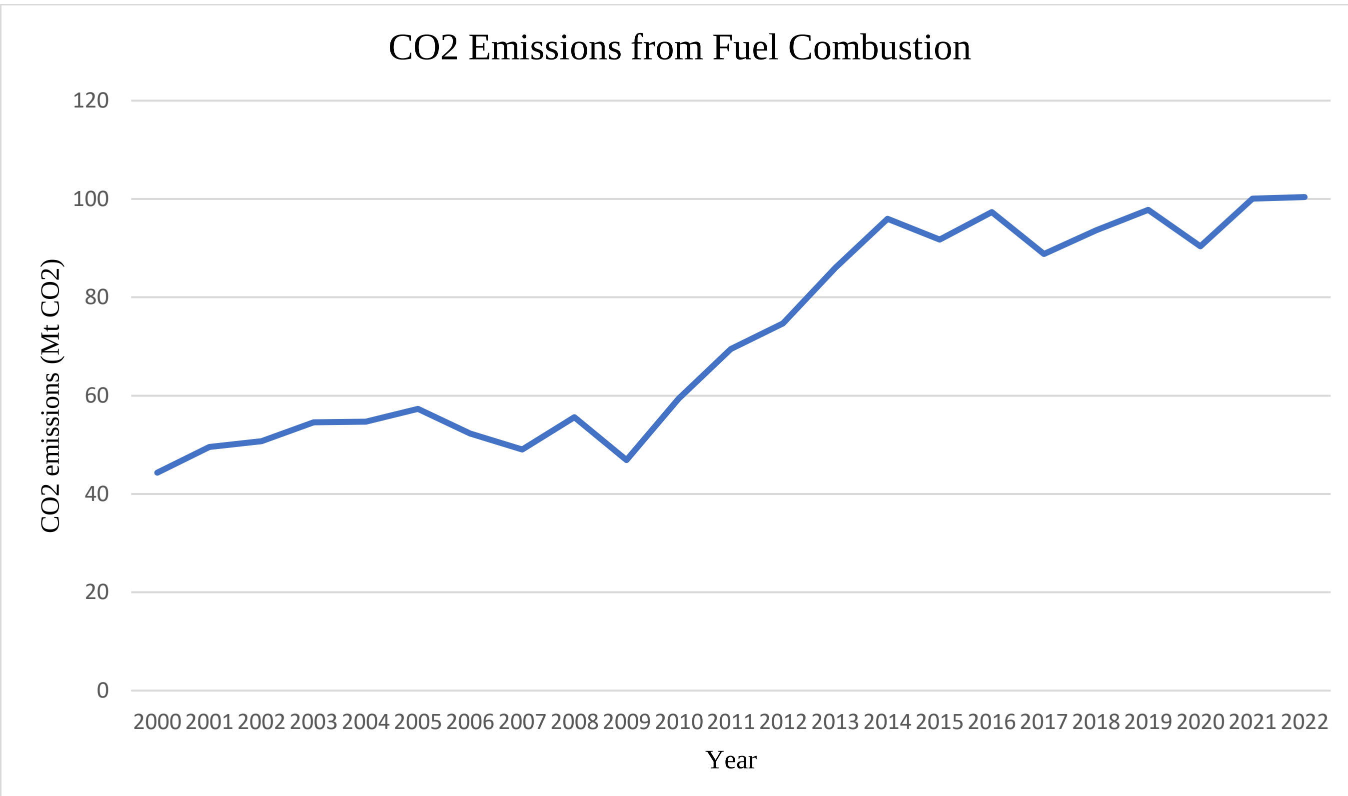


Figure 2.2: Carbon Emissions from Fuel Combustion in Nigeria between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

The behaviour of CO_2 emissions intensity in Nigeria, from Figure 2.3, shows a clear downward trend over this period. The emissions intensity decreased by approximately 71.7%, from 0.345 kg per PPP $ in 2000 to 0.097 kg in 2020. This consistent decline indicates a significant reduction in the amount of CO_2 emissions produced per unit of economic output.

In the early 2000s, Nigeria's CO_2 emissions intensity was relatively high, starting at 0.345 kg per PPP $ in 2000. By 2004, it had dropped to 0.225 kg per PPP $, a 34.7% decrease from the 2000 level. Several factors contributed to this early decline. Globally, there was increasing awareness of climate change, prompting discussions around reducing emissions. Although Nigeria was not a leading player in these conversations, international developments began to influence domestic energy and environmental policies. Locally, there were early attempts to diversify the economy and improve energy efficiency, particularly through reforms in the oil and gas sector, which resulted in a modest decline in emissions relative to economic growth.

The period from 2005 to 2008 saw a sharper reduction in emissions intensity, dropping from 0.204 kg per PPP $ in 2005 to 0.139 kg in 2008, representing a 31.8% reduction. This significant decline can be attributed to the global drive for emissions reductions following the adoption of the Kyoto Protocol in 2005. Technological advances in energy efficiency and renewable energy adoption, particularly in developed economies, influenced global emissions trends. In Nigeria, reforms in the energy sector, including the expansion of gas infrastructure and reductions in gas flaring, helped to improve carbon management. Nigeria's gradual efforts to improve energy efficiency in the oil and gas sector and reduce flaring contributed to the steady decline in emissions intensity during this period.

Between 2009 and 2012, emissions intensity fluctuated slightly but maintained a downward trend, with minor fluctuations around 0.112–0.114 kg per PPP $. The decline resumed steadily after 2013, as CO_2 intensity fell from 0.120 kg in 2013 to 0.109 kg in 2018. This period coincides with the global recovery from the 2008 financial crisis, which temporarily slowed industrial activity and emissions. Locally, Nigeria's efforts to diversify its economy and expand renewable energy access played a role in reducing emissions. Additionally, political instability and economic disruptions, particularly from the Boko Haram insurgency in northern Nigeria, also contributed to lower economic activity and, by extension, emissions reductions during this time.

The final phase, from 2017 to 2020, saw continued decreases in emissions intensity, falling to 0.097 kg in 2020. This represents the lowest emissions intensity during the period and a 10.2% decrease from the 2017 level. The global energy transition accelerated during this period, with increasing international efforts to shift away from fossil fuels and toward renewable energy. The onset of the COVID-19 pandemic in 2020 further reduced emissions globally as industrial activity, transportation, and energy demand dropped sharply. In Nigeria, the economic slowdown caused by the pandemic, combined with continued efforts to improve energy efficiency, contributed to the reduction in emissions intensity. The mean emissions intensity over the 21-year period is approximately 0.170 kg per PPP $. The highest recorded emissions intensity was 0.345 kg per PPP $ in 2000, while the lowest was 0.097 kg per PPP $ in 2020.

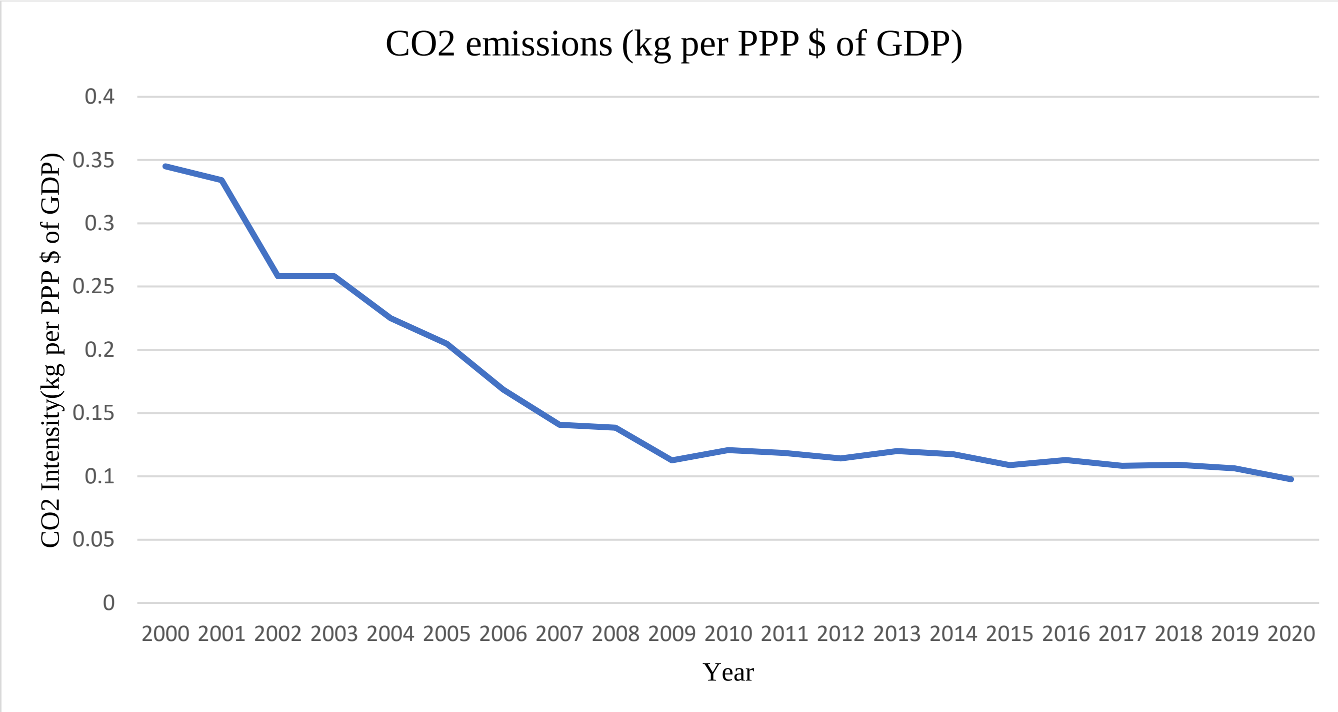


Figure 2.3: CO2 Emissions Intensity of GDP in Nigeria between 2000 and 2022
Source: Author's Computation using Data from World Development Indicators

The data on Nigeria's energy intensity, reveals a fluctuating but overall downward trend. Energy intensity, which measures how much energy is consumed to generate economic output, generally reflects the efficiency of energy use within an economy. Figure 2.4 highlights that the highest energy intensity occurred in 2000, at 4354.27 MJ per thousand USD, making it the least energy-efficient year during this period. By 2022, energy intensity had decreased to 2930.76 MJ, reflecting a significant reduction of 32.7% over two decades, indicating steady improvements in energy efficiency.

From 2000 to 2006, Nigeria saw a consistent decline in energy intensity, dropping by 26.9% by 2006. This early decline can be linked to global advancements in energy efficiency and Nigeria's internal reforms, particularly in reducing inefficiencies in the oil and gas sector and efforts to curb gas flaring. The period from 2007 to 2009 saw further steady declines, with energy intensity falling by 15.5%. This can largely be attributed to the global financial crisis of 2008, which reduced industrial activity and energy demand worldwide, as well as in Nigeria, where oil production and other energy-intensive industries were impacted.

Between 2010 and 2015, the data reflects a gradual decline, with energy intensity reducing by 12.7%. This period coincides with Nigeria's attempts to diversify its economy and improve energy efficiency, though challenges such as poor energy access and infrastructure deficits limited greater progress. From 2016 to 2019, energy intensity fluctuated slightly but showed signs of stabilization, oscillating between 2595.82 MJ and 2847.02 MJ. Global efforts to promote cleaner energy and improve energy efficiency continued during this time, but Nigeria's political and economic challenges, including oil price volatility and energy infrastructure gaps, prevented more substantial improvements.

The period between 2020 and 2022 was marked by the global impact of the COVID-19 pandemic, which led to a reduction in energy demand and, subsequently, a modest decrease in energy intensity in 2020. As the global economy recovered in 2021 and 2022, energy demand increased, causing a slight rise in energy intensity to 2930.76 MJ in 2022. The lowest recorded energy intensity occurred in 2009 at 2512.08 MJ, a 42.3% reduction from the 2000 peak, largely due to the economic slowdown from the global financial crisis. Overall, the mean energy intensity over the 22-year period is approximately 3140.28 MJ per thousand USD, indicating that Nigeria required around 3140 MJ of energy per unit of economic output on average. Despite some fluctuations, the general trend reflects improvements in energy efficiency over the period.

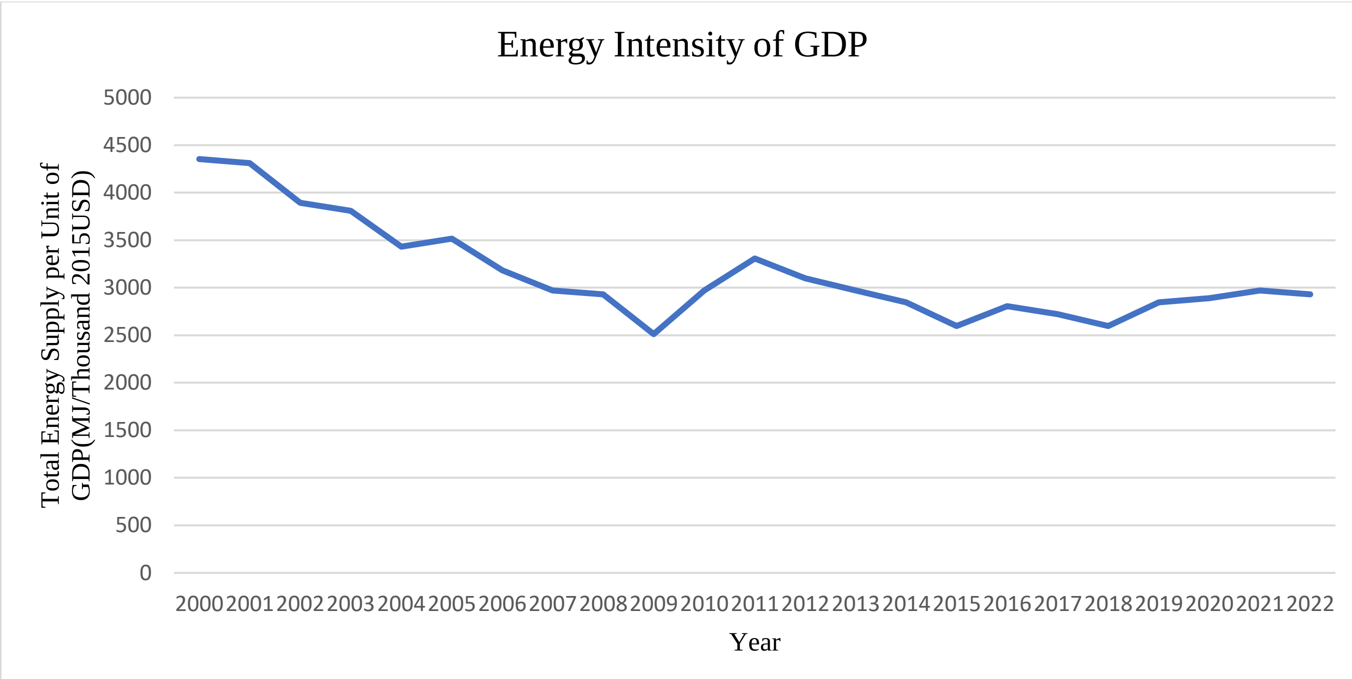


Figure 2.4: Energy Intensity in Nigeria between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

The data on Nigeria's carbon emissions by fuel type from 2000 to 2022 shows varying trends for coal, oil, and natural gas. The behavior of emissions reflects both global energy trends and local dynamics in Nigeria's energy sector, from Figure 2.5.

Coal emissions began at a modest 0.146 Mt CO2 in 2000 and witnessed significant growth, reaching 3.636 Mt CO2 by 2021 before slightly dropping to 3.343 Mt CO2 in 2022. The sharp rise, especially from 0.707 Mt CO2 in 2011 to over 3.6 Mt CO2 by 2021, represents a staggering 431.8% increase. This spike can be attributed to Nigeria's growing reliance on coal for energy as part of its industrial expansion and efforts to diversify energy sources beyond oil. Globally, during this period, many developing nations, including Nigeria, expanded coal use as part of rapid urbanization and industrialization, despite international pressure to reduce reliance on coal due to its high carbon intensity.

Oil-related carbon emissions fluctuated over the period, rising from 29.038 Mt CO2 in 2000 to 66.823 Mt CO2 in 2022, a 130.2% increase. The highest point occurred in 2022, reflecting Nigeria's continued dependence on oil as a primary energy source and export product. This trend mirrors the volatility of the global oil market and Nigeria's economic reliance on the oil sector. The peak periods, such as 2012 to 2019, align with higher oil production and global price booms. However, fluctuations in oil emissions can also be linked to internal disruptions, including militancy in the Niger Delta, which affected oil output, and the volatility of global oil prices, particularly during the 2008 financial crisis and the 2014 oil price collapse. Despite a slight decline in emissions during 2020, likely caused by reduced energy demand during the COVID-19 pandemic, oil-related emissions resumed their upward trajectory as the economy recovered.

