DEEP DECARBONIZATION PATHWAYS (DDP) FOR NIGERIA'S LOW EMISSION DEVELOPMENT UP TO 2060

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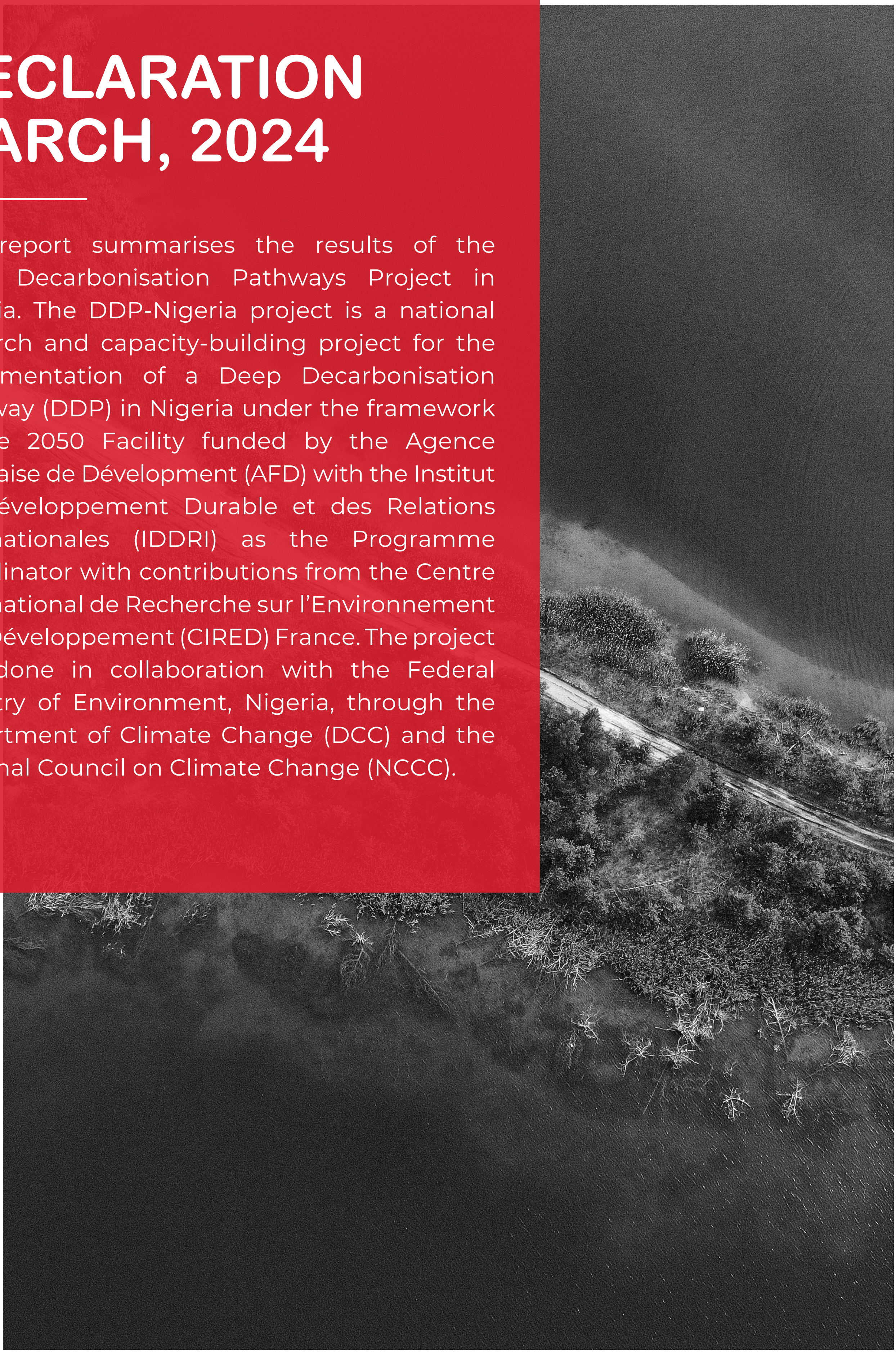
This report summarises the results of the Deep Decarbonisation Pathways Project in Nigeria. The DDP-Nigeria project is a national research and capacity-building project for the implementation of a Deep Decarbonisation Pathway (DDP) in Nigeria under the framework of the 2050 Facility funded by the Agence Française de Dévelopment (AFD) with the Institut du Développement Durable et des Relations Internationales (IDDRI) as the Programme Coordinator with contributions from the Centre International de Recherche sur l'Environnement et le Développement (CIRED) France. The project was done in collaboration with the Federal Ministry of Environment, Nigeria, through the Department of Climate Change (DCC) and the National Council on Climate Change (NCCC).



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The DDP-Nigeria team enjoyed the collaboration of Natural Eco Capital and the 2050 Pathways in the elaboration of Nigeria's Long-Term Low Emission Development Strategy (LT-LEDS).

The DDP-Nigeria team acknowledges the efforts of the technical committee and the advisory board created by the DCC, through which input from the MDAs was received. The committees provided a valuable platform for continued dialogue with policymakers and pushed hard to ensure that the scenarios and policies were relevant to the Nigerian context. The Administrative Office of the Centre for Climate Change and Development, Alex Ekwueme Federal University Ndufu-Alike, is acknowledged for all the support and direction in ensuring that the DDP-Nigeria project was successful.

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ABBREVIATIONS

AAGR	Average Annual Growth Rate
AE-FUNAI	Alex-Ekwueme Federal University Ndufu-Alike
AFD	French Development Agency
AFOLU	Agriculture, Forest, and Other Land Uses
BAU	Business as Usual
BU	Bottom-up
CBN	Central Bank of Nigeria
CCCD	Centre for Climate Change and Development
CCS	Carbon Capture Storage
CGEM	Computable General Equilibrium Model
COP	Conference of the Parties
CPEEL	Centre for Petroleum, Energy Economics, and Law
CPS	Currently Policy Scenario
ETP	Energy Transition Plan
EV	Electric Vehicle
FGN	Federal Government of Nigeria
gCO2e per kWh	Grams of Carbon Dioxide Equivalent per kilowatt hour
GDP	Gross Domestic Product
GES	Gas Economy Scenario
GHG	Green House Gas
IDDRI	Institut du Développement Durable et des Relations Internationales
IPCC	Inter-Governmental Panel on Climate Change (IPCC)

IPPU	Industrial Processes and Product Use
KLEM	Capital, Labour, Energy and Material
KLEM-NGA	Capital, Labour, Energy and Material Model for Nigeria
LEAP	Low Emission Analysis Platform
LEAP-NGA	Low Emission Analysis Platform for Nigeria
LPG	Liquified Petroleum Gas
LT-LEDS	Long-Term Low Emission Development Strategy
LTS	Long-Term Strategy
LULUCF	Land Use, Land-Use Change, and Forestry
MAED	Model Analysis of Energy Demand
MtCO2e	Million Tonnes of Carbon Dioxide Equivalent
NCCC	National Council on Climate Change
NCCC	National Council on Climate Change
NDC	Nationally Determined Contribution
NGA	Nigeria
NIIA	Nigerian Institute of International Affairs
PJ	Petajoule
REDD+	Reducing Emissions from Deforestation and Forest Degradation
REER	Real Effective Exchange Rate
RES	Renewable Energy Scenario
SAM	Social Accounting Matrix
SEI	Stockholm Environment Institute
UK	United Kingdoms
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar

EXECUTIVE SUMMARY

The report is anchored on the analytical work commissioned under the Deep Decarbonisation Pathways (DDP) Project in Nigeria (DDP-Nigeria). The DDP-Nigeria project is a national research and capacity-building project for the implementation of a Deep Decarbonisation Pathway (DDP) Project in Nigeria under the framework of the 2050 Facility funded by the Agence Française de Dévelopment (AFD) with the Institut du Développement Durable et des Relations Internationales (IDDRI) as the Programme Coordinator. The project was done in collaboration with the Federal Ministry of Environment, Nigeria.

The project was conceived to appropriately respond to the low emission development commitment of the Federal Government of Nigeria in many local and international forums. In developed nations, low-emission development policies are crafted based on rigorous studies of the economic sectors, which are heavily based on long-term modelling of development scenarios. It was, therefore, urgent to take up studies that are focused on adequate modelling of low emission development scenarios based on evidence on the ground, namely demographic data, economic data, energy demand and supply data, energy sources, proven energy conversion technologies, carbon financing mechanisms, energy losses, and energy diffusion data using a variety of high-fidelity models, namely LEAP and KLEM.

The current significant contribution of the energy sector to the Nigerian economy, combined with the depletion of the country's fossil resources and the global climate crisis, call for the development of a hybrid energy-economy modelling structure to assess the consequences of changes in domestic consumption, fossil fuel production, and energy trade on Nigeria's economic development. By integrating various fields of expertise in a consistent manner, a hybrid framework enables the provision of comprehensive support for decision-making regarding both socioeconomic development

paths and the evolution of sustainable energy systems from primary energy supply to final consumption.

The priority is to develop ways to industrialise and transition without significantly increasing the country's carbon profile. To achieve this, Nigeria would need to execute mitigation and adaptation methods and strategies that significantly improve macroeconomic stability, economic transformation, and job creation while minimizing the negative effects of climate change on development. This analysis explores the various facets of Nigeria's energy transition, examining the driving forces, challenges, opportunities, and policy initiatives shaping this crucial transition. The focus is a consideration of the pathways to achieve an energy and green economy transition in ways that are sensitive to Nigeria's current economic reality and resource endowment, as well as the global goal of decarbonization.

It is appreciated that leveraging climate action to promote economic development in Nigeria is not only a realistic but also a necessary strategy. Climate considerations can result in inclusive and sustainable growth when incorporated into economic development initiatives. The objective is to build a climate-resilient economy that not only promotes growth and poverty reduction but also creates good green jobs and contributes to the reduction of greenhouse gas emissions and environmental sustainability. In doing so, Nigeria will be able to position itself for a more resilient and affluent future by proactively tackling the issue of stranded assets.

Nigeria has shown commitment to embark on energy transition and climate action that will enable it to achieve the goal of economic growth and meet the development aspirations of its citizens in ways that are consistent with global climate goals. Nigeria has made some progress in developing policies to support the transition to renewable energy sources. The National Energy Policy of 2003, the Electric Power Sector Reform Act of 2005, and the Nigeria Renewable Energy Master Plan developed in 2006 are examples of policies that articulate the government's commitment to renewable energy development. Others include the Nationally Determined Contributions (NDC), the Energy Transition Plan (ETP), and more recently, the Long-Term Low Emission Development Strategy (LT-LEDS), which benefited from the modelling efforts presented in this report. These policies address various aspects, including environmental concerns, energy utilization efficiency, financing, and policy implementation. However, there is a need for further development and implementation of policies that specifically focus on promoting and supporting energy transition in light of the net-zero by 2060 pledge made by the country at COP26 in Glasgow.

As has been widely reported, the Energy Transition Plan (ETP) provided the basis for the Net zero emissions by 2060 pledge made by the Nigerian government at COP26 in 2021. Since then, the Long-Term Low Emissions Development Strategy (LT LEDS), recently concluded, has provided quantifications using four scenarios: Business as Usual (BAU), Currently Policy Scenario (CPS), Gas Economy Scenario (GES), and Renewable Energy Scenario (RES), all of which provide alternative pathways for achieving Nigeria's net zero pledge by 2060 as well as the macro-economic implications of the transition pathways.

The BAU imagines a significant increase in Nigeria's GHG emissions from all sectors due to a growing GDP and population, without any mitigation efforts. It describes the trajectory of the Nigerian energy system, largely based on the prolongation of current trends. The CPS imagines an economic trajectory that is guided by the ambitions of Nigeria's Energy Transition Plan and the country's Nationally Determined Contributions including achieving over 90% of power generation from renewable energy resources by 2050. The GES imagines Nigeria utilizing its natural gas resources as a transition fuel and for energy-intensive industries while also implementing critical demand-side policies such as modal shifts in transportation. The RES envisages ambitious emission reductions that allow Nigeria to reach a net-zero objective by 2060. It assumes around 98% zero-emission energy penetration in the power sector by 2060, with over 97% generated by renewable energy resources, the remainder coming from nuclear power.

This report contributed significantly to the quantification part of the recent LT-LEDS work.

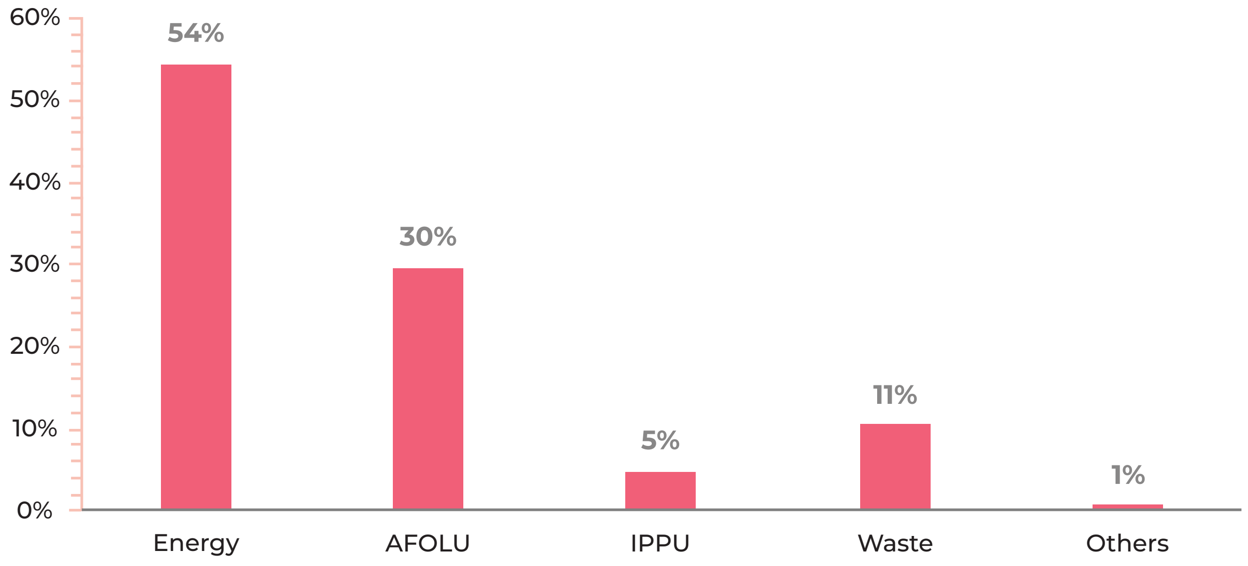
Key Findings

- The energy consumption of the country was estimated at 3601.90 petajoules (PJ) for 2018 (the base year), dominated by firewood consumption. Under a BAU scenario, Nigeria's energy consumption will be 10,858 PJ by 2060, and cumulative emissions will be about 1053 MtCO2. This will represent a 201 percent increase in the current 2018 energy consumption by 2060. Equally important is the fact that fossil fuel use, as well as firewood and charcoal, will continue to play a significant role in the energy space up to 2060, with their far-reaching consequences on health, biological diversity, and climate change.

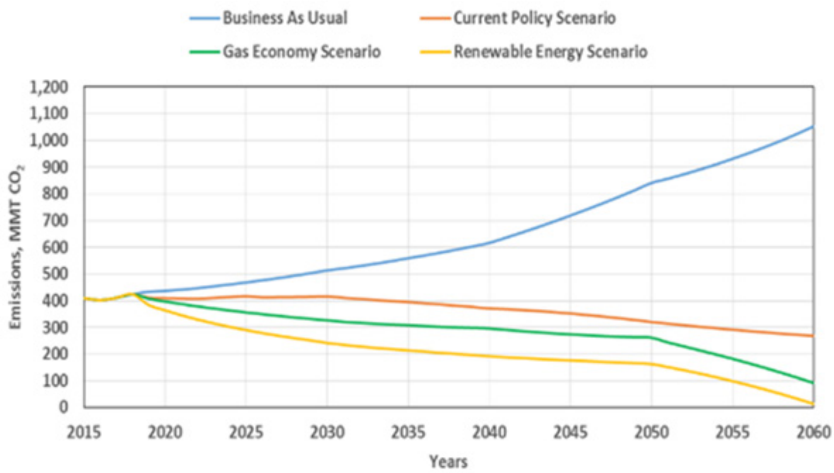
- Under the CPS, fossil (excluding gas) use grows and dominates the energy space up to 2040 (1223 PJ). However, by 2050, electricity becomes the dominant source of energy, accounting for 45.7 percent of the total.

- Under the GES, wood and charcoal at 1421 PJ are the dominant energy in 2030, while fossil fuel (gas) grows and dominates the energy space beyond 2040 and up to 2060. Also for the RES, wood and charcoal at 1528 PJ will dominate the energy space in 2030, while electricity will dominate beyond 2050. The GES scenario shows higher total energy consumption than the CPS and the RES. Which is attributed to the efficiency of energy conversion technology.

- The energy sector contributes about 54% of the national emissions (424.30 MtCO2eq), which is followed by Agriculture, Forestry, and Other Land Use (AFOLU); contributing about 30% of the national emissions in 2018 (see the figure below). More than 50% of the emissions from the energy sector were from the oil and gas subsector in 2018, which are related to commercial production and transformation of oil and gas.



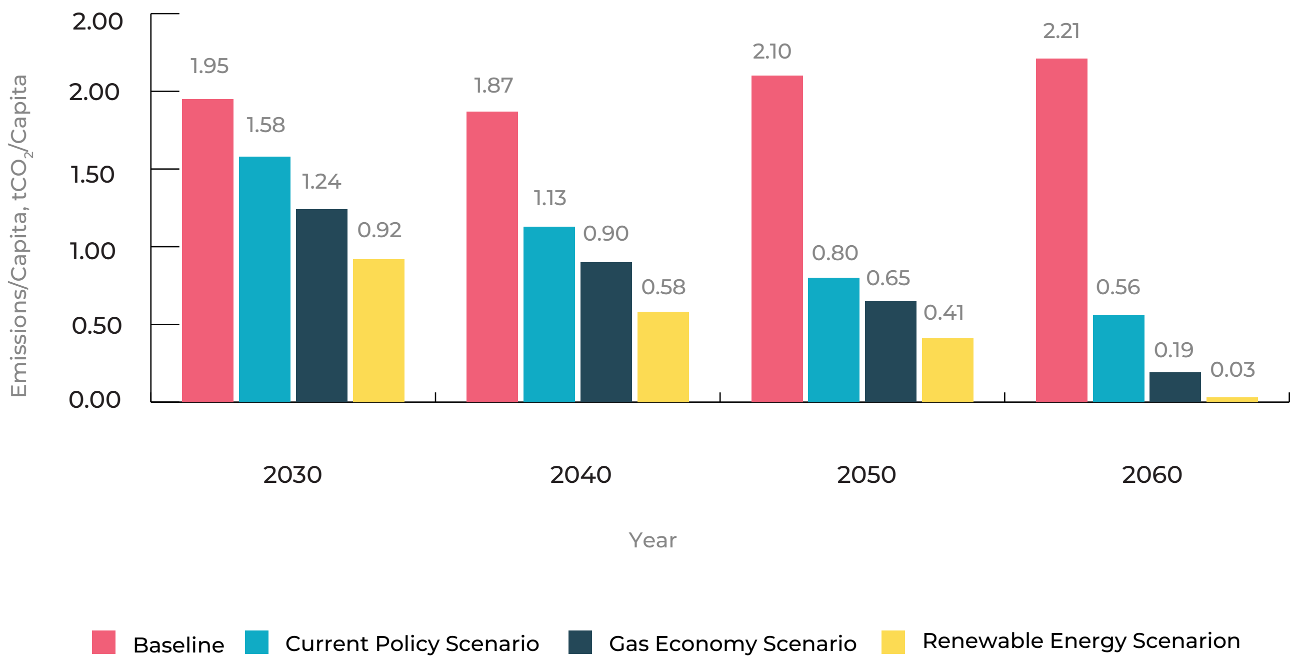
- In 2030, the emissions of the BAU, CPS, GES, and RES stood at 514, 416, 327, and 242 MtCO2eq, respectively (see the figure below). The results for 2030 show that the CPS will reduce emissions by 1.7% of the base year (2018 value), while GES and RES can reduce emissions by 22.8% and 42.9%, respectively. It should be noted that the amount of emissions under GES would be significantly higher, except that the scenario entails the use of Carbon Capture Storage (CCS).



- The results indicate that the CPS, GES, and RES, respectively, could reduce the base year emissions by 24.4%, 30.1%, and 61.5% in 2050, whereas the reduction would be 36.7%, 78.3%, and 96.8% in 2060, respectively. Only the RES shows the potential to achieve the government's net zero emissions pledge at COP26.

- Besides the carbon capture technology, the emissions reduction in the GES and RES are also driven by nature-based carbon sinks (afforestation and reforestation) at rates of 5% and 2.5% annually, respectively.

- By 2030, the CPS, GES, and RES, respectively, will have emissions per capita of 1.95, 1.58, 1.24, and 0.92 tCO2eq/capita, whereas they will be 2.21, 0.56, 0.19, and 0.03 tCO2eq/capita by 2060 (see the figure below). The implication is that the RES has the best potential to achieve a net-zero target by 2060, i.e., the average person will only emit 30 CO2eq by 2060.



- By 2060, the emission factors of the mitigation scenarios will fall to 1, 0.3, and 10 gCO2e per kWh, respectively, for GES, CPS, and RES, as compared with 461 gCO2e per kWh for the BAU.

- From a purely macroeconomic point of view, the CPS, GES, and RES+ emerge as the most promising. In 2060, the CPS scenario has the highest real GDP at 4,089.61 million 2021 USD with a growth rate of 5.53%; GES shows a real GDP of 4,069.31 million 2021 USD with a growth rate of 5.52%; and RES+ shows a GDP of 4,067.97 million 2021 USD with a growth rate of 5.52%. Notably, RES+, however, marks the benefits of the surmised international support that differentiates it from RES: its GDP dominates all other scenarios up to 2054, when it roughly falls in line with the CPS and ends up 2.1% below potential GDP (like GES) in 2060. RES real GDP increasingly lags behind all other scenarios from 2032 on, with an average annual growth rate (AAGR).

- **Over the 39-year period, the cumulated international financial aid amounts to 880 billion USD in 2021 USD. This is a rough half of the overall cost of Nigeria's Energy Transition Plan, estimated at 1.9 trillion USD (see Introduction).**

- The unemployment rate decreases in all scenarios until 2035, thanks to successful structural transformation and increased employment in non-energy domestic production. However, CPS, GES, and RES+ are more effective in reducing unemployment, respectively achieving a 5.30%, 5.85%, and 6.00% unemployment rate in 2060. Conversely, RES performs the worst among the scenarios—8.16%—reflecting its lower competitiveness due to higher energy costs.

- All scenarios show improvements in energy efficiency, with RES and RES+ demonstrating the most significant gains. However, these scenarios also face higher energy costs, impacting competitiveness in both domestic and international markets.

- The scenarios have varied impacts on Nigeria's energy trade balance. In Baseline, the unchecked rise of domestic energy consumptions, together with an energy mix highly based on fossil fuels, indicates that Nigeria will become a net energy importer (in money value) in 2042, necessitating 0.9% of its 2060 GDP to cover the incurred net costs.

- GES experiences a rapid decline in its export capacity because of uncontrolled domestic energy demand. However, the development of natural gas extraction and the substitution of domestically extracted gas for imports of refined oil products allow Nigeria to remain a net energy exporter.

- CPS, RES, and RES+ benefit from transitions away from fossil fuels and lower domestic energy demand, allowing Nigeria to remain a net energy exporter. In those scenarios, net export revenues, although rapidly declining in the early years, remain above 2% of GDP.

Economy-Wide Implications and Recommendations

- **Aggressive Climate Change Mitigation :**

The decarbonisation of the Nigerian economy will strongly depend on the use of natural gas as a transition fuel and the utilisation of renewable energy sources (solar, wind, hydropower, and bioenergy) and other clean energy sources (e.g., nuclear) coupled with climate-smart sectorial measures (e.g., energy efficiency and energy management measures).

- **Holistically Navigate the Climate Change Landscape :**

Evidence-based policies with implementable plans should be prioritised for climate change mitigation, adaptation, and resilience to holistically respond to the Paris Agreement without distorting the aim to achieve the Sustainable Development Goals.

- **Industry Decarbonisation Policies :**

Enabling industry decarbonisation policies aiming at reducing the carbon footprint of various economic sectors by promoting cleaner and more sustainable practices should be prioritised. The industrial sector is a significant contributor to greenhouse gas emissions due to processes like manufacturing, energy production, and transportation. Implementing policies to decarbonize industries is crucial for achieving climate goals and mitigating the impacts of climate change.

- **Waste Sector Decarbonisation :**

There should be deliberate efforts to adopt environmentally sustainable and climate-resilient practices in the waste sector, aiming at minimising the environmental impact of waste disposal, reducing greenhouse gas emissions, and contributing to overall climate change mitigation and adaptation efforts.

- **Climate-Smart Agriculture and Transport :**

Enabling policies targeting the adoption of climate-smart agricultural and transport practices help increase resilience to climate change, and climate change mitigation should be highly encouraged since agriculture and transport contribute significantly to the emission profile of the country.

- **Technology Assimilation and Transfer :**

Providing training programs and capacity-building initiatives can help industries adopt new technologies and practices, supporting a skilled workforce in the transition to low-carbon processes.

- **Supporting Diversification and Renewable Energy :**

Policies should prioritize economic diversification and investment in renewable energy (solar, wind, hydropower, and bioenergy), especially considering the balanced benefits offered by the RES+ scenario in terms of economic growth and unemployment reduction.

- **Support for GES and RES+ :**

Policies should support both the GES and the RES+. While GES shows potential for immediate economic benefits, the RES+ scenario offers a balanced approach, coupling economic growth with sustainability. However, the viability of the RES+ scenario hinges on substantial international financial support, estimated at USD 960 billion over 38 years, accounting for roughly half of the overall cost of Nigeria's Energy Transition Plan (USD 1.9 trillion).

- **International Aid and Long-term Planning :**

Pursuing international aid is crucial for the RES+ scenario. Policymakers should actively engage in global dialogues to secure this support, aligning with commitments like the UNFCCC's annual USD 100 billion support pledge. Long-term strategic planning is essential, considering the trade-offs between immediate economic needs and sustainable development goals.

- **Public Awareness and Education :**

Creating awareness among the public about climate change and its impacts is essential for building support for mitigation efforts. Education campaigns can encourage sustainable practices and behaviours, including energy efficiency measures.

01
INTRODUCTION

1.1 | Background

Climate change has a range of effects on the Earth's systems, negatively impacting ecosystems, weather patterns, and human societies globally. Climate change continues to compound the development challenges of Nigeria, making attaining national sustainable development goals, particularly in the short-term, difficult for the country [1]. This is because the country's largely fragile economy is strongly vulnerable to the impacts of climate change, as many of the sectors, particularly the agriculture sector, which contributes about 24 % to its GDP, are climate sensitive.

Successive reports of the Inter-Governmental Panel on Climate Change (IPCC) have attributed climate change to the increased concentration of greenhouse gases (GHGs) in the earth's atmosphere, which is due to anthropogenic activities such as industrial processes, burning of fossil fuels, deforestation, and unsustainable agricultural practices (IPCC, 2014; IPCC, 2018; IPCC, 2022). Therefore, it is incumbent to decarbonise (i.e., reduce the emission of GHGs) the global economy. Efforts to decarbonise the global economy involve initiatives and strategies aimed at reducing GHG emissions to mitigate climate change. There is not a single, unified global initiative to decarbonise, but rather a combination of international agreements, national policies, industry commitments, and technological advancements.