Natural gas emissions showed a steady increase from 15.147 Mt CO2 in 2000 to a peak of 39.882 Mt CO2 in 2016 before declining to 30.222 Mt CO2 in 2022. This represents a 99.5% increase from 2000 to 2022, despite the recent decline. The increase in emissions from natural gas coincides with Nigeria's push to reduce gas flaring and utilize natural gas for power generation, industrial processes, and exports. This was part of broader efforts to shift from oil and coal to relatively cleaner energy sources. The peak in 2016 can be explained by increased gas production and consumption, driven by the expansion of gas infrastructure and government policies to promote natural gas use. However, the subsequent decline reflects the challenges in fully integrating gas into the power sector due to infrastructure constraints and inconsistent supply.

The mean carbon emissions for coal, oil, and natural gas are approximately 1.06 Mt CO2 for coal, 45.77 Mt CO2 for oil, and 26.31 Mt CO2 for natural gas. The highest emission value was recorded for oil in 2022 at 66.823 Mt CO2, while the lowest was coal in 2000 at 0.146 Mt CO2. The sharp rise in coal emissions represents the most significant percentage increase over the period, from 0.146 Mt CO2 to 3.636 Mt CO2, marking a 2390% increase.

The results show distinct contributions of coal, oil, and natural gas to CO2 emissions in Nigeria, reflecting their varying roles in the country's energy mix over time. Oil remains the largest contributor to CO2 emissions throughout the period, consistently accounting for the bulk of Nigeria's carbon emissions. From 29.038 Mt CO2 in 2000 to 66.823 Mt CO2 in 2022, oil's contribution underscores Nigeria's deep reliance on oil as the main energy source and economic driver. Oil-related emissions show steady growth, aligning with periods of higher oil production and export revenues. The dominance of oil, despite efforts to diversify energy sources, highlights the country's dependence on fossil fuels for economic growth and export earnings.

Natural gas plays the second-largest role in CO2 emissions. Starting at 15.147 Mt CO2 in 2000 and peaking at 39.882 Mt CO2 in 2016, natural gas emissions show a significant rise due to the government's push to utilize gas for power generation and industrial use. The growth in natural gas usage reflects an attempt to shift towards cleaner energy compared to oil and coal. However, while natural gas is less carbon-intensive than oil and coal, it still contributes considerably to Nigeria's emissions, showing that the country's energy transition is still in progress.

Coal, while historically contributing the least to CO2 emissions, has shown the most rapid growth. From 0.146 Mt CO2 in 2000 to 3.636 Mt CO2 in 2021, coal's contribution increased dramatically, marking a 2390% growth over the period. This reflects Nigeria's increased use of coal in industrial processes and energy production. Although coal's absolute emissions are much lower than oil and natural gas, its rapid rise is concerning because of its high carbon intensity, especially as Nigeria seeks to expand industrialization.

In summary, oil continues to be the predominant source of CO2 emissions, indicating that efforts to decarbonize Nigeria's economy will need to focus significantly on reducing oil dependence, especially in energy production and transportation. Natural gas offers a relatively cleaner alternative to oil and coal, but its rising emissions highlight the need for more stringent measures to minimize flaring and enhance efficiency in gas use. Coal emissions, though starting from a low base, have grown exponentially, suggesting that its increasing use in Nigeria's energy mix could hinder the country's climate goals unless more sustainable practices are adopted.

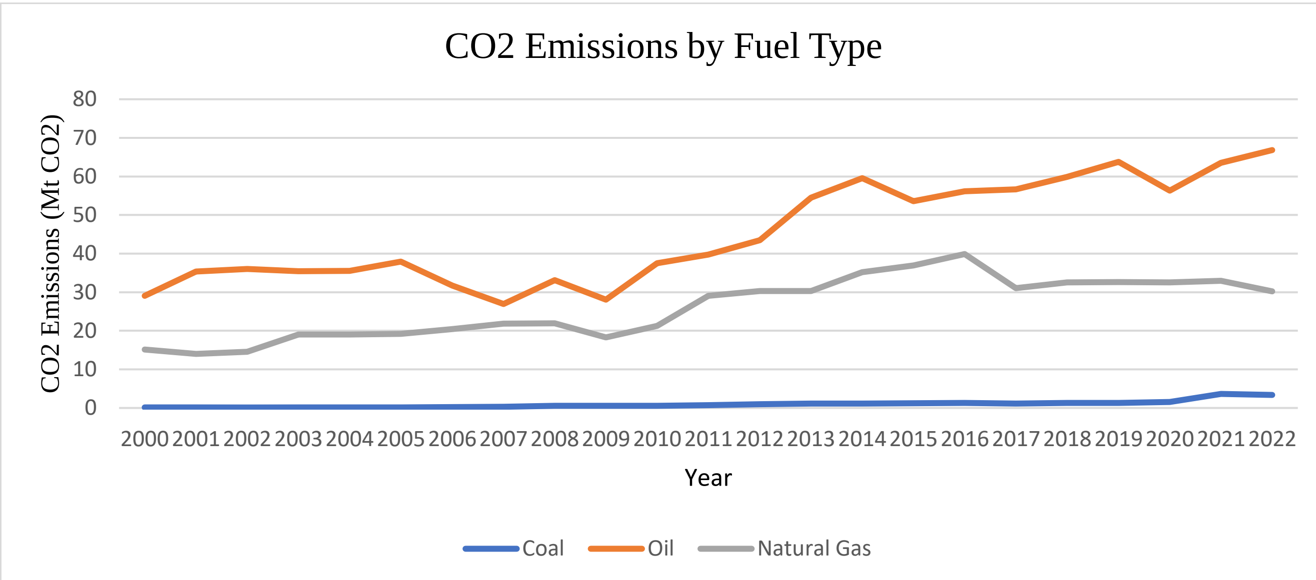


Figure 2.5: CO2 Emissions by Fuel Type in Nigeria between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

The behavior of CO2 emissions by sector in Nigeria from 2000 to 2022 reflects a complex interplay of local and global dynamics influencing the country's energy consumption and industrial activity. Overall, emissions increased significantly in the electricity and heat production and transport sectors, while emissions from industry and residential areas exhibited fluctuating trends.

Figure 2.6 shows that electricity and heat producers saw a steady rise in CO2 emissions, peaking at 22.306 Mt CO2 in 2016, after which they fluctuated slightly before declining to 14.963 Mt CO2 in 2022. This increase can be attributed to the growing demand for electricity driven by population growth and urbanization, as well as Nigeria's reliance on fossil fuels for power generation. The mean CO2 emissions for this sector over the 22-year period is approximately 11.39 Mt CO2, indicating that while there was significant growth, it faced some stabilization toward the end of the period.

In the transport sector, emissions increased from 21.831 Mt CO2 in 2000 to a high of 60.783 Mt CO2 in 2022, marking a trend of escalating emissions driven by increased vehicle ownership and road usage, alongside inadequate public transport systems. The transport sector's mean over the years is approximately 40.5 Mt CO2, reflecting a consistent rise as the economy expanded and urban mobility demands increased.

Conversely, the industrial sector showed fluctuations with a notable peak of 11.333 Mt CO2 in 2021, while experiencing dips during other years, such as a low of 2.463 Mt CO2 in 2002. The fluctuations can be attributed to the varying levels of industrial activity and economic conditions, including policy shifts and economic challenges that affected production levels. Its mean emissions over the period were around 7.72 Mt CO2.

Residential emissions were relatively low and decreased to a low of 1.312 Mt CO2 in 2007, reflecting improved energy efficiency and a shift toward cleaner energy sources like natural gas. The overall mean for residential emissions was approximately 2.42 Mt CO2, indicating their limited contribution to national emissions compared to other sectors.

Notably, the commercial and public services and agriculture sectors exhibited very low emissions, with the highest emissions recorded in these sectors being 0.018 Mt CO2 in 2002 for commercial services and 0.032 Mt CO2 for agriculture in 2005. The emissions from these sectors remained largely insignificant over the years, suggesting minimal energy consumption or reliance on low-emission technologies.

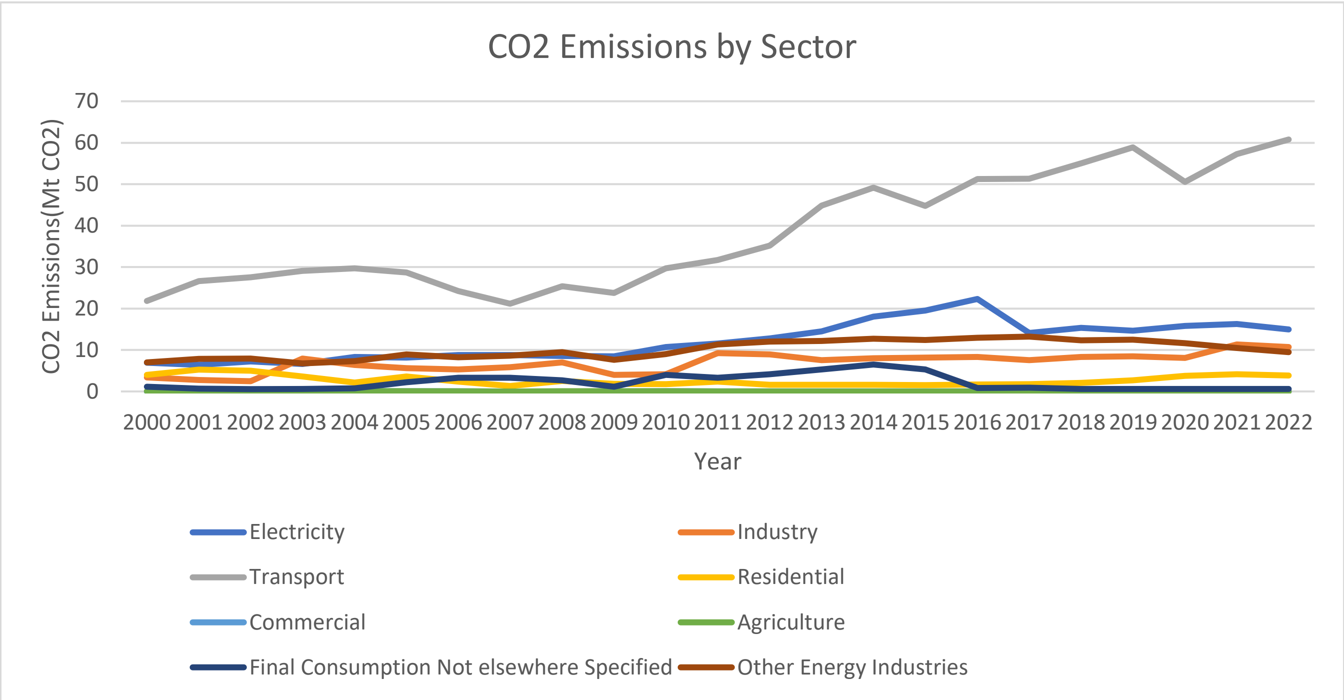


Figure 2.6: CO2 Emissions by Sector in Nigeria between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

According to Figure 2.7, the total energy supply in Nigeria from 2000 to 2022 exhibits significant fluctuations across different fuel types, reflecting both global trends and local realities. Starting with coal, there is a marked increase in supply, particularly from 2000 to 2014, where the total escalates from 1,556 terajoules (TJ) in 2000 to 13,077 TJ in 2015. This growth can be attributed to Nigeria's efforts to diversify its energy mix and increase electricity generation capacity amid rising demand. However, coal supply peaked dramatically in 2021 at 38,442 TJ, likely influenced by increased investments in coal infrastructure and global shifts towards coal as a readily available energy source, despite environmental concerns.

In contrast, the oil sector shows a more stable yet declining trend after peaking at 1,005,844 TJ in 2011, with subsequent years revealing a decline to 969,779 TJ by 2021. This decline reflects the global shift towards renewable energy sources, the impact of fluctuating oil prices, and the Nigerian government's efforts to reduce dependency on fossil fuels due to economic and environmental pressures. The average oil supply over the 22-year period is approximately 756,068 TJ, with the highest supply in 2011.

Natural gas supply trends demonstrate a gradual increase, from 241,109 TJ in 2000 to a peak of 696,937 TJ in 2021, which correlates with Nigeria's significant natural gas reserves and the global push for cleaner energy alternatives. This upward trend in natural gas usage mirrors a broader global transition towards reducing carbon emissions and a push for cleaner fuels.

Hydropower supply remains relatively low and fluctuates between 20,260 TJ and 33,135 TJ, reflecting Nigeria's struggles with seasonal variability and infrastructural deficits in harnessing hydro resources effectively. Meanwhile, the contribution from wind, solar, and other renewable sources, though initially negligible, shows a gradual increase from 7 TJ in 2012 to 362 TJ in 2022, indicating a slow but growing recognition of the need for sustainable energy practices in response to climate change and energy access challenges.

In terms of percentage contributions, the most significant share comes from oil, averaging around 70% of total energy supply from 2000 to 2022. Conversely, renewable energy sources, including biofuels and waste, have shown a promising increase, rising from approximately 18.4% in 2000 to about 28.6% in 2022, underscoring a gradual shift towards more sustainable energy practices.

The mean total energy supply over this period is approximately 722,904 TJ, with the lowest point recorded for wind and solar at 0 TJ until 2012, highlighting the nascent state of Nigeria's renewable energy sector in the early 2000s. The highest total energy supply was recorded in 2021 at 1,489,444 TJ, reflecting a culmination of both natural gas and coal supply peaks, while the lowest was during early 2000s for wind and solar energy.

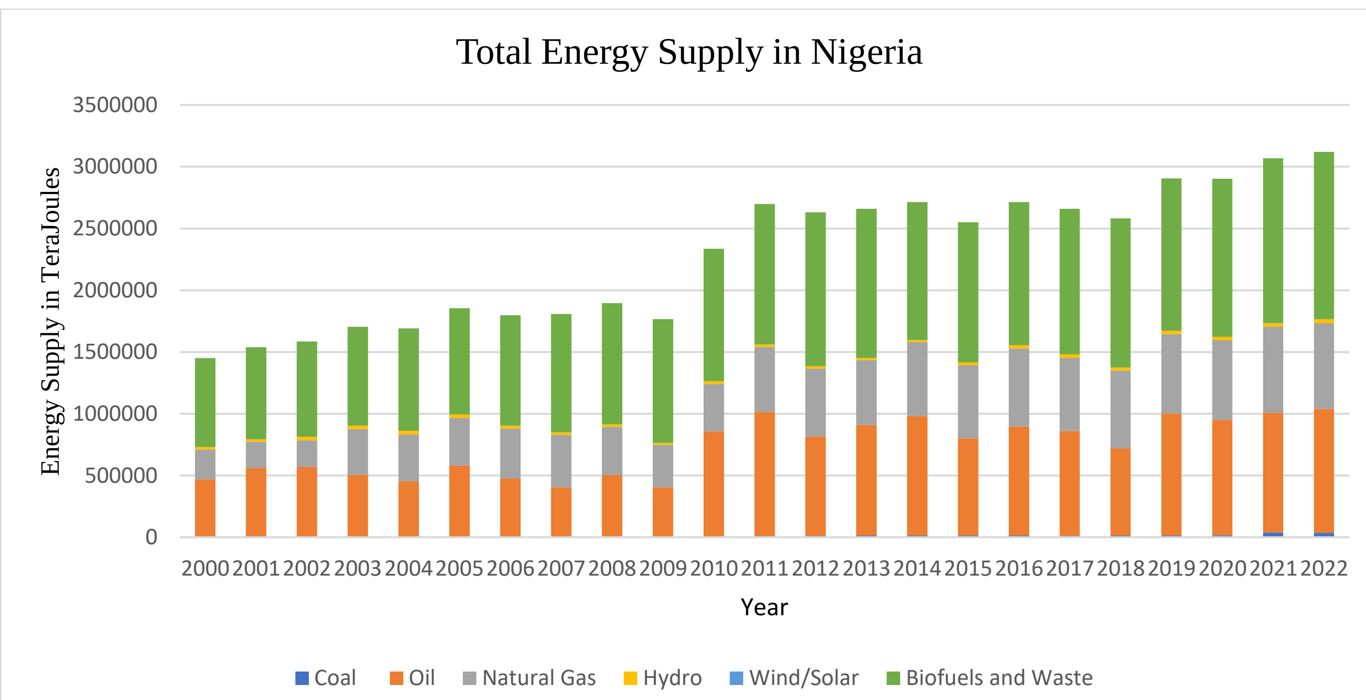


Figure 2.7: Total Energy Supply between 2000 and 2022
Source: Author’s Computation using Data from The International Energy Agency

Figure 2.8 analyzes domestic energy production in Nigeria from 2000 to 2022. This reveals significant trends and shifts among various energy sources, reflecting both local and global dynamics. Notably, coal production has shown a remarkable upward trajectory, increasing from 1,556 terajoules in 2000 to an astounding 38,442 terajoules by 2021, which represents a staggering increase of over 2,400%. This trend can be attributed to Nigeria's efforts to diversify its energy mix and reduce reliance on oil, particularly as global oil prices fluctuated and concerns over climate change prompted a push for cleaner energy sources. In contrast, crude oil production exhibited a decline from approximately 4,923,513 terajoules in 2000 to 2,555,025 terajoules by 2022, a decrease of about 48%. This decline is indicative of aging oil infrastructure, challenges related to oil theft, and increasing international pressure to transition to renewable energy sources.

Natural gas production has also shown steady growth, increasing from 426,132 terajoules in 2000 to 1,576,931 terajoules in 2022, which highlights Nigeria's potential as a major gas producer in a global context where natural gas is often seen as a transitional fuel in the energy transition narrative. Meanwhile, hydroelectric power production has experienced fluctuations, peaking at 33,135 terajoules in 2022, which suggests ongoing investments in hydropower infrastructure and the importance of seasonal rainfall patterns impacting hydro generation capacity.

The sector of wind, solar, and other renewables remains nascent, with production growing from negligible levels to 366 terajoules by 2021, reflecting the global trend towards renewable energy and Nigeria's commitment to increasing its renewable energy share in response to climate change commitments. Biofuels and waste also exhibited consistent growth, increasing from 719,911 terajoules in 2000 to 1,352,837 terajoules in 2022, showcasing a growing recognition of the importance of sustainable waste management and bioenergy production.

In terms of mean values, coal production averaged around 9,052 terajoules over the entire period, while crude oil maintained an average of about 4,724,648 terajoules, indicating the dominance of oil in Nigeria's energy landscape despite its decline in recent years. The highest point of energy production was crude oil in 2000, while the lowest was for wind, solar, and other renewables, which started at zero.

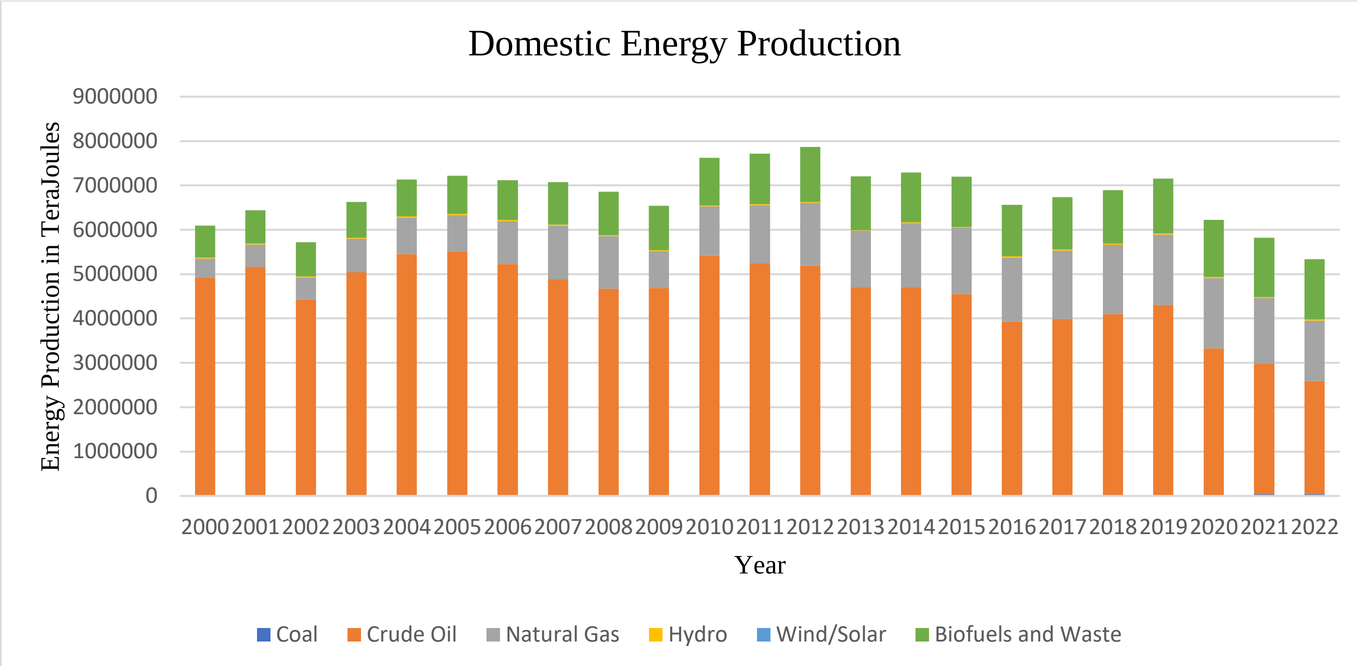


Figure 2.8: Domestic Energy Production between 2000 and 2022
Source: Author's Computation using Data from The International Energy Agency

Nigeria's Real Gross Domestic Product (RGDP) from 2000 to 2023 shows a steady upward trend, reflecting a combination of economic growth and the impact of various global and local factors. Figure 2.9 reveals that RGDP rose from ₦23,688.28 billion in 2000 to ₦76,684.94 billion in 2023, marking a growth of over 223% over the period. This sustained growth can largely be attributed to several factors, including economic reforms, the rise in global oil prices during much of the 2000s, and diversification efforts aimed at strengthening non-oil sectors like telecommunications, agriculture, and services. For example, between 2000 and 2014, Nigeria experienced robust economic expansion, with GDP growing at an average annual rate of about 7%. This period also coincided with the global commodity boom, during which Nigeria, as a major oil exporter, benefited from high crude oil prices, contributing to significant GDP growth.

The highest point in Nigeria's real GDP occurred in 2023, with a value of ₦76,684.94 billion, while the lowest point was in 2000 at ₦23,688.28 billion. The average GDP over the 24-year period is approximately ₦53,650.91 billion, showing the long-term upward trend of the economy. However, there were periods of economic slowdown, most notably around 2015 and 2016, where GDP grew more modestly and even contracted slightly in 2016, falling from ₦69,023.93 billion in 2015 to ₦67,931.24 billion. This was due to the global oil price crash in 2014-2016, which affected Nigeria's oil-dependent economy, and was further compounded by domestic issues such as declining oil production due to militant activities in the Niger Delta and currency devaluation.

The impact of the COVID-19 pandemic is also evident in the GDP figures for 2020, where GDP dropped to ₦70,014.37 billion from ₦71,387.83 billion in 2019, a contraction of approximately 1.9%. This decline reflected the global economic downturn caused by the pandemic, including disruptions to trade, lockdowns, and reduced oil demand. Nevertheless, the Nigerian economy showed resilience, with a recovery in 2021 (₦72,393.67 billion) and continued growth into 2022 and 2023 as global markets rebounded and local sectors adapted to post-pandemic conditions.

In percentage terms, real GDP grew by about 6.67% from 2000 to 2001 and by approximately 12.74% from 2002 to 2003, reflecting early economic reforms. The slowest growth occurred between 2016 and 2017, where GDP grew by only 0.82%, signaling the challenges faced by the economy in recovering from the recession.

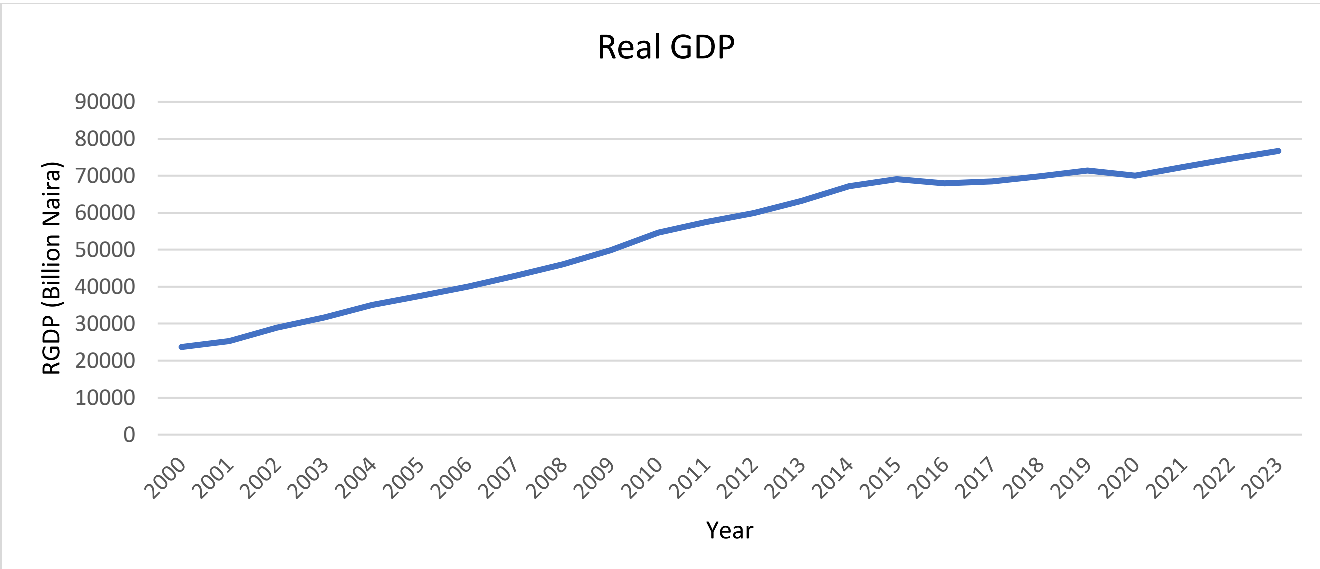


Figure 2.9: Real Gross Domestic Product in Nigeria between 2001 and 2023
Source: Author's Computation using Data from CBN Statistical Bulletin

Between 2000 and 2023, Nigeria's four major economic sectors—agriculture, manufacturing, industry, and services—display varied growth patterns, reflecting both global and local realities that influenced their value-added contributions to the economy. This is represented through Figure 2.10.

Agriculture, long a cornerstone of Nigeria's economy, experienced steady growth during this period. In 2000, agriculture's value-added contribution was ₦4,840.97 billion, growing to ₦19,306.49 billion by 2023. This represents a significant increase of about 299%. The rise in agricultural output can be attributed to various government policies promoting agricultural transformation, such as the Agricultural Transformation Agenda (ATA) initiated in 2011, which focused on improving the sector's productivity. The importance of agriculture as a reliable source of income and food security during periods of economic uncertainty, especially when oil prices dropped, also contributed to its growth. On average, agriculture contributed ₦13,284.88 billion over this period, peaking in 2023.

Manufacturing displayed a similar upward trend but with notable fluctuations. From ₦1,505.66 billion in 2000, manufacturing value added increased to ₦6,754.96 billion in 2023. However, growth slowed in certain years, such as during the 2016 recession when the sector contracted, reflecting challenges like inadequate infrastructure, exchange rate volatility, and rising production costs. Global factors such as the 2008 financial crisis also affected manufacturing output as it created capital shortages and reduced global demand for Nigerian manufactured goods. Despite these challenges, Nigeria's growing middle class and increased demand for consumer goods have driven manufacturing growth. Manufacturing peaked in 2023, with an average contribution of ₦4,207.91 billion over the period.

The industrial sector, dominated by oil and gas, showed more volatility. Industry value added grew from ₦7,982.19 billion in 2000 to ₦7,543.51 billion in 2023. However, its highest point was ₦10,770.43 billion in 2011, while the lowest point came in 2022 at ₦7,534.19 billion. The sector's fluctuating performance is closely tied to global oil price shocks, domestic oil production issues, and policy shifts. For example, Nigeria's oil industry was severely affected by the 2014-2016 global oil price collapse and domestic challenges such as militancy in the Niger Delta, which disrupted oil production. The declining trend in recent years reflects the growing emphasis on economic diversification away from oil dependence. On average, the industrial sector contributed ₦9,274.19 billion over the period.

The services sector, the largest contributor to Nigeria's GDP in recent years, experienced continuous growth, rising from ₦9,359.45 billion in 2000 to ₦43,079.98 billion in 2023. This represents a massive growth of approximately 360%, reflecting Nigeria's shift toward a service-based economy, driven by sectors like telecommunications, banking, and trade. The rise of digital services, particularly the telecoms boom in the 2000s, coupled with financial sector reforms and expansion, fueled the growth of services. The services sector was largely resilient during global downturns like the 2008 financial crisis and the COVID-19 pandemic, although it was affected by the economic slowdown in 2016. The highest value added from services was in 2023, with an average contribution of ₦26,677.85 billion during the period.

In percentage terms, the services sector consistently accounted for the largest share of GDP, growing from about 31% of total value added in 2000 to nearly 42% in 2023, underscoring Nigeria's gradual transition to a more diversified and service-oriented economy. Meanwhile, agriculture's share, although still significant, decreased proportionally as other sectors, particularly services, expanded. Manufacturing and industry, despite growth, contributed less to overall GDP than services.

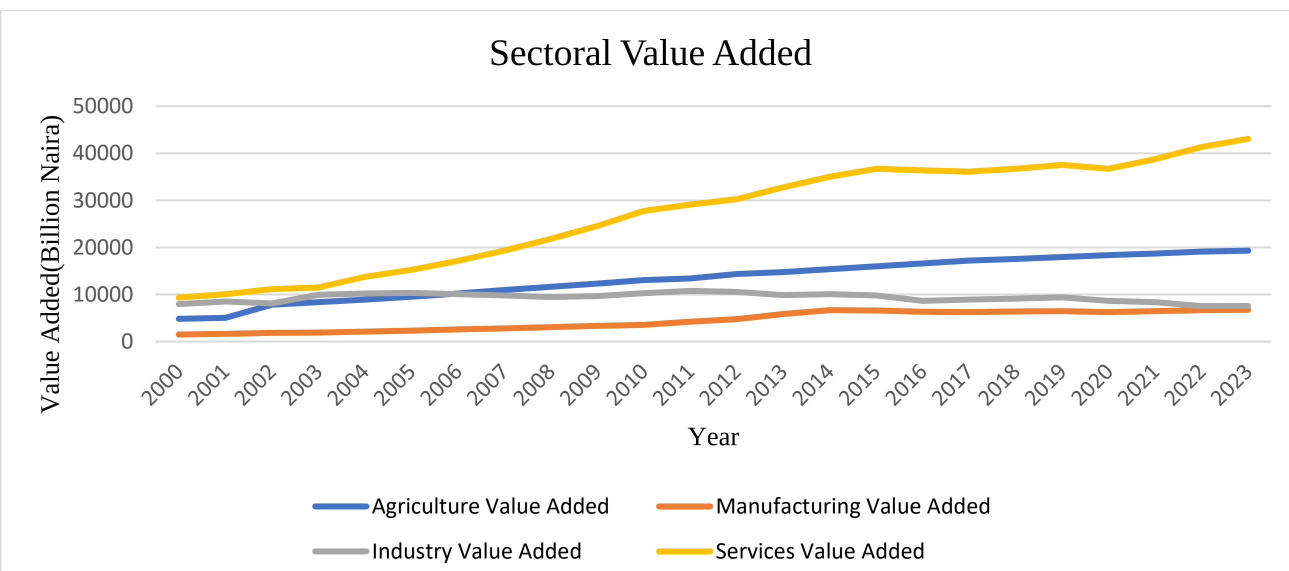


Figure 2.10: Real Gross Domestic Product in Nigeria between 2001 and 2023
Source: Author's Computation using Data from CBN Statistical Bulletin

The trend analysis of Nigeria's energy production, economic performance, and carbon emissions from 2000 to 2023 reveals the intertwined nature of industrial expansion, energy consumption, and environmental challenges. Nigeria's growing reliance on fossil fuels—oil, natural gas, and coal—has fueled significant economic growth, but at a cost to environmental sustainability. The carbon emissions data underscores how oil remains the dominant source of emissions, driven by the nation's oil-centric energy structure and export dependency. Despite recent attempts to diversify energy sources and integrate renewables, fossil fuels continue to dominate the energy mix, reflecting both historical reliance and economic inertia.

The rise in coal emissions, in particular, highlights a concerning trend, as its use has surged rapidly over the past decade. While coal historically accounted for a small fraction of the energy mix, its increased exploitation—likely due to cost and availability—poses a significant challenge to Nigeria's efforts to curb emissions. At the same time, natural gas, which could serve as a transitional energy source, has faced underutilization issues, limiting its potential as a cleaner alternative to oil and coal. These realities reflect both local and global pressures, such as fluctuating oil prices, international energy demand, and Nigeria's economic diversification struggles.

The economic data reveals that Nigeria's growth has largely been propelled by the services and agriculture sectors, with manufacturing and industry contributing but facing hurdles such as infrastructure deficits and exchange rate volatility. While real GDP showed impressive growth between 2000 and 2023, challenges in industrialization and over-reliance on oil revenues suggest that long-term sustainability requires a more balanced and diversified economic structure.

Summary of Gaps

Based on the reviewed literature, the succeeding paragraphs summarize the gaps in literature, and justify the need for this study. Despite the fact that studies on the economic effects of energy policy in Nigeria exist, studies on CGE models and macroeconomic modeling have remained incredibly few (Emodi et al., 2019). Iyabo (2021) employed a discourse analysis to investigate how renewable energy policy can improve electricity demand under the NREEEP. Similar to this, Lin and Ankrah (2019) used ridge-regression to analyze the output and substitution elasticity of renewable and non-renewable energy sources in Nigeria and to evaluate the economic impact of renewable energy. Using the translog framework and a dataset from 1980 to 2015, production function model, the results showed that neither energy source exerted a significant impact on economic output.