One of the efforts to decarbonise the global economy is through the energy transition, which refers to a global shift from traditional, fossil fuel-based energy sources to more sustainable and renewable alternatives. This transition is driven by the need to address environmental concerns, such as climate change and air pollution, as well as to ensure a more secure and resilient energy future. However, the energy transition poses both challenges and opportunities for oil-rich countries, like Nigeria for example. These nations, often heavily dependent on revenues from the extraction and export of fossil fuels, particularly oil and gas, face significant economic implications as the global energy landscape shifts towards cleaner and more sustainable alternatives.

Nigeria, often referred to as the "Giant of Africa," has long been a significant player in the global energy market due to its vast oil and gas reserves. Oil has contributed significantly to the total export revenue since the 1990s, for example, over 86% of the total export revenues in 2021[2]. According to a study conducted by the Central Bank of Nigeria (CBN) and the Nigerian Institute of International Affairs (NIIA), foreign direct investment in the oil and gas sector significantly impacts Nigeria's

[1] Diemuodeke, E.O. and Okereke, C. (2020) Energy Scenarios for Ambitious and Effective Nigeria's Nationally Determined Contributions. Journal of Energy Technology Policy

[2] OPEC (2021) Nigeria facts and figures, Annual Statistical Bulletin. Available at: https://www.opec.org/opec_web/en/about_us/167.htm

economic growth. But even if the oil and gas sector remains reasonably strong over the next three decades, the imperative to decarbonise the economy remains strong, given its contribution to climate change. In addition, it is necessary for Nigeria to seize the opportunities in the global shift from oil and gas utilization to the decarbonisation space to position its economy on the path of shared socio-economic prosperity in the long term. The country is increasingly recognizing the need to diversify its energy mix, reduce its carbon footprint, and enhance energy security. As a Party to the Paris Agreement, Nigeria has made key commitments aimed at reducing GHG emissions to mitigate climate change.

1.2 Nigeria's Key Commitments to Climate Change Mitigation

1.2.1 Nationally Determined Contribution

The Nationally Determined Contribution (NDC) is a near-term emission abatement strategy regarding how Nigeria pledges to reduce its carbon emissions by 2030. As a signatory to the Paris Agreement (Article 4.2), Nigeria is required to "prepare, communicate, and maintain" successive nationally determined contributions (NDCs) that it intends to achieve. Nigeria disclosed its Nationally Determined Contribution (NDC) in 2015. In the NDC of 2015, Nigeria targeted a reduction in its emissions of 20% under the"Unconditional NDC" – if no external support is received. However, with international assistance, Nigeria pledged a 45% emissions reduction below its business as usual by 2030. As stipulated by the Paris Agreement, Nigeria's NDC was revised and updated in 2021 to reflect a higher degree of ambition. In the updated NDC, Nigeria maintains its unconditional pledge of lowering its emissions to 346 MtCO2eq but offers to

pursue a more ambitious conditional pledge of lowering its emissions to 241 MtCO2eq, i.e., 47% below the business as usual, and a lower absolute GHG emissions level than the one stated in the 2015 NDC.

Some strategic measures that the revised NDC enshrined to meet the conditional NDC target include:

- I Ending gas flaring by 2030,
- II Elimination of diesel and petrol generators by 2030,
- III 48% and 13% penetration of LPG and improved cookstoves, respectively, in the household sector,
- IV Reduction in energy intensity by 2.5%, annually, across all sectors

V 30% of grid-connected electricity generation from renewable energy,

VI Installation of 13GW of off-grid renewable energy solutions,

VII Elimination of kerosene lighting by 2030,

VIII Reducing transmission and distribution losses to 8% by 2030, (ix) all vehicles to meet EURO IV emission limits by 2030,

IX All vehicles to meet EURO IV emission limits by 2030,

X 25% of trucks and buses to run on CNG by 2030, while, Bus Rapid Transport will account for 22.1% of passenger-km by 2035,

XI Reducing the burning of crop residues by 50% by 2030,

XII 50% of cultivated land adopts intermittent aeration of rice paddy fields,

XIII 46,219 ha of forest cover in the country is to be protected; and 46,219 ha of forest cover in the country to be protected and

XIV Reduce the area of forestland used for fuelwood harvesting by 19346 ha.

The NDC assumptions were modelled using the Low Emissions Analysis Platform (LEAP). The team was led by Ricardo, Hans Verolme and local consultants, with the modelling was conducted by the Stockholm Environment Institute (SEI).

1.2.2 The Energy Transition Plan

The Energy Transition Plan (ETP) is a strategy developed by McKinsey aiming to explore Nigeria's journey to net zero, with a focus on the renewable transition. Work kicked off on the ETP in March 2021, in the run up to COP26. The McKinsey team developed three scenarios, modelled using McKinsey's proprietary software. These scenarios were:

01 A baseline scenario (based on the current pathway for macroeconomic development and without decarbonisation effort);

02 An NDC-guided scenario (incorporating existing national programs with decarbonisation effects); and

03 A net zero 2050 scenario (focusing on electrification and the renewable transition).

All scenarios were initially modelled to 2050, with additional work then done to explore how costs would spread or change if the net zero target date was extended to 2060 (for example, by better aligning with natural product replacement cycles in industry, or to allow for more time for EVs to penetrate the second-hand market). However, a 2060 pathway was not modelled. The ETP is very ambitious on renewables. For example, net zero by 2050 required 200 GW of solar, which meant around 7-8GW per year. This was benchmarked against other geographies that had experienced rapid uptake of solar – for example, California and Germany at around 2-3 GW a year. Hence another reason for pushing the net zero target back to 2060 to allow for more realistic uptake rates.

1.2.3 Nigeria's Climate Change Act, 2021

The Climate Change Act 2021 provides the legal framework for achieving low greenhouse gas emissions that is inclusive of green growth and sustainable economic development. The Act was signed into law in November 2021 by President Muhammadu Buhari. The Act demonstrates a commendable first step that the government has taken to meet its obligations to combat climate change under the various treaties to which it has subscribed. The Act provides a comprehensive regulatory framework to achieve its long-term climate goals, encompassing a net-zero target, funding, , environmental and economic accountability, and championing climate actions. The Act ensures that Nigeria formulates programmes for achieving its long-term climate change mitigation and adaptation targets. The Act sets a target of 2050 –2070 to attain net-zero greenhouse gas emissions, in line with Nigeria's international climate action commitments. Some important highlights of the Act are establishing the National Council on Climate Change, establishing a Climate Change Fund, providing a carbon budget and national climate change action plan, and undertaking vulnerability and risk assessment.

1.2.4 Nigeria's Net-Zero Emission Commitment in Glasgow

At the Conference of Parties (COP26) held in Glasgow in 2021, the Federal Government of Nigeria made three significant pledges, which include the net zero emission pledge, the global methane pledge, and the declaration on forest and land use. The President of the Federal Republic of Nigeria, Muhammadu Buhari, pledged that Nigeria will cut down its emissions and reach net zero by 2060. The role of gas in supporting renewable energy-based systems in the country's energy transition roadmap is at the heart of this pledge. Furthermore, the President explained that 7 GW of renewable energy would be added annually to address the country's clean energy shortage, and that the government is committed to electrifying 5 million households with decentralized solar solutions by 2030. Also, the government joined other countries in pledging to reduce global methane emissions by 30% by 2030, below 2020 levels. Regarding forest and land use, 141 countries, including Nigeria, pledged to conserve and restore forests over the next 10 years. These pledges are very ambitious and require that many sectoral strategies be put in place and policies enforced to attain them.

1.3 | Report Structure

This report starts by providing background to the report, followed by an in-depth description of the methodology used for the analysis, which includes scenarios development and modelling platforms. Thereafter, results from the analysis are presented in a logical manner: power generation capacity, energy consumption, emissions, sectoral analysis and macroeconomic implications. The synthesis of the findings for policymakers, with a focus on sectoral nuances are presented. The work concludes with the implications of the report and recommendations, as reflected in the executive summary.

02
METHODOLOGY

2.1 | Scenarios Development

A scenario-thinking approach is a great way to explore different potential futures and analyse the outcomes of different decisions. However, it is important to remember that scenarios are not meant to predict the future with certainty. In this regard, four scenarios were developed, based on Nigeria's Deep Decarbonisation Pathways (DDP) project, to support the modelling exercise. The goal is to deeply decarbonise the country by 2060, while also improving key macroeconomic indicators like GDP, employment, and poverty levels. These scenarios were developed through a combination of bottom-up and top-down modelling frameworks and take into account both energy and non-energy induced emissions.

In formulating the four DDP scenarios (as depicted in Figure 1), consideration was given to Nigeria's development goals of universal energy access, resource availability, climate change, economic competitiveness, poverty eradication (through employment), food security, improved education quality, and other key national development priorities, namely the Nationally Determined Contribution (NDC), the Energy Transition Plan (ETP), and the Long-Term Strategy (LTS). In addition, Nigeria's net-zero emission commitment by 2060 at COP 26 in Glasgow[3] was considered through aggressively utilising renewable energy and adopting energy efficiency and management measures across all sectors, along with agro-waste and forest management measures (e. g. reforestation and afforestation). Therefore, the scenario analysis involved elaborating scenario pathways, including required technologies, fuel switching, renewable and non-renewable energy penetration, deforestation, and forest degradation (REDD+) and economic implications. The scenarios are implemented within different modelling frameworks, which are based on extensive context-sensitive data. However, there is still room to incorporate new policies, technologies, and economic variables into the scenarios and modelling frameworks to gain a better understanding of the energy and macroeconomic implications of deep decarbonisation in Nigeria. The storylines supporting each of the four scenarios are presented in the following subsections.

[3] Federal Republic of Nigeria (2021)

https://statehouse.gov.ng/news/at-cop26-president-buhari-pledges-net-zero-emissions-by-2060-says-nigeria-will-maintain-gas-based-energy-transition/#:~:text=The%20Statehouse%2C%20Abuja-,At%20COP26%2C%20President%20Buhari%20Pledges%20Net%20Zero%20Emissions%20by%202060,Maintain%20Gas%2DBased%20Energy%20Transition&text=President%20Muhammadu%20Buhari%20Tuesday%20in,to%20net%20zero%20by%202060

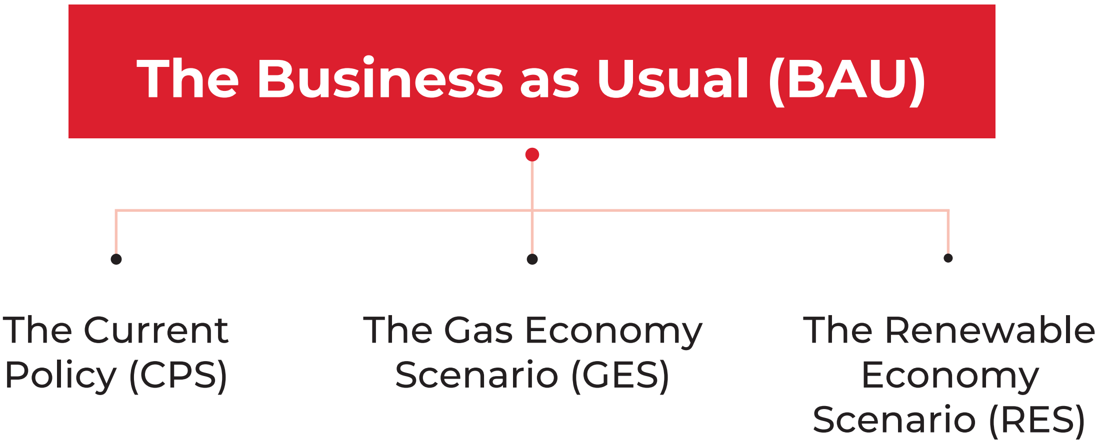


Figure 1 DDP Scenarios

2.1.1 Business As Usual (BAU)

The BAU imagines a significant increase in Nigeria's GHG emissions from all sectors due to a growing GDP and population, without any mitigation efforts. Indeed, it describes a trajectory of the Nigerian energy system largely based on the prolongation of current trends, with the assumption that energy subsidies observed in the calibration year remain in place. On the side of supply, wood and fossil fuels remain the main energy resources in 2060, while use of renewables is low and gas flaring is still happening at current rates. The 2060 power generation mix is dominated by gas (64%) and coal (24%), while hydroelectricity (8%) dwarfs other renewable options. Household and transport energy demands are projected based on increases in population and income levels, while energy demand from agricultural, services and industry sectors are indexed on the GDP growth rate.

2.1.2 Current Policy Scenario (CPS)

The CPS imagines an economy that is guided by the ambition of Nigeria's Energy Transition Plan and the country's Nationally Determined Contributions to mitigation in the framework of the UNFCCC process. Accordingly, by 2050, over 90% of power generation is attributed to renewable energy resources. Moreover, gas flaring is expected to end by 2030, and the use of wood is strongly decreased in the total primary energy supply by 2060. Regarding energy demand, 85% of inefficient household technologies are replaced, while backup fossil fuel generators are eliminated by 2060. Bioenergy with carbon capture and storage accounts for 50% of cement production, and electric vehicles replace more than 85% of fossil fuel-powered cars and buses. In addition, modal shares of buses and three-wheelers reach 43% and 40%, respectively. Energy intensity of the industry sector is identical to that of the BAU. Energy intensity of transportation, as well as the absolute energy consumption of households, are strongly decreased thanks to efficiency gains in final energy uses and an emphasis on the use of electric vehicles (EVs).

2.1.3 Gas Economy Scenario (GES)

The GES describes an aggressive exploitation and utilization of Nigeria's natural gas resources. It assumes that natural gas with carbon capture and sequestration accounts for 57% of supply for energy-intensive industries and 35% of power generation by 2060, with zero gas flaring by 2030. On the demand side, modal shares of 50% and 20%, respectively, are achieved for buses and three-wheelers by 2060. In the residential sector, 100% of inefficient technologies are replaced, LPG, natural gas and electricity technologies supply 90% of cooking energy needs by 2060. Industrial energy intensity is equivalent to that of the BAU. The energy intensity of transportation also remains at the same high level as in the BAU due to the low penetration of EVs. Furthermore, an aggressive reforestation rate, at 5% annually, is assumed to support nature-based carbon sinks, while forestry management practices are in line with global mechanism of reducing emissions from deforestation and forest degradation (REDD+)

2.1.4 Renewable Energy Scenario (RES)

The RES envisages ambitious emission reductions that allow Nigeria to reach a net-zero objective by 2060. It assumes around 98% zero-emission energy penetration in the power sector by 2060, with over 97% generated by renewable energy resources, the remainder coming from nuclear power. Electricity accounts for most energy uses in the service, transport, and industrial sectors. For passenger transportation, the modal shares of buses and three-wheelers reach 50% and 20% respectively, as they do in the CPS and GES. Clean cooking accounts for 95% of cooking energy and inefficient household technologies are replaced totally by efficient technologies by 2060. The energy intensity of industries is slightly decreased compared to the other scenarios. Energy demand for household transport is even lower than in the CPS scenario, thanks to increasing efficiency in final energy uses and a strong penetration of EVs. Households' residential demand is also strongly decreased compared to the Baseline scenario, by up to 81% in 2060. Enteric fermentation is reduced by 5, 8, and 10%, respectively, by 2030, 2050, and 2060. In addition, a moderate reforestation rate, at 2.3% annually, is assumed to support nature-based carbon sinks, while forestry management practices are in line with the global mechanism of reducing emissions from deforestation and forest degradation (REDD+). Furthermore, emissions from waste decrease by 5, 10, 15, and 20%, respectively, by 2030, 2040, 2050, 2060, due to improved waste management and waste-to-energy practices.

2.1.5 Renewable Energy Scenario Plus (RES+)

This scenario was explored only in the macroeconomics modelling framework, making the scenarios under the macroeconomic modelling five scenarios. The RES+ scenario considers the RES evolution of the Nigerian energy system but relies on international aid to fund the incremental energy supply investment required to shift from the CPS to the RES energy trajectory. The RES+ envisages that part of the Nigerian energy supply investment effort is supposed to come from international aid (in the form of grants)[4] .

[4] The trade deficit gradually decreases from 3.5% of GDP in 2021 to 1% in 2035 and beyond in all scenarios except RES+, in which the trade balance deficit is relaxed.

2.2 | Modelling

2.2.1 Energy and Emissions

The Low Emission Analysis Platform (LEAP) modelling platform was the tool of choice for energy and emission modelling. The LEAP modelling platform is a high-fidelity software adopted by many nations (nearly 190 countries) for integrated energy planning and climate change mitigation assessment through energy mix and emissions accounting[5] .

The Nigeria LEAP (LEAP-NGA) model structure was designed to reflect the sector-tailored integrated scenarios, as described in 2.1. As a result, the LEAP-NGA model, which is anchored on the LEAP bottom-up model architecture, provided the quantitative information about the energy mix and emissions of the country under the various DDP scenarios. LEAP-NGA structure was developed by integrating all the country's sectors: energy, Agriculture, Forestry, and other Land Use (AFOLU), industry, services, and waste (see Figure 2 for the structure of LEAP-NGA). The energy sector comprises residential and building, power, transport, and oil and gas subsectors. The LEAP-NGA model relies on the key BAU assumptions (Appendix 1) and key policy assumptions supporting each of the four DDP scenarios (Appendix 2) and Nigeria's context-sensitive data showing the data sources. The LEAP-NGA model is used to track energy mix, consumption pattern, production, resource extraction and emissions under featured scenarios.

It is important to note that, the result obtained using these models were computed based on the 100-Year global warming potential (GWP), which is consistent with the Intergovernmental Panel on Climate Change (IPCC) guidelines.

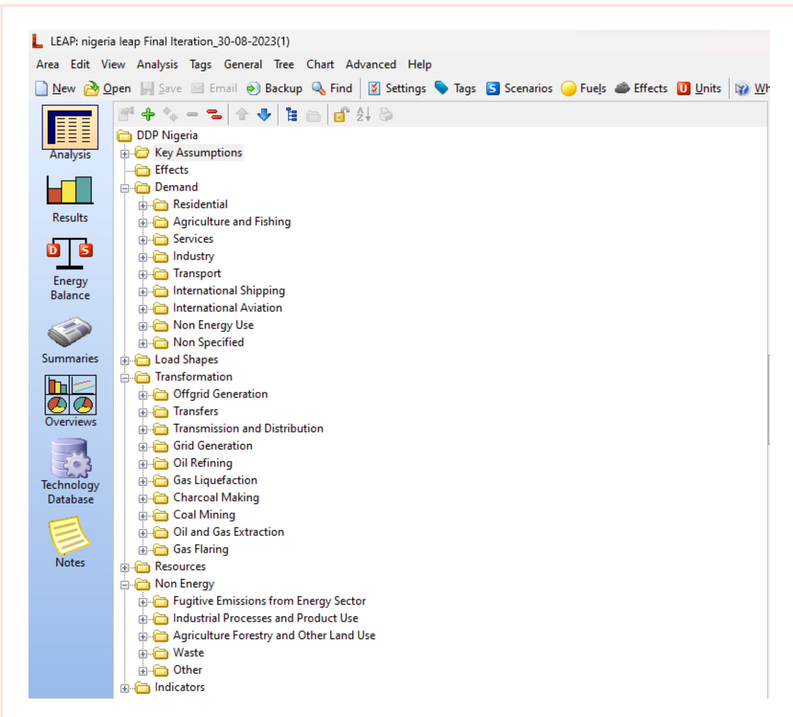


Figure 2 LEAP-NGA's Structure

[5] C. Heaps (2021) The Low Emission Analysis Platform. https://www.sei.org/tools/leap-long-range-energy-alternatives-planning-system/

2.2.2 Macroeconomics

To produce energy-economy outlooks of the Nigerian economy, a hybrid modelling structure was developed, which combines the strengths of the bottom-up, technology-rich LEAP model of Nigeria's energy system and the top-down, macroeconomic KLEM-NGA model[6]. The hybrid model maximise the consistency of that soft-linking by building it on an original, hybrid energy-economy database that reconciles Nigeria's national accounting and energy balance data.

The KLEM-NGA model was developed under the Nigeria-DDP project as stated previously. KLEM is a dynamic, recursive computable general equilibrium (CGE) macroeconomic model that pictures economic growth as driven by exogenous assumptions on labour supply and productivity, as well as on the investment rate i.e., the share of GDP devoted to building up capital stock. As its name conveys, KLEM models two primary factors capital (K) and labour (L), and two sectors or products energy (E) and the remainder of the economy ('materials' M). This level of aggregation is meant to focus KLEM's analysis on overall macroeconomic impacts while maximising the ability to interpret the model's results. Its main limitation is to overlook influence of structural change within the non-energy sector. The purpose of the KLEM model is to compute macroeconomic trajectories under constraint of exogenous energy flows and prices informed by some bottom-up (BU) model, on both international and domestic markets.

Beyond its core specifications, the KLEM model deviates from the standard Solow model by a set of constraints that are partly imposed by its treatment of energy systems, and partly called for by its modelling of trajectories encompassing short-term horizons. Because KLEM is designed to couple with a BU energy modelling framework, full exogeneity of the energy system is a first constraint of the model (Ghersi, 2015). Accordingly, the growth trajectories traced by KLEM are built around exogenous energy volumes. The cost structure of energy supply beyond its own energy intensity, as well as the specific net taxes and trade margins on each energy sale, are also adjusted to match any assumption on the dynamics of annualised investment, operational expenses, or domestic and trade prices. These constraints on volumes, costs and prices weigh on economic growth, by reserving part of value-added to a fixed energy expense and part of primary factors endowments to the supply of some exogenous volume of energy. Outside energy systems, the short-term constraint is on the potential under-utilization of labour, particularly relevant for the Nigerian labour market. KLEM considers that some inertia of real wages prevents full market clearing, i.e., induces unemployment. Rather than specifying labour supply behaviour, it merely correlates the unemployment rate and the real wage in a "wage curve".

In the version adapted to the Nigerian economy, KLEM-NGA, the trade balance (including energy) is exogenous following neoclassical practice, yet macroeconomic closure is on domestic savings rather than on investment, following Johansen (1960), to reflect the control of public policies on national savings — be it only through the control of public investment. This implies growth trajectories more robust to scenario variants, at the cost of final consumption variations. The investment effort is set as a share of GDP, whose evolution is calibrated to warrant that

[6] For a description of the KLEM model, please refer to recent country implementations for Saudi Arabia (Soummane, Ghersi, & Lefevre, 2019) and China (Su, Ghersi, Teng, Le Treut, & Liang, 2021). The paper detailing the modelling for this report is currently under review at a peer-reviewed scientific journal. In addition, the future implementation of the IMACLIM model, the multisectoral version of the KLEM model, will allow exploring structural change issues.

the capital stock grows apace with efficient labour when potential growth, defined by efficient labour increases, concretises.

The KLEM-NGA and LEAP-NGA models were coupled by the iterative exchange of modelling results up to convergence (as shown in Figure 3). The exchange focuses on the energy system variables (prices and physical flows), forced into KLEM-NGA from LEAP-NGA, and on the growth of the real GDP calculated by KLEM-NGA, fed back from KLEM-NGA into the LEAP-NGA model as main driver of the growth of energy consumptions.

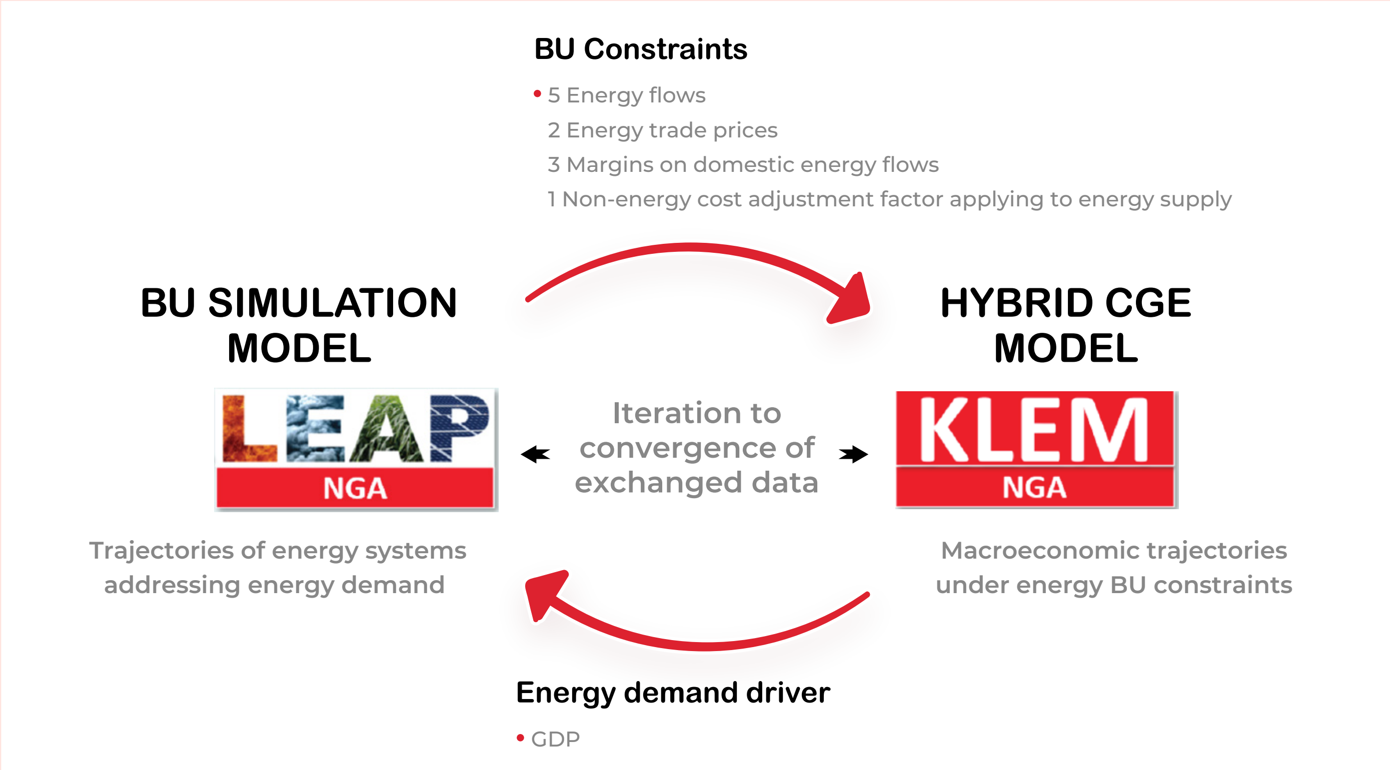


Figure 3. Dynamic Calibration of LEAP-NGA and KLEM-NGA

The iterative process starts by running KLEM-NGA in annual time steps from 2018, the calibration year, to 2060, the time horizon common to both models. KLEM-NGA thus traces the growth trajectory compatible with the five energy consumptions and trade flows aggregated from LEAP and the corresponding set of average, flow-specific prices, which it translates into average energy supply cost variations as well as variations of the specific margins (deviations of consumer prices from average supply costs) levied on each energy use. The computed real GDP trajectory is then fed back to LEAP, to update that model's projection of the energy system.

The process[7] is iterated until the GDP growth trajectory traced by KLEM-NGA varies less than a 10^{-6} tolerance threshold between one iteration and the next. The resulting LEAP-NGA and KLEM-NGA outputs provide a consistent, highly detailed picture of the Nigeria energy system embedded into the country's broader economy, at activity levels that take account of feedback loops between energy, non-energy and primary factors supply, demand and relative prices.

[7] This convergence process could start by running KLEM-NGA using exogenous constraints regarding energy consumption, trade and prices, then providing LEAP with the resulting trajectories for real GDP. The deterministic mechanism of the convergence process warrants that the equilibrium obtained would be identical to that reached by starting with LEAP simulations based on growth assumptions other than those stemming from KLEM-NGA.