According to Omoju et al., (2020), gaps abound in the energy policy literature. First, studies on the aggregate macroeconomic impacts of environmental and renewable-energy policies in developing countries in general, and Nigeria in particular are very rare. Most empirical studies in the literature have focused considerably on developed countries such as Organization for Economic Cooperation and Development (OECD) and European Union (EU) countries, and their conclusions may not correspond to Nigeria or other developing countries. Nigeria depends on fossil fuel production and export for foreign exchange, government revenue, and electricity generation; hence the macroeconomic and sector-linked impacts of dirty energy-related dynamics differ significantly from gas dynamics.

Between the formulation of energy policies in Nigeria in 2003 and the current Energy Transition Plan, only one study empirically investigated economy-wide impacts of one of these policies. Omoju et al., (2020) investigated the economy wide impacts and welfare effects of the NREEEP on a number of macroeconomic indicators through the instrument of electricity production subsidy. However, there is very sparse academic literature on the economy wide effects of implementing the Energy Transition Plan.

The original 2018 social accounting matrix (SAM) does not have the capacity to accommodate studies on carbon emissions because these accounts do not exist in it. There is need to modify the SAM to reflect the role that emissions reduction through energy transition plays in driving macroeconomic performance.

3. Methodology

Analytical Framework

The transmission mechanism begins with the introduction of emissions reduction policies into the Nigerian economy through the implementation of the Energy Transition Plan, which advocates for a shift away from dirty fossil fuels towards cleaner alternatives such as natural gas.

This policy initiative is primarily targeted at the industrial, manufacturing, agriculture, and service sectors, as they represent the cornerstone of Nigeria's productive capacity. Given the centrality of these sectors to the economy, the government finds it pragmatic to drive emissions reduction policies through the production and supply side. Consequently, the four major sectors are incentivized to invest in alternative energy technologies, particularly those reliant on natural gas. As a result, the adoption of these technologies gradually reduces emissions intensity and energy intensity within each sector over time (Abiola Olawale, 2024).

These reductions in intensity, indicative of energy efficiency improvements, yield positive outcomes at multiple levels (Trotta, 2020). Firstly, they contribute to a decline in the emissions footprint of the economy, aligning with sustainability objectives. Secondly, the enhanced efficiency translates into improved sectoral contributions to value added, reflecting increased productivity and competitiveness. This, in turn, has a ripple effect on household incomes, as higher productivity levels enable firms to offer better wages and salaries. As households benefit from increased income levels, they gain greater purchasing power to afford the newly adopted energy-efficient technologies. This not only fosters widespread adoption of cleaner energy solutions but also stimulates further economic activity. The cumulative effect of these developments is manifested in an overall increase in real GDP over the 12-year period.

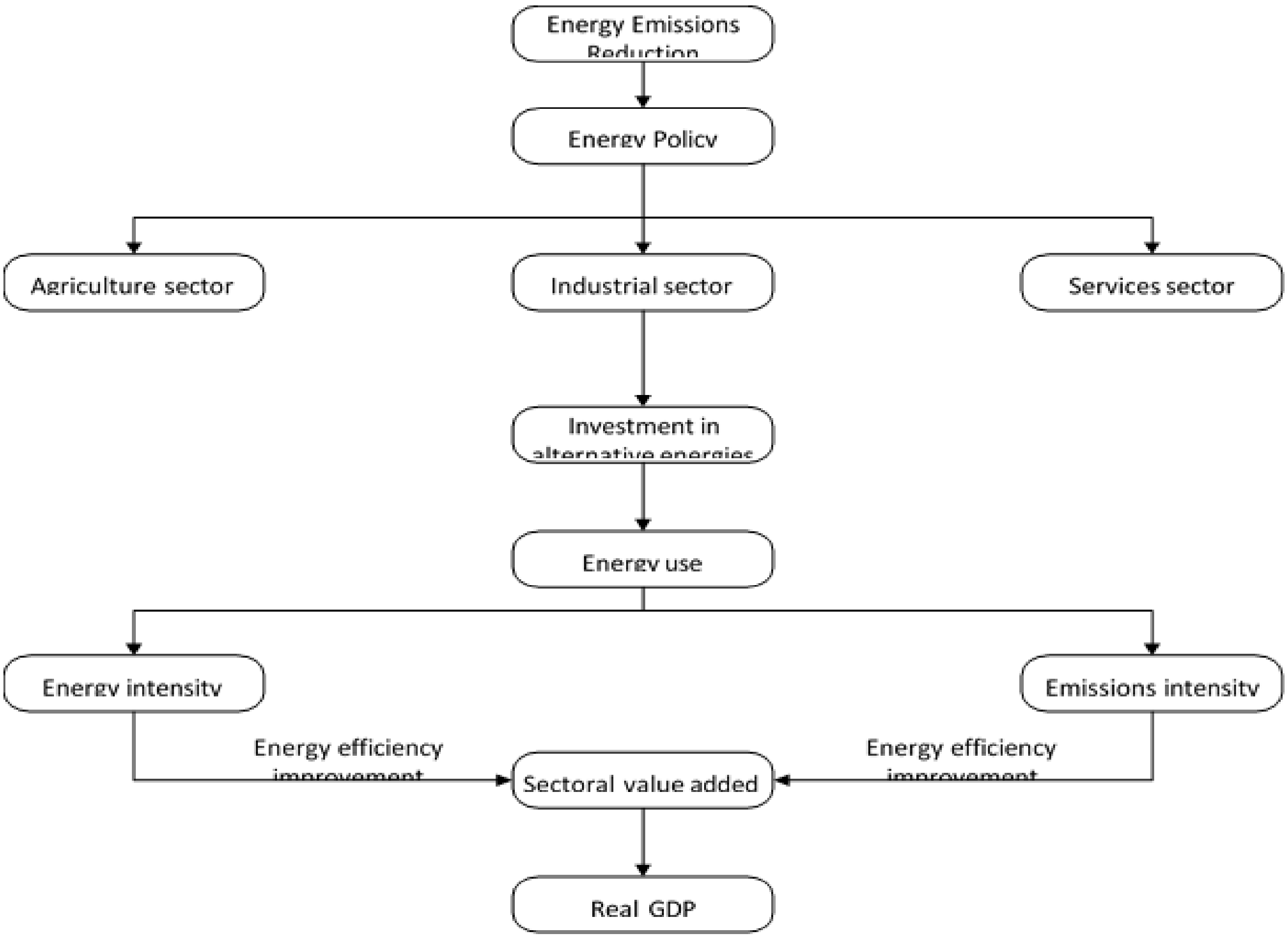


Figure 3.1: Analytical Framework
Source: Author's Computation

Model Specification

This section presents the mathematical model statement for this study using a STAND Dynamic Recursive Computable General Equilibrium model. A CGE model is a mathematical representation of the different behaviors of economic agents and how these behaviors bring about equilibrium in an economy (Lemelin & Savard, 2022). The model shows the flow of interdependence and interrelation among economic agents.

The model is made up of 4 blocks, namely supply, demand, price and macro constraint blocks. These blocks combined, comprise of 88 equations. These equations form a system of nonlinear, simultaneous relationships that show how economic agents react to assumed policy changes. The model follows the neoclassical school of economic thought. These relationships are explained in each block. This subsection closes with the details of the model closure.

The supply block of the computable general equilibrium model is structured to address the local production and supply of goods and services, particularly focusing on the demand for energy products and the resulting emissions (Zhou & Chen, 2021). All the equations in this model are adapted from Akinyemi et al (2017), as well as the PEP 1-t CGE Model blocks. It utilizes CES functions to model energy production and emissions across multiple sectors. These functions quantify the production of energy products and associated emissions, considering factors such as input substitution and technology coefficients. Additionally, the model incorporates capital and labor inputs in the production process, including skilled and unskilled labor, as well as land. These inputs are essential for understanding the dynamics of energy production and its environmental implications within the economy.

The supply block defines how various inputs like energy, labor, and capital are combined in production. Equation 3.1 describes the energy composite for sector 1, indicating how inputs and technological efficiency are combined to generate energy in this sector. Equation 3.2 specifies total energy production, showing how capital-energy elasticities influence energy inputs in production. Equations 3.3 and 3.4 describe the energy composite for sector 2, detailing how capital and energy inputs are combined using a constant elasticity of substitution function. Similarly, equations 3.5 and 3.6 deal with the energy supply for sector 3, where energy and capital inputs are aggregated.

Equations 3.7 through 3.10 explain how energy from sectors 1, 2, and 3 is combined into a single energy composite. These equations describe how each sector's energy inputs are connected to the overall energy supply. In equations 3.11 and 3.12, the model introduces the capital composite, specifying how different types of capital are aggregated in the economy. Equations 3.13 and 3.14 describe the relationship between energy and capital inputs in production, determining how they are combined to influence total output.

Equations 3.15 to 3.17 detail the equilibrium condition for energy and capital inputs. These equations focus on the rental price of capital and energy, as well as how these prices determine total returns on capital and energy. In equation 3.18, the labor composite is introduced, representing the demand for labor as an aggregation of various labor types. Equation 3.19 explains how labor demand in each sector is determined by wage rates and labor productivity.

Equations 3.20 and 3.21 focus on the capital-labor relationship, describing how these two factors of production combine with their respective elasticities to produce output. Equations 3.22 to 3.24 describe the equilibrium condition for labor and capital returns, ensuring that the returns to these factors match their respective contributions to production. Similarly, equation 3.25 defines labor demand in a nested structure, showing how labor types are aggregated using a constant elasticity of substitution function. In equation 3.26, labor demand is specified as a function of wage rates and labor supply.

Equations 3.27 and 3.28 describe the nested relationship between labor and capital in production. They indicate how these factors combine to produce output, depending on their relative prices and elasticities. Equations 3.29 and 3.30 provide equilibrium conditions for labor and capital, ensuring that the returns to labor and capital match their contributions. Finally, equation 3.31 establishes the equilibrium wage rate in the economy, ensuring that the wage matches labor supply.

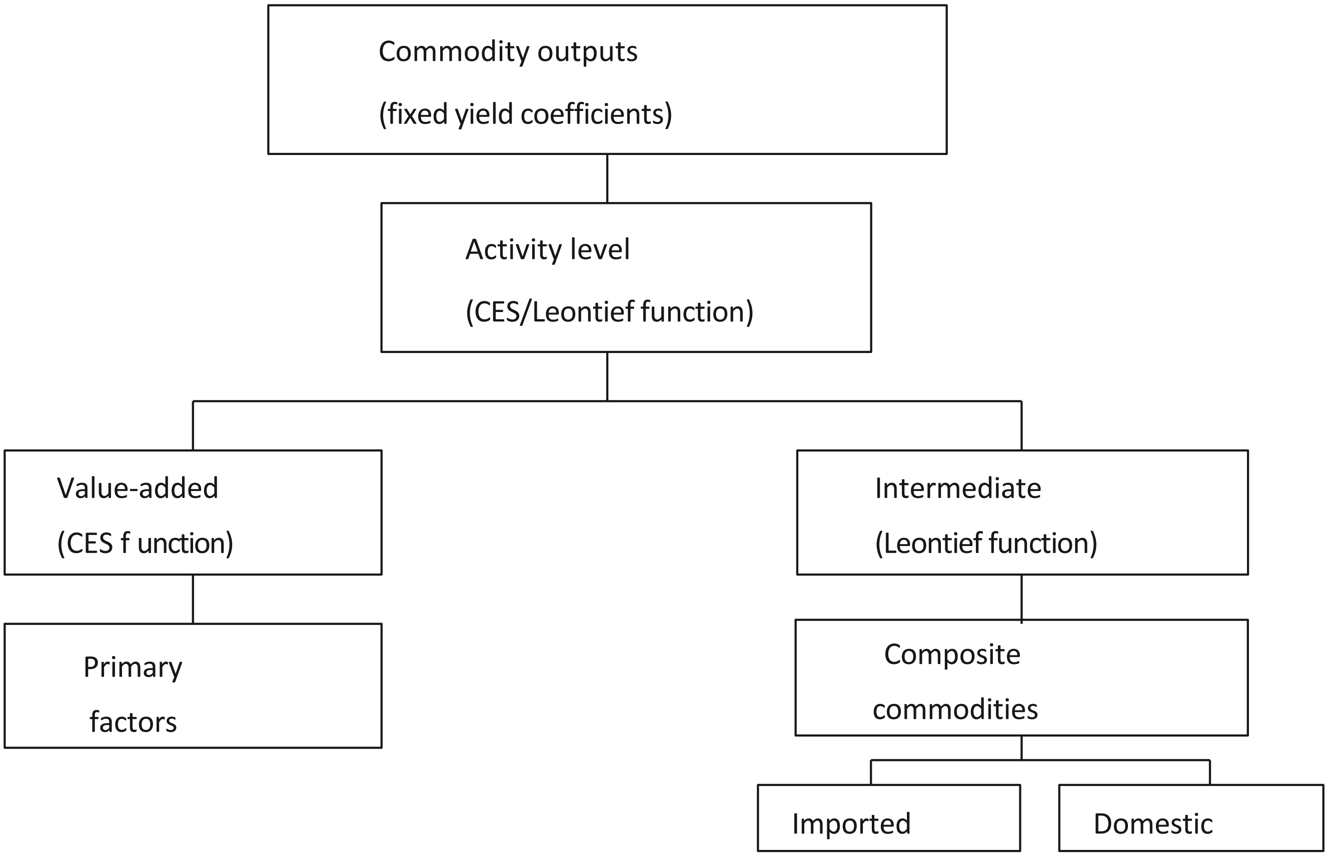


Figure 3.2: Production/Supply Block of the CGE Model
Source: Akinyemi (2017)

Furthermore, the supply block features various equations that outline the relationships between different production factors and the supply of products. It includes functions to determine the supply of intermediate consumption, exports, and local products, incorporating considerations such as price dynamics and input-output relationships. Additionally, the model accounts for the interplay between energy production, intermediate consumption, and extended value-added activities. These equations collectively provide a comprehensive framework for analyzing the supply side of the economy, emphasizing the intricate connections between energy production, emissions, and other production factors.

The demand block of the CGE model consists of several sections, each addressing different aspects of household and industry demand for goods and services, as well as energy emissions., as well as energy emissions (Felici et al., 2020). These sections include the function for household final consumption, which incorporates consumption behavior and disposable income. Another section focuses on demand for intermediate consumption, outlining how firms utilize inputs to produce goods and services. Additionally, there's a section dedicated to investment demand, capturing the factors influencing firms' investment decisions.

Furthermore, the model incorporates aggregate demand for products, which encompasses various components such as household consumption, government expenditure, and investment. The demand for energy products is specifically addressed through the CES function, which accounts for both imports and demand for local products (Feizi et al., 2022). This section elucidates the relationship between imports, domestic production, and price dynamics within the energy sector. Overall, these sections collectively model the intricate interplay between household and industry demand, investment decisions, and energy emissions within the economy.

The demand block explains how goods and services are consumed, invested in, and demanded across the economy. Equation 3.32 defines the value-added function, where labor and capital inputs combine to form total output. Equation 3.33 further explains how these inputs are aggregated through a constant elasticity of substitution function to form value-added. In equation 3.34, the price of value-added is determined by the returns to capital and labor.

Equations 3.35 and 3.36 define the equilibrium for value-added, ensuring that the total returns to capital and labor match the value added from production. Equation 3.37 introduces the composite good demand function, which aggregates the demand for different goods in the economy. Equation 3.38 shows how individual inputs are demanded based on their price and the overall composite price index.

In equations 3.39 and 3.40, the total output function is described as a combination of value-added and intermediate consumption. These equations explain how these two components combine to form total production in the economy. Equation 3.41 specifies the price condition for total output, ensuring that the output price equals the combined price of value-added and intermediate goods.

Equations 3.42 and 3.43 show the demand for composite goods and explain how domestic demand and exports combine to meet total demand. Equation 3.44 defines the relationship between domestic and export prices, determining how goods are allocated between domestic markets and exports. Equation 3.45 provides the equilibrium condition for output prices, ensuring that the price of total output equals the domestic and export prices, weighted by their respective shares.

Equation 3.46 establishes the equilibrium for total supply, ensuring that total supply of goods equals domestic demand. Equation 3.47 defines the equilibrium price for domestic goods, ensuring that it matches the supply of goods. In equation 3.48, the consumption function for households is introduced, where household consumption is determined by disposable income and savings. Equation 3.49 explains household income as a combination of labor, capital, and transfer incomes, while equation 3.50 shows total household income, including contributions from various sectors.

The price block is a crucial component of the STAND computable general equilibrium (CGE) model, which focuses on analyzing the effects of price changes and market dynamics on an economy (Rintamäki, 2021). The essence of the price block lies in its ability to capture the interactions between supply and demand, price adjustments, and the implications for key economic variables. The price block comprises several key components that collectively determine the price dynamics and its impacts. The block represents the supply and demand relationships in the economy across sectors and markets (Balasubramanian & Balachandra, 2021). It captures the interactions between producers and consumers, taking into account factors such as production costs, preferences, and technological factors. The supply and demand curves are used to determine equilibrium prices and quantities in each market.