Compared to previous modelling efforts of the Nigerian energy-economy nexus, the developed KLEM-LEAP methodology stands out in several ways. Firstly, it couples BU and TD modelling approaches through soft-linking, thereby combining the strengths of the two paradigms. Consistency of the soft-linking is enhanced by upstream efforts to make the energy balance and national accounting data consistent. These efforts notably result in the modelling of energy prices specific to each economic agent, a significant improvement over the CGE standard. Secondly, the KLEM-LEAP architecture produces a dynamic exploration of growth up to the medium term of the year 2060, rather than a static, counterfactual analysis. Finally, the versatility of the KLEM model allows, on the one hand, acknowledging the specific conditions of the Nigerian economy (labour market imperfections, external constraint), and on the other hand, exploring macroeconomic stabilization scenarios through the controlled extension of the model to additional constraints and variables.

Macroeconomic assumptions for the KLEM-NGA

A) Potential growth and the investment effort

Potential growth results from the combination of exogenous assumptions about active population growth (labour supply) and labour productivity (Figure 4). For the years 2018 to 2021, these assumptions flow from the statistical series of real GDP and employed population reported by The World Bank's World Development Indicators for Nigeria, i.e. encompass the effects of the Covid-19 pandemic. In further years and up to 2060, they derive from the second scenario of the Shared Socioeconomic Pathways (SSP2) developed by the Intergovernmental Panel on Climate Change (IPCC). The potential average annual growth rate of real GDP resulting from these assumptions over the period 2021-2060 is of 5.87%. That rate compares favourably with historical trends of 3.68% over 1961-2021, 3.07% over 1980-2021 or 5.23% over 2000-2021 (The World Bank, World Development Indicators).

Up to 2021, the investment-to-GDP ratio[8] is drawn from the World Bank data. From 2022 to 2060, it is calibrated in accordance with the potential growth trajectory, to warrant that the capital stock grows at the potential growth rate if that potential materialises. This results in investment efforts declining over the projection horizon, from 33.1% of GDP in 2021 (World Bank data) to 28.7% of GDP in 2060[9].

[8] There is no assumption regarding capital productivity in KLEM-NGA. Transformations, notably linked to structural changes in the economic activity, will be more legitimately analysed within the multisectoral framework of IMACLIM-NGA, of which KLEM-NGA is the precursor.

[9] The gross fixed capital formation (% of GDP) average over the period 2000-2021 was 22.7% in Nigeria, 21.9% in Sub-Saharan Africa, 25.85% in Senegal, 20.7% in Mali, and 25% at the global level (The World Bank, World Development Indicators).

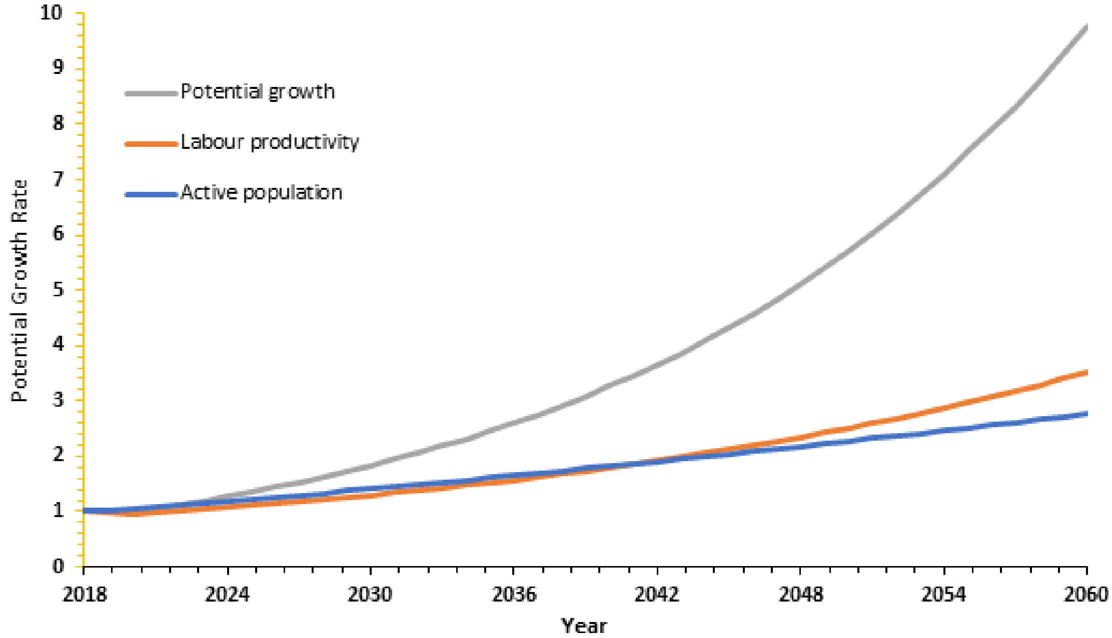


Figure 4: Exogenous labour productivity and active population trajectories in KLEM-NGA

Source: Authors' computations on The World Bank (2018-2021) and IPCC, SSP2 (2021-2060) data.

B) Trade balance objective

On top of the above shared macroeconomic assumptions, all scenarios constrain the aggregate trade balance of the Nigerian economy to follow some exogenous trajectory. At each simulation year, the targeted trade balance is attained by the adjustment of the real effective exchange rate (REER). This means that any variation of traded energy volumes computed by the energy system modelling of LEAP will be compensated by non-energy trade to fulfil the trade balance objective. The macroeconomic consequences of altered energy trade will thus appear through the induced adjustment of the REER, which retroacts on production costs and the purchasing power of households, rather than through the variation of the trade balance.

For all scenarios except RES+, this trade balance constraint is defined as a gradual (linear) reduction of the aggregate trade deficit, energy commodities included, from 3.5% of GDP in 2021 (World Bank data) to 1% in 2035 and beyond[10]. Both the 2035 date of convergence and the 1% residual deficit are exogenous assumptions guided by the consecutive accumulated foreign debt, but with significant impact on the macroeconomics of the different scenarios: relaxing either the deficit target or the year when it is imposed allows increased foreign savings contribution to the Nigerian economy i.e., improved macroeconomic conditions, but at the cost of an increased accumulation of foreign debt. Conversely, tighter objectives reduce the external debt but degrade economic

[10] The option of exogenous investment effort and trade balance corresponds to the so-called Johansen macroeconomic closure: public policies control the level of savings in the national economy to guarantee a certain investment effort, given the contribution of imported savings (the opposite of the goods and services balance).

growth. However, there is no anticipated reason why the sensitivity of scenarios to the two assumptions should substantially differ, which implies that the choices of 2035 and 1% deficit should be fairly neutral to scenario comparison.

The RES+ scenario differs from the RES scenario precisely on their trade balance assumptions. RES+ is meant to model the possibility that foreign aid covers part of the incremental costs of shifting from CPS to RES energy systems, reflecting the 'conditionality' of the stronger climate mitigation objective of Nigeria. To that end, the trade balance objective of the RES+ scenario is relaxed by an amount equivalent to the difference between the investment in energy supply required by the CPS and RES scenarios for the years 2035 to 2060.[11] Importantly, this extra investment requirement only covers the supply side of the mitigation effort. Still, the relaxed trade deficit constraint allows limiting the crowding-out effect that hampers growth in the RES scenario, thus sustaining economic growth.

C) Positive trade shock

Without additional assumption, considering the current imbalances and the expected reduction of energy exports, the constraint of stabilising the trade deficit to 1% of GDP would induce a strong downward adjustment of the Nigerian REER, i.e., an increase of the costs of Nigerian imports for both the Nigerian producers and consumers, to the detriment of economic activity. KLEM-LEAP simulations[12] reveal that the Baseline scenario would thus induce an average annual GDP growth rate of 4.45% over 2018-2060, substantially lower than the potential 5.57% rate, which would translate into GDP 33% below its potential in 2060. Moreover, the degraded economic performance would come at the cost of a significant increase of the unemployment rate, from 9.8% in 2021 to 26% in 2060[13].

This poor socioeconomic performance prompted the development of the Baseline scenario as envisioning positive structural transformations of the Nigerian economy, materialised as a positive competitiveness shock. This shock simultaneously increases the domestic sourcing of Nigerian non-energy consumptions and the non-energy export capacity. It is modelled as impacting both the non-energy import trend negatively and the non-energy export trend positively. Both trends remain subject to price elasticities, but the positive trade shock reduces the REER adjustments required to hit the targeted trade balance when energy trade decreases its own contribution — as we will see it does under Baseline conditions.

[11] The laxer 2035 deficit also relaxes the linear trade deficit trajectory to convergence from 2021 to 2035, being its end point.

[12] Due to their unsustainable trajectories, these simulations are not reported in this paper.

[13] The rate is that reported by the World Bank statistics for the latest year replicated by KLEM through dynamic calibration. It considers the contribution of informal labour to employment, which is why it is much lower than the rate reported by official Nigerian statistics.

Rather than assuming some level of shock and measuring its macroeconomic consequences, the flexibility of KLEM allows to reverse causalities and reveal what shock is necessary to converge the Nigerian economy towards some stabilised growth path. We define that path by extending the macroeconomic constraints of the model to an unemployment rate objective declining from 9.8% in 2021 to 5.0% in 2035 and beyond. The resulting trade shock must grow rapidly to reach 74% increase of non-energy export volumes (i.e., 1 - 1/1.74 = 43% decrease of non-energy import volumes) in 2030, before culminating at approximately 100% in 2035, then slowly decreasing down to 78% in 2060 (Figure 5). The 100% peak of 2035 implies doubled export capacities as well as halved import requirements at that horizon. The magnitude of the shock is better interpreted by considering that non-energy imports and exports mobilise respectively 13.2% and 2.4% of Nigerian GDP at our 2018 calibration year. The development of domestic alternatives to imports is thus the major political objective to be pursued to concretise our Baseline scenario.

The trade shock computed under Baseline energy conditions is applied identically and exogenously to the CPS, GES, RES, and RES+ scenarios, which must — or can — therefore relax the unemployment constraint.

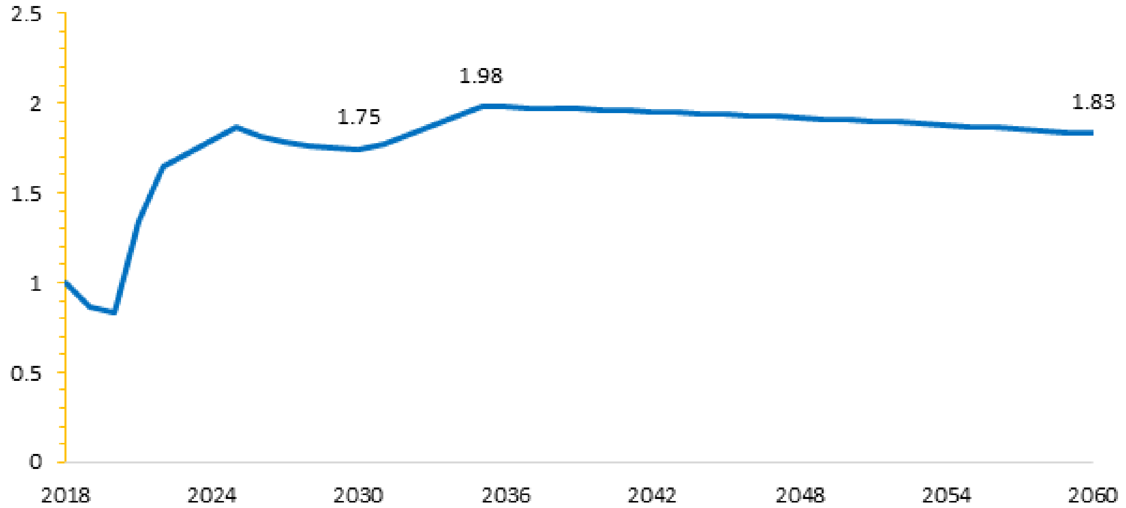


Figure 5. Trade shock calibrated on Baseline and generalised to all scenarios, index 1 in 2018

Source: Converged KLEM-NGA/LEAP Nigeria computation by the Authors. Common to the five reported scenarios, the trade shock applies to the trend of non-energy exports; its inverse applies to the trend of non-energy imports.

2.3 | Key Modelling Assumptions

The key modelling assumptions used to develop the BAU are presented in Appendix 1, whereas the key policy assumptions for all the scenarios are presented in Appendix 2.

03

MODELLING RESULTS

The results from the various approaches agreed and are presented in the following subsections.

3.1 | Power Generation and Energy Consumption

3.1.1 Power Generation

Figure 6 shows the electricity generation for all the scenarios for 2030, 2040, 2050, 2060. In the BAU, electricity generation will increase 9 folds from 28 TWh in 2018 to 257 TWh (grid: 213 TWh; off grid: 44 TWh) in 2060. For CPS scenario, electricity generation will increase by 23 folds from 28 TWh in 2018 to 637 TWh (grid: 622 TWh; off grid: 15 TWh) by 2060. For GES, electricity will increase by 17 folds from 28 TWh in 2018 to 484 TWh (grid: 468 TWh; off grid: 16 TWh) by 2060. For RES, electricity generation will increase by 27 folds from 28 TWh in 2018 to 761 TWh (grid: 647 TWh; off grid: 114 TWh) by 2060. The electricity generation is highest in the RES because more electricity will be demanded to meet the energy needs of the different sectors of the economy in the RES than in other scenarios. The energy demand in the RES will be dominated by electricity because the transport, residential (e.g., cooking), industry sectors will be driven by electrification. This is possible because renewable energy is better converted to electricity than being used as primary fuels in other sectors of the economy.

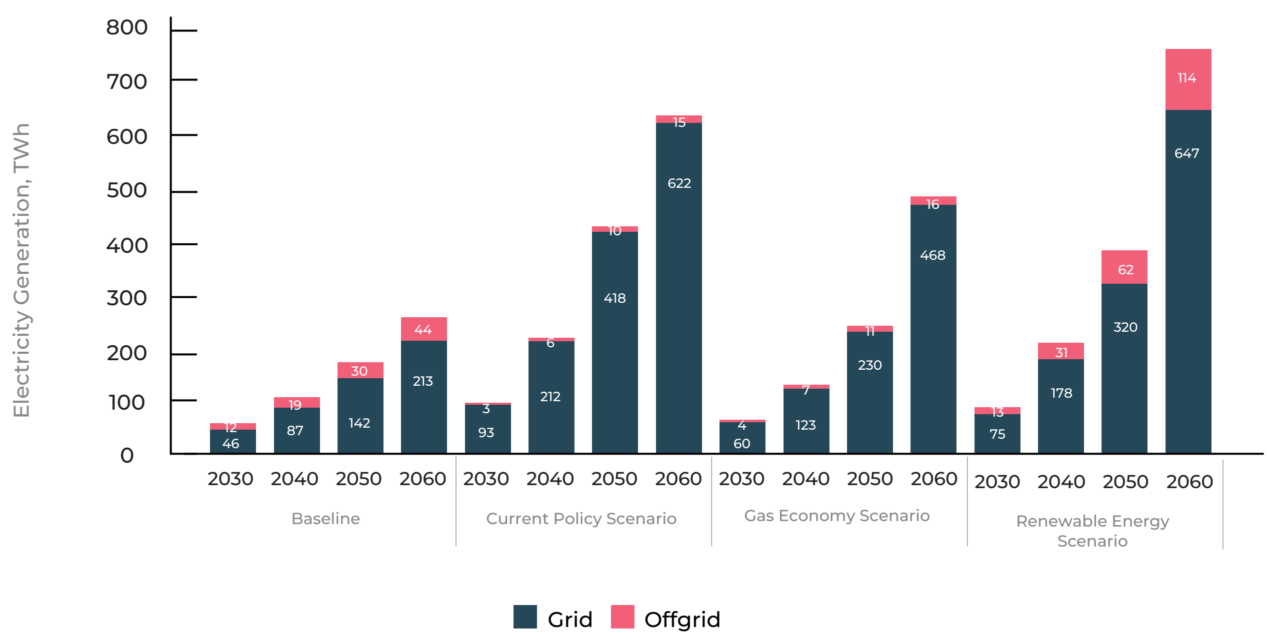
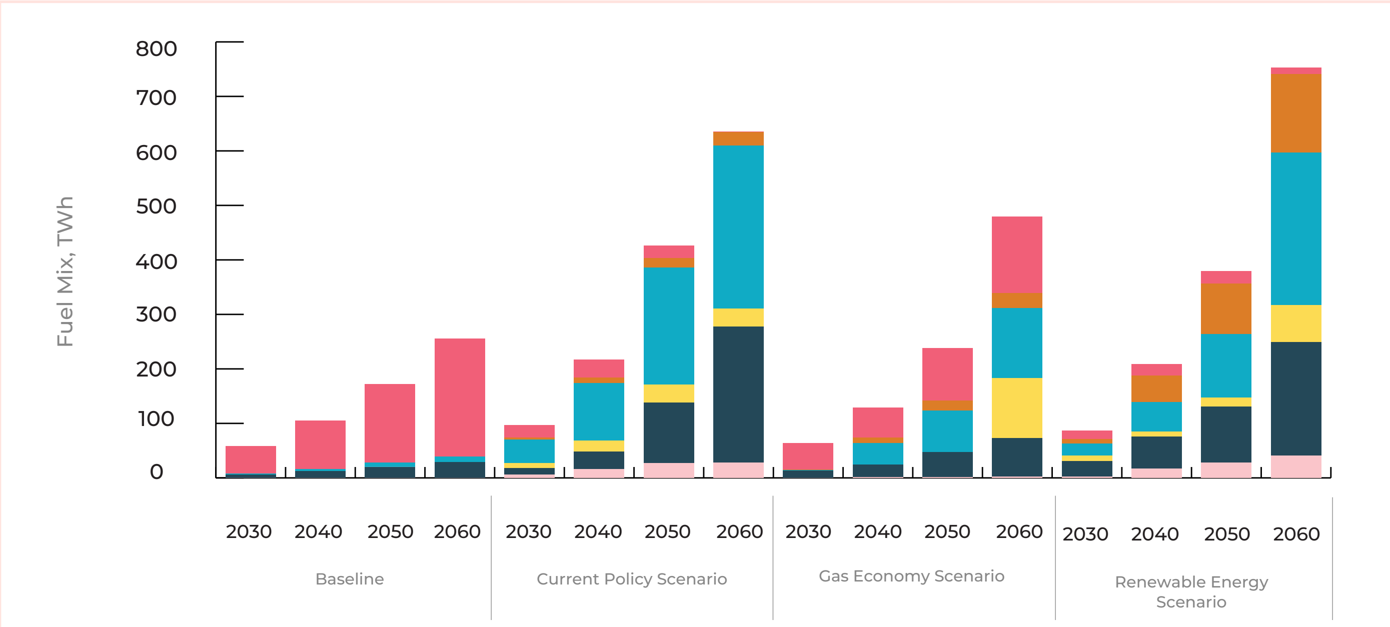


Figure 6. Power generation capacity of scenarios

Figure 7 shows the electricity generation mix. The BAU shows that most of the electricity generation is from fossil sources (gas power plants and diesel generators), contributing 84 % of the generation by 2060. For the CPS scenario, most of the electricity generation by 2060 will be from solar and hydro (large and small hydro) at 47 % and 39 %, respectively. For GES, most of the electricity generation will be from fossil fuel (gas power plant with carbon capture), solar, nuclear, and hydro at 29 %, 27 %, 23%, and 15%, respectively. For RES, electricity generation is mainly from solar, hydro, biomass and nuclear at 37 %, 27 %, 19 % and 9 %, respectively. The 9 % of power generation from nuclear power is well aligned with the Nigerian Nuclear Power Programme. It is expected that the implementation of the programme will evolve along safety and risk measures and capacity development.



Fossil fuel	50	89	144	217	23	33	23	1	49	55	96	140	16	21	23	12
Biomass	0	0	0	0	4	10	17	24	1	10	18	27	8	49	92	144
Solar	2	4	8	10	43	105	215	299	1	40	77	129	22	54	117	280
Nuclear	0	0	0	0	9	21	33	33	0	0	0	110	10	9	16	68
Hydro	6	12	20	29	12	32	111	250	13	23	46	71	29	59	103	208
Wind	0	0	0	0	6	16	27	28	0	1	1	2	2	17	28	41

Figure 7 Electricity generation mix

Figure 8 shows the power generation capacities of the four scenarios. For the BAU scenario, the power generation capacity will increase 4-fold from the 2018 value to 140GW by 2060, while CPS, GES and RES will increase by 18, 8 and 11 folds by 2060. Although the RES requires more electricity generation than the CPS, the power generation capacity of the RES is lower than that of the CPS because of the high energy density and conversion efficiency that will be deployed in the RES mix. Figure 9 and Figure 9 show the power capacity by a mix of technologies in the grid and off-grid, respectively.

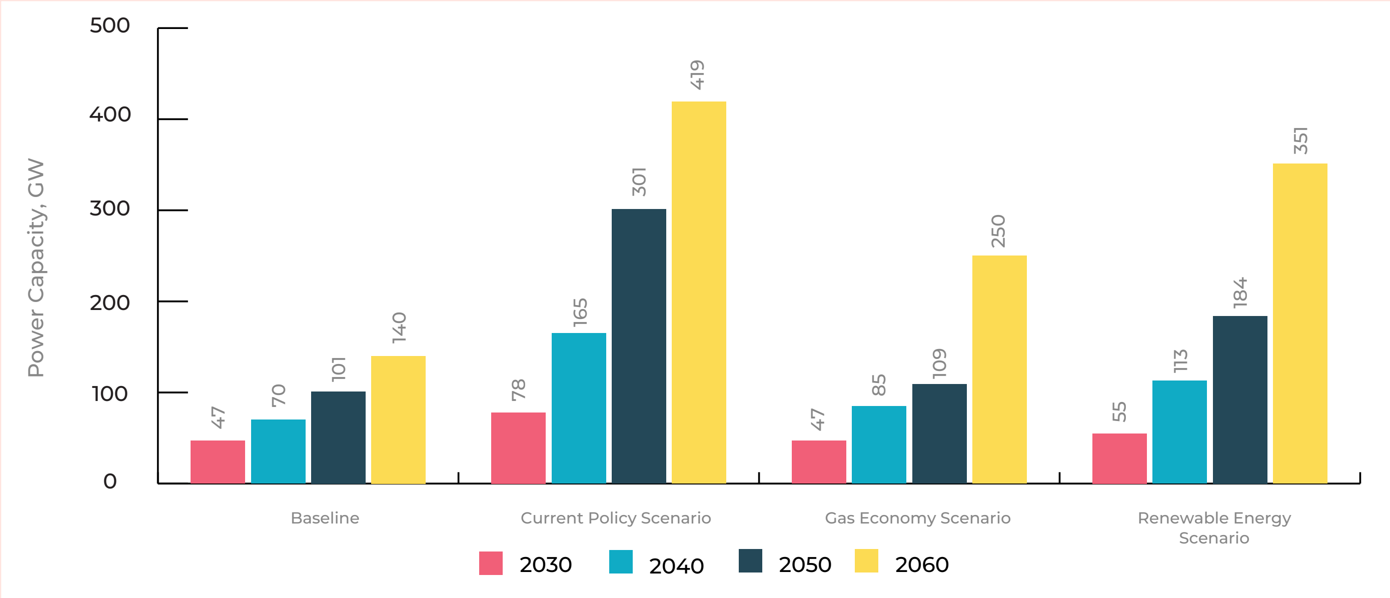
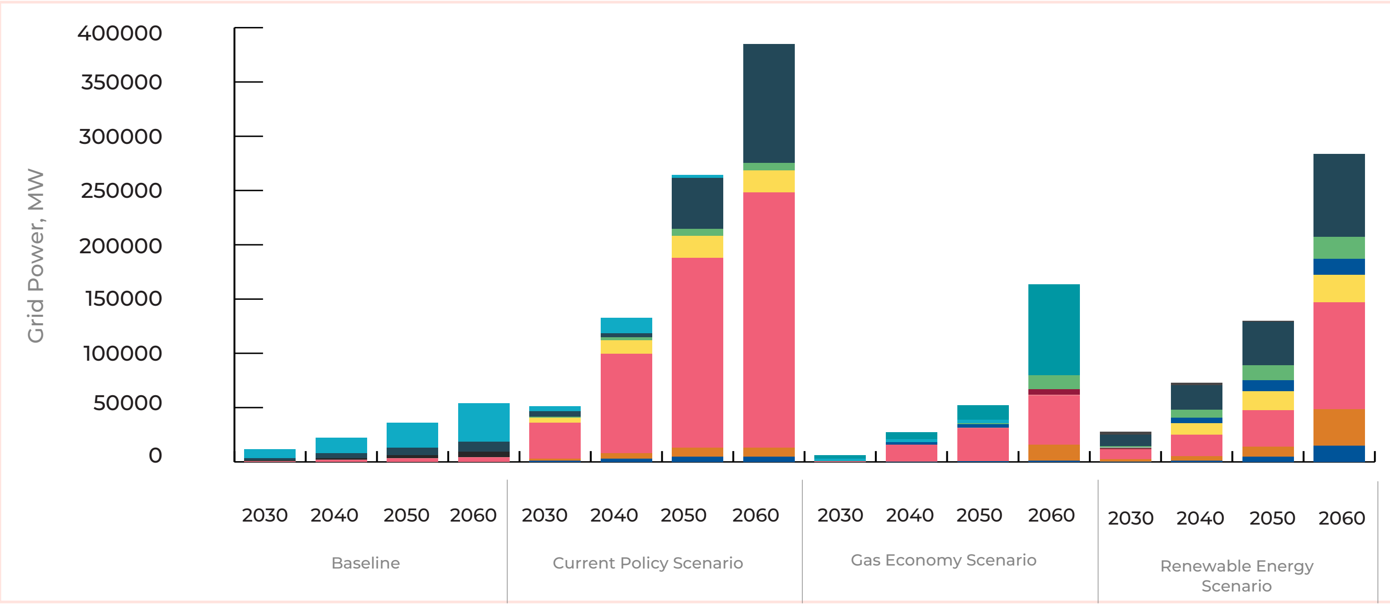
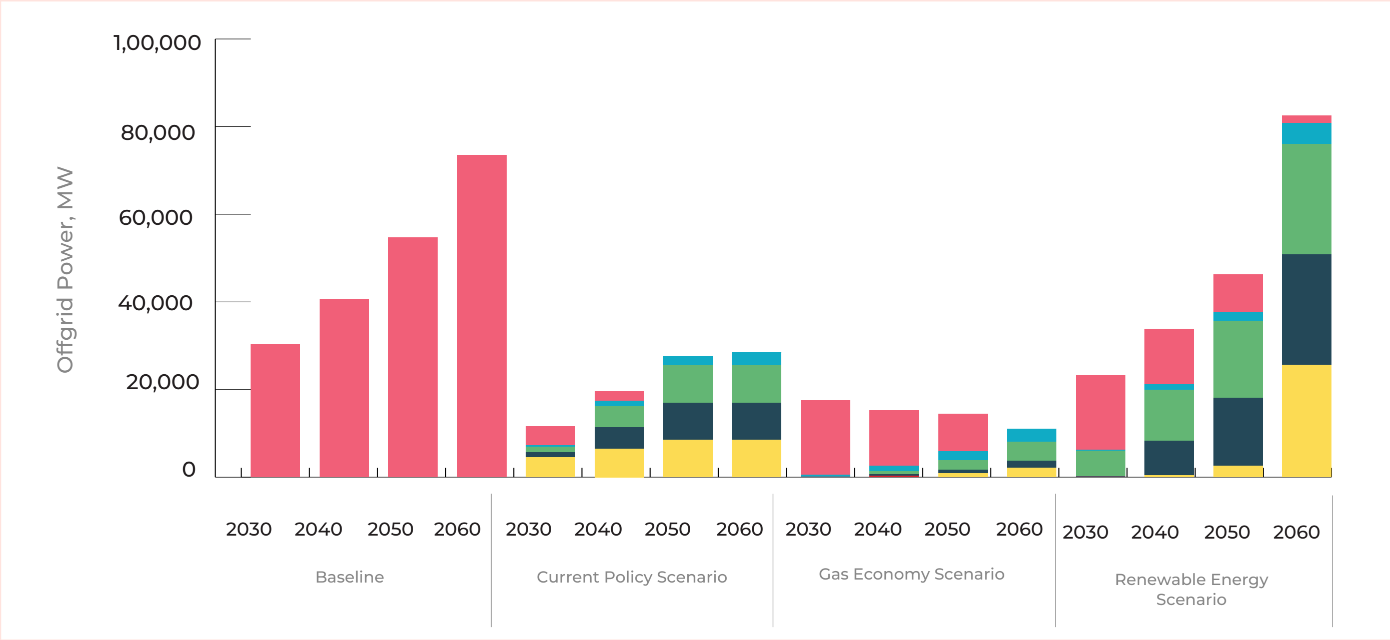


Figure 8 Power generation capacity



NG with CCS	0	0	0	0	0	0	0	0	5000	1500	2000	1500	3000	2000	1000	0
Gas	8220	14640	23400	34980	1300	8666	4333	0	1570	2500	2000	1500	3000	2000	1000	0
Large Hydro	2010	4097	6573	9640	4990	14630	49260	10, 9640	4300	9000	16000	24000	10410	22760	40100	76640
Coal	520	1590	3050	4980	5000	3333	1667	0	500	1000	500	0	0	0	0	0
Biomass	50	50	50	50	1100	3067	5033	7000	50	367	683	1000	1000	7333	13667	20000
Biogas from waste	50	50	50	50	0	0	0	0	100	2000	3500	5000	1000	5000	10000	15000
Wind	100	100	100	100	4296	12148	20000	20000	100	300	500	1000	1000	10500	17750	25000
Solar PV Utility	620	1690	3030	4010	33100	91700	17, 4980	23, 5360	500	15333	30167	45000	9048	19983	33657	68958
Nuclear	0	0	0	0	2000	5000	8000	8000	10	25	50	15000	2335	4185	8775	33155
CSP	0	0	0	0	1000	3000	5000	5000	10	340	670	1000	100	1000	5000	15000

Figure 9 Grid generation capacity by technology



Generators	35644	47903	64377	86517	5000	2500	0	0	20,000	15000	10,000	0	2000	15000	10,000	2100
Small hydro	53	53	53	53	500	1500	2500	3500	500	1500	2500	3500	300	1367	2433	5600
Rooftop PV	80	80	80	80	1393	5697	10,000	10,000	50	750	2500	5000	6890	13760	20630	29700
Standalone PV	10	10	10	10	1393	5697	10,000	10,000	25	500	1000	2000	120	9247	18373	29700
Hybrid Solar	7	7	7	7	5314	7657	10,000	10,000	50	300	1000	2500	100	500	3000	30150

Figure 10 Off-grid power generation capacity by technology

Figure 11 shows the amount of power to be installed yearly for the various technologies/fuels from 2023 to meet the power requirements of the four scenarios. The BAU shows that 1608MW of backup generators will be needed yearly. High solar installation is required for the CPS and the RES at 6700MW and 4300MW, respectively. While the GES requires 3625MW of gas power plants annually. Other power capacities are also shown in the figure.