The block considers the mechanisms through which prices adjust in response to changes in supply and demand conditions. This can include modelling price elasticities of supply and demand, which measure the responsiveness of producers and consumers to changes in prices. The model can simulate how prices respond to shifts in supply or demand shocks and the speed at which price adjustments occur. The block ensures market clearing conditions, where supply matches demand in each sector and market. It ensures that the quantity demanded equals the quantity supplied at the equilibrium price. The model can capture disequilibrium conditions and the adjustments required to reach market clearing, such as excess demand or excess supply (Hurtubia et al., 2019). The block considers the factors that influence price formation in the economy. This includes the cost of production, input prices, technological factors, market power, and other determinants. The model can incorporate various price formation mechanisms, such as cost-plus pricing, competitive pricing, or mark-up pricing, depending on the assumptions and characteristics of the markets.

The prices block determines the price levels for goods, services, and production factors such as wages and capital rents. Equation 3.51 describes the total demand for intermediate goods, aggregating this demand across sectors. In equation 3.52, the price condition for intermediate goods is defined, showing how the price of intermediate goods is determined by domestic and import prices.

Equation 3.53 explains the investment demand function, specifying how investment is determined by sectoral capital requirements. Equation 3.54 shows how total output is allocated between consumption, government spending, investment, and exports. Equation 3.55 describes the import demand function, where imports and domestic goods combine to meet total demand, while equation 3.56 defines the price relationship between imports and domestic goods.

Equation 3.57 establishes the price condition where total supply equals total demand for composite goods, ensuring that prices adjust to maintain balance. Equation 3.58 defines the equilibrium for domestic supply, where total domestic demand equals supply. Equation 3.59 describes the equilibrium price for domestic goods, while equation 3.60 ensures that domestic demand matches supply.

Equation 3.61 shows the total labor force as a proportion of labor supplied in each sector, while equation 3.62 defines the wage rate as determined by labor supply and productivity. In equation 3.63, the equilibrium wage rate is determined for each sector, ensuring that it matches the total labor supplied. Equation 3.64 provides the equilibrium condition for capital supply, where total demand for capital equals supply, and equation 3.65 defines the capital demand function in the energy sector. Finally, equation 3.66 establishes the equilibrium for the price of capital, ensuring that total capital prices match rental prices and energy returns.

The block incorporates price elasticities, which represent the responsiveness of demand or supply to changes in prices. These elasticities capture the sensitivity of consumers and producers to price changes and are crucial for understanding market dynamics and the impact of price shocks on quantities demanded or supplied. The block considers the implications of price changes for inflation and deflation. It allows for the modelling of changes in the general price level over time and the effects on consumers' purchasing power, investment decisions, and the overall macroeconomic stability. By integrating these components, the price block in the STAND CGE model enables the analysis of the effects of price changes, market dynamics, and supply- demand interactions on sectoral outputs, consumption patterns, investment decisions, and overall economic performance (Prohnițchi, 2021). It provides insights into the relationships between prices, market equilibrium, resource allocation, and the welfare implications of price adjustments in an economy.

The macroconstraints block imposes key macroeconomic balances in the model, such as savings-investment equilibrium, government budget balance, and external trade balance. Equation 3.67 represents the demand for land, where total land demand is determined by its price and productivity. Equation 3.68 defines the export demand function, where exports are determined by the relative price of domestic goods to world prices.

Equation 3.69 provides the relationship between export and domestic prices, showing how the prices adjust in response to foreign demand. In equation 3.70, the current account balance is determined, ensuring that exports, imports, and foreign transfers are balanced. Equation 3.71 describes the stock of capital as a function of investment and depreciation, while equation 3.72 defines the investment function based on sectoral capital requirements.

Equation 3.73 introduces the price index for capital, determined by the price of investment goods, while equation 3.74 establishes the savings-investment equilibrium, ensuring that total savings equal investment. Equation 3.75 defines household savings as a proportion of household income, while equation 3.76 introduces corporate savings as a function of after-tax profits.

Equation 3.77 describes total income for firms, which includes labor, capital, and transfer incomes. Equation 3.78 provides the government budget constraint, ensuring that government revenue matches expenditure. Equation 3.79 defines government savings as the difference between government revenue and expenditure.

Equation 3.80 describes total government income, including taxes, transfers, and factor incomes. Equation 3.81 establishes the current account balance as a proportion of GDP, while equation 3.82 defines GDP as the sum of consumption, investment, government spending, and net exports. Equation 3.83 describes the price of exports, determined by the world price and export taxes, while equation 3.84 defines the price index for output. Equation 3.85 determines the price of imports based on world prices and import tariffs, while equation 3.86 defines the price index for consumption goods. Finally, equation 3.87 provides the consumer price index, and equation 3.88 establishes the aggregate price index for the economy.

This CGE model follows a neoclassical closure with flexible exchange rates, characterized by market clearance for goods, flexible prices, fixed capital and land supplies, and an investment-driven rule for savings. The inclusion of imperfections in the labor market and fixed returns on energy and emissions adds complexity, while the flexible exchange rate allows the economy to adjust to external imbalances. This closure setup reflects a theoretical framework where market forces drive the economy toward equilibrium, but with certain key variables, like capital and energy, being exogenously determined.

Seven of the model equations showing the interdependencies among energy resources and production have been extracted presented below:

$$KD(J,KEE1) = [\alpha_{nrg1}(J,KEE1)\ .\ \frac{RE1(J)}{R(J,KEE1)}]^{\sigma_{nrg1}(J)}\ .\ A_{nrg1}(J)^{\sigma_{nrg1}(J)-1}\ .\ NRG1(J) \qquad (3.1)$$

$$NRG = A_{nrg}\left[\sum \alpha_{nrg}(KEE)\,((KD,KEE)^{-\rho nrg})\right]^{-\frac{1}{\rho nrg}} \qquad (3.2)$$

$$NRG2(J) = A_{nrg2}(J)\ .\ [\textstyle\sum_{KEE2}\alpha_{nrg2}(J,KEE2)\ .\ KD(J,KEE2)^{-\rho_{nrg2}(J)}]^{-\frac{1}{\rho_{nrg2}(J)}} \qquad (3.3)$$

$$KD(J,KEE2) = [\alpha_{nrg2}(J,KEE2)\ .\ \frac{RE2(J)}{R(J,KEE2)}]^{\sigma_{nrg2}(J)}\ .\ A_{nrg2}(J)^{\sigma_{nrg2}(J)-1}\ .\ NRG2(J) \qquad (3.4)$$

$$NRG3(J) = A_{nrg3}(J)\ .\ [\textstyle\sum_{KEE3}\alpha_{nrg3}(J,KEE3)\ .\ KD(J,KEE3)^{-\rho_{nrg3}(J)}]^{-\frac{1}{\rho_{nrg3}(J)}} \qquad (3.5)$$

$$KD(J,KEE3) = [\alpha_{nrg3}(J,KEE3)\ .\ \frac{RE3(J)}{R(J,KEE3)}]^{\sigma_{nrg3}(J)}\ .\ A_{nrg3}(J)^{\sigma_{nrg3}(J)-1}\ .\ NRG3(J) \qquad (3.6)$$

$$NRG(J) = B_{nrg}(J)\ .\ [NRG1(J)^{\beta_{nrg1}(J)}\ .\ [NRG2(J)^{\beta_{nrg2}(J)}\ .\ [NRG3(J)^{\beta_{nrg3}(J)} \qquad (3.7)$$

Where;

$KD(J, KEE1)$: Demand for energy composite KEE in sector J.

$\alpha_{nrg1}(J, KEE1)$: Share parameter for energy input KEE in sector J.

$RE1 \ldots 3(J)$: Quantity of energy resource used in sector J (where RE1, RE2 and RE3 denote specific energy resources).

$R(J, KEE1)$: Price of energy composite KEE in sector J.

$\sigma_{nrg1\ldots3}(J)$: Elasticity of substitution for energy composite KEE in sector J.

A_{nrg}: Efficiency parameter for energy use in sector J.

NRG: Total Energy Use in Sector J

ρnrg: Substitution parameter for energy composites in sector J.

$B_{nrg}(J)$: Aggregation parameter for energy use in sector J.

$\beta_{nrg1}(J)$: Share parameter for the contribution of different energy composites in the total energy use in sector J.

Sources of Data

The source of data for the study is the 2018 social accounting matrix (SAM) created by James Thurlow. It is the most recently published SAM of Nigeria as the writing of this report. A social accounting matrix (SAM) is a comprehensive and detailed dataset that provides a systematic representation of the structure of an economy or a region in a particular year. It shows the interrelations between different sectors of the economy and the households, government, and the rest of the world. A SAM is constructed as a square matrix, with each row and column representing a specific economic activity, such as production, consumption, investment, taxes, imports, and exports. The entries of the matrix represent the monetary value of transactions between the different economic activities (Thurlow, 2021).

The 2018 SAM is broadly structured into sectors, commodities, factors of production, economic agents, taxes and investment. This structure is that of production and trade in the Nigerian economy in 2018. In detail, there three major industries which are agriculture, industry and services. Under the agriculture industry, there are four activities namely crop production, livestock production, fishery and forestry. Crop production is further disaggregated into twelve (12) activities. Livestock production is disaggregated three (3) activities, while forestry and fishery activities are not disaggregated at all. The sectors are divided into five (5) industry activities which are mining, manufacturing, electricity, water supply and construction. The manufacturing industry is sub-divided into (9) activities. Electricity is disaggregated into electricity, gas and steam, while water supply is split between water supply and sewage. The service sector is disaggregated into eleven (11) activities. This makes a total of forty-two (42) activities in the SAM. Each of these activities earlier stated has a corresponding commodity attached to it. This implies that there are 42 commodities in the SAM.

Under the economic agents, there are two (2) representative households (rural and urban), and one (1) representative firm. There is only one government represented, and it is the government of the domestic economy. The households, firm and government, are the domestic agents, while in this set, households and firms are the non-government agents. The foreign economy agent is connoted as rest of the world (ROW). Row is also a non-government agent, but it is not a domestic agent.

There are broadly two (2) factors of production, namely labor and capital. Labor is disaggregated into three (3) categories based on level of education, while capital is disaggregated into land and capital. Three (3) taxes are taken into account in this SAM namely direct taxes, import taxes and taxes on activities. The final composite of the SAM is the investment account.

This study has modified the SAM to be able to capture the uniqueness of the study. Nine accounts were added to the 2018 SAM to capture the dynamics of the relationship this study is interested in. These new accounts are natural gas production, petroleum oil production, electricity production from natural gas, electricity production from petroleum oil, electricity production from renewable energy, natural gas commodity, petroleum oil commodity, natural gas energy volume, petroleum oil energy volume, electricity energy volume, as well as emissions from oil, natural gas, and electricity use.

The SAM used in this study was modified to be able to capture the dynamics of this study. To achieve this, new activity accounts were added specifically for electricity production from different sources. Electricity production from oil was added to track the economic activities related to generating electricity using oil as a source of energy. It is critical for understanding the role of oil-based energy in the economy and its associated emissions. Electricity production from natural gas was included to focus on electricity generated from natural gas. Given that natural gas is considered a cleaner alternative to oil, this addition allows for a more nuanced analysis of the transition from higher-emission energy sources to those that are relatively cleaner. Electricity production from renewables captures electricity generated from renewable energy sources, reflecting Nigeria's efforts towards a more sustainable energy future. The inclusion of this account is crucial for analyzing the economic implications of increasing renewable energy adoption and its impact on emissions reduction.

Additionally, the modified SAM has new accounts that capture emissions and their economic implications. These modifications focus on different sources of emissions and the integration of carbon credit mechanisms. One of the key additions is the account for emissions from natural gas, which tracks the environmental impact of using natural gas as an energy source. This is represented by the identifier em-gas. Similarly, another account labeled emissions from petroleum (identified as em-petr) captures the emissions associated with petroleum-based energy usage, providing a clearer picture of the carbon footprint from this sector. Additionally, an account labeled emissions from electricity (em-elec) tracks the emissions generated from electricity production, enabling the analysis of how different energy sources—such as oil, gas, and renewables—contribute to overall emissions in the economy.

Moreover, the modified SAM includes an account for taxes related to carbon credits, identified as esub. This account represents the economic transactions involved in carbon credits, such as taxes or subsidies, which are integral to emission reduction policies. By including these accounts, the modified SAM offers a more comprehensive view of the environmental impact of energy production and consumption in Nigeria. These additions are particularly important for analyzing how the country's energy transition and emission reduction strategies are reflected in both economic and environmental terms.

The production of natural gas, petroleum and electricity falls under the supply side of the Nigerian economy. Under this supply side, electricity production is from three sources being oil, natural gas and renewable energy. On the demand side, there are energy commodities for sale in the domestic energy market, being natural gas, petroleum products and electricity. The volumes of these three energy sources available in the open market also validate the availability of the corresponding commodities in the energy market. The SAM also accounts for the expectation that the demand and supply of these energy sources is responsible for energy emissions, which the government is trying to reduce by policy. Finally, energy from all the sources is considered as a factor of production.

Model Assumptions

The Computable General Equilibrium model used in this study is fueled by five (5) major assumptions. These assumptions are explained in the paragraph below.

The CGE model utilized in this study focused solely on sectoral energy consumption and emissions due to its predominant role in energy utilization within the Nigerian economy (Akinyemi et al., 2017). By concentrating on these two sectors, which collectively account for the majority of energy consumption, the model can offer insights into the primary drivers of energy demand and emissions generation. This targeted approach allows for a more nuanced understanding of energy-related dynamics, enabling policymakers to devise more effective strategies for energy management and emission reduction.

The second assumption is that all the emissions are from energy sources. The assumption that all emissions are from energy sources implies that the model focuses exclusively on emissions generated through energy-related activities within the economy (Bauer et al., 2020). This assumption is grounded in the recognition that energy consumption and production processes are primary drivers of greenhouse gas emissions, particularly in the context of Nigeria's economy. By limiting the scope of emissions to energy sources, the model simplifies the analysis by focusing on a significant and readily identifiable contributor to climate change. This assumption allows for a more targeted approach to policy analysis and scenario modeling, as it directs attention to the key drivers of emissions within the energy sector. It simplifies the modeling process by excluding emissions from non-energy-related activities, such as agriculture, land use, and waste management, which may require different analytical frameworks and data sources.

An essential assumption underlying the model is the existence of emissions subsidies within the Nigerian economy (Adekunle & Oseni, 2021). This assumption reflects the current absence of a recognized carbon market that would enable the generation and trading of carbon credits among different economic agents. With emissions subsidies in place, the model can simulate scenarios where emissions are effectively incentivized or penalized, thereby capturing the potential impact of policy interventions on emission levels and environmental outcomes.

A pivotal aspect of the model is its treatment of emissions as an environmental commodity that can be traded, akin to other goods and services in the market. This assumption allows for the exploration of emissions trading schemes, wherein the government can leverage revenue generated from trading emissions to finance climate change mitigation initiatives. By integrating this feature into the model, policymakers gain valuable insights into the economic feasibility and potential benefits of adopting emissions trading as a strategy for achieving climate goals while fostering sustainable development (Honegger & Reiner, 2018).

The structural framework of the model adheres to standard neo-classical assumptions, including market clearing conditions across all sectors, the absence of excess profits, and balanced budgets for each economic agent. By incorporating these fundamental principles, the model provides a coherent and internally consistent representation of the economy, facilitating analyzes of various policy scenarios and their implications. Moreover, adherence to neo-classical assumptions ensures that the model's outputs are grounded in economic theory, enhancing its credibility and utility for informing policymaking decisions aimed at promoting economic efficiency and stability.

Scenario Description

Scenarios play a crucial role in driving simulations under Computable General Equilibrium (CGE) modeling by providing a framework for analyzing the potential impacts of different policy choices, external shocks, or future developments on the economy (Foure et al., 2020). These scenarios typically involve altering exogenous variables, such as government policies, technological advancements, or changes in global market conditions, and observing the resulting changes in equilibrium outcomes.

Two scenarios are responsible for driving the major objective of this study, which is to determine the potential emission reduction pathways for Nigeria, based on the Energy Transition Plan, along with their macroeconomic implications (Wei et al., 2022). It is imperative to note again that the Energy Transition Plan is a priority of the Nigerian government largely because it is a response to its commitment to the Paris Agreement (Ezeamama, 2020). The outcome of this is that all the countries under the Agreement commit to fulfilling their Nationally Determined Contributions (NDCs). These NDCs are strategies that each country decides to execute, in order to ensure that global emission reduction targets are met. Also, the emissions reduction target period is between 2018 and 2030, which is 12 years. In the Nigerian case, the NDCs have a two-pronged approach (Ozor et al., 2020).

This two-pronged approach includes a 20% unconditional emissions reduction target, and a 47% Conditional emissions reduction target. the 20% unconditional emissions reduction target demonstrates Nigeria's unilateral commitment to mitigating climate change, while the 47% conditional emissions reduction target reflects its willingness to undertake more ambitious actions with external support. The 20% unconditional emissions reduction target set by the Nigerian government refers to a commitment to reduce greenhouse gas emissions by 20% compared to a baseline level, without any specific conditions attached (Adeyeye et al., 2023). This means that Nigeria pledges to achieve this reduction regardless of external factors or support from other countries. It represents a unilateral effort by Nigeria to mitigate its contribution to global climate change and fulfill its obligations under the Paris Agreement. This target indicates Nigeria's recognition of the importance of taking proactive measures to address climate change and its willingness to undertake significant emission reduction efforts independently.