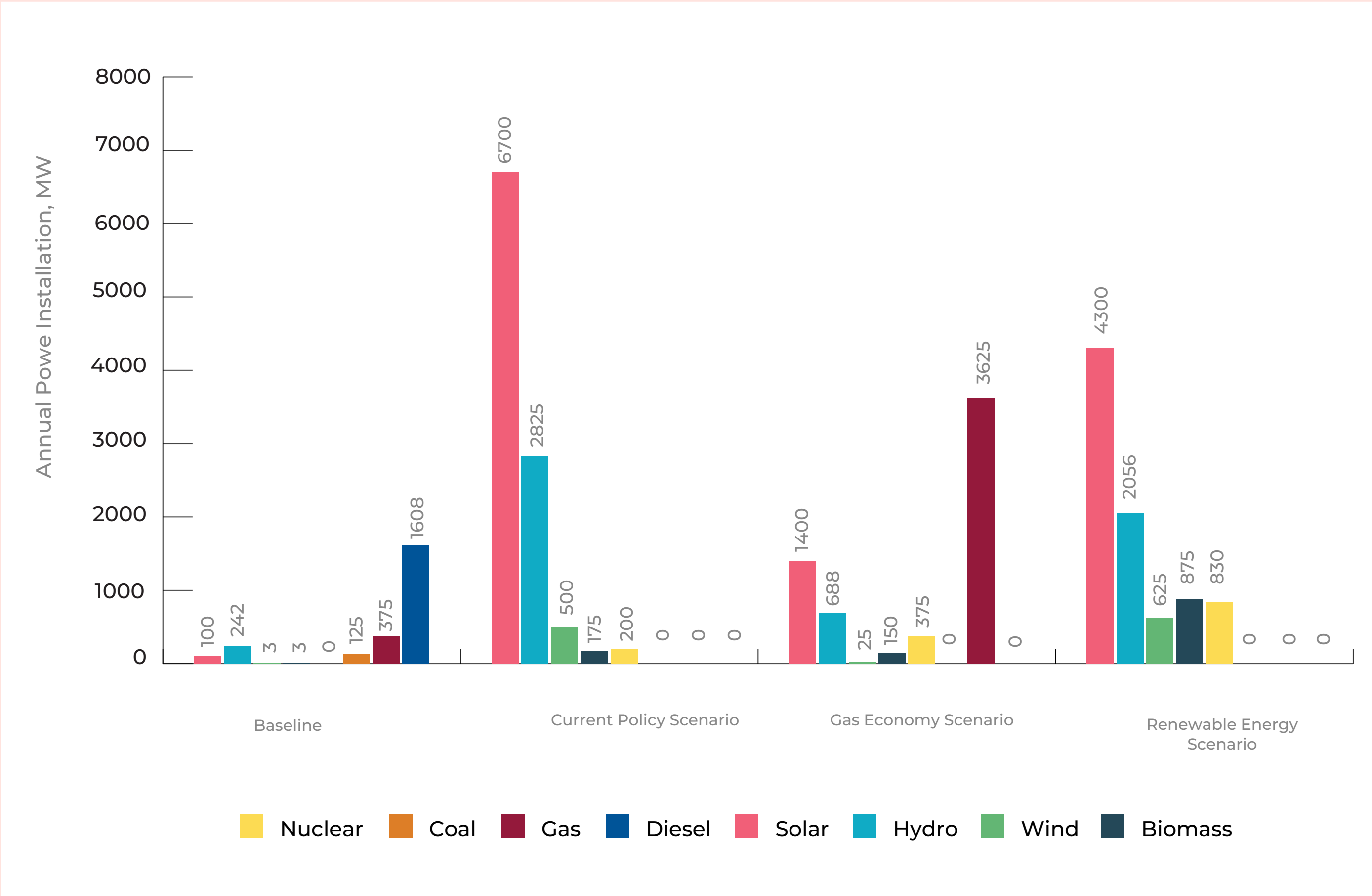


Figure 11 Annual power installation by scenarios

From the analysis of the power sector, the decarbonization scenarios show that (i) the "energy for all" target can be achieved by 2030, (ii) the CPS and GES have more ambitions to reduce emissions in the power sector than other scenarios by 2060; however, on aggregated national emissions accounting the RES has the highest potential due to the use of the emission for biomass regeneration through the afforestation and reforestation measures in the AFOLU sector and (iii) the GES will require significant investment in the grid electricity generation because of the large scale installation of gas power plants with carbon capture and sequestration (CCS) since gas power plants with CCS technology are expensive (2635 USD/kW as the capital expenditure, excluding operational expenditure)[14] as against gas power plants without CCS (1500 USD/kW capital expenditure)[15] .

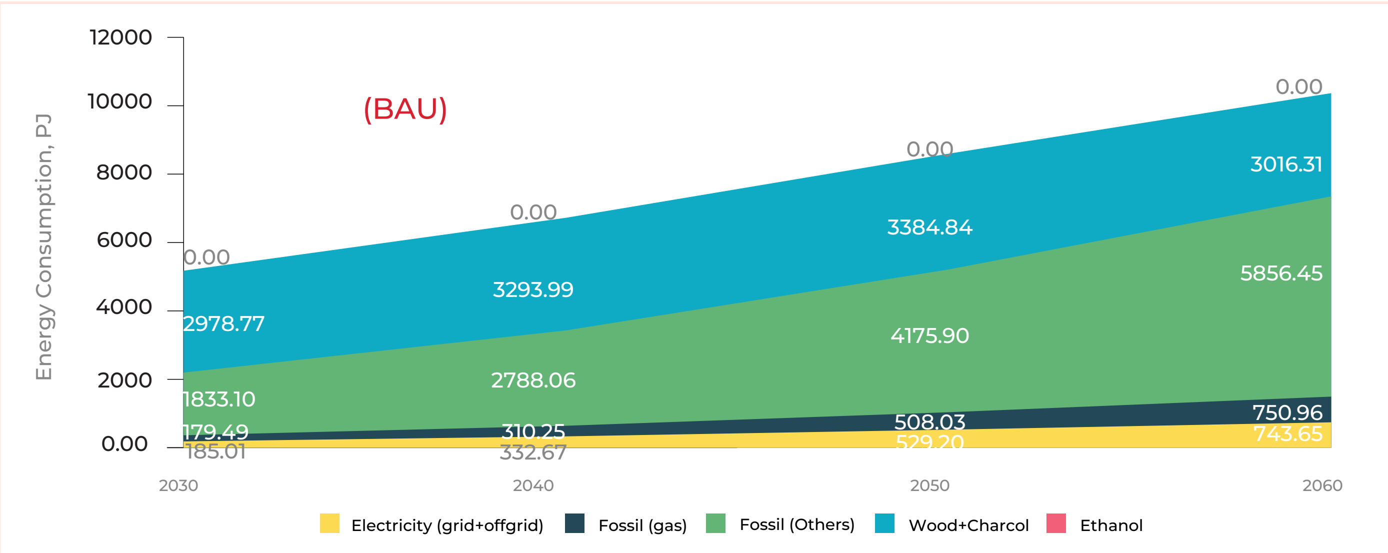
[14] The cost data for CCGT with carbon capture were derived from AEO (2020) cost data - https://www.eia.gov/analysis/studies/powerplants/capitalcost/pdf/capital_cost_AEO2020.pdf

[15] The cost data were sourced from a report that reflects true cost of electricity generation in Nigeria - https://ng.boell.org/sites/default/files/true_cost_of_power_technical_report_final.pdf

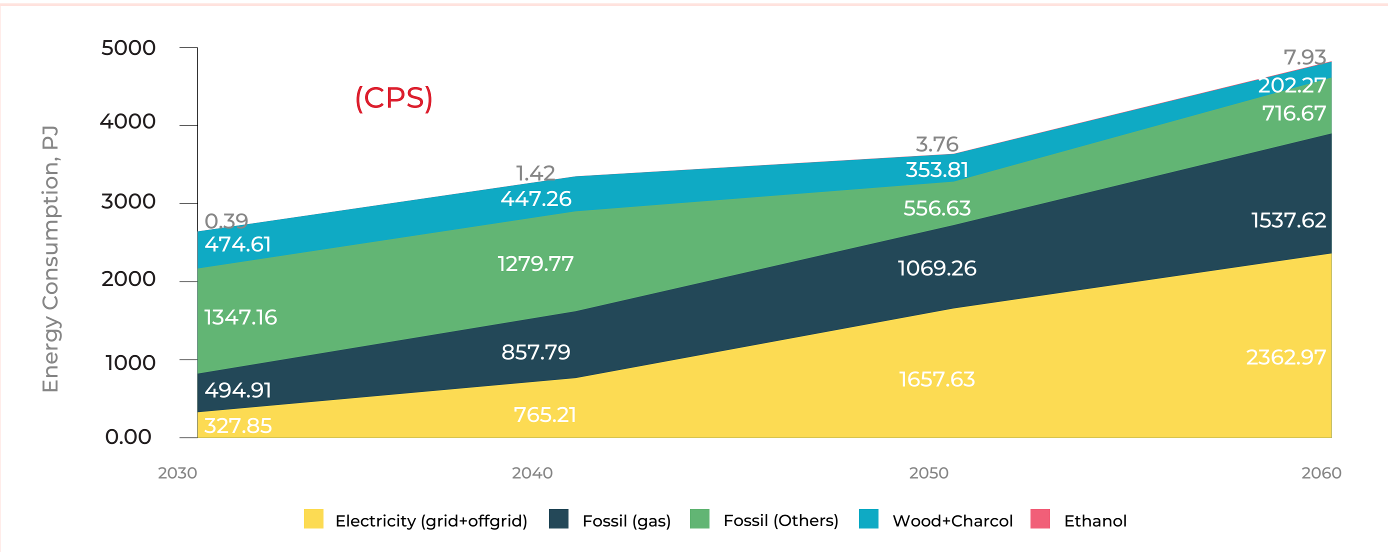
3.1.2 Energy Consumption

Figure 12 presents the energy mix across all four scenarios – the energy is classified into electricity (grid and off-grid), fossil (gas), fossil (others – kerosene, gasoline, diesel, and coal), wood and charcoal and ethanol. For the BAU (Figure 12a), firewood and charcoal (at 2948 Petajoule (PJ)) will dominate the energy space in 2030, whereas fossil fuel (others), with insignificant contribution from coal at 0.82 PJ, will dominate the energy space beyond 2030.

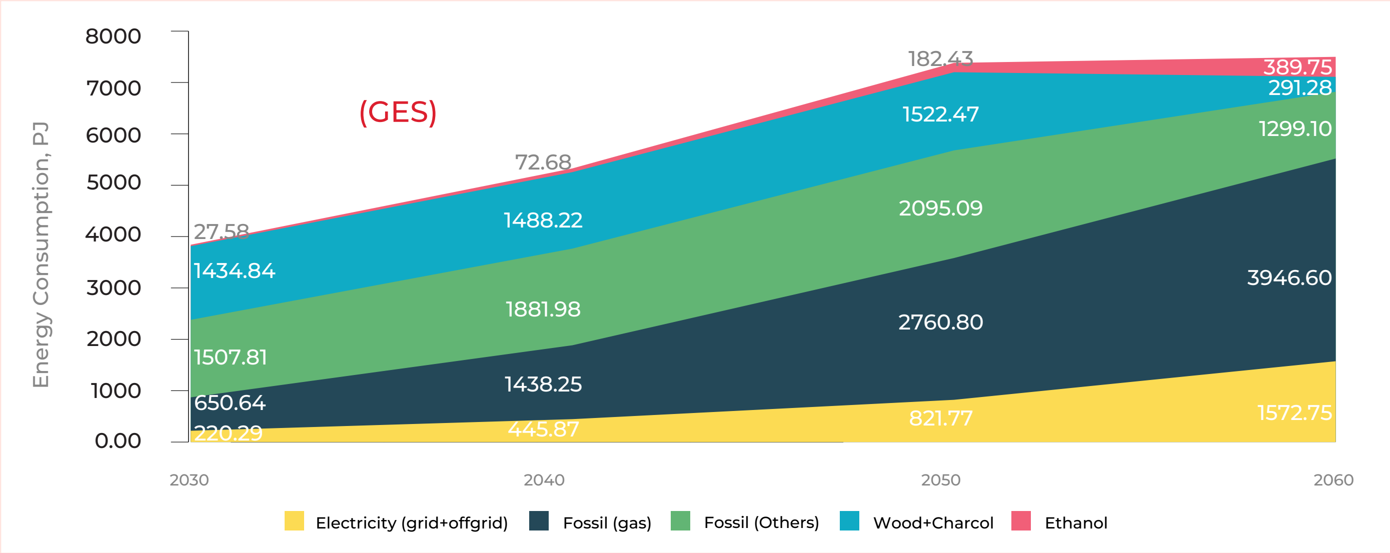
Figure 12b, the CPS, indicates that fossil (others) will dominate energy space between 2030 (1266PJ) and 2040 (1223 PJ), with electricity controlling the energy space beyond 2040. Furthermore, for the GES, fossil (others) at 1421 PJ will dictate the energy space in 2030, while fossil (gas) will dominate the energy space beyond 2040 (Figure 12c). For the RES, firewood, and charcoal (at 1528 PJ) will dominate the energy space in 2030, while electricity will dominate beyond 2050 (see Figure 12d). The GES energy scenario shows higher total energy consumption than the CPS and the RES. This is attributed to lower efficiency of energy conversion of the GES.



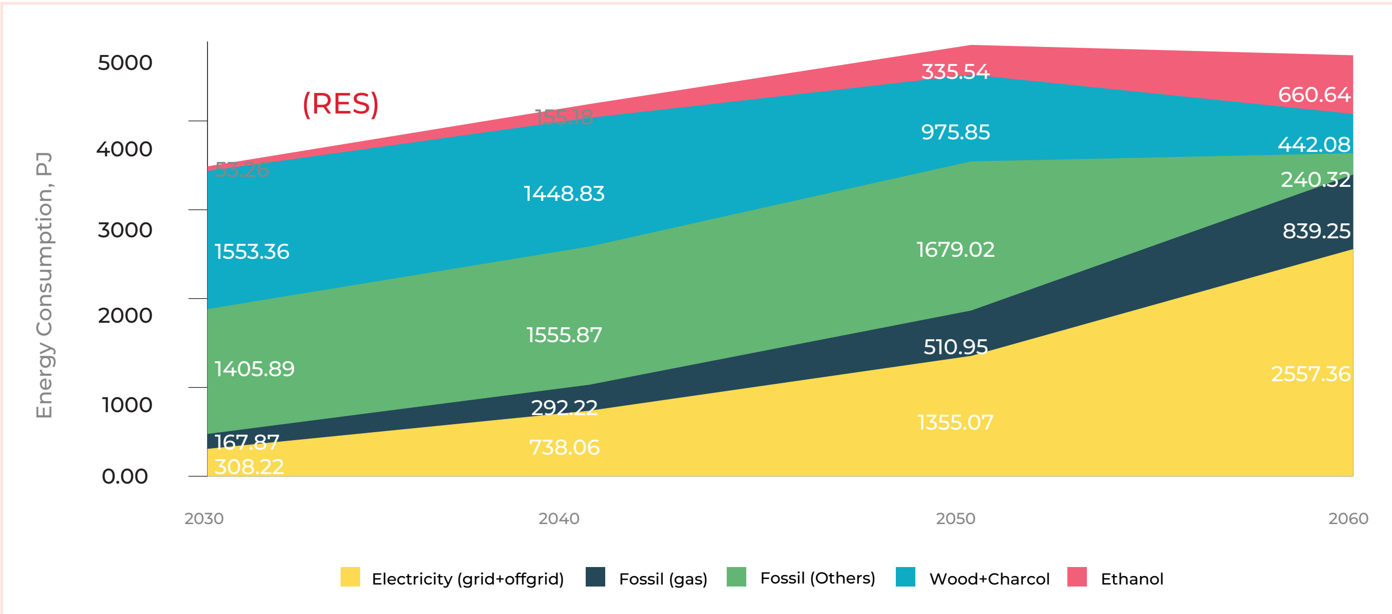
(a) Business As Usual (BAU)



(b) Current Policy Scenario



(c) Gas Economy Scenario (GES)



(d) Renewable Energy Scenario (RES)

Figure 12 Energy share across the scenarios

Nigeria's buildings and residential sector is a substantial consumer of the total delivered primary and final energy of the economy, with an energy consumption of 2423 PJ in 2020, according to the BAU analysis (Figure 13). The energy consumption in the BAU will grow steadily with the population growth exacerbated by **(i) cooking involving inefficient use of biomass in the traditional cookstove and the use of fossil-based cookstoves (LPG and kerosene) and (ii) use of inefficient appliances[16]).** In addition, it has been established that energy consumption in the

[16] Omene Tietie, D.E, Diemuodeke, E.O., Owebo, K., Okereke, C. et al. (2021) Long-term energy demand-side modelling of Nigerian household sector - https://doi.org/10.1016/j.egycc.2021.100065

buildings and residential sector is adversely affected by poor architectural design and inefficient appliances[17], though the emissions from these sources of energy consumption are accounted for at the point of generation, power sector, for example.

The CPS has the lowest energy consumption across the horizon (Figure 13), which is attributed to the massive electrification of building and residential services, cooking, for example. In 2060, the RES will record the highest emission (at 801 PJ) among the three decarbonization scenarios because of a mix of electricity and improved biomass cookstoves. However, considering the use of emission to support the regeneration of biomass (the afforestation and reforestation measures) in the AFOLU sector, the RES emissions become comparable with the CPS emissions. A conscientious effort to see a shift from traditional biomass use for cooking, deployment of more energy-efficient electrical appliances and a higher focus on electricity and exploitation of other efficient cooking, lighting and space cooling systems will contribute to the realistic decrease in energy intensity in the residential sector as energy demand sources get increasingly decarbonized in all the scenarios.

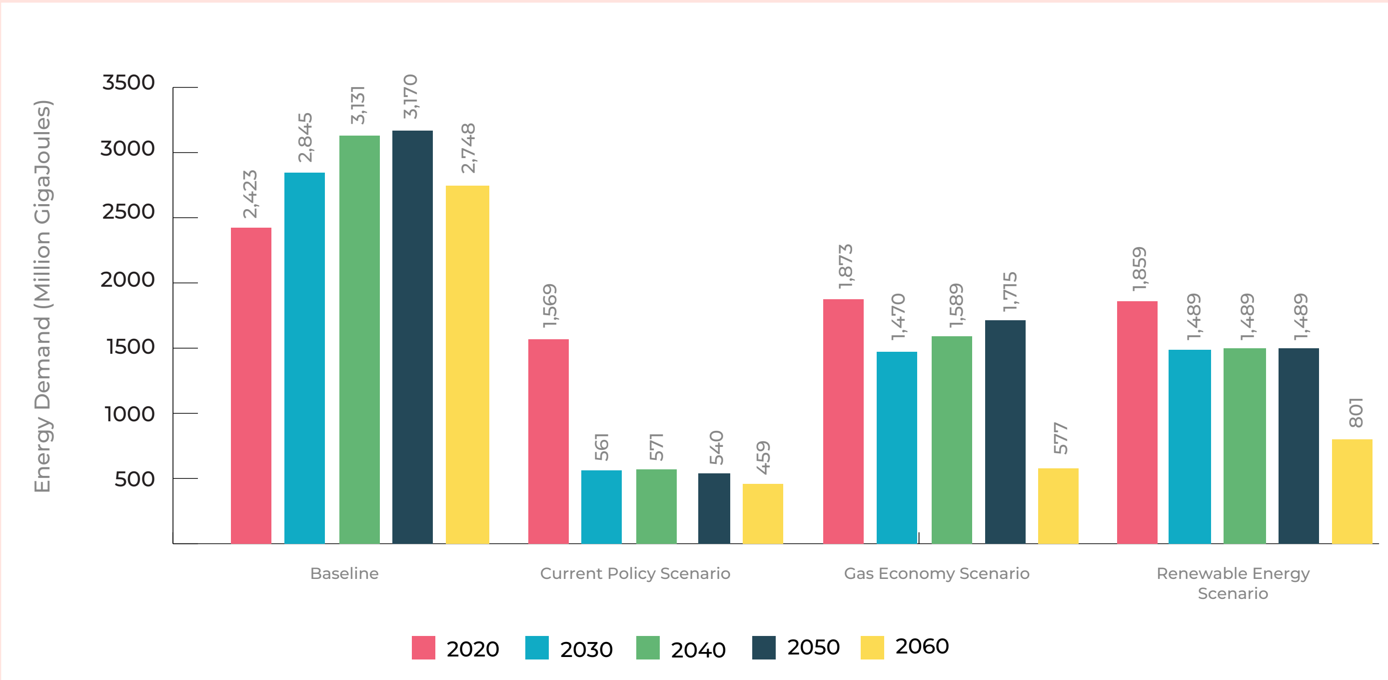


Figure 13 Building and residential sector energy demand under various scenarios

[17] Ochedi et al. (2022) A framework approach to the design of energy efficient residential buildings in Nigeria - https://doi.org/10.1016/j.enbenv.2021.07.001

The energy resource assessed in the residential sector includes electricity (off-grid and on-grid), natural gas, liquefied Petroleum gas (LPG), kerosene, wood, charcoal, dung, and other biomass waste, solar and candle, with percentage contribution shown in Figure 14. The relatively high volume of wood and charcoal use in GES and RES by 2060 is attributed to the significant adoption of improved cookstoves matched with the reforestation programme at the rate of 5 % and 2.3 %, respectively.