On the other hand, the 47% conditional emissions reduction target signifies Nigeria's commitment to further reduce greenhouse gas emissions by 47% compared to the baseline level, contingent upon certain conditions being met (Gençsü et al., 2022). These conditions typically involve receiving financial assistance, technology transfer, capacity building, or other forms of support from developed countries or international organizations. The conditional target reflects Nigeria's acknowledgment of the challenges it faces in achieving substantial emissions reductions on its own and its reliance on external assistance to implement more ambitious mitigation measures. It underscores the importance of international cooperation and solidarity in addressing climate change effectively, particularly for developing countries like Nigeria with limited resources and capacity.

These impacts of these approaches have been analyzed via this study. With these two targets of the Nigerian government, the study has been able to display how real gross domestic product, which is the variable representing macroeconomic performance, is affected if the government achieves these two commitments. The scenarios are described below.

Scenario One: A gradual reduction of 1.67 % in energy emissions over a 12-year period, totaling into a 20 % reduction by 2030. This logic is driven by the fact that emissions reduction is a very expensive endeavor that could deprive the government from meeting other important obligations, if the 20 % reduction target were to be implemented in one shot (Giuliano et al., 2020).

Scenario Two: A gradual emissions reduction of 3.92 % over 12 years, amounting to 47 % in the 12th year, which is 2030 (Mi & Sun, 2021).

4. Discussion of Results

Impact of Emissions Reduction on Sectoral Emissions Intensity

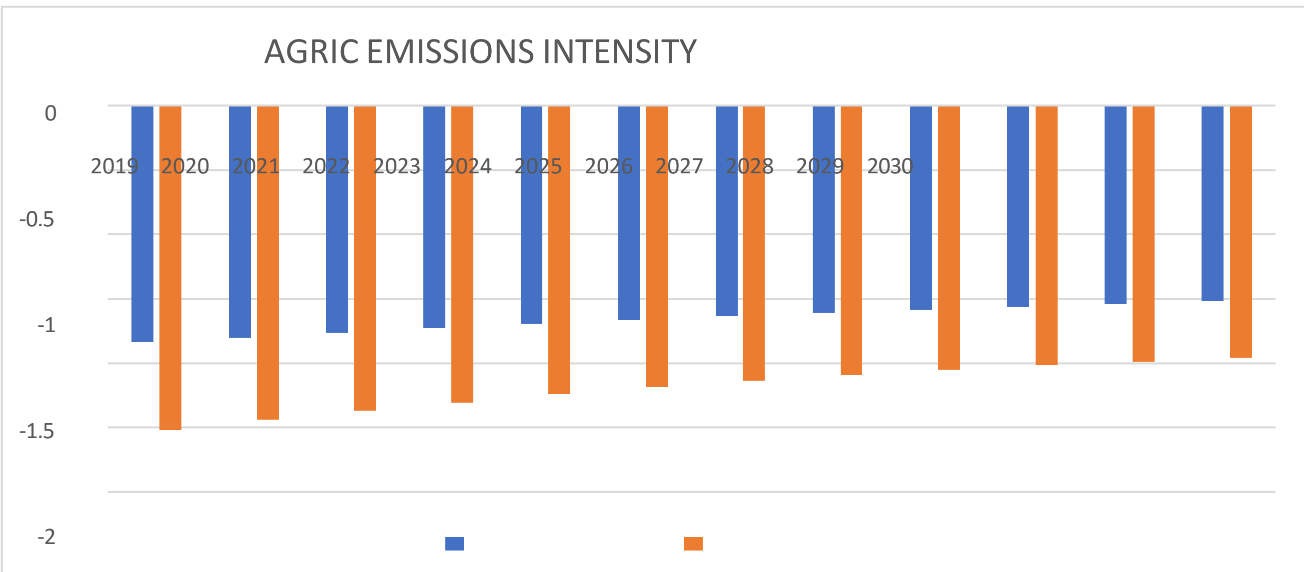
Figure 4.1 shows that the emissions intensity of the agriculture sector expresses a similar behavior with that of the household earlier explained. There is a steady increase in the emissions intensity of this sector between 2019 and 2030. In spite of this steady increase, all the yearly values are in the negative. In 2019, there is a decrease in emissions intensity from business as usual by 1.84 % and 2.52 %. These figures represent the 20 % and 47 % emissions reduction strategies respectively. By 2023, the reductions are by 1.70 % and 2.24%, while the reductions are 1.52 % and 1.70 % by 2030. The 12-year average values under both emissions' reduction strategies are reductions by 1.66 % and 2.19 %. Also, emissions intensity for the agriculture sector reduces more noticeably under the 47 % scenario than under the 20 % scenario.

These results for the agriculture sector are as expected because the sector is largely subsistence in structure. To this end, the technologies used to execute agricultural activities in Nigeria do not require as much energy consumption of brown fossil fuels (coal and petroleum oil) as the industrial and manufacturing sectors do. It is important to remember that the Energy Transition Plan requires a shift from the use of brown fossils to cleaner fossils (natural gas). Since the agriculture sector largely does not run on the brown fossil fuels in the first place, its contribution to energy emissions reflects this fact before and after transition. Also, because emissions intensity is calculated as fraction of GDP, the low contribution of the agriculture sector to GDP reflects in the volume of emissions it generates for every Naira of GDP considered.

The steady increase in emissions intensity of the agriculture sector between 2019 and 2030, despite overall negative yearly values, aligns with the sector's subsistence nature and lower energy consumption of brown fossil fuels. The results show that emissions intensity reductions are more noticeable under the 47 % reduction scenario compared to the 20 % scenario. Supporting literature, such as the work of (Tubiello et al., 2021) discusses how the agriculture sector's emissions intensity is influenced by the shift towards more sustainable agricultural practices and technologies, which typically have lower energy requirements. This is consistent with the observed reductions in emissions intensity under the emissions reduction strategies. Additionally, Lal et al., (2020) highlights that subsistence farming practices, common in developing countries like Nigeria, tend to have lower emissions intensity due to minimal use of energy-intensive inputs. This supports the finding that the agriculture sector's emissions intensity decreases with policy implementation. Contrasting literature, however, presents a different view. Springmann et al., (2021) argue that emissions reduction policies may not significantly impact the agriculture sector due to its already low energy consumption. They suggest that larger gains in emissions reductions might come from more energy-intensive sectors, indicating that the observed steady increase in emissions intensity could be less substantial. Similarly, Smith et al., (2020) indicate that while emissions reduction strategies can lower emissions intensity in agriculture, the impact might be limited without significant technological advancements and infrastructural improvements.

The results for the industrial sector emissions intensity show a steady decline over the 12-year period. In the first year after the 20 % and 47 % shocks were applied, being 2019, emissions intensity fell by 1.70 % and 2.33 % respectively, compared to the 2018 baseline. By 2023, there was a further decline from the baseline by 1.86 % and 2.45 %, and an even further fall in emissions intensity of the industrial sector by up to 2.05 % and 2.59 % respectively as at 2030. The average values of industrial sector emissions intensity between 2019 and 2030 show reductions by 1.89 % and 2.47% under both 20 % and 47 % emissions reduction strategies. Also, the reductions in energy intensity are higher under the 47 % scenario.

Figure 4.1: Projected Agriculture Sector Emissions Intensity after Implementing ETP



Source: Author’s Compilation. Blue bars represent the 20% scenario, orange bars represent the 47% scenario.

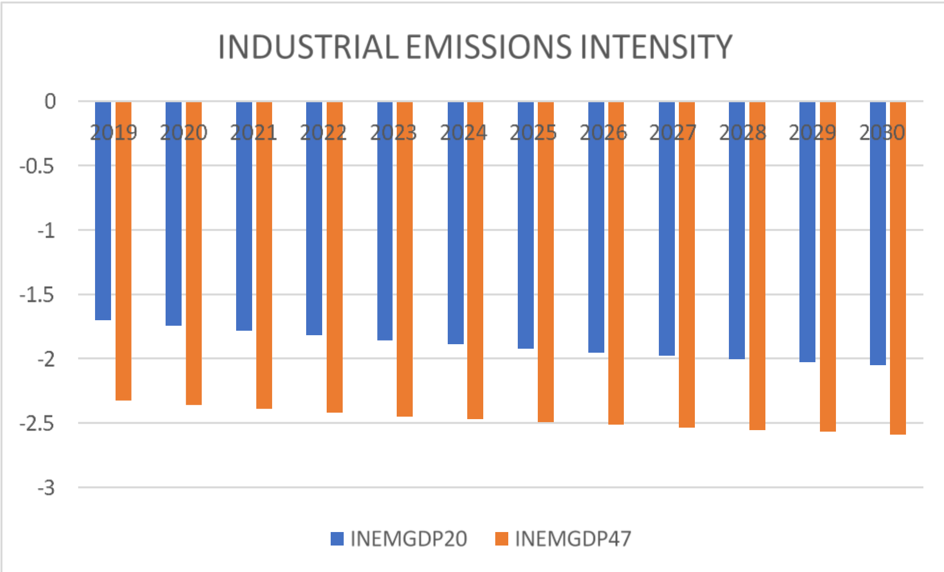


Figure 4.2: Projected Industrial Sector Emissions Intensity after Implementing ETP
Source: Author's Compilation

This overall reduction in the emissions intensity of the industrial sector is an expected outcome after the emissions reduction strategies are applied. This is because the industrial sector in Nigeria is the highest emitter of carbon, and is most inclined to replace its energy consumption and technologies due to the energy transition. Energy transition requires a departure from business-as-usual production structures, because it alters the type of energy used in production. This is exactly what happens to the industrial sector when the government drives emissions reduction strategies. The sector has to make the largest changes in energy consumption, shifting from dirty fossils to cleaner ones. This huge departure by the highest emitting sector reflects in its emissions intensity outcomes. It is safe to say that the results show the highest regulatory compliance by the industrial sector.

The steady decline in emissions intensity of the industrial sector over the 12-year period is an expected outcome after the implementation of emissions reduction strategies. The industrial sector, being the highest emitter of carbon in Nigeria, shows the largest regulatory compliance and energy transition, resulting in significant reductions. Supporting literature emphasizes that industrial sectors typically show significant reductions in emissions intensity following stringent environmental regulations due to shifts in energy consumption and adoption of cleaner technologies. For instance, Dechezleprêtre et al., (2019) provide evidence of substantial declines in emissions intensity in response to environmental regulations, aligning with the observed trend in Nigeria's industrial sector. Additionally, Aldy and Pizer (2020) highlight those industries are often the first to adopt new technologies and energy sources in response to emissions reduction policies, leading to substantial decreases in emissions intensity. However, contrasting literature suggests that while emissions reduction policies can drive initial declines in industrial emissions intensity, the long-term impact depends on sustained investments in clean technologies and innovation. Fankhauser et al. (2021) note that without continuous improvements, the reductions might plateau. Similarly, Carattini et al. (2020)) argue that regulatory compliance might lead to short-term reductions in emissions intensity but could face diminishing returns if industries do not continually adapt and innovate.

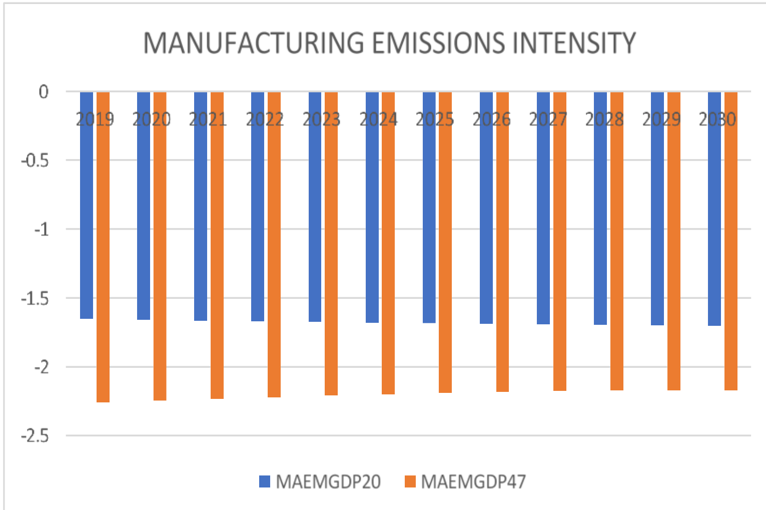


Figure 4.3: Projected Manufacturing Sector Emissions Intensity after Implementing ETP
Source: Author's Compilation

The results for the manufacturing sector emissions intensity also demonstrate a marginal progression over the 12-year period, though all the figures are negative. Following the implementation of the 20 % and 47 % emissions reduction strategies in 2019, emissions intensity experienced a decline of 1.65 % and 2.26 % respectively compared to the 2018 baseline. Subsequently, in 2023, there was a further decrease from the baseline by 1.67 % and 2.21 %. As the years progressed, the trend continued with a continual decrease in emissions intensity.

By 2030, emissions intensity in the manufacturing sector is projected to reduce by 1.70 % and 2.17 % respectively under the 20 % and 47 % emissions reduction scenarios. On average, over the 12-year period from 2019 to 2030, emissions intensity in the manufacturing sector is expected to decrease by 1.68 % and 2.20 % under the 20 % and 47 % emissions reduction strategies respectively. These findings indicate a consistent and substantial reduction in emissions intensity in the manufacturing sector, with greater reductions observed under the 47 % emissions reduction scenario compared to the 20 % scenario.

These outcomes for the manufacturing sector are as expected, with the manufacturing sector being the second highest emitter of carbon in Nigeria. The same expected fate as the industrial sector is the consideration for the manufacturing sector, as regulatory compliance will coerce the sector into energy transition. This should lead to changes in the structure of emissions in this sector, which reflects in the decline. The volume of carbon emissions produced for every Naira that the manufacturing sector contributes to GDP over the 12-year period is increasing, although very marginally, due to energy transition.

The manufacturing sector shows a marginal progression in emissions intensity over the 12-year period, with consistent and substantial reductions under both emissions reduction scenarios. This sector, being the second-highest emitter, follows a similar pattern to the industrial sector in terms of regulatory compliance and energy transition. Supporting literature, such as Popp et al. (2020) discusses how manufacturing sectors respond to emissions reduction policies by adopting cleaner technologies and improving energy efficiency, resulting in decreased emissions intensity. This aligns with the observed trends in Nigeria's manufacturing sector. Cosbey et al. (2019) highlight the impact of emissions reduction policies on manufacturing sectors, noting that significant reductions in emissions intensity can be achieved through technological advancements and shifts in production practices. On the other hand, contrasting literature suggests that while initial reductions in emissions intensity are achievable, the long-term sustainability of these reductions depends on continuous technological innovation and policy support. Stern and Zenghelis (2021) caution that the long-term sustainability of emissions intensity reductions in the manufacturing sector requires ongoing advancements and support. Similarly, Acemoglu et al. (2020) argue that manufacturing sectors might face challenges in maintaining reduced emissions intensity without significant structural changes and investments in cleaner technologies.

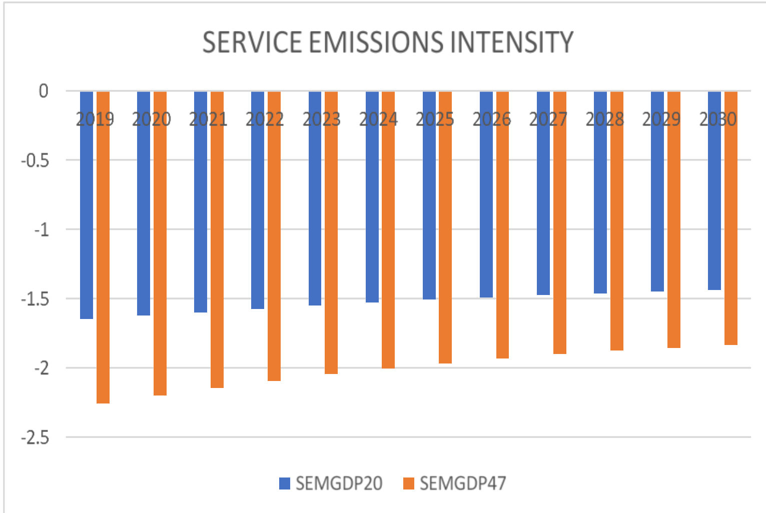


Figure 4.4: Projected Manufacturing Sector Emissions Intensity after Implementing ETP
Source: Author's Compilation

The results for the service sector emissions intensity also indicate a consistent increase over the 12-year period, although the individual years show reductions from the business-as-usual case. Following the implementation of the 20% and 47% emissions reduction strategies in 2019, emissions intensity experienced a decline of 1.65% and 2.26% respectively compared to the 2018 baseline. Subsequently, in 2020, there was a further increase from the baseline by 1.62% and 2.2%, followed by additional reductions in emissions intensity of the service sector by up to 1.60 % and 2.15% respectively. As the years progressed, the trend continued with a continual increase in emissions intensity. By 2030, emissions intensity in the service sector is projected to reduce by 1.53% and 2.01% respectively under the 20% and 47% emissions reduction scenarios. On average, over the 12-year period from 2019 to 2030, emissions intensity in the service sector is expected to decrease by 1.53% and 2.01% under the 20% and 47% emissions reduction strategies respectively. These findings show greater reductions observed under the 47% emissions reduction scenario compared to the 20% scenario.