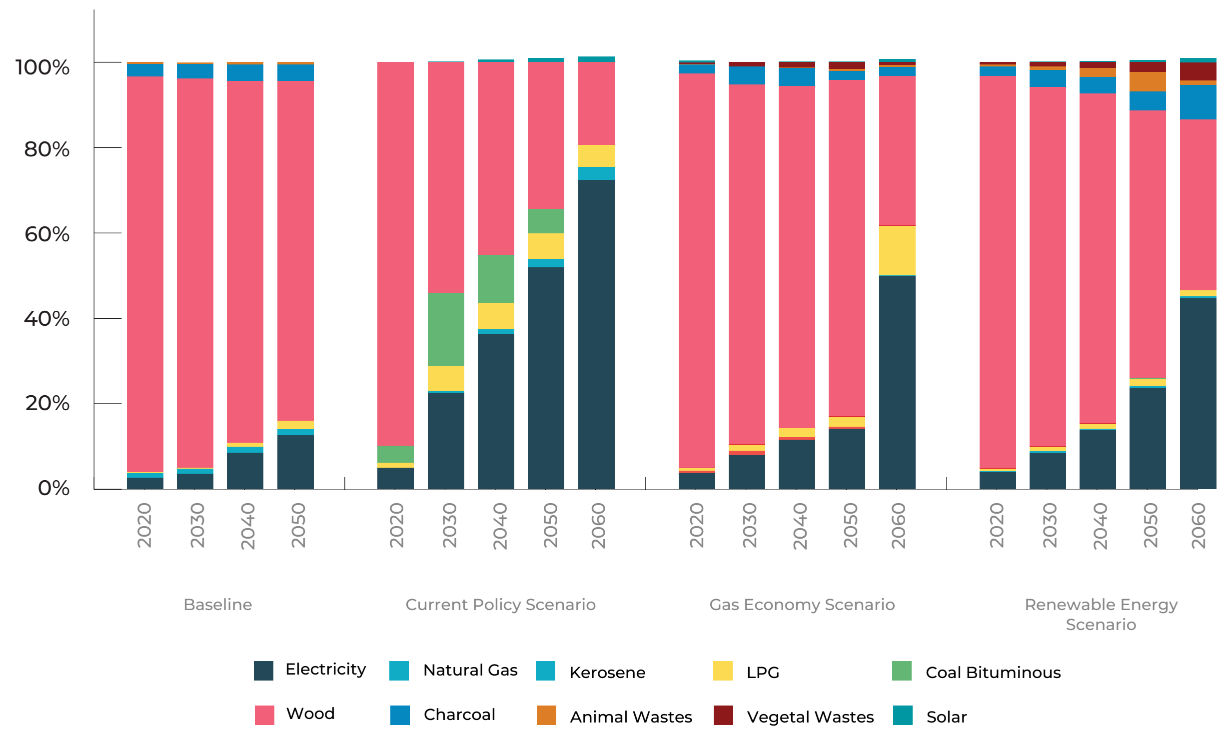
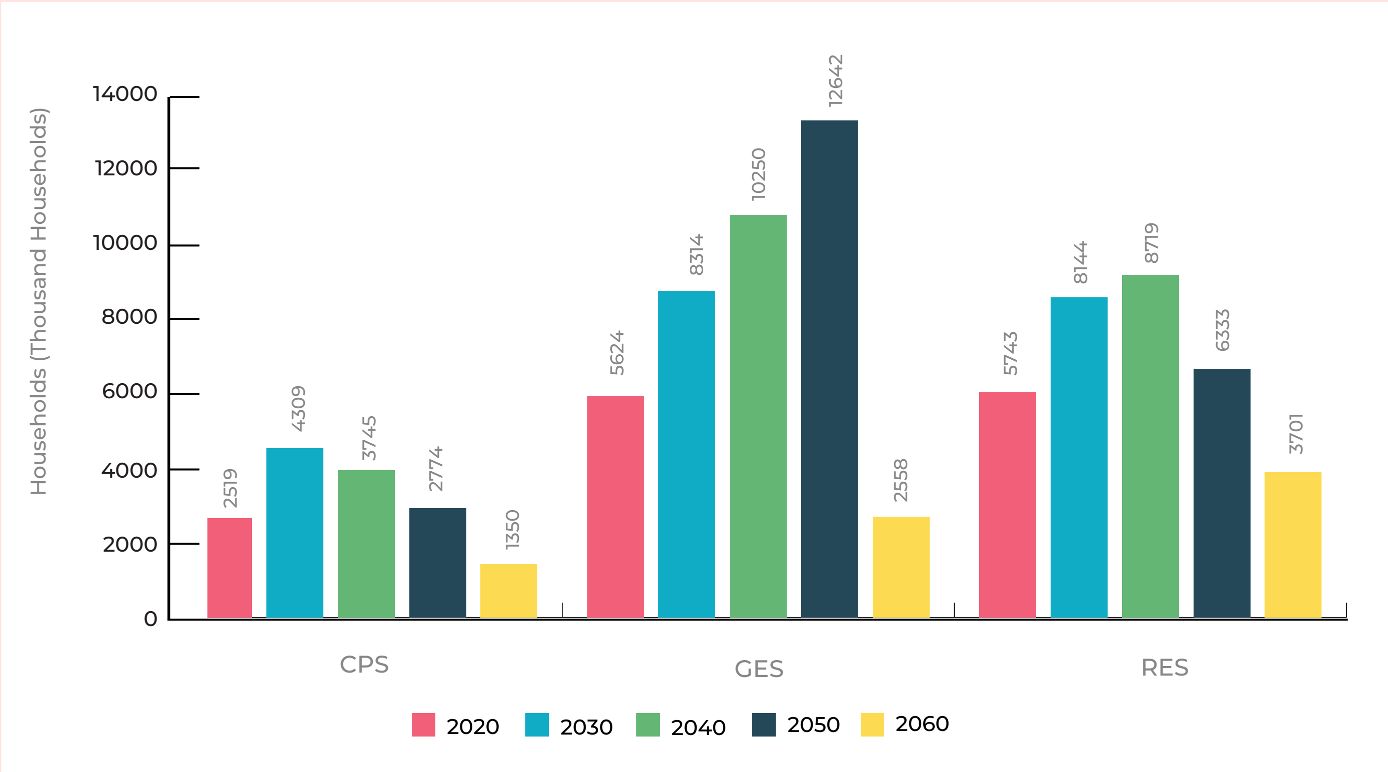


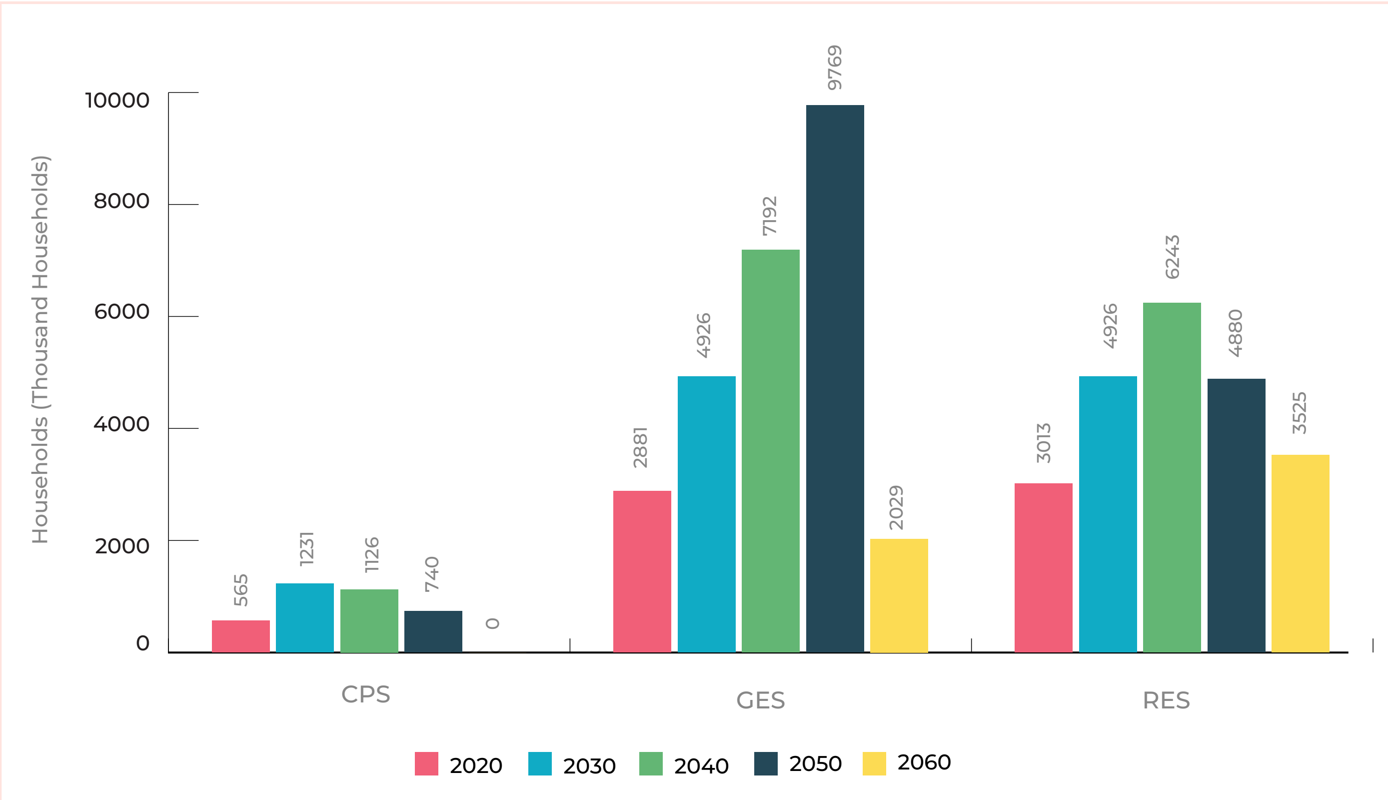
Figure 14 Percentage share of fuel used in building and residential sector

Figure 15a shows the number of households that will use the improved cookstoves, across the horizon for the three decarbonization scenarios. As expected, the RES has the highest number of households that will use the improved cookstoves by 2060 because the improved cookstoves can be classified as renewable energy with the adequate match of reforestation and forest management programmes. However, the number of households using improved cookstoves (4.31 million households) in the current policy scenario (CPS) is less than the number (7.3 million households) presented in the NDC by 2030, which reflects the ETP electrification of cooking services since CPS is anchored on NDC and ETP.

Figure 15b and Figure 15c show the share of urban and rural of the number of households with improved cookstoves, with the urban population having a higher share because of the growth in urban population; urban households grew from 56 % in 2020 to 81 % by 2060. The adoption of improved biomass cookstoves (especially in the GES) was envisaged to be driven by the freezing of petroleum products subsidies which will drive prices of kerosene and LPG higher with the resulting shift to biomass use, especially in rural communities. However, health concerns about the use of improved biomass cookstoves are still a subject of debate and research as some existing improved biomass (briquette and pelletized biomass) cookstoves show reduced health risks[18] .

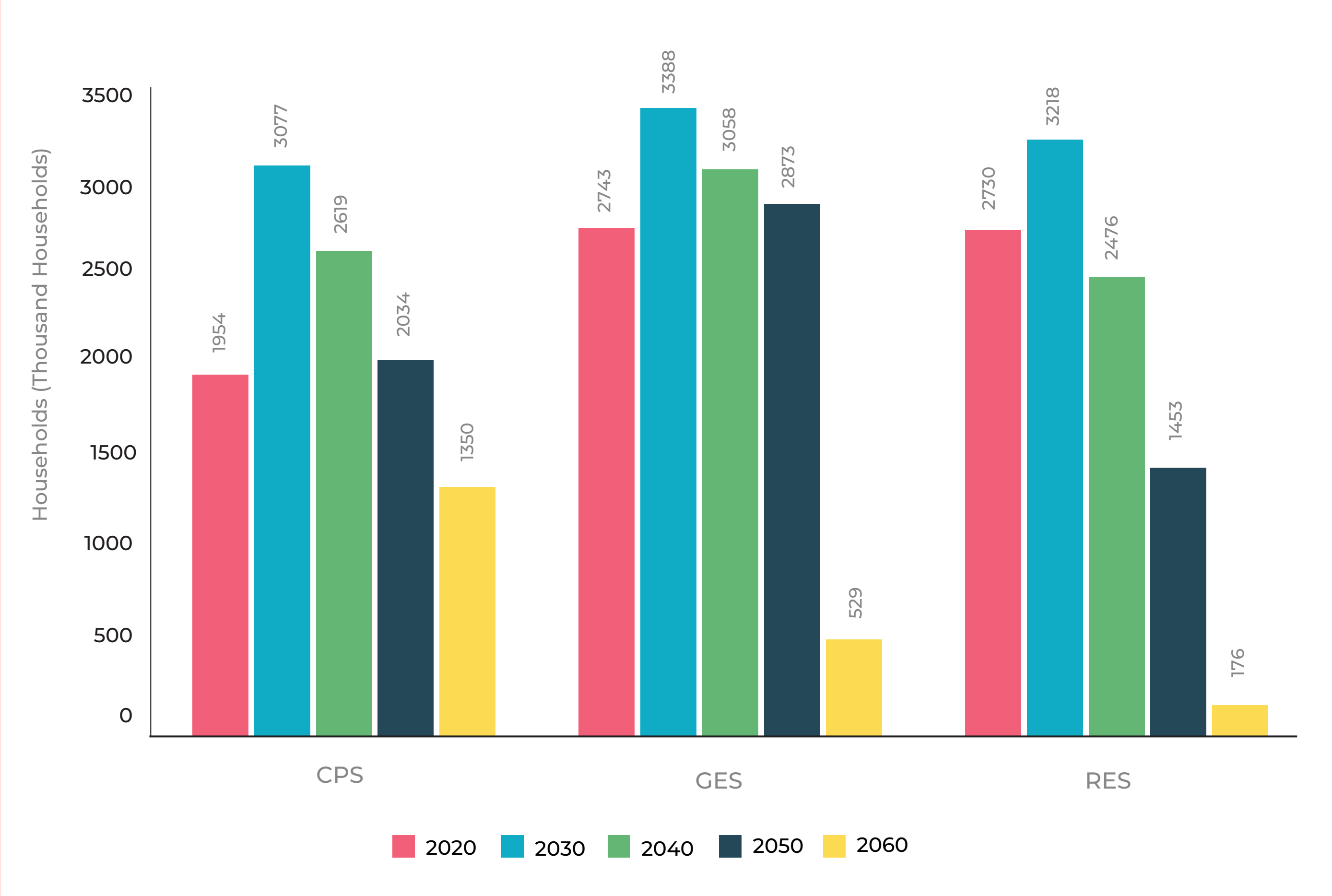


(a) Total number of households using improved cookstoves



(b) Rural split of households using improved cookstoves

[18] Thakur et al. (2018) Impact of improved cookstoves on women's and child health in low- and middle-income countries: a systematic review and meta-analysis - http://dx.doi.org/10.1136/thoraxjnl-2017-210952



(c) Urban split of households using improved cookstove

Figure 15 Number of households using improved cookstoves under various scenarios

3.2 | Emissions

3.2.1 Base Year Emissions

The total GHG emissions for 2018, which serves as the base year, is 424 MtCO2eq. The emissions were aggregated from all the sectors, namely Residential and Buildings, Agriculture, Forest, and Other Land Uses (AFOLU), Oil and Gas, Power, Industry, Transport, Services, and Waste and emissions from other sources (indirect N2O emissions), as shown in Figure 16. The analysis indicates that energy sector emissions (i.e., from oil and gas extraction, power, building and residential, and transport subsectors) account for 54.3% (229.4 MtCO2eq) of total emissions. However, at the subsector levels, AFOLU sector dictates emission at 125.70 MtCO2eq, which is equivalent to 29.6% of the total emissions in 2018.

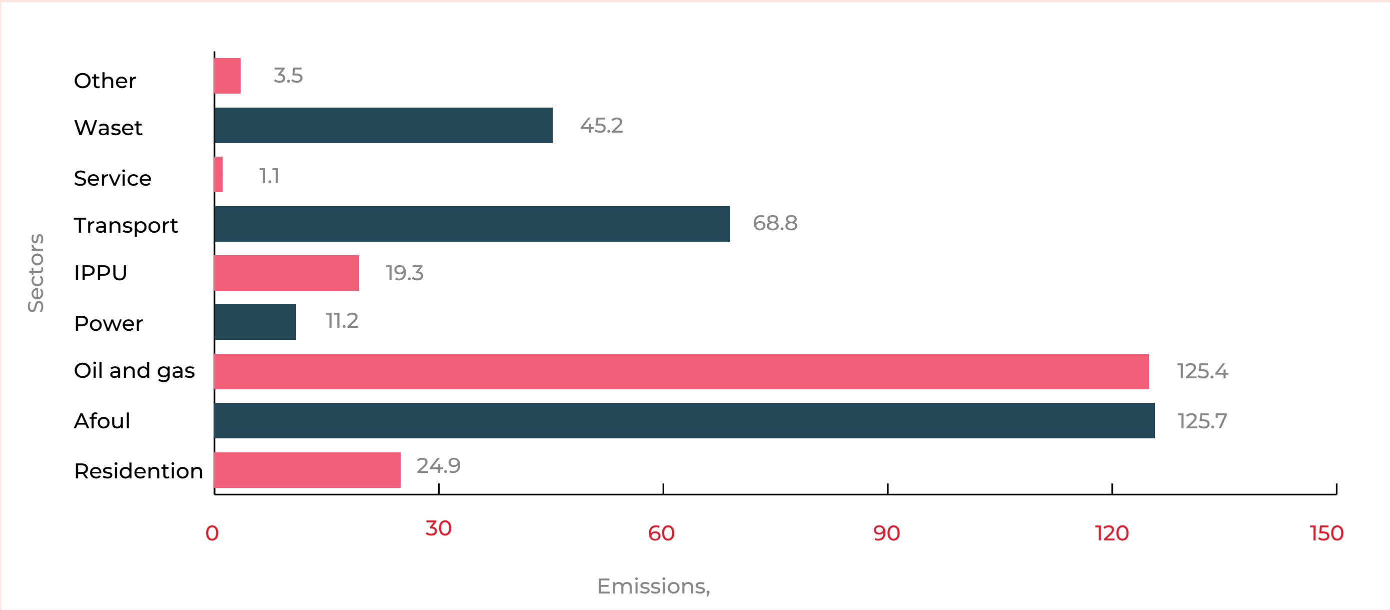


Figure 16. Sectoral Emissions Profile in 2018

The high emissions from AFOLU are driven mainly by enteric fermentation, and land use, land-use change, and forestry (LULUCF). The share of AFOLU emission is followed by oil and gas extraction, transport, waste, residential, Industrial Processes and Product Use (IPPU), power, others, and services at 29.4%, 16.2%, 10.6%, 5.9%, 4.6%, 2.6%, 0.8% and 0.3%, respectively, as shown in Figure 17. In addition, the share of emissions by the energy, AFOLU, waste, IPPU and other sectors are at 54.3%, 29.6%, 10.6%, 4.6% and 0.8 %, respectively, as shown in Figure 18. It is shown that more than 50% of the emissions from the energy sector are from the oil and gas subsector.

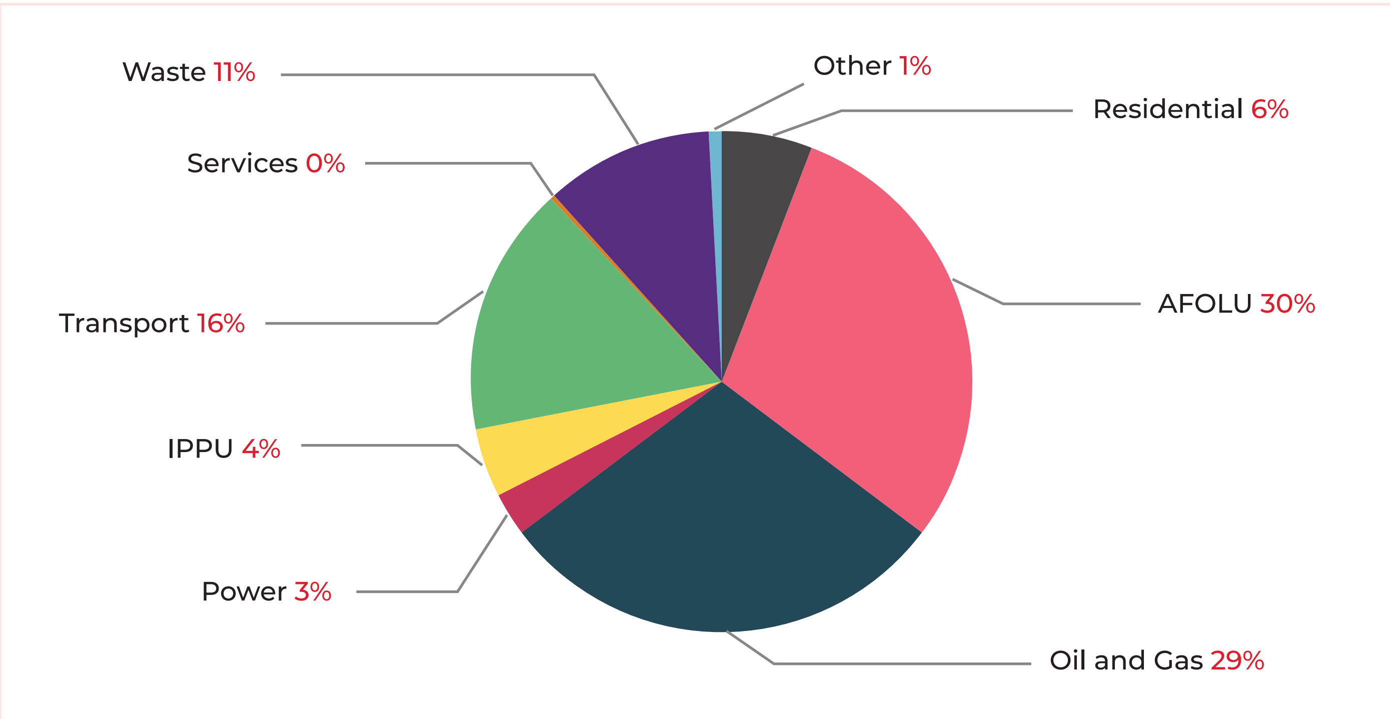


Figure 17. Sectoral emissions contribution by a percentage in 2018

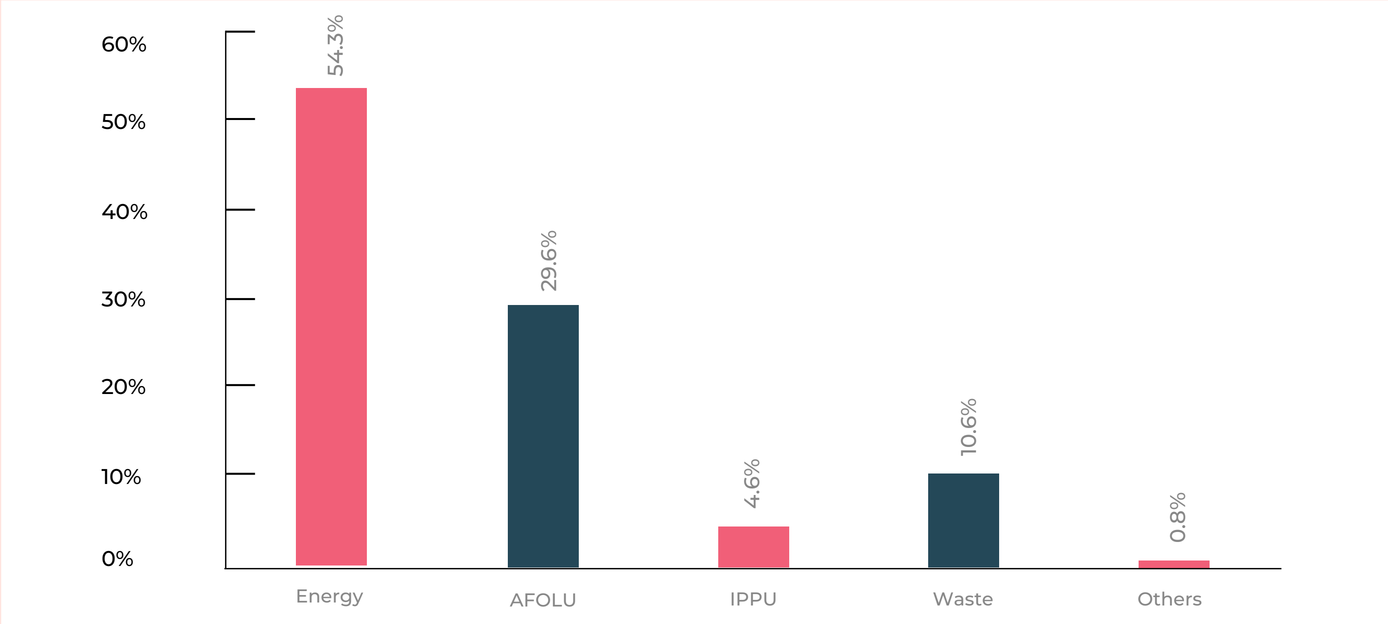


Figure 18. Aggregated percentage emission contribution in 2018

3.2.2 Scenarios Emissions

The analysis of the scenarios on the Nigeria LEAP model yielded important aggregated national emissions profiles for the scenarios, as shown in Figure 19. In 2030, the emissions of the BAU, CPS, GES and RES stood at 513.7, 415.98, 326.8 and 242.0 MtCO2eq, respectively. The results for 2030 show that the CPS, GES, and RES can reduce emissions by 1.96%, 22.99% and 42.96 %, respectively, compared to 2018, the base year, with emissions of 424.30 MtCO2eq. Again, the LT-LEDS BAU is higher than the NDC BAU's value (452.7 MtCO2eq) by about 13 % in 2030. The difference between the LT-LEDS BAU and NDC BAU could be attributed to the more granular analysis of activities in the AFOLU and the transport sectors in the DDP modelling approach. The emission from the energy sector (265 MtCO2eq) in 2030 is higher than the updated NDC's value (252 MtCO2eq) and ETP's value (216 MtCO2eq) by about 5 % and 18 %, respectively.

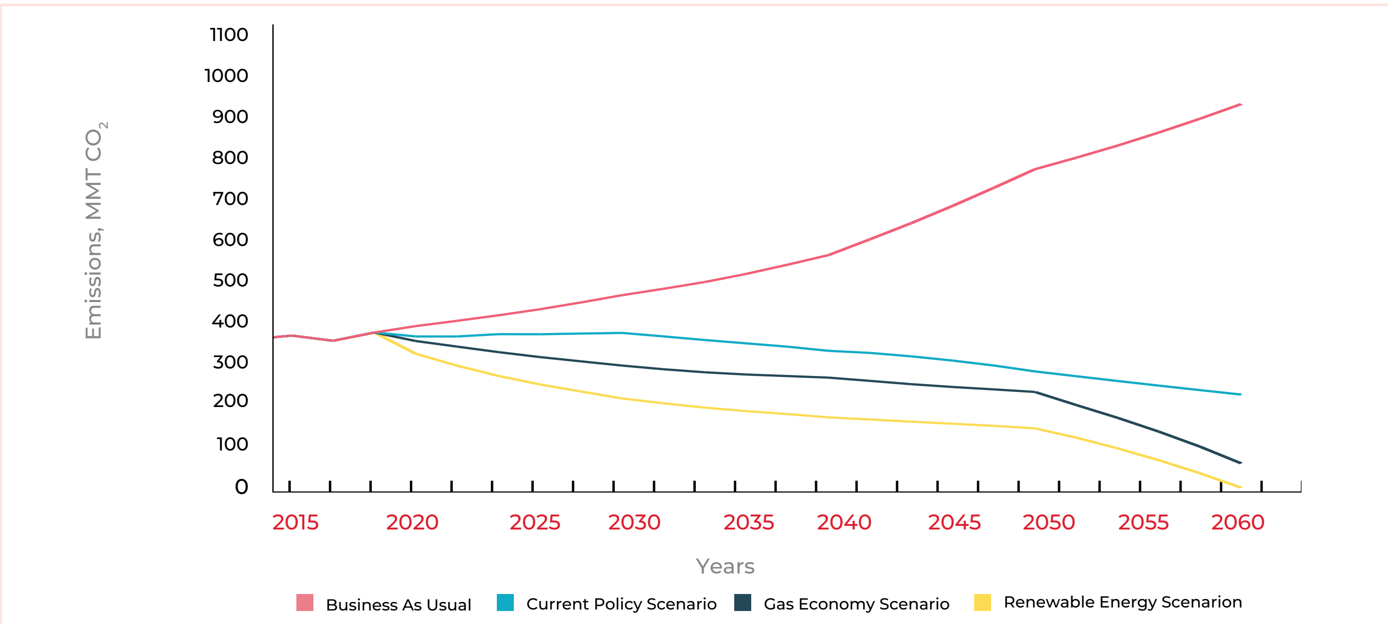


Figure 19. Emission profiles for all scenarios

Figure 20 shows the evolution of emissions for the scenarios. The results indicate that the CPS, GES, and RES, respectively, could reduce the base year emissions by 24.5 %, 38.3 % and 61.5 % in 2050, whereas the reduction would be by 36.7 %, 78.3 % and 96.8 % in 2060. It is worth noting that only the RES passed the vision of Nigeria's LTV-2050 of cutting emissions by 50 % by 2050. The CPS has not performed close to net-zero by 2060 because the ETP's total emission amount does not account for over 60 % of emissions from AFOLU. The implication is that the GES and RES have better potential than ETP and CPS to support the Nigeria's low emission economy by 2060; however, only the RES points in the direction of net zero emission.

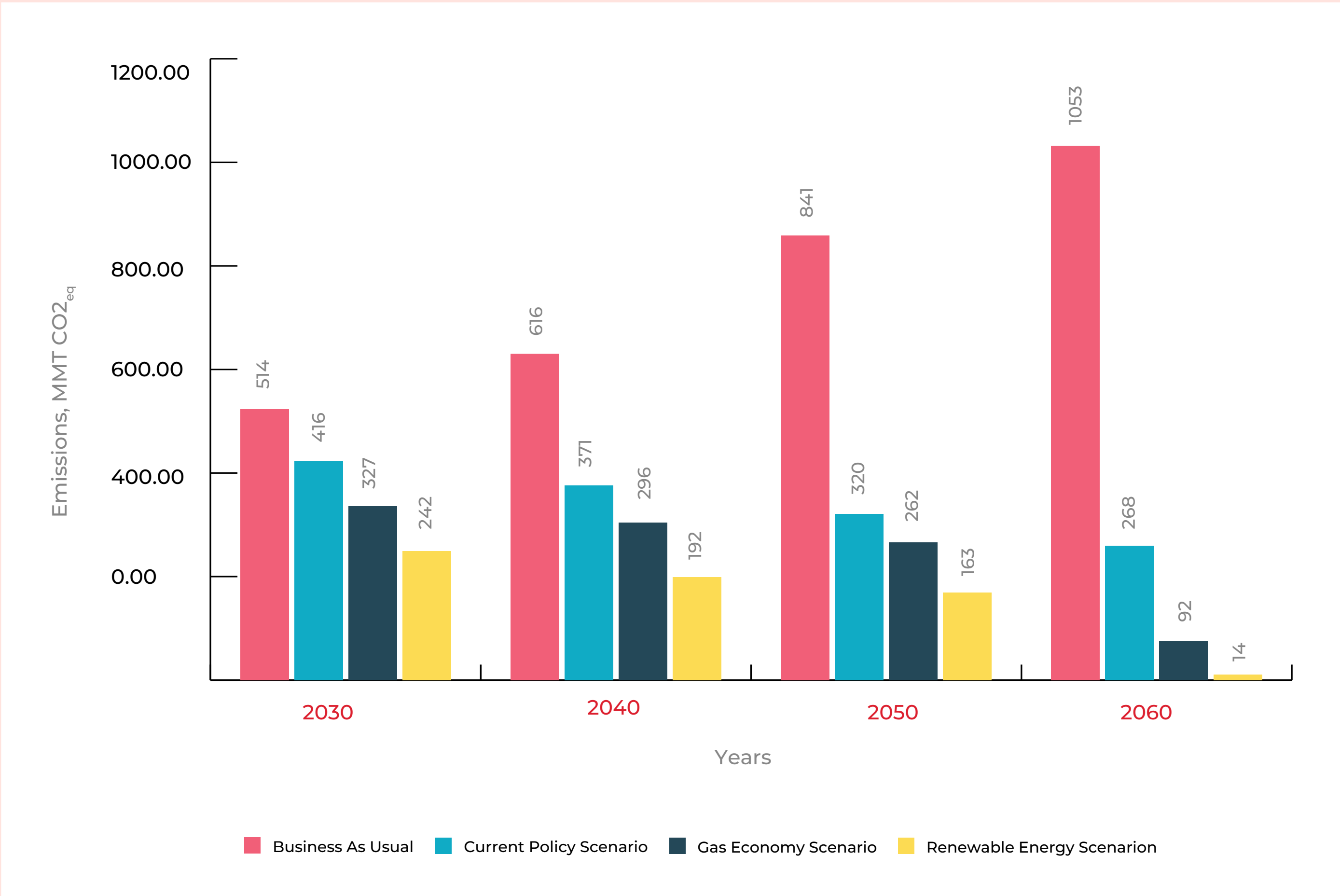


Figure 20. Evolution of emissions by scenarios

Figure 21 shows evolution of emissions per capita for the scenarios. The results indicate that the CPS, GES, and RES, respectively, will have emissions per capita of 1.95, 1.58, 1.24, and 0.92 tCO2eq/Capita by 2030; whereas it will be 2.21, 0.56, 0.19 and 0.03 tCO2eq/Capita by 2060. The implication is that the RES has best potential to achieve net-zero target by 2060; i.e. average person will only emit 30 CO2eq by 2060.

Figure 21. Emissions per capita

Figure 22 shows the emission contribution by sectors (energy, AFOLU, IPPU, waste and others) to each scenario; where emissions from oil and gas extraction, building and residential, transport and power aggregate to the energy sector's emissions. In 2030, under the BAU case, the shares of the energy, AFOLU, IPPU, waste and others, are respectively, 50.4 %, 32.8 %, 4.3 %, 11.6 % and 0.9 %; under the CPS case, the share of energy, AFOLU, IPPU, waste and others, respectively, are 52.3 %, 34.4 %, 3.6 %, 8.6 % and 1.0 %; under the GES case, the share of energy, AFOLU, IPPU, waste and others, respectively, are 73.4 %, 10.9 %, 3.4 %, 11.0 % and 1.3 %; and under the RES case, the shares of energy, AFOLU, IPPU, waste and others, respectively, are 66.3 %, 18.8 %, 4.1 %, 9.7 %, and 1.1 %. However, in 2050 and 2060, AFOLU will serve as a carbon sink for GES and RES, which is attributed to aggressive afforestation, forest management and forest waste-to-energy.

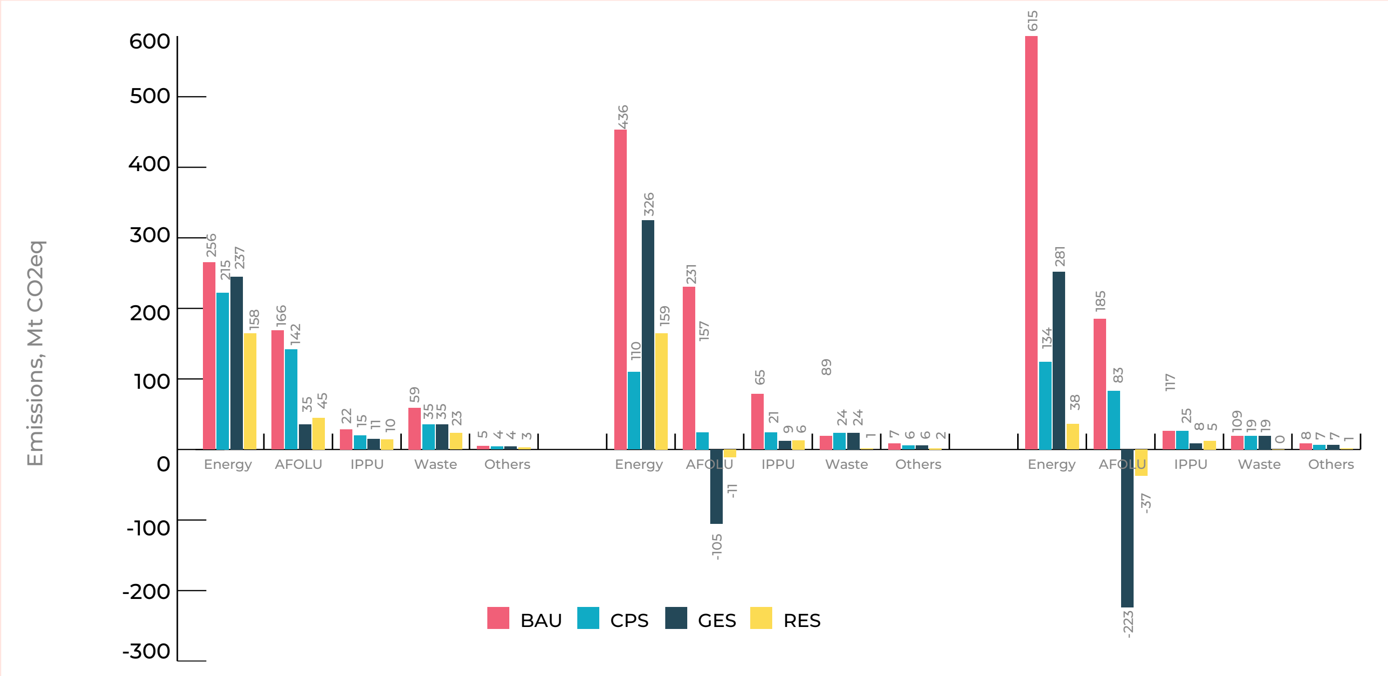


Figure 22. Sectoral emissions contribution to each scenario

3.2.3 Emissions from Sectors

3.2.3.1 Oil and Gas Sector

Figure 23 shows the emissions from the scenarios with respect to the time horizon under the oil and gas sector. As expected, the figure indicates that the BAU has the highest emissions across the years under consideration. However, there will be remarkable reductions in emissions in the next four decades, for example, about 79 % emission reduction in 2060 compared with the base year (2018) emissions. The GES and RES have a huge reduction in emissions in 2060 compared with 2018 emissions at 97.4 % and 98.5 %, respectively. The drastic reduction can be attributed to the use of carbon capture technology, the application of advanced technology for methane leak containment, the elimination of gas flaring and the elimination of other fugitive emissions.

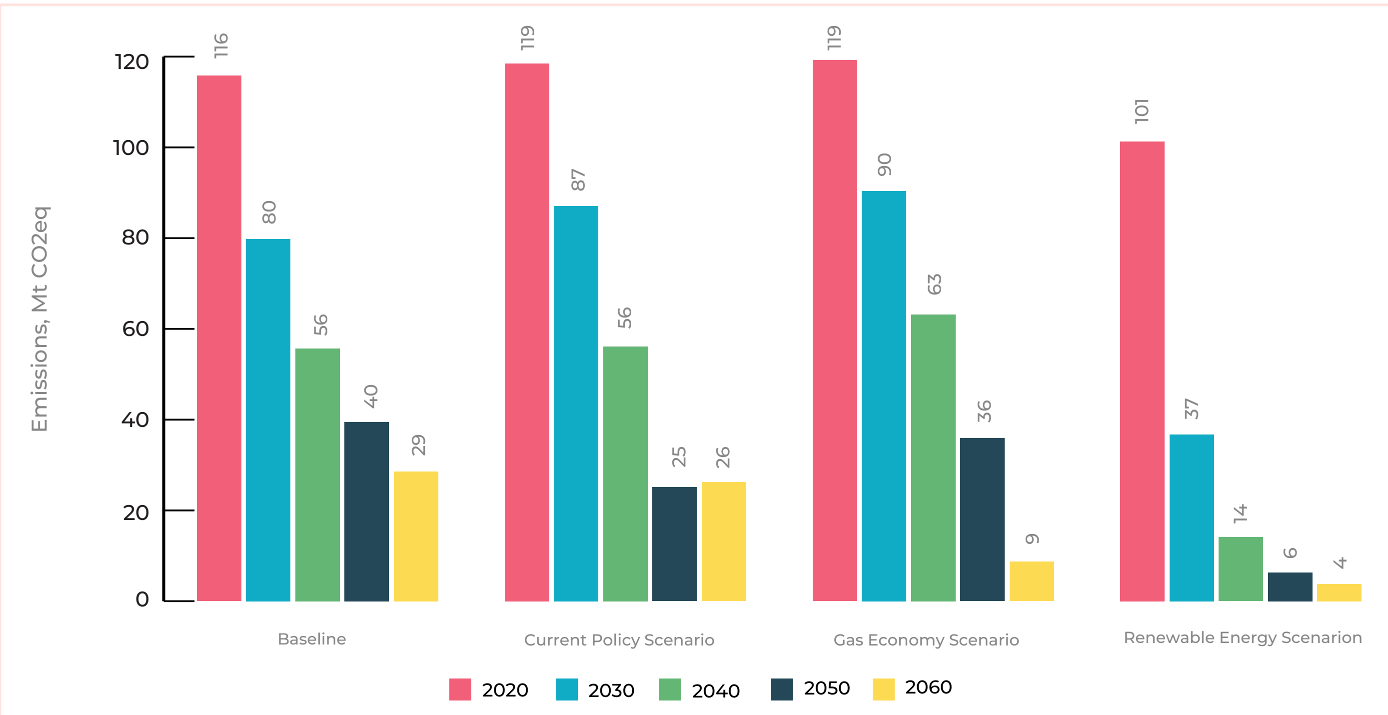


Figure 23 Emissions from the oil and gas sector under various scenarios

Figure 24 presents the contributions of emissions from the oil and gas sector to the total emissions under various scenarios and time horizons. It is shown that between 2020 and 2030, the oil and gas sector will contribute significantly to the total emissions across the scenarios, which is followed by average marginal reduction beyond 2030 except for the RES scenario. The relatively high percentage in emissions contribution between 2050 and 2060 by the oil and gas sector (at low emissions of 4 MtCO2eq in 2060, for example) under the RES scenario is attributed to massive natural-based carbon sink due to reforestation (at the rate of 2.3 % per annum) and excellent forest management. The natural carbon sink (negative emissions) from the AFOLU sector will intuitively amplify the little emissions (4 MtCO2eq) from the oil and gas sector in the total emission (14 MtCO2eq in 2060, for example). In addition, the oil and gas sector emissions contribution to the aggregated energy sector in 2030 and 2060 will be 30 % (BAU), 39 % (CPS), 37 % (GES) and 22 % (RES), and 4.5 % (BAU), 17.7 % (CPS), 1.2 % (GES) and 5.4 %(RES), respectively.

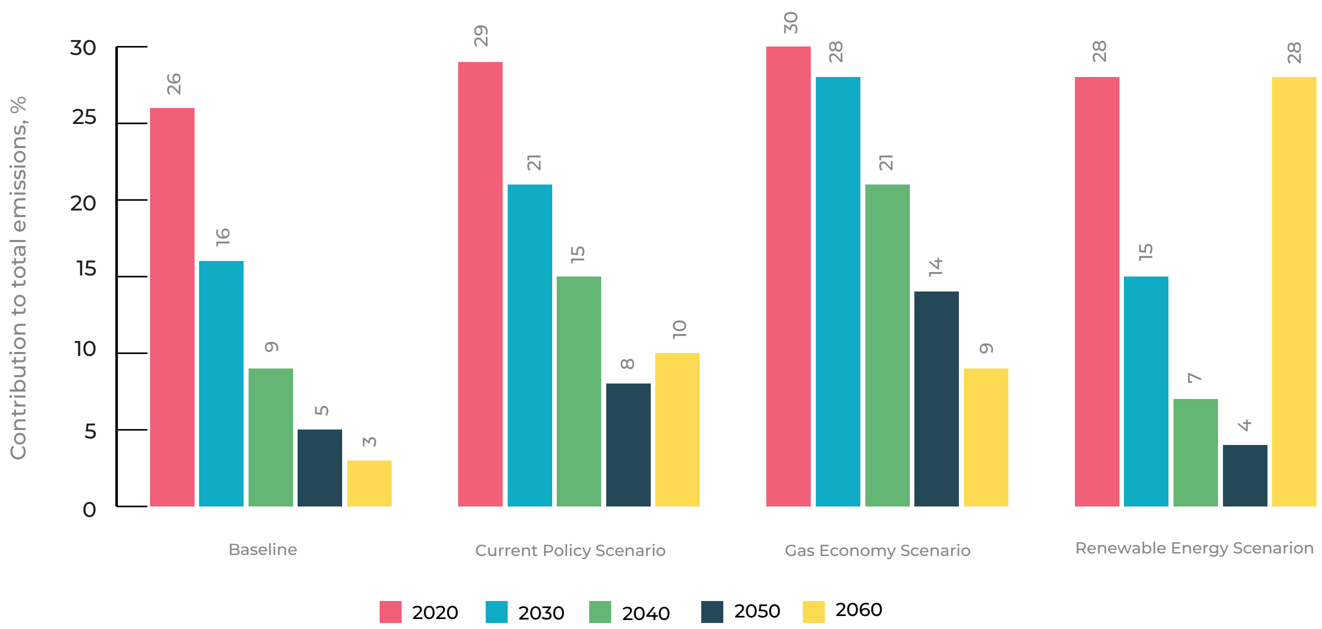


Figure 24 Oil and Gas Sector Emissions Contribution to Total Emissions

It is necessary for Nigeria to seize the opportunities in the global shift from oil and gas utilization to the decarbonization space to position its economy on the path of shared socio-economic prosperity in the long term. For example, the current analysis shows that more than 50 % of the emissions from the energy sector were from the oil and gas subsector in 2018, which are related to commercial production and transformation of oil and gas.

3.2.3.2 Emissions from Power Sector

Figure 25 shows the GHG emissions of power generation for the four scenarios. The GHG emissions of the BAU scenario will grow steadily from 15 to 118 MtCO2eq by 2060. The emissions of the CPS scenario will peak at 18 MtCO2eq in 2040 and drop to 0.4 MtCO2eq by 2060. A similar trend is observable in the GES, peaking at 14 MtCO2eq in 2050 and dropping to 0.1 MtCO2eq in 2060. The low emissions in these scenarios are associated with the penetration of renewable energy and the deployment of carbon capture technologies, respectively. The emissions of the renewable energy scenario will peak at 23 MtCO2eq in 2050 and drop to about 7 MtCO2eq by 2060. Although the RES deploys renewable energy technology, the emissions from biomass are the reason for 7 MtCO2eq in 2060.

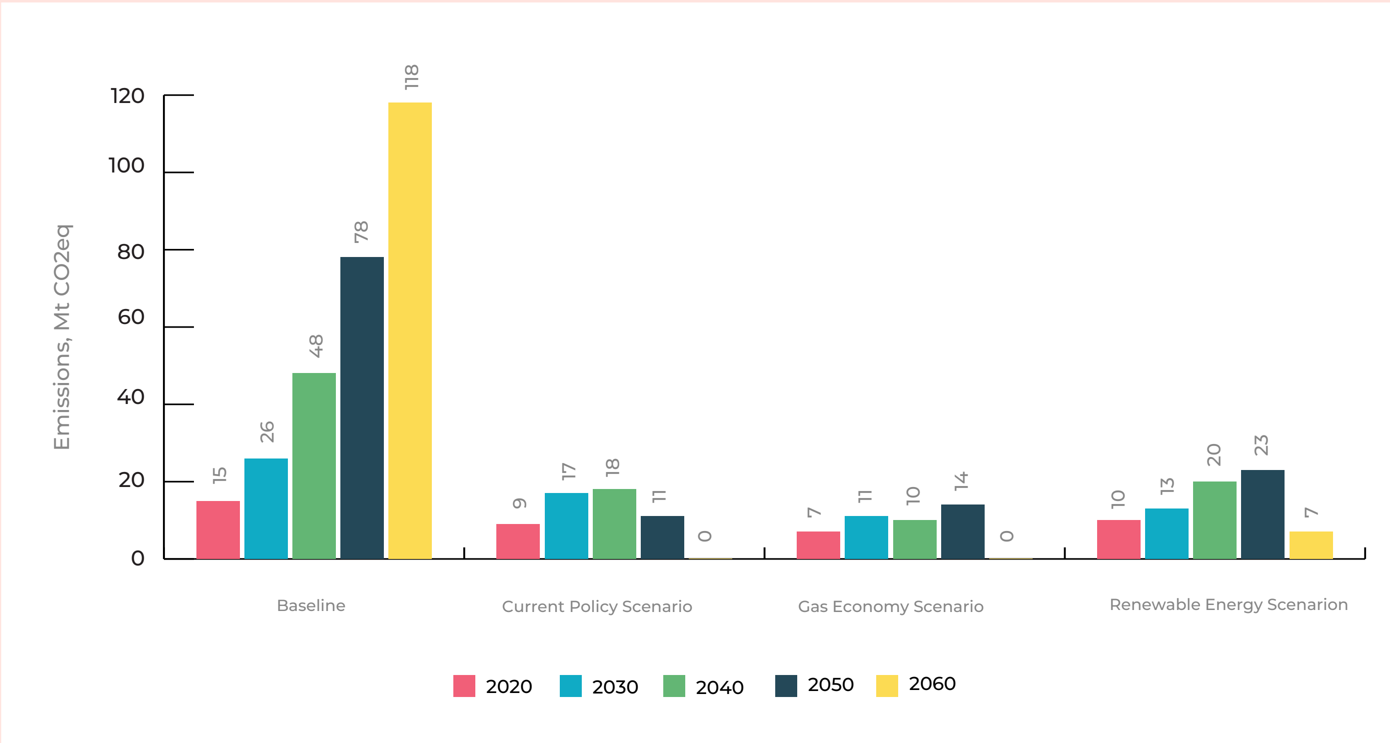


Figure 25. Emissions from the Power sector under various scenarios

Figure 26 shows the emission factor of the baseline and LT-LEDS scenarios. The BAU shows an increase in the power sector emission factor from 429 gCO2e per kWh of electricity generation in 2020 to 461 gCO2e per kWh in 2060. However, the figure shows reductions in emission factors of the mitigation scenarios. The emission factor of the CPS will peak at 176 gCO2e per kWh in 2030 and decrease to 1 gCO2e per kWh in 2060. The emission factor of the RES will gradually decrease from 210 gCO2e per kWh in 2020 to 10 gCO2e per kWh in 2060. For the GES, the emission factor decreases from 191 gCO2e per kWh in 2020 to 0.3 gCO2e per kWh in 2060. By 2060, the emission factors of the mitigation scenarios will fall to 1, 0.3 and 10 gCO2e per kWh, respectively, for GES, CPS and RES, as compared with 461 gCO2e per kWh of the BAU. It is observed that the emission factor from RES will be the highest among the three decarbonization scenarios by 2060, even though it is renewable energy dominated. However, the RES emission factor will be the lowest on an aggregated national emission accounting due to the absorption of biomass emission by regenerating biomass to drive the afforestation and reforestation considered in the AFOLU sector. The observation is attributed to emissions from the use of biomass in electricity generation plants. The huge reduction seen in the emissions of these scenarios, when compared to the baseline scenario emissions, is due to carbon capture technologies and the deployment of renewable energy and nuclear power technologies.

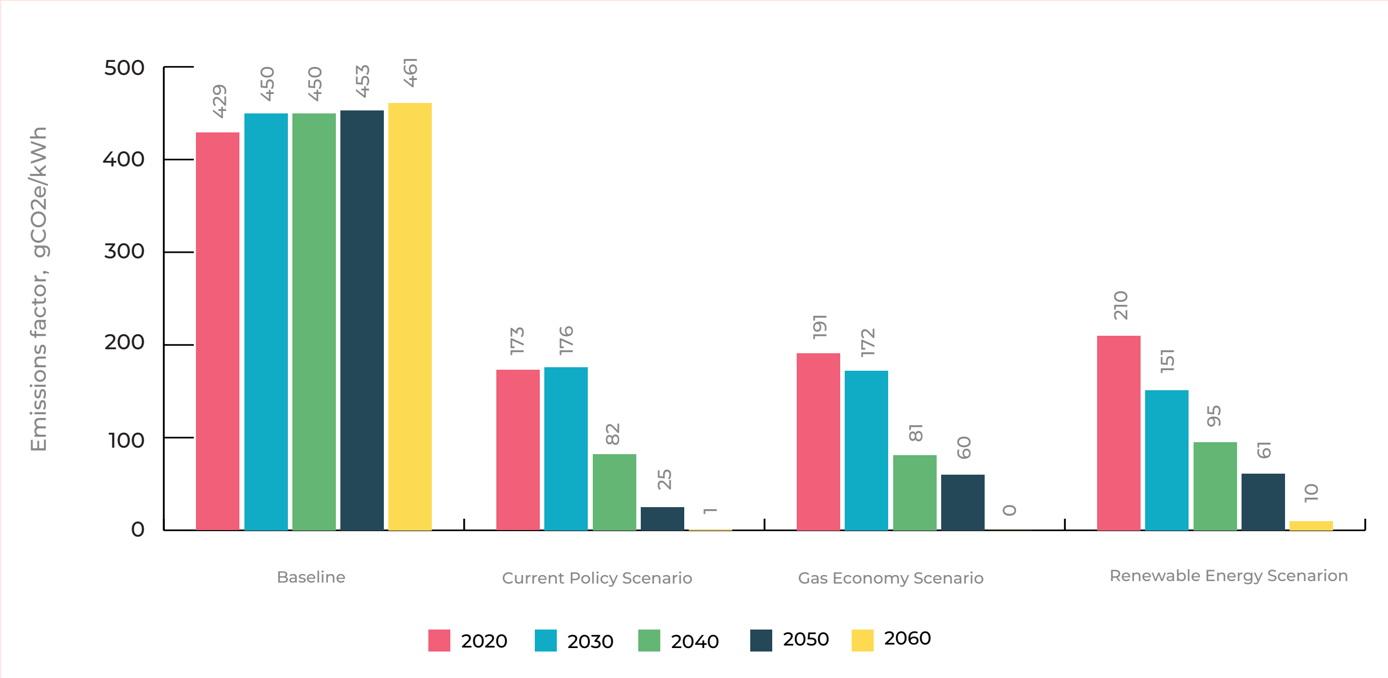


Figure 26. Emission factor for Power sector

3.2.3.3 Emissions from AFOLU Sector

The Agriculture, Forestry, and Other Land Use (AFOLU) sector is Nigeria's second highest producer of greenhouse gas emissions, after the energy sector and the decarbonization of the AFOLU sector is very challenging due to "difficulties in emission estimation, the disperse nature of AFOLU emissions, and the complex links between AFOLU activities and poverty reduction."[19] In the BAU, the AFOLU will contribute 32.8 % of the emissions in 2030, while in the CPS, GES and RES, the contribution of the AFOLU is 34.4 %, 10.9 % and 18.8 %, respectively.

The result shows that AFOLU emissions contribution in RES is higher than the GES because of the better consideration of afforestation and reforestation measures in GES. The emission share continues to increase for the BAU until 2060, when there is a marginal decrease in the emissions, as shown in Figure 27, which could be attributed to the deforestation rate.

According to the U.N. FAO, between 1990 and 2010, Nigeria lost an average of 409,650 ha or 2.38 % per year of forested land. Thus, Nigeria lost 47.5 % of its forest cover over these two decades (about 8,193,000 ha). If nothing is done, Nigeria would have lost another 25 % of its 2020 forest cover by 2060. Hence, the implication is that at least 2.3 % reforestation rate per annum would be required to reverse the deforestation. Furthermore, Nigeria's national forest policy aims to increase national forest cover from the current 6 % to 25 % (the level it was in 2000) by 2030[20]. The reforestation will have to outpace deforestation to achieve this in the near to medium term. Therefore, it is impossible to imagine a transition to net-zero carbon economy in Nigeria without the deep of the AFOLU sector. Going forward, the Gas Economy Scenario (GES) adopted a

[19] Anyanwu, C. N., Ojike, O., Emodi, N. V., Ekwe, E. B., Okereke, C., Diemuodeke, E. O., ... & Nnamani, U. A. (2023). Deep decarbonization options for the agriculture, forestry, and other land use (AFOLU) sector in Africa: a systematic literature review. Environmental monitoring and assessment, 195(5), 565.

[20] National Forest Policy, 2020 – Federal Ministry of Environment

reforestation rate of 5 % to accommodate the reversal of the forest loss and natural carbon sink for the expected emissions from the diverse uses of gas in the economy – power generation, transport, cooking, and industry. The AFOLU emissions in the CPS show a remarkable decrease compared to the BAU. On average, the AFOLU emissions in the CPS indicate about a 46% reduction between 2050 and 2060 compared to the AFOLU emissions from the BAU in the same time horizon. However, the AFOLU sector serves as a carbon sink in the GES and RES between 2040 and 2060 and 2050 and 2060, respectively, as shown in Figure 27.