These results show that the emissions intensity of the service sector is increasing over the 12- year period, and this can be explained from the angle of dependence. The service sector does not produce goods, like the manufacturing and industrial sectors. However, the service sector is also dependent on energy intensive activities such as transportation, self-generation of power, as well sector is expected to experience increasing emissions intensity because of its increasing dependence on these energy intensive activities. A plausible reason for this is growing contribution of the service sector to GDP over the years.

The service sector shows a consistent increase in emissions intensity over the 12-year period, despite yearly reductions from the business-as-usual scenario. This trend is attributed to the sector's dependence on energy-intensive activities such as transportation and self-generation of power. Supporting literature, like the work of Gillingham et al., (2021), discusses how the service sector's emissions intensity can increase due to its reliance on energy-intensive activities and its indirect dependence on other sectors' emissions. This supports the observed increase in emissions intensity in Nigeria's service sector. Jones et al. (2020) highlight the challenges faced by the service sector in reducing emissions intensity due to its dependency on transportation and other energy-intensive services. Contrasting literature, however, suggests that the service sector can achieve emissions intensity reductions through digitalization and automation. der Ploeg and Rezai, (2020) indicate potential for decreases in intensity, challenging the observed increasing trend. Schubert and Turnovsky (2021) argue that the service sector has opportunities to reduce emissions intensity by adopting more energy-efficient practices and technologies.

Impact of Emissions Reduction on Sectoral Energy Intensity

Another important aggregate that implementing the emissions reduction strategies is expected to affect is energy intensity. Energy intensity is the average cost of converting a unit of energy to output. This is theoretically consistent measure of energy efficiency in an economy. It is important to note that the apriori expectation of implementing the emissions reduction strategies, on the behavior of energy intensity, is a consistent decrease. This study considers energy intensity from only household and firm activities, because combines, they are responsible for over 80 % of energy consumed in Nigeria.

The results for the agricultural sector energy intensity (AGENI) exhibit a consistent decline over the 12-year period. Following the implementation of the 20 % and 47 % emissions reduction strategies in 2019, agricultural sector energy intensity experienced a decrease of 0.16% and 0.24 % respectively compared to the 2018 baseline. Subsequently, in 2020, there was a further reduction from the baseline by 0.19 % and 0.30 %, followed by additional decreases in agricultural sector energy intensity by up to 0.27 % and 0.47 % respectively.

The trend continued with a continual decline in agricultural sector energy intensity. By 2030, agricultural sector energy intensity is projected to decrease by 0.59 % and 0.93 % respectively under the 20 % and 47 % emissions reduction scenarios. On average, over the 12-year period from 2019 to 2030, agricultural sector energy intensity is expected to decrease by 0.38 % and 0.62 % under the 20 % and 47 % emissions reduction strategies respectively. These findings demonstrate a consistent and noticeable reduction in agricultural sector energy intensity, indicating the effectiveness of the emissions reduction strategies in curbing energy consumption per unit of agricultural output. Furthermore, the greater reductions observed under the 47 % emissions reduction scenario highlight the importance of more ambitious emissions reduction targets in achieving significant improvements in energy intensity.

Table 4.1: Projected Agriculture Sector Energy Intensity after Implementing ETP

AGENI			INENI			MAENI			SENI		
BAU	20%	47%	BAU	20%	47%	BAU	20%	47%	BAU	20%	47%
1.50576	-0.16035	-0.23581	1.391948	-0.14894	-2.56464	1.351793	-0.14384	-0.21187	1.350227	-0.14384	-0.21187
1.473593	-0.19376	-0.30463	1.426965	-0.18963	-0.29819	1.357807	-0.17887	-0.28162	1.328644	-0.17514	-0.27573
1.4441	-0.23209	-0.38316	1.461469	-0.23855	-2.5295	1.363719	-0.22014	-0.36379	1.308625	-0.21123	-0.3491
1.417166	-0.27422	-0.46571	1.495139	-0.29506	-0.49998	1.36974	-0.26686	-0.45337	1.290368	-0.2512	-0.42687
1.392562	-0.31864	-0.54676	1.527734	-0.35784	-2.44366	1.375973	-0.31774	-0.545	1.273893	-0.29374	-0.504
1.370021	-0.36371	-0.6225	1.559078	-0.42512	-0.72397	1.38244	-0.37125	-0.63459	1.259119	-0.33737	-0.57697
1.349269	-0.40797	-0.69104	1.589051	-0.49509	-2.34497	1.389112	-0.42589	-0.71972	1.245915	-0.38079	-0.64398
1.33006	-0.45037	-0.75188	1.61758	-0.56615	-0.9374	1.395931	-0.48045	-0.79928	1.234133	-0.42303	-0.7045
1.312177	-0.49018	-0.80527	1.644627	-0.63702	-2.25339	1.402822	-0.534	-0.87297	1.223625	-0.46342	-0.7587
1.295436	-0.52702	-0.85187	1.670185	-0.70672	-1.12819	1.40971	-0.58594	-0.94091	1.214251	-0.50159	-0.80709
1.279685	-0.56073	-0.89243	1.694267	-0.77457	-2.17413	1.416522	-0.63584	-1.00344	1.205886	-0.53736	-0.85032
1.264798	-0.59129	-0.92776	1.716902	-0.84009	-1.29473	1.423195	-0.68345	-1.061	1.198417	-0.5707	-0.88907

Source: Author’s Computation from GAMS

The results for the agricultural sector energy intensity (AGENI) exhibit a consistent decline over the 12-year period. Following the implementation of the 20% and 47% emissions reduction strategies in 2019, agricultural sector energy intensity experienced a decrease of 0.16% and 0.24% respectively compared to the 2018 baseline. Subsequently, in 2020, there was a further reduction from the baseline by 0.19% and 0.30%, followed by additional decreases in agricultural sector energy intensity by up to 0.27% and 0.47% respectively.

The trend continued with a continual decline in agricultural sector energy intensity. By 2030, agricultural sector energy intensity is projected to decrease by 0.59% and 0.93% respectively under the 20% and 47% emissions reduction scenarios. On average, over the 12-year period from 2019 to 2030, agricultural sector energy intensity is expected to decrease by 0.38% and 0.62% under the 20% and 47% emissions reduction strategies respectively. These findings demonstrate a consistent and noticeable reduction in agricultural sector energy intensity, indicating the effectiveness of the emissions reduction strategies in curbing energy consumption per unit of agricultural output. Furthermore, the greater reductions observed under the 47% emissions reduction scenario highlight the importance of more ambitious emissions reduction targets in achieving significant improvements in energy intensity.

The agricultural sector’s consistent decline in energy intensity aligns with literature emphasizing the potential for sustainable agricultural practices to reduce energy consumption. Zhang et al. (2020) argue that the adoption of sustainable farming techniques, such as precision agriculture and improved irrigation methods, can significantly lower energy intensity in agriculture. Their research supports the study's findings, suggesting that emissions reduction strategies can effectively curb energy consumption per unit of agricultural output. Additionally, Zilberman et al., (2019) highlight that integrating renewable energy sources, such as solar-powered irrigation systems, can further enhance energy efficiency in agriculture.

In contrast, Smith et al. (2021) provide a differing perspective by suggesting that the impact of emissions reduction policies on agriculture might be limited due to its already low energy consumption compared to other sectors. They argue that significant gains in energy intensity might be more challenging to achieve in agriculture, as it does not consume as much energy as industrial or manufacturing sectors. This view highlights the importance of considering sector- specific characteristics when evaluating the effectiveness of emissions reduction strategies.

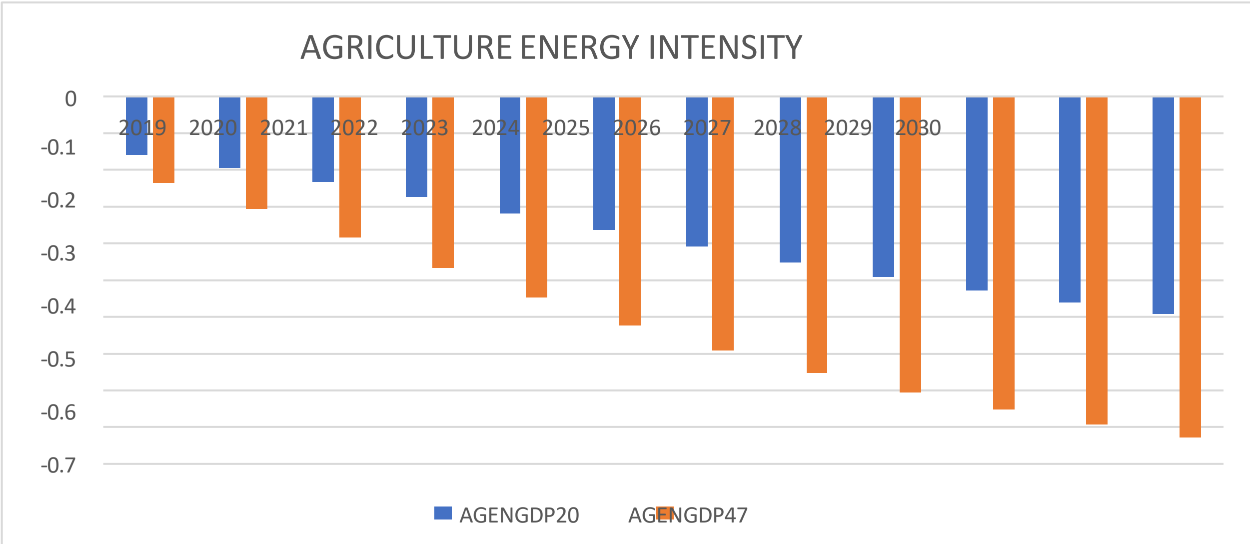


Figure 4.5: Projected Agriculture Sector Energy Intensity after Implementing ETP
Source: Author's Compilation

The results for the industrial sector energy intensity (INENI) indicate an overall decline under the 20% scenario, and an expected overall increase under the 47%. Following the implementation of the 20% and 47% emissions reduction strategies in 2019, industrial sector energy intensity experienced a decrease of 0.15% and 2.56% respectively compared to the 2018 baseline. Subsequently, in 2020, there was a further reduction from the baseline by 0.19% and 0.30%, followed by additional decreases in industrial sector energy intensity by up to 0.24% and 0.50% respectively.

By 2030, industrial sector energy intensity is projected to decrease by 0.84% and 1.29% respectively under the 20% and 47% emissions reduction scenarios. On average, over the 12- year period from 2019 to 2030, industrial sector energy intensity is expected to decrease by 0.47% and 1.60% under the 20% and 47% emissions reduction strategies respectively. These findings highlight the effectiveness of the emissions reduction strategies in reducing energy consumption per unit of industrial output. The substantial reductions observed, particularly under the 47% emissions reduction scenario, underscore the importance of ambitious emissions reduction targets in achieving significant improvements in energy intensity within the industrial sector.

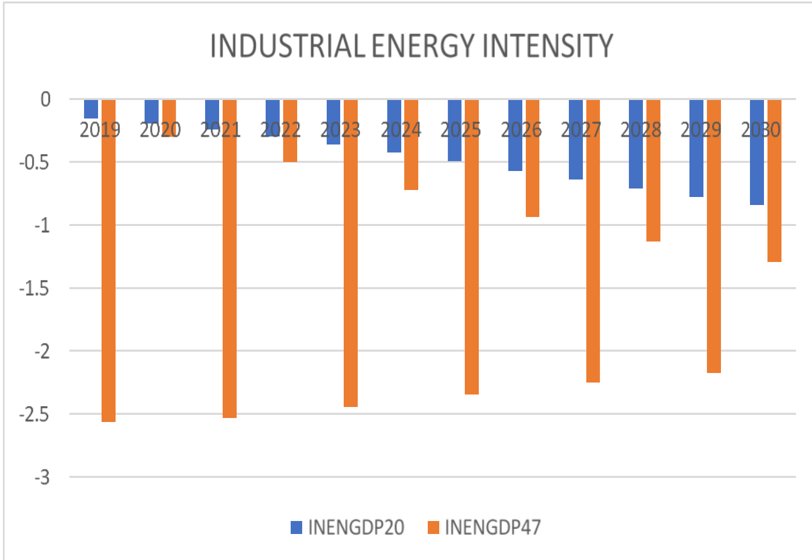


Figure 4.6: Projected Industrial Sector Energy Intensity after Implementing ETP
Source: Author's Compilation

The results reveal an interesting possibility. Emissions intensity of the industrial sector showed an overall decline in trend for both conditional and unconditional emissions reduction strategies. However, under industrial sector energy intensity results, there is a decreasing trend in energy intensity under the unconditional emissions reduction strategy, while there is a noticeable increasing trend in energy intensity under the conditional emissions reduction strategy. One apparent explanation for this is the rebound effect, also known as Jevons' Paradox.

This refers to a situation where efficiency improvements or reductions in resource consumption leads to increased overall consumption of that resource rather than the expected decrease. In other words, as efficiency increases and the cost of using a resource decrease, the response might be to increase usage of that resource, partially or fully offsetting the initial gains in efficiency. The observed trends could be indicative of a rebound effect, where efficiency improvements lead to increased overall energy usage rather than the expected decrease. As industries become more efficient in their energy use, they may find it more economical to expand production or engage in additional activities that require energy, offsetting some or all of the initial gains in energy efficiency, leading to increasing energy efficiency under the 47 % scenario, even though emissions intensity is reducing.

The industrial sector's energy intensity results reveal a more complex picture, with a decreasing trend under the 20% scenario and an increasing trend under the 47% scenario, suggesting the presence of a rebound effect. The rebound effect, also known as Jevons' Paradox, is well- documented in the literature. Madlener and Turner (2021) explain that efficiency improvements in energy use can lead to increased overall consumption as the cost of using the resource decreases, which partially or fully offsets the initial gains in efficiency. This aligns with the study's findings that under the 47% emissions reduction scenario, energy efficiency improvements may lead to increased energy usage due to expanded industrial activities.

Supporting literature by Worrell et al., (2019) discusses how environmental regulations and emissions reduction strategies can lead to substantial declines in industrial emissions intensity by encouraging the adoption of cleaner technologies and more efficient production processes. However, contrasting views, such as those presented by Greenstone and Nath (2020), suggest that without sustained investments in clean technologies and continuous policy support, the reductions in energy intensity might plateau, limiting the long-term effectiveness of emissions reduction strategies.

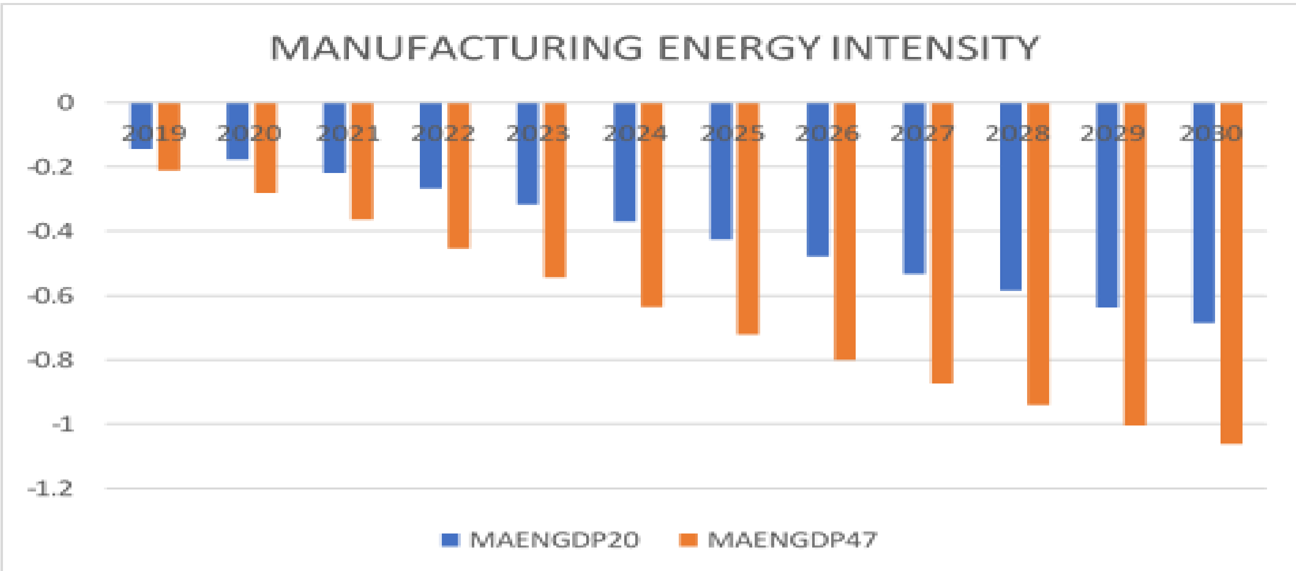


Figure 4.7: Projected Manufacturing Sector Energy Intensity after Implementing ETP
Source: Author's Compilation

The results for the manufacturing sector emissions intensity also demonstrate an expected consistent decrease over the 12-year period. Following the application of the 20 % and 47 % shocks in 2019, emissions intensity decreased by 0.14 % and 0.21 % respectively compared to the 2018 baseline. This initial reduction indicates the immediate impact of the emissions reduction strategies on emissions intensity. As the years progressed, the decline in emissions intensity continued, with further reductions observed in subsequent years.