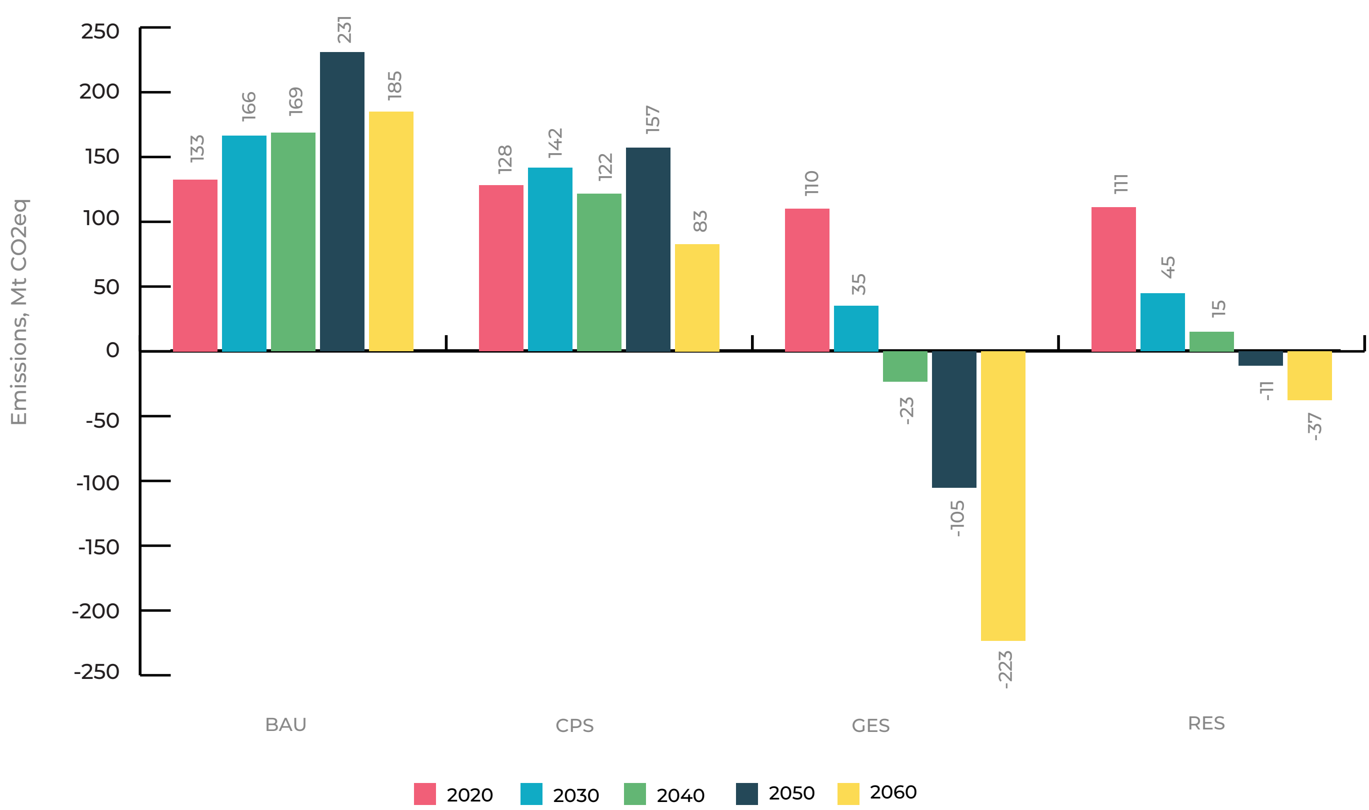


Figure 27. Emissions from AFOLU under the various scenarios

Some of the specific agricultural activities that lead to GHG emissions are enteric fermentation in domestic livestock rearing, land use land-use change and forestry (LULUCF), livestock manure management, rice cultivation, agricultural soil management, and field burning of agricultural residues, liming, urea fertilization and on-farm energy use. However, enteric fermentation and LULUCF account for over 65 % of AFOLU BAU's emissions between 2020 and 2050, as demonstrated in Figure 28. These observations call for the combination of strategies (e.g., ranching of animals to reduce enteric fermentation, reforestation as a mitigation strategy alongside climate-smart agriculture practices) to reduce emissions from the AFOLU sector. Increasing resilience to climate change and effectively reducing GHG emissions in the AFOLU sector will be feasible within LTV-2050's vision for AFOLU, which is elaborated in the adaptation section.

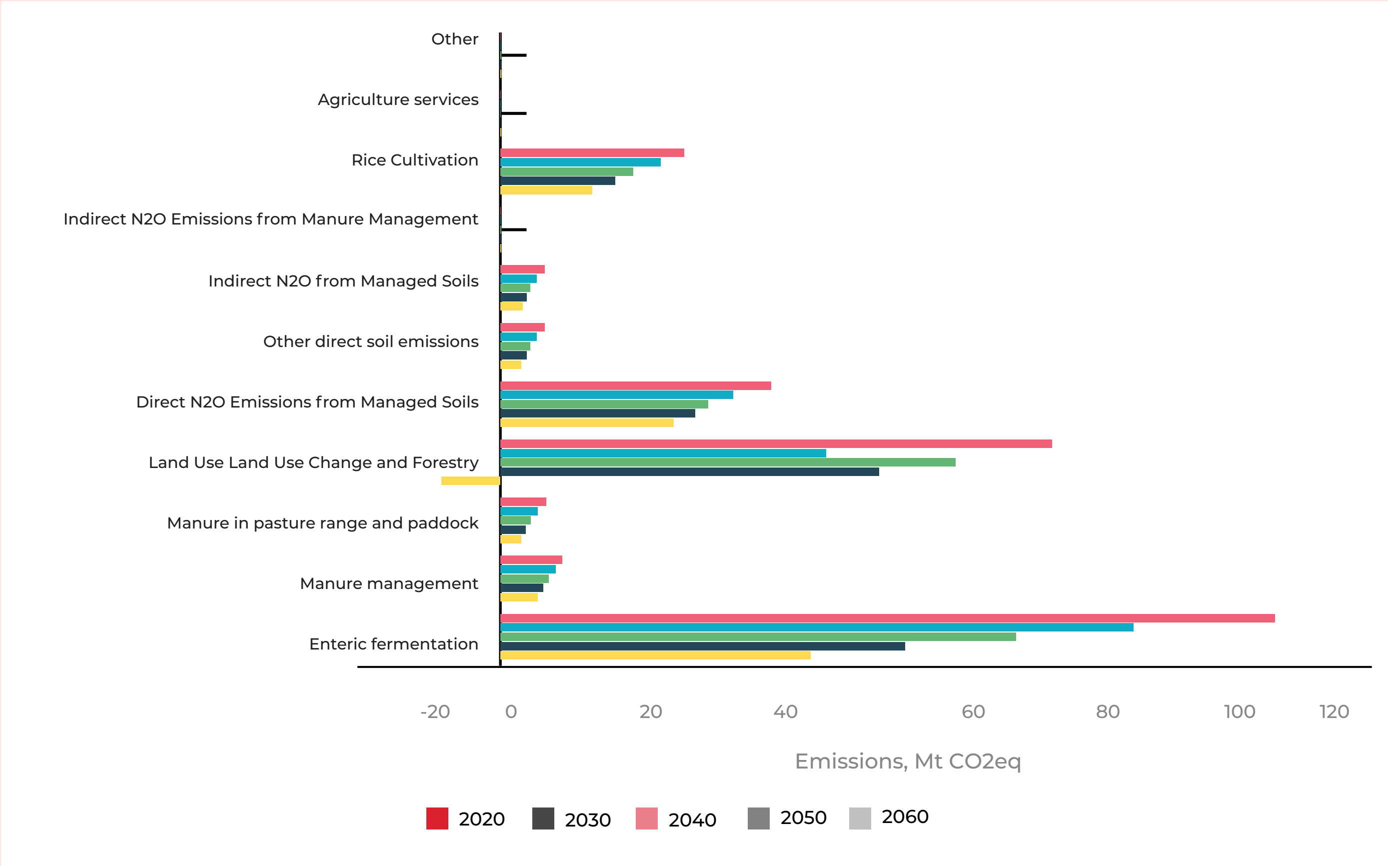


Figure 28 AFOLU activities contributing to emissions in BAU

3.2.3.4 Emissions from Building and Residential Sector

The emission from the building and residential sector is presented in Figure 29, which indicates that the emissions from the BAU grows moderately across the years at 26.0, 30.8, 33.8, 34.4 and 30.4 MtCO2eq in 2020, 2030, 2040, 2050 and 2060, respectively. However, emissions from CPS, GES and RES will reduce by 84 %, 71 % and 79 %, respectively, in 2060 compared with the base year (2018) emissions. The high emission reduction in CPS is attributed to a high level of electrification (71 %), and moderate use of gas (8 %) in the building and residential sector compared to 46 % and 11 % and 44 % and 1 % electricity and gas utilization for GES and CPS, respectively. The emissions were assessed with respect to building operations, referred to as **operational emissions;** whilst other forms of emission obtainable from this sector which are produced during the mining, processing, manufacturing, transporting, and installation of building materials are referred to **as embodied emissions** are accounted for in the industrial sector. The major drivers of energy demand and emissions in the residential sector are population growth, household income and urbanization recognizable in (i) an increase in population causing demand for new residential floor spaces; (ii) more construction of a new building to bridge the current housing deficit in the country; (iii) high cost of living pushing low-income earners to use ineffective appliances and fuels; (iv) more demand for residential floor spaces by high-income earners; (v) demolition and upgrade of old buildings to modern buildings in the urban areas; (vi) changes in construction practices (vii) increase in end-use demand and energy intensity; amongst others. Activities in the residential sector from which GHGs result are cooking lighting, refrigeration air-conditioning and the construction process, these demands vary between the urban and the rural sectors.

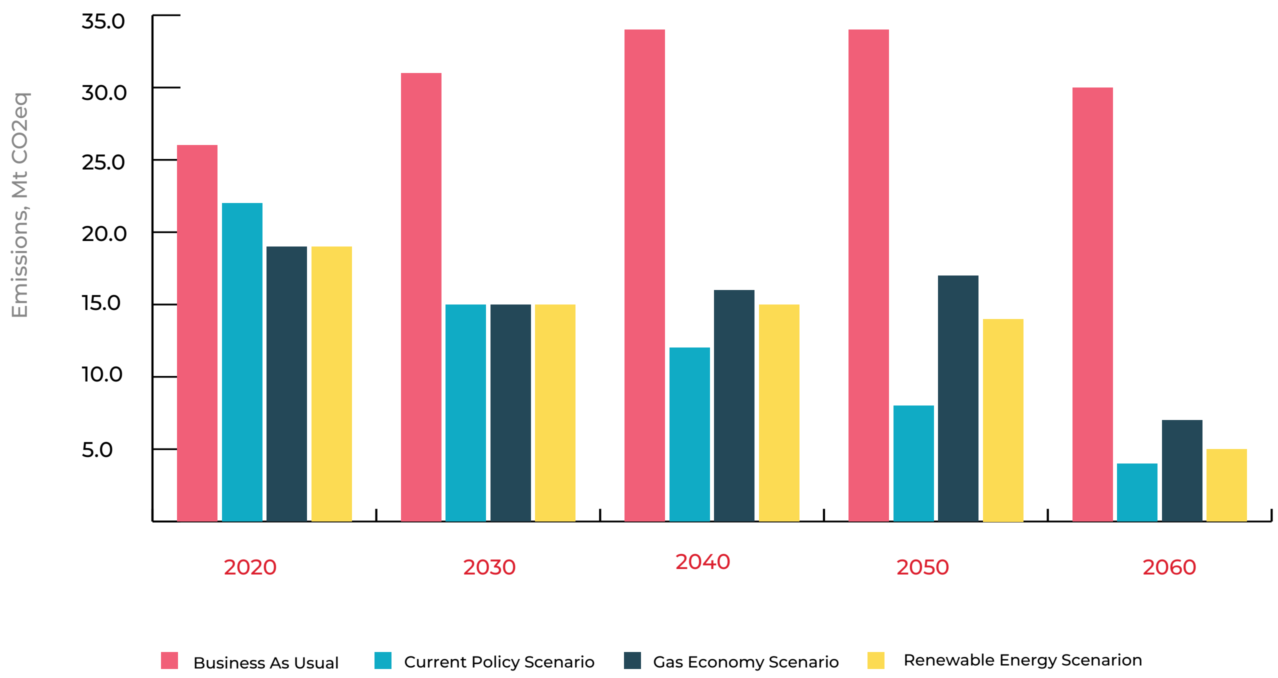


Figure 29 Building and residential sector emissions from scenarios

3.2.3.5 Emissions from Transport Sector

Energy consumption in the transport sector is expected to increase significantly with economic growth and population increase from 2018 to 2060. The transport sector model is divided into domestic aviation, road, rail, and domestic shipping. In domestic aviation, passenger air travels increased from 9.1 billion p-km to 131.1 billion p-km from 2018 to 2060. On the other hand, air freight increased from 19.8 million tonne-km to 286 million tonne-km between 2018-2060. Road transport is subdivided into passenger and freight. Passenger and freight vehicle activities within road transport rose from 9.6 and 2.7 million vehicles in 2018 to 51.2 and 14.4 million in 2060, respectively. Road passenger vehicles are composed of cars and taxis (62.8%), motorcycles and three-wheelers (12.8%), and buses (24.4%), while freight is composed of light-duty vehicles (59.1%) and heavy-duty vehicles (40.9%) in the base year, 2018. Similarly, rail transport is subdivided into passenger and freight, with rail passenger mobility increasing from 1.7 billion p-km in 2018 to 5.1 billion p-km in 2060, while rail freight movement increases from 168.4 million tonne-km to 1.34 million tonne-km between 2018 and 2060.

The transport model adopts the transport configuration of the National Gas Expansion Program (NGEP) and the 2021 updated NDC. The distribution of the transport sector and sub-sector emissions for the three scenarios under the period of 2020-2060 is shown in Figure 30. Across the alternative scenarios, emissions peaks in 2040 in the CPS (95.59 MtCO2eq) and 2050 in both GES (236.34 MtCO2eq) and RES (111.99 MtCO2eq) scenarios. The rate of decline, which visibly lowers the projected increase in GHG under the BAU scenario, is attributed to the policy assumptions outlined in appendix 2.

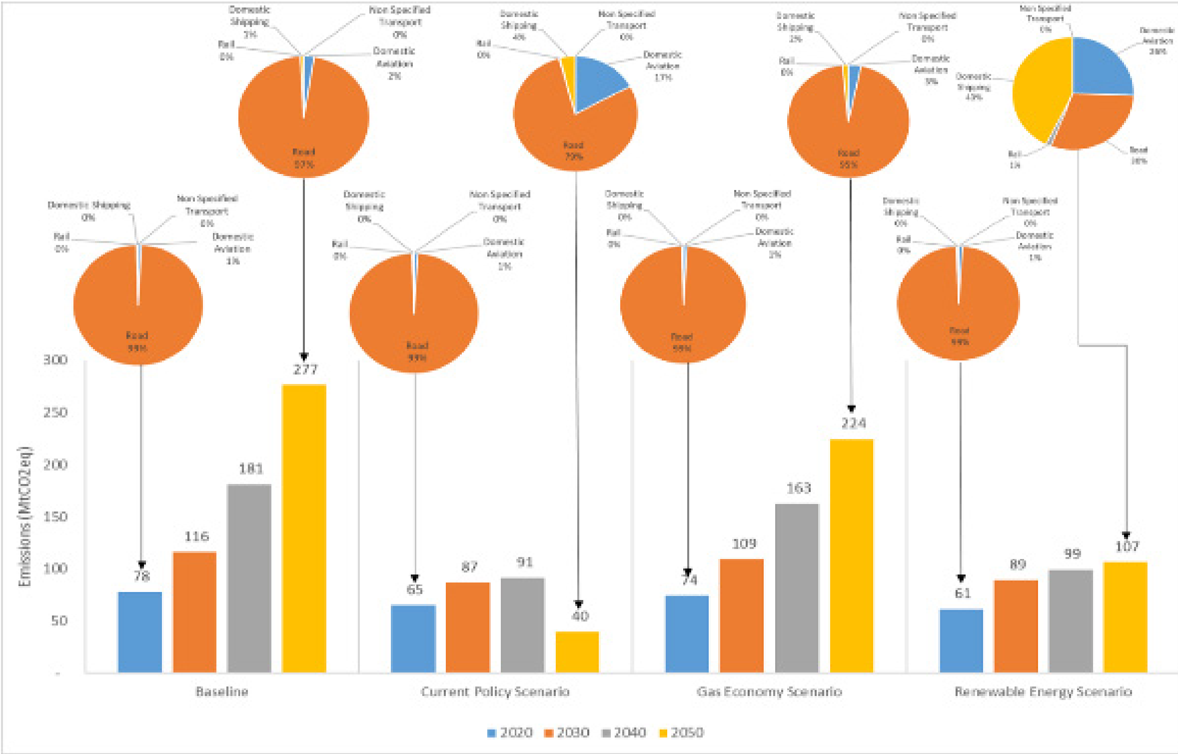


Figure 30. Transport sector emissions across scenarios

Transport emissions under the GES are higher than the CPS and RES scenarios due to the high integration of CNG vehicles in the transport sector, which is expected to replace 45 % of Nigeria's current passenger and freight mobility stock. Although non-mobility measures such as car sharing, cycling, and walking are implemented to decrease passenger movements within the model, emissions in the GES will only decrease to 212.45 MtCO2eq by 2060. In the CPS scenario, the lower emission trend compared to the GES is attributed to the shift in transport mode as 43 % of car users are expected to move to BRT buses following the updated NDC program. Also, the dependency on diesel for freight transport (LDV and HDV) decreases as the use of LPG and electricity increases by 15 % and 85 %, respectively. The decrease in emissions under the GES reshapes the percentage contribution of transport modes as road mobility emissions reduce to 79 % in 2060 from 98 % in 2020. In the more ambitious RES, Nigeria's transport sector is decarbonized with a target of shifting 50 % of road passenger car transport to BRT buses and 40 % of the buses are fully electric. About 80 % of the remaining road passenger vehicles are expected to be electrified, while 40 % of buses will be powered by ethanol before 2060. Other non-mobility measures are implemented in addition to the introduction of EURO IV efficiency standards for all road vehicles. A combination of the transportation sector policies in the RES will displace 205.62 MtCO2eq and 51.34 MtCO2eq recorded in the GES and CPS scenarios by 2060, respectively.

3.2.3.6 Emissions from Industry Sector

The emissions from the industry sector are presented in Figure 31. From the BAU, emission will reach 133.39 MtCO2eq in 2060, which is about 7 times the 2018 emissions. The cement industry contributed 42.9% (8.3 MtCO2eq) of the industry emissions (19.34 MtCO2eq in 2018, whereas it will contribute about 43.9 % (58.5 MtCO2eq) of the 2060 emissions under the BAU scenario (2.3 % increase). However, the emission presented does not account for the emissions associated with power generation to avoid double accounting of the power sector emissions. The emissions from GES and RES are steadily decreasing because of the massive utilisation of carbon capture and sequestration technology and electrified efficient systems in the cement industry. To obtain the industrial emissions reduction in 2060, the CPS scenario will require about 42 % of CCS in energy requirements from natural gas utilizations. Similarly, the GES and RES will require about 58 and 22 %, respectively of CCS.

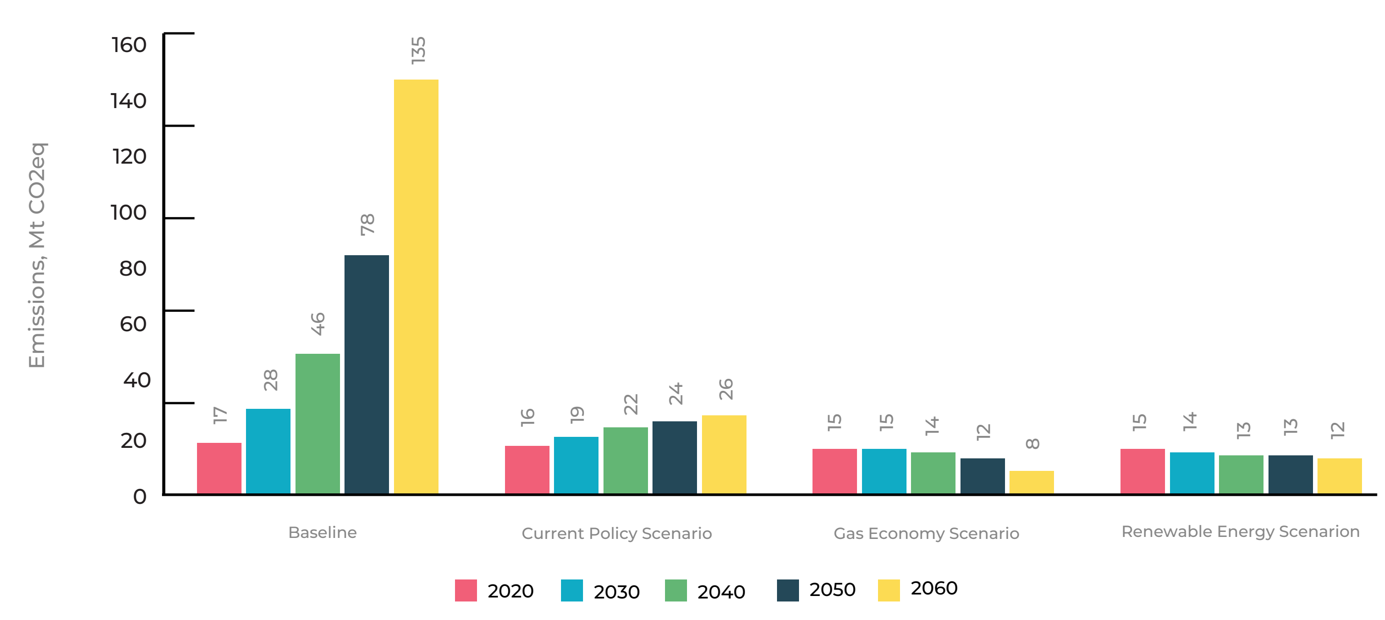


Figure 31. Industry emissions from various scenarios

3.2.3.7 Emissions from Waste Sector

Wastes (solid and liquid) constitute a significant threat to health and the environment due to uncontrolled and illegal dumping of wastes in open spaces, without proper waste management[21]. Waste management aims to reduce the amount of "unusable substances" and prevent potential environmental and health hazards. In general, waste mismanagement is epidemic in Nigeria, and it is responsible for air, soil, and water contaminations with severe health challenges. The waste, trash, or garbage, is derived from the mix of everyday items from local residences, businesses, industries, and public institutions, including hospitals and schools. The wastes contain biomass-derived materials (for example, paper, food scraps, cardboard etc.) and non-biomass-derived materials (for example, plastics, glass, metals, appliances, and batteries). Biodegradable wastes are responsible for the emission of GHGs like methane, nitrogen oxide and carbon dioxide. In recent years, Nigeria experienced an increased volume of electronic waste (e-waste). Nigeria is the leading importer of electronic and electrical appliances in the African continent, with half a million-tonne of waste generation capacity annually[22] . E-waste is attributed to some health

[21] Diemuodeke E.O. et al (2022) Agricultural waste-derived management for bioenergy: a paradigm shift in the waste perceptions; https://doi.org/10.1007/978-3-031-06562-0_13.

[22] UNEP: Nigeria acts to fight growing e-waste epidemic; https://www.unep.org/gef/news-and-stories/press-release/nigeria-acts-fight-growing-e-waste-epidemic

challenges like respiratory and dermatological diseases, eye infections and a decrease in life expectancy. However, the Nigerian Government has recently made move towards the curbing of the e-waste challenges in the country by amending the national environmental regulations for sustainable e-waste management[23] .

The emissions of the waste sector are presented in Figure 32. The emissions in waste fall from 43.37 MtCO2eq in 2020 to 19.33 MtCO2eq in 2060 and 40.73 MtCO2eq in 2020 to 0.15 MtCO2eq in 2060, for the GES and RES, respectively. The fall in waste emissions is due to improved waste management practices and waste-to-energy generation, assuming a circular economy, especially in RES. On the other hand, most of the waste in the RES is used for power generation, where the emissions have been well accounted for in the power generation processes using the waste.

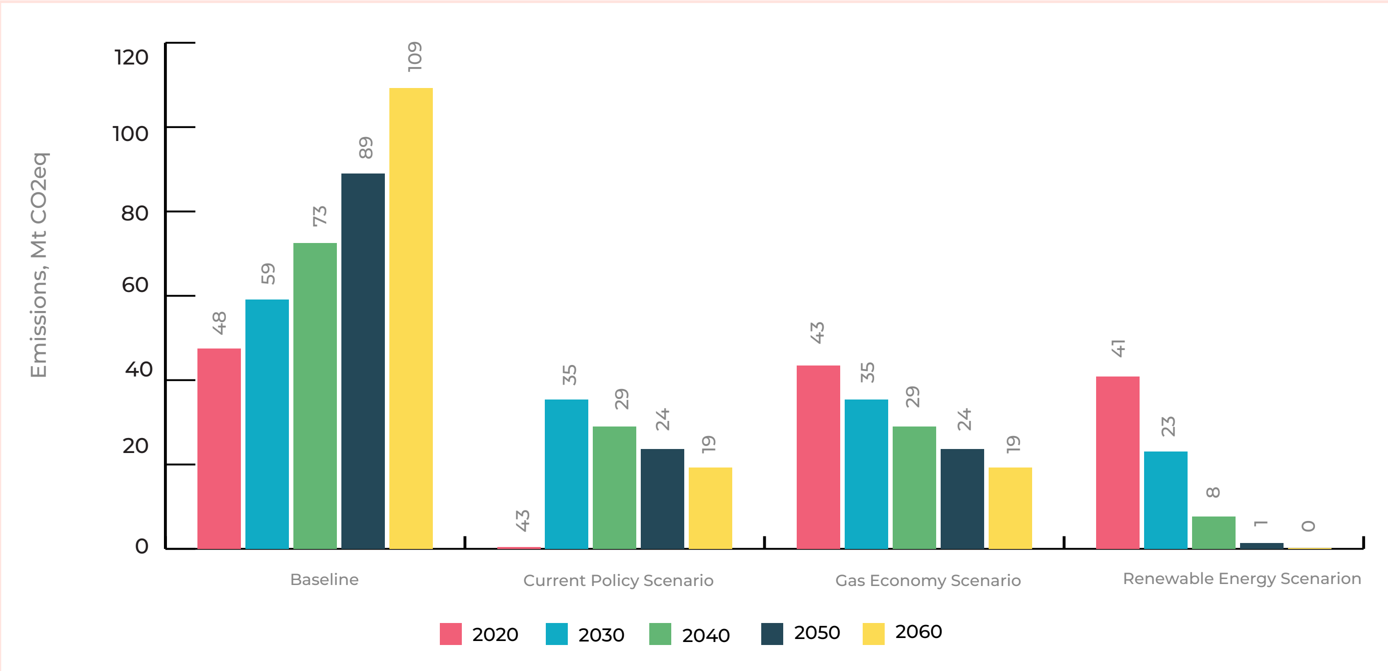


Figure 32 Emissions from Waste sector under various scenarios

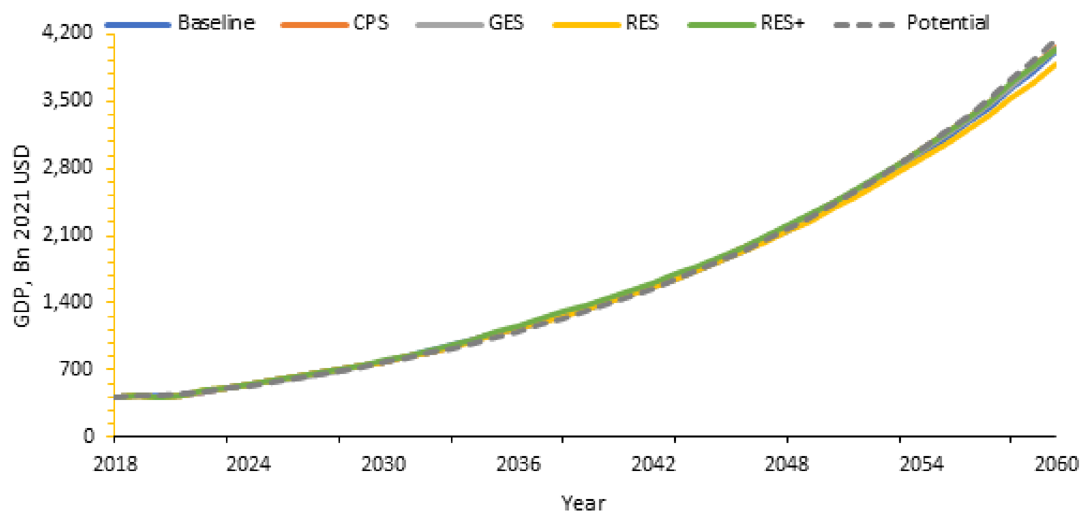
3.3 | Macroeconomics

The macroeconomic results are outlined based on the modelling approach presented in the modelling section. Besides the four scenarios (BAU, CPS, GES and RES) elaborated for energy modelling, an additional scenario (RES+) was considered in the macroeconomic, as explained in section 2.1.5. All results are based on the structural transformation of the Nigerian economy induced by a positive trade shock. The economic transformations necessary to converge Nigeria towards a stabilised growth path are modelled in the form of a positive, non-price competitiveness shock acting symmetrically to increase exports and reduce imports of non-energy goods and services.