By 2030, emissions intensity decreased by 0.64 % and 1.06 % under the 20 % and 47 % emissions reduction strategies respectively. This long-term trend suggests that the implementation of emissions reduction measures has been effective in reducing emissions intensity within the manufacturing sector. The average values of emissions intensity between 2019 and 2030 indicate an overall reduction of 0.40 % and 0.66 % under the 20 % and 47 % emissions reduction strategies respectively. These averages highlight the sustained efforts and effectiveness of the emissions reduction strategies in curbing emissions intensity within the manufacturing sector. Overall, the results suggest success of the emissions reduction strategies for the manufacturing sector over the 12-year period, demonstrating a commitment to sustainability and environmental responsibility.

The manufacturing sector shows a consistent decrease in energy intensity, which is supported by studies highlighting the sector's potential for energy efficiency improvements. The International Energy Agency (IEA, 2019) reports that manufacturing sectors can achieve significant reductions in energy intensity through the adoption of advanced technologies, such as automation and digitalization, which enhance production efficiency and reduce energy consumption. This supports the study's findings, suggesting that emissions reduction strategies can effectively lower energy intensity in the manufacturing sector. However, Qureshi and Girardet (2020) provide a more cautious perspective, arguing that while initial reductions in energy intensity are achievable, maintaining long-term sustainability requires ongoing advancements and strong policy frameworks. They emphasize the need for continuous innovation and investment in clean technologies to sustain the downward trend in energy intensity in the manufacturing sector.

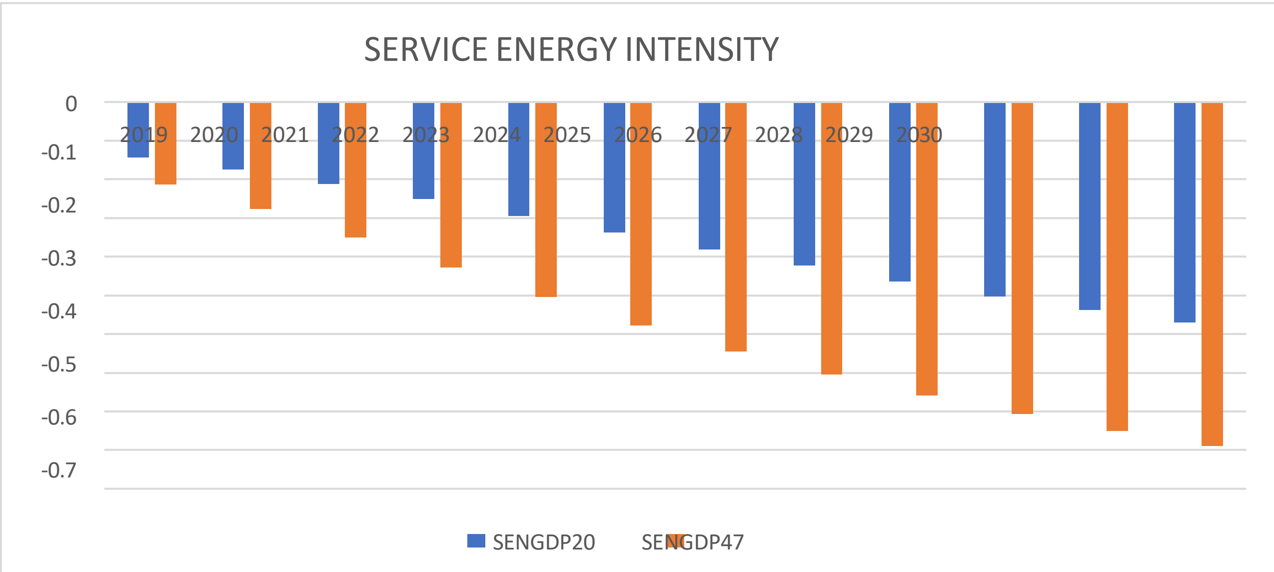


Figure 4.8: Projected Service Sector Energy Intensity after Implementing ETP
Source: Author’s Compilation based on Tables

The results for the service sector energy intensity also exhibit a consistent decline over the 12-year period. Following the implementation of the 20 % and 47 % shocks in 2019, energy intensity decreased by 0.14 % and 0.21 % respectively compared to the 2018 baseline. This initial reduction indicates the immediate impact of the emissions reduction strategies on energy intensity within the service sector. The downward trend in energy intensity continued, with further reductions observed in subsequent years. By 2030, energy intensity decreased by 0.57 % and 0.89 % under the 20 % and 47 % emissions reduction strategies respectively. This sustained decrease in energy intensity reflects the effectiveness of the emissions reduction measures implemented within the service sector.

The average values of energy intensity between 2019 and 2030 indicate an overall reduction of 0.36 % and 0.58 % under the 20 % and 47 % emissions reduction strategies respectively. These averages underscore the consistent efforts and success of the emissions reduction strategies in lowering energy intensity within the service sector over the 12-year period. This implies that the average cost of converting one unit of energy to output is reducing overtime, indicating progressive improvements in energy efficiency of this sector. Overall, the results suggest that the service sector has been successful in reducing its emissions intensity, demonstrating a commitment to environmental sustainability and contributing to overall emissions reduction efforts.

The service sector’s consistent decline in energy intensity reflects the sector's potential for energy efficiency improvements, particularly through digitalization and automation. Stern and Zenghelis

(2019) highlight that the service sector can achieve significant energy savings by adopting digital technologies and optimizing energy use in buildings and transportation. This aligns with the study's findings that emissions reduction strategies can effectively lower energy intensity in the service sector. However, Jenkins et al. (2021) discuss the challenges the service sector faces due to its reliance on energy-intensive activities such as transportation and self- generation of power. They argue that despite improvements in energy efficiency, the increasing dependence on energy-intensive activities could offset some of the gains. This view provides a nuanced understanding of the challenges in achieving sustained reductions in energy intensity within the service sector.

Impact of Emission Reduction on Real Gross Domestic Product

The implementation of the unconditional (20 %) and conditional (47 %) emissions reduction strategies is expected to bring about some changes in key environmental aggregates in an economy. Such aggregates include emissions intensity and energy intensity. In this sub-section, the results for emissions intensity are discussed, while the results for energy intensity are discussed in the next sub-section. It is important to note that 2018 is the baseline year, or year of reference for the results, and all results are interpreted as a departure from the baseline value. It is also important to note that the apriori expectation of implementing the emissions reduction strategies, on the behavior of emissions intensity, is a consistent decrease. Also, a key assumption is that all emissions come from household and firm activities. Another key assumption is that all emissions are carbon emissions from energy consumption.

From Figure 4.9, the results for real GDP (RGDP) indicate a mixed trend over the 12-year period, even though there is a clear overall reduction in RGDP. Following the implementation of the 20% and 47% emissions reduction strategies in 2019, there was a slight decrease in RGDP compared to the baseline year of 2018. This initial decline in RGDP can be attributed to the adjustments and transitional effects associated with the adoption of emissions reduction measures, which might have temporarily impacted economic output. The average values of RGDP between 2019 and 2030 indicate an overall reduction in economic output compared to the baseline, with higher reductions observed under the 47% emissions reduction scenario compared to the 20% scenario.

These reductions in RGDP between 2019 and 2030, as compared to the 2018 baseline can be explained. In the bid to ensure emissions reduction, firms move away from their traditional production mix, because government regulation demands energy transition. This shift from traditional production requires investment, and this reduces the amount of investment available to pump into production processes. Output is affected negatively, hence the declining trend in real GDP under both emissions' reduction strategies.

The mixed trend observed in real GDP (RGDP) over the 12-year period following the implementation of 20% and 47% emissions reduction strategies in 2019 aligns with existing literature on the economic impacts of stringent environmental policies. The initial decrease in RGDP post-2019 can be attributed to the transitional effects of adopting emissions reduction measures, which often disrupt traditional production processes and necessitate significant investments in new technologies and infrastructures.

Several studies corroborate the notion that stringent emissions reduction strategies can lead to short-term economic downturns due to the transitional adjustments required. For instance, (Bowen and Fankhauser, 2020) argue that while emissions reduction policies are crucial for sustainable development, they often entail upfront costs and adjustments that can negatively impact economic output in the short term. This is consistent with the observed initial decline in RGDP in the studied period. Furthermore, research by (Stern and Zenghelis, 2021) indicates that the shift towards low-carbon technologies and production methods can initially suppress economic growth as firms divert investments from production to compliance with new regulations and development of cleaner technologies. This diversion of resources aligns with the noted reduction in investment availability for traditional production processes, leading to a decrease in overall output.

Conversely, some studies present findings that suggest the economic impacts of emissions reduction strategies may not necessarily lead to long-term reductions in RGDP. For example, the work by (Hepburn et al., 2020) highlights that, while there may be short-term economic adjustments, the long-term benefits of emissions reduction strategies, such as increased efficiency and innovation, can offset initial economic drawbacks. They argue that well-designed policies can stimulate green investment, leading to new economic opportunities and job creation, potentially mitigating the negative impacts on RGDP. Similarly, a study by (Aghion et al., 2019) suggests that the negative short-term impacts on GDP can be counterbalanced by long-term gains in economic performance due to enhanced energy efficiency and the development of new industries. This study implies that, although initial investments in low-carbon technologies can be costly, they pave the way for sustainable economic growth in the long run.

The results of the observed reduction in RGDP following the implementation of emissions reduction strategies are thus supported by literature that recognizes the short-term economic costs associated with transitioning to lower emissions. Bowen and Fankhauser, (2020) and Stern and Zenghelis, (2021) provide empirical support for the notion that such transitions require substantial investments that can temporarily reduce economic output. However, it is essential to balance this perspective with literature that emphasizes potential long-term economic benefits. Aghion et al., (2019) and Hepburn et al., (2020)) argue that the initial economic downturn can be mitigated by the long-term gains from increased efficiency, innovation, and the development of green industries. These findings suggest that the observed reduction in RGDP might be a temporary phenomenon, with potential for recovery and growth as the economy adjusts to the new low-carbon paradigm.

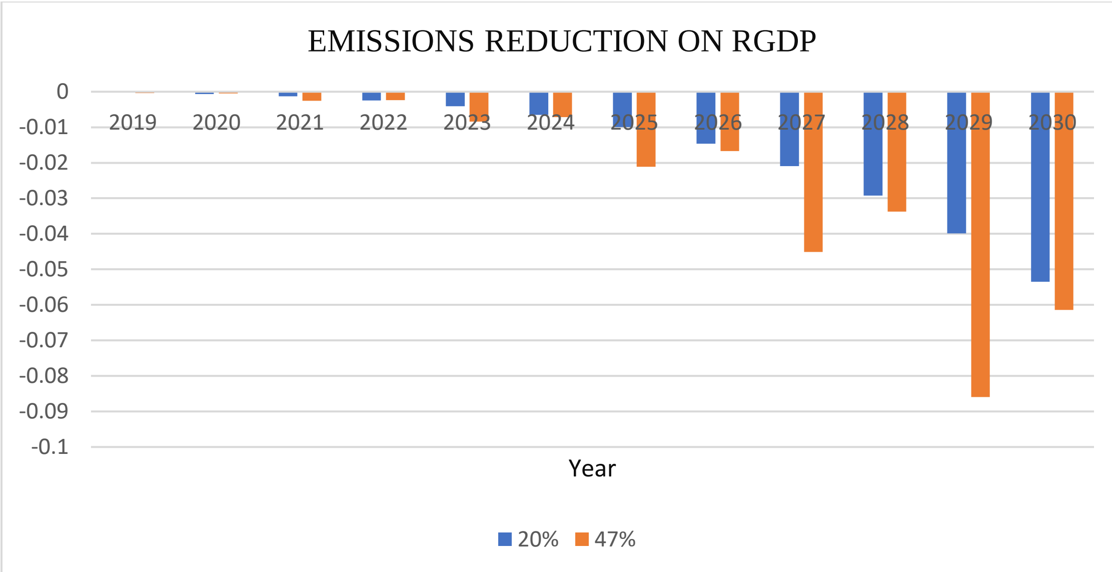


Figure 4.9: Projected Real GDP after Implementation of Energy Transition Plan
Source: Author's Compilation

5. Conclusion

The findings explained in section 4 have implications for the 4 major sector classifications of the Nigerian economy. The business-as-usual level, which is the year 2018, represents what the outcomes of the variables of interest are, in the absence of any emissions reduction strategies.

Reducing emissions by 20 % is economically more beneficial, while reducing emissions by 47 % is environmentally more beneficial. The drive to minimize emission levels through fuel subsidy removal comes with an additional cost of loss in economic value. The loss in real GDP is higher under the 47 % scenario, than under the 20 % scenario. This is because it is more costly for the government to pursue the conditional emissions reduction strategy than the unconditional emissions reduction strategy. The Energy Transition Plan is in more in favor of the 47 % strategy than the 20 % strategy, as the goal of the plan is improved environmental sustainability. This explains the trade-off between a fossil fuel driven growth (brown growth) and environmental sustainability (green growth).

Therefore, there is need to compensate for the loss in GDP. The drive towards environmental sustainability is expected to increasingly damage the economy, hence the justification to request for foreign aid from developed countries. This is to the end that the abatement of carbon emissions will benefit the world. The Nigerian Energy Transition Plan is environmentally friendly. Switching to natural gas as the transition fuel is an efficient alternative, as long as there is access to foreign aid.

The industrial sector is the biggest loser in this framework. The results from emissions intensity, energy intensity, and sectoral value-added show that the industrial sector has the highest reductions in emission and energy intensity over the 12-year period. It also has the largest losses in value added over the period. This is the highest carbon emitting sector, and the highest energy consuming sector at baseline, even though it was the sector with the third highest contribution to GDP. The significant reductions in emissions and energy intensity within the industrial sector indicate the effectiveness of emissions reduction policies. Implementing the Energy Transition Plan (ETP) in Nigeria, under the CGE framework, reveals significant implications for the industrial sector. This sector experiences the highest reductions in emissions and energy intensity, as well as the largest losses in sectoral value-added over the 12-year period. These outcomes, while beneficial for environmental sustainability, pose economic challenges due to the sector's substantial contribution to GDP.

The agriculture sector is the most advantaged sector in this framework. The agriculture sector takes third place in the emissions intensity and energy intensity race. However, it is the sector with the best performing value-added outcomes between 2019 and 2030. The low emissions and energy intensities of the agriculture sector are indicative of the low energy use in the sector as at baseline. It could also be because of improvements in sustainable agriculture practices. While the agriculture sector may have lower energy intensity compared to other sectors, there is still potential for further reducing carbon emissions by transitioning to alternative energy sources for agricultural operations.

The sectoral analysis presented underscores the nuanced nature of Nigeria's economy and the importance of tailored policy interventions. While all sectors exhibit improvements in energy efficiency, variations in the magnitude of reductions highlight sector-specific challenges and opportunities. Sectoral policies aimed at promoting industrialization, agricultural productivity, and service sector expansion are essential for maximizing economic value added and driving sustainable growth. Achieving ambitious emission reduction targets necessitates collaboration and access to external funding. Nigeria's commitment to reducing emissions intensity not only enhances its global standing as a responsible environmental steward but also positions the country to leverage international cooperation and financial support. By strategically pursuing external funding opportunities, Nigeria can accelerate its transition towards a low-carbon economy and unlock opportunities for sustainable development.

The marginal differences observed in real GDP growth between emission reduction scenarios underscore the importance of balancing economic objectives with environmental imperatives. While more ambitious targets may require external support, this support is a key variable that will compensate for the losses in GDP due to the Energy Transition commitment. A balanced approach that prioritizes the need to foreign aid to optimize outcomes has the capacity to ensure inclusive and resilient economic development.

The alignment of empirical findings with the expected transmission mechanism reinforces the potential for emissions reduction policies to drive sustainable economic growth in Nigeria. From the introduction of policies to sectoral implementation and economic implications, the findings validate the anticipated impacts of emissions reduction strategies on macroeconomic performance. Reducing energy emissions remains pivotal in Nigeria's quest for sustainable development and economic prosperity by 2030. As the nation navigates the complexities of energy transition, concerted efforts to align environmental objectives with economic imperatives will be crucial. By embracing innovation, fostering collaboration, and prioritizing inclusive growth, Nigeria can chart a course towards a greener, more resilient future.

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