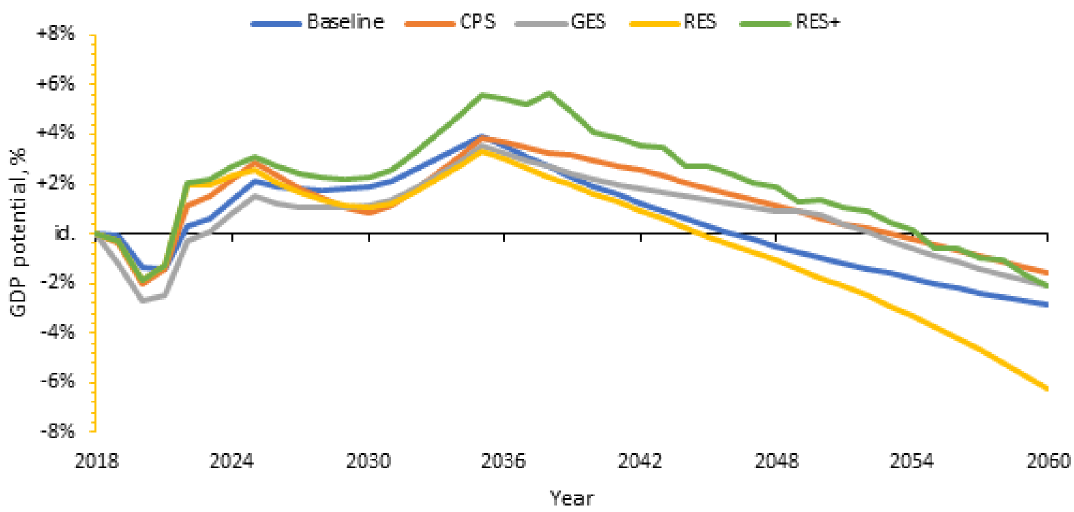
[23] NESREA: https://www.nesrea.gov.ng/wp-content/uploads/2023/01/EE-sector-regulations-2022.pdf

3.3.1 Economic growth

One first important result of our modelling experiments is that energy system options do not significantly impact Nigerian activity growth over the explored horizon (Figure 33b). By construction, the positive trade shock introduced to shape the Baseline scenario into a 'stabilised' benchmark trajectory, i.e., one of controlled trade deficit and reduced unemployment, induces growth roughly in line with its potential of combined labour supply and productivity gains.[24] The sustained pace at which this potential increases dwarfs any activity differential across scenarios.



(a) GDP in billion 2021 USD



(e) GDP as share of potential growth

Figure 33. Economic activity for the five scenarios

[24] It is important to underline that this economic performance is conditional to the successful implementation of public policies aimed at generating the positive, non-price competitiveness shock, at no macroeconomically significant cost.

Looking at the year-by-year spreads to the GDP potential (Figure 33a) allows better reading of results. In broad terms, all scenarios perform below potential at the end of the horizon. The Current Policy (CPS) and Gas Economy (GES) scenarios induce activity levels that are slightly higher than Baseline activity from 2036 and 2039 on, respectively,[25] while the Renewable Energy Scenario (RES) activity increasingly lags behind all other scenarios from 2032 on, with an average annual growth rate (AAGR)[26] 0.09 points (Baseline) to 0.12 points (CPS) lower. RES+, however, marks the benefits of the surmised international support that differentiates it from RES: its GDP dominates all other scenarios up to 2054, when it roughly falls in line with the CPS and ends up 2.1% below potential GDP (like GES) in 2060.[27]

Before 2035, the growth of all scenarios increasingly overshoots its potential thanks to the gradual reduction of the unemployment rate (Figure 34).[28] The positive trade shock benefits activity by mobilising more of the available workforce to address the rising foreign demand for Nigerian exports and, more importantly, the substitution of national production to imports. The 2035 peaking of the favourable trade shock (see Figure 5) induces a sharp turning point for the comparison of all scenarios to potential growth, as well as, expectedly, for their unemployment results.[29] RES+ fares better than other scenarios except Baseline regarding unemployment until 2043, although following an ambitious energy transition. It notably succeeds in reducing unemployment to 4.8% in 2038 and maintains this rate below 6% until 2060. Conversely, RES fares the worse, gradually detaching itself from the broad group of all other scenarios.

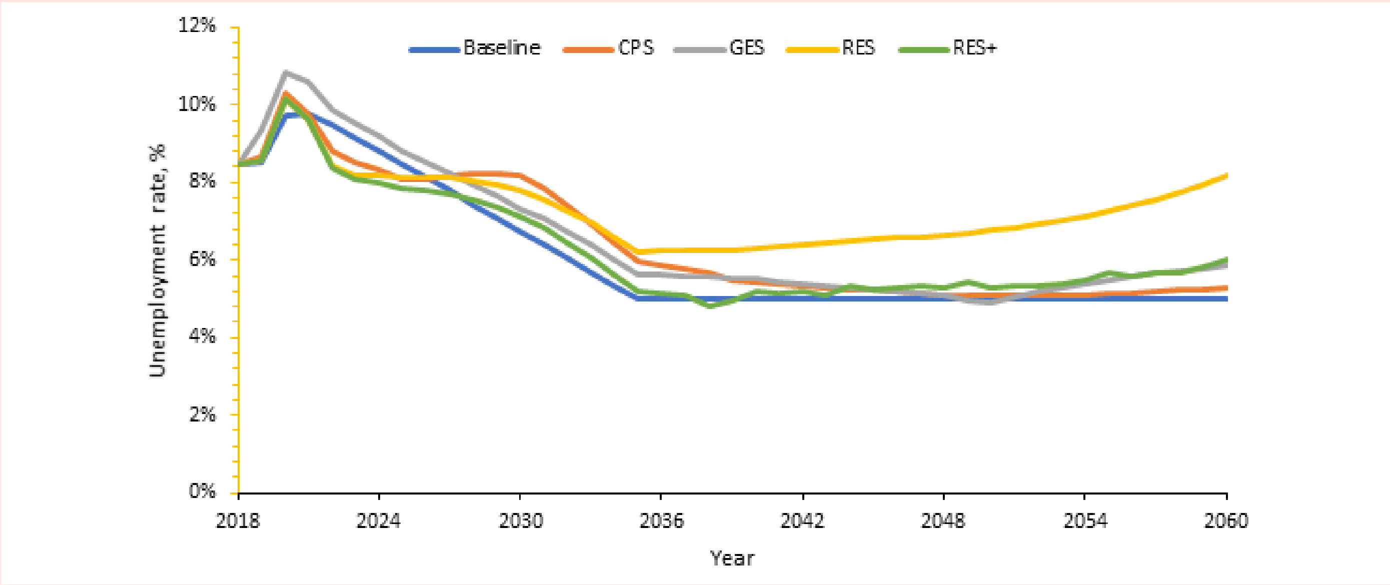


Figure 34 Unemployment rate, five scenarios

[25] CPS also performs better than Baseline from a GDP perspective in the first years of projections (2022-2026).

[26] The AAGR (2018-2060) are 5.5% (Baseline), 5.53% (CPS), 5,52% (GES), 5.41% (RES) and 5.52% (RES+).

[27] The specific profile of the RES+ GDP spread to the quite monotonous potential GDP trajectory is caused by the discrete representation of energy supply investments in LEAP, which are the source of its differentiation from RES.

[28] Potential growth only considers labour supply (active population) and labour productivity variations, under the implicit assumption of a constant unemployment rate.

[29] The sharpness of the turning point must not be over interpreted. It results from the choice of a linear convergence of the unemployment rate to 5% in 2035 as target to the trade shock calibration process. Smoother convergence assumptions would deliver smoother GDP and unemployment profiles.

Table 1 presents the overview of the key socioeconomic results for the five scenarios. The detailed modelling results highlight two major causes to that scenario differentiation: the impact of scenario assumptions on the cost share of energy in non-energy production, and on energy trade.

GDP	Real GDP (In Million 2021 USD)	Real GDP growth rate	Unemployment rate
Baseline	4036.39	5.50%	5.00%
CPS	4089.61	5.53%	5.30%
GES	4069.31	5.52%	5.85%
RES	3896.10	5.41%	8.16%
RES+	4067.97	5.52%	6.00%
Note: *The trade shock applied under baseline conditions, by design, targets an unemployment rate of 5% from 2035 to 2060.			

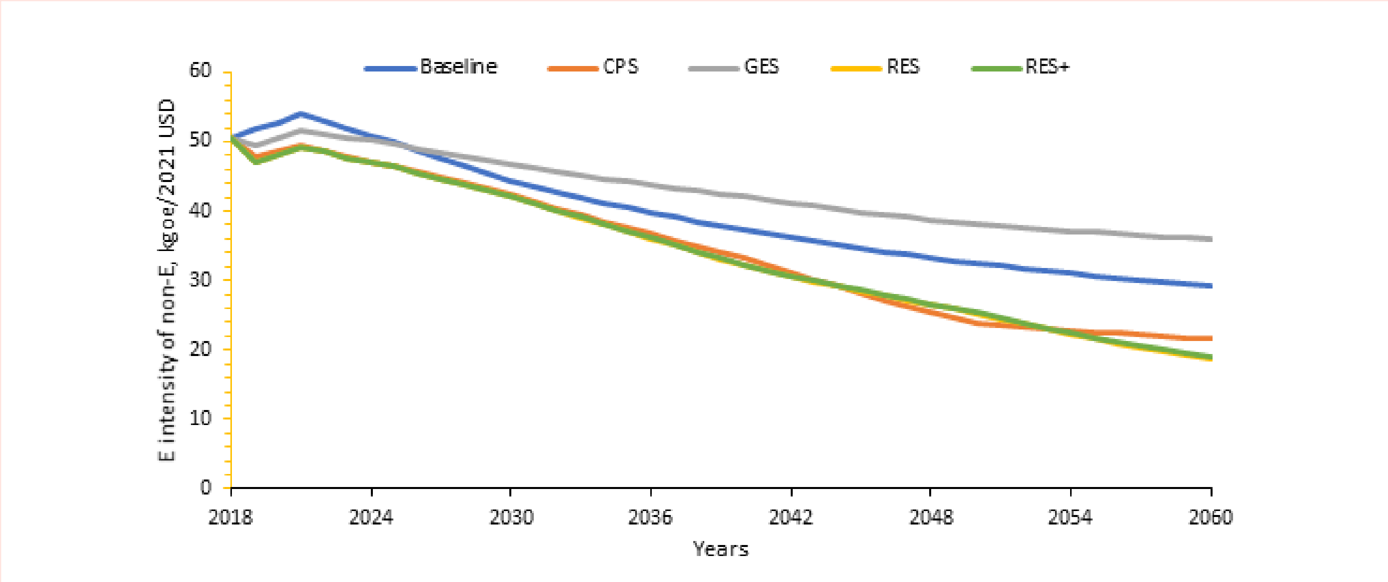
Table 1 Table of key results by 2060 end of modelling horizon

3.3.2 Energy intensity and energy cost share of non-energy activity

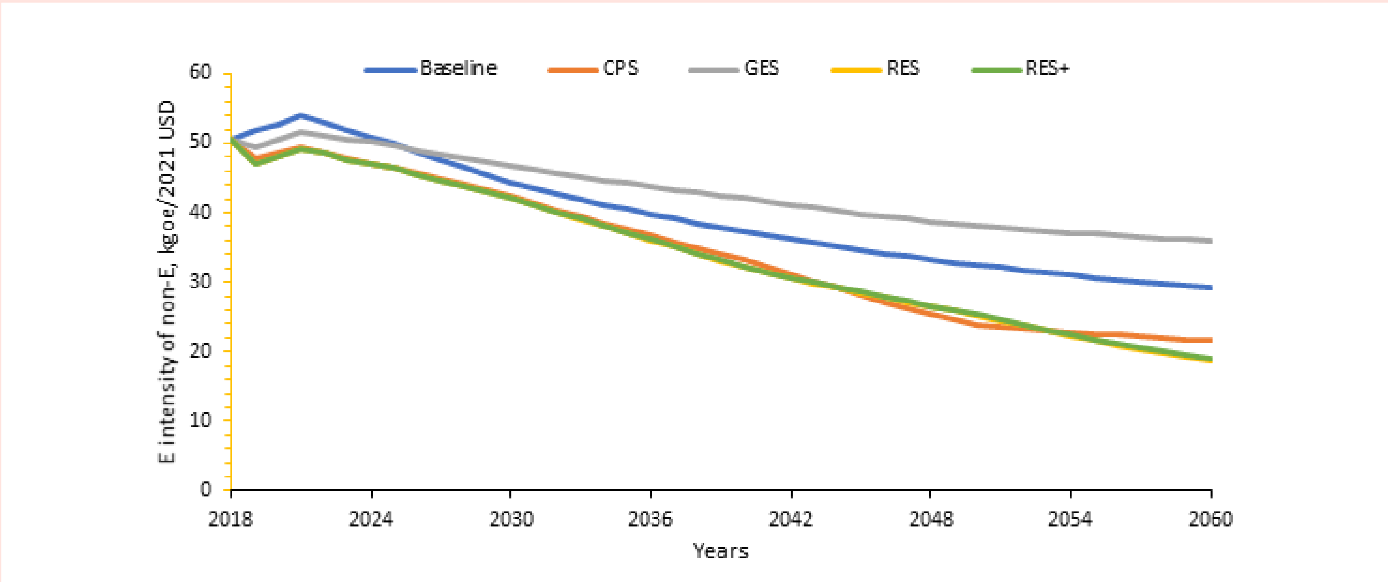
Non-energy production constitutes the larger share of Nigerian economic activity. It generates 86% of Nigerian GDP at our 2018 calibration year, and the proportion increases through time in all scenarios as the limited availability of oil and gas resources significantly constrains the development of fossil fuel supply activities. KLEM is designed in such a way that any increase of the cost share of energy in non-energy production drags growth of that production below its potential through losses of competitiveness on domestic and international markets, in favour of the international variety of non-energy goods and services. The evolution of that cost share hangs in turn on the combined evolutions of the energy intensity of non-energy production and the price of energy faced by non-energy firms.

In all scenarios, the energy intensity of non-energy production decreases through time (Figure 35a), which denotes energy efficiency gains — an assumption common to most energy-economy outlooks on all countries and regions of the world.[30] In Baseline, gains happen at the average pace of 1.30% a year. CPS brings that pace to 2.01% a year, while RES and RES+ push it further to 2.33% and 2.31% a year respectively. In contrast, GES only records gains of 0.81% per year. At our 2060 end-horizon, the increasing gap between scenarios results in the highest intensity (GES) being more than 90% above the lowest (RES/RES+).

[30] The hike of energy intensities from 2018 to 2019 points at inconsistencies between the macroeconomic and energy data sources that our KLEM-LEAP architecture calibrates on for statistically covered years beyond 2018 (see Annex C). This issue could not be investigated before completion of the reported simulations. It will be in future work.



(a) Energy intensity of non-energy



(b) Cost share of Energy in non-energy production

Figure 35 Energy intensity and energy cost share of non-energy production

Strongly differing energy price trajectories — not explicitly reported for the sake of concision — radically change the ordering of scenarios when considering the cost shares of energy (Figure 35b). In the Baseline, the cost share of energy in non-energy production rises substantially in early years, betraying strong energy price increases that reflect specific investment requirements up to 2040. In later years, it reduces at a pace higher than that of energy intensity, which denotes decreasing energy prices relative to other input prices. In contrast, the closely aligned RES and RES+ cost shares increase a bit less in early years, but also decrease less rapidly after the 2025 turning point common to all scenarios, to such extent that they have barely returned to their 2018 value in 2060. At that point, they are 67% (RES+) to 70% (RES) higher than in Baseline, although their energy intensities are 35% (RES+) to 36% (RES) lower, marking the energy cost increases that they induce. CPS and GES navigate between Baseline and RES/RES+ values but end up converging to the lower Baseline trajectory for the former and overcoming the higher RES/RES+ one for the latter, due to different energy profiles (supply and demand).

The above ordering of cost share evolutions is the reason for the lower activity of RES compared to CPS or Baseline, as well as that for the relative closeness of the latter two scenarios. As already expressed, higher cost shares affect competitiveness on domestic and international markets. However, the trade balance is pre-determined in all scenarios, including in RES+ (although laxer). The loss of competitiveness thus induces downward adjustments of the real effective exchange rate (REER) to warrant that the trade balance constraint is met. These adjustments are the ultimate cause of the loss of activity through the increase of import costs for producers and consumers alike. As expected from the modelling choice of controlling trade deficits, i.e., the foreign debt accumulation, trade effects are central to the macroeconomic consequences generated by energy system costs differentiation.

There are, however, more direct consequences of the five scenarios on trade: their impacts on imports and exports of energy commodities.

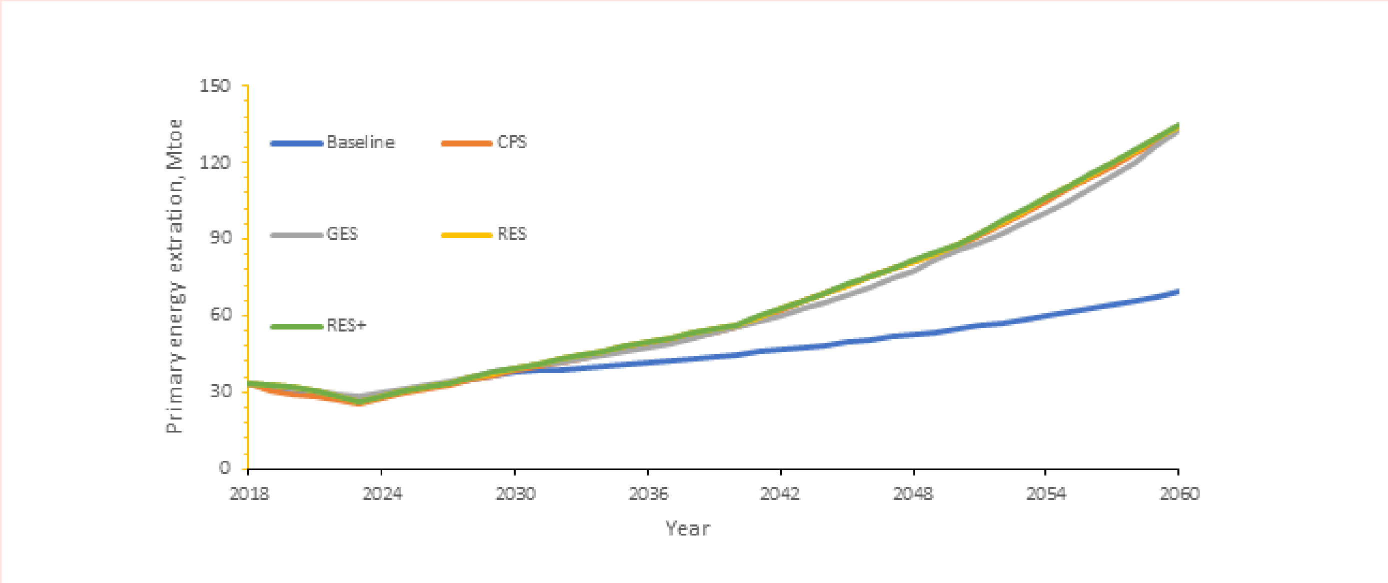
3.3.3 Trade effects through the evolution of energy imports and exports

The impact of scenarios on energy trade and its propagation to non-energy trade via the trade balance constraint is the other major driver of scenario differentiation. The drop of the energy trade contribution to Nigerian GDP is inscribed in the comparative dynamics of Nigerian oil and gas extraction and the economy's potential growth.

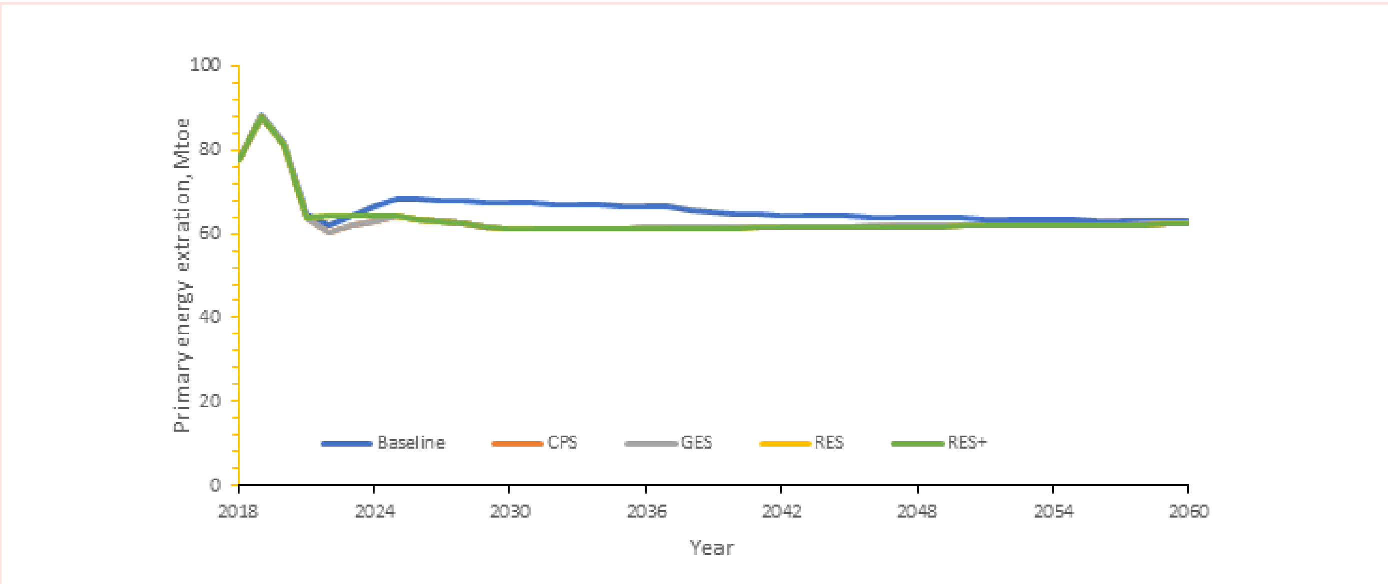
Energy scenarios reveal a pivotal, yet distinct role for natural gas in Nigeria's transition. Under Baseline, natural gas production exhibits a steady increase, indicative of a continuation of current trends (Figure 36a). In contrast, transition scenarios project a dramatic increase in production, reaching 133 Mtoe by 2060 in CPS or GES (a 92.1% rise from Baseline) and 134 Mtoe in RES and RES+ (93.3% above the Baseline).[31] Even though the focus on natural gas is motivated by the dual objectives of meeting domestic energy demand and leveraging export potential, it is mainly used domestically in GES due to relatively lower efficiency in conversion and uncontrolled domestic energy demand, leading to a faster depletion partly explaining the increased energy cost share (Figure 35b). In contrast, in CPS, RES and RES+, natural gas export capacities are larger, with differences explained by distinct associated efficiencies and ambitions in energy supply and demand over time, with gas facilitating a smoother transition towards a low-carbon economy and ensuring energy security.

In all transition scenarios, a consistent decrease in crude oil production from Baseline levels is observed (Figure 36b). This trend indicates a strategic move away from Nigeria's traditional reliance on oil, aligning with global environmental commitments. While oil extraction from 2018 to 2060 amounts to 2,848 Mtoe in Baseline, it reaches 2,725, 2,726 and 2,729 Mtoe in CPS, GES, and RES/RES+ respectively.

[31] Differences in production levels are due to differences in production process efficiency, while all transition scenarios extract the same quantity of natural gas from the ground.



(a) Natural gas extration



(b) Crude oil extration

Figure 36. Natural gas and crude oil extraction, five scenarios

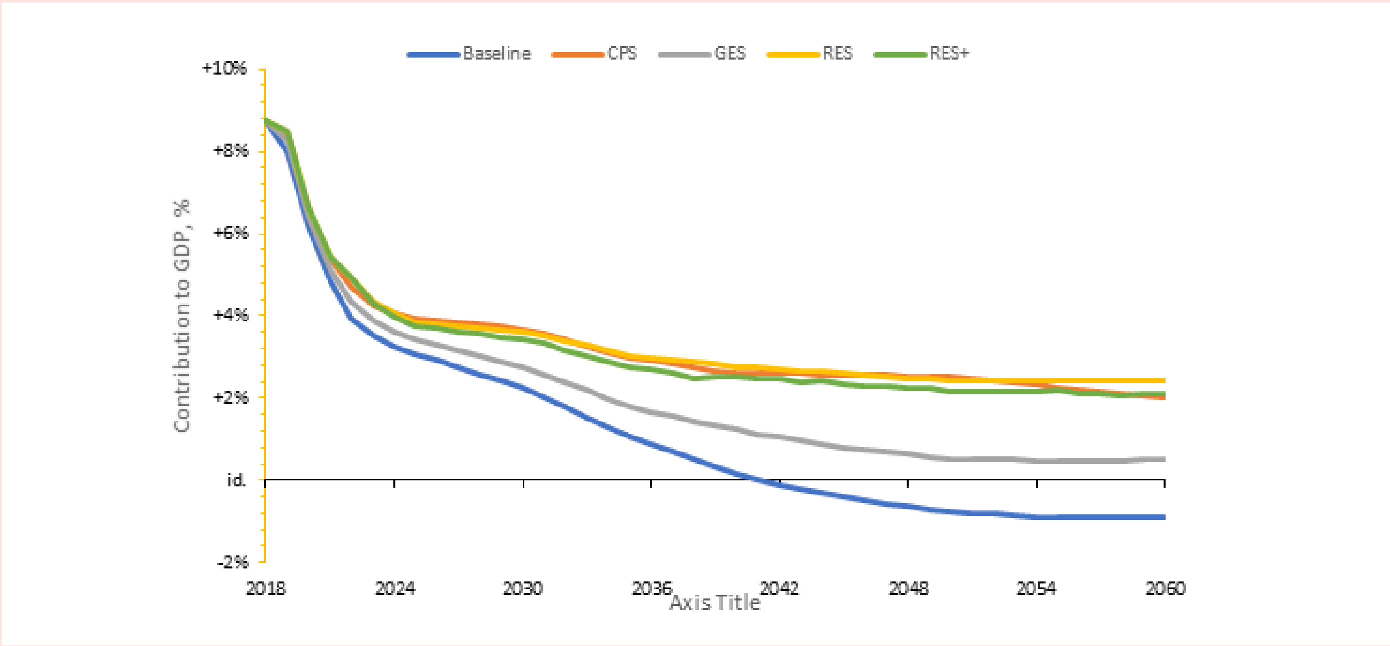
The distinct trends in oil and natural gas domestic consumptions generate significant implications for the country's energy trade balance and associated revenues at the projected international prices.[32] In CPS, natural gas export revenues from 2022 to 2060 are 700 billion USD higher than in Baseline, while this number only reaches 29.5 billion USD for GES due to much higher domestic uses. A more ambitious transition and the better management of energy demand under RES and RES+ increases gas export revenues to 922 billion USD above Baseline, highlighting the key role of natural gas in Nigeria's economic landscape even on transition pathways.

[32] Central Bank of Nigeria data on crude oil exports (crude oil price 2018 to 2022); Then for the projection year, this study used the "EnerGreen below 2°C" scenario by Enerdata (crude oil price from 2031 on, natural gas price from 2018 to 2060). The price of crude oil for the years 2023 to 2030 is a linear interpolation between the 2022 price of CBN source and the 2031 price of Enerdata source. See https://www.enerdata.net/publications/reports-presentations/energy-climate-scenarios-2050.html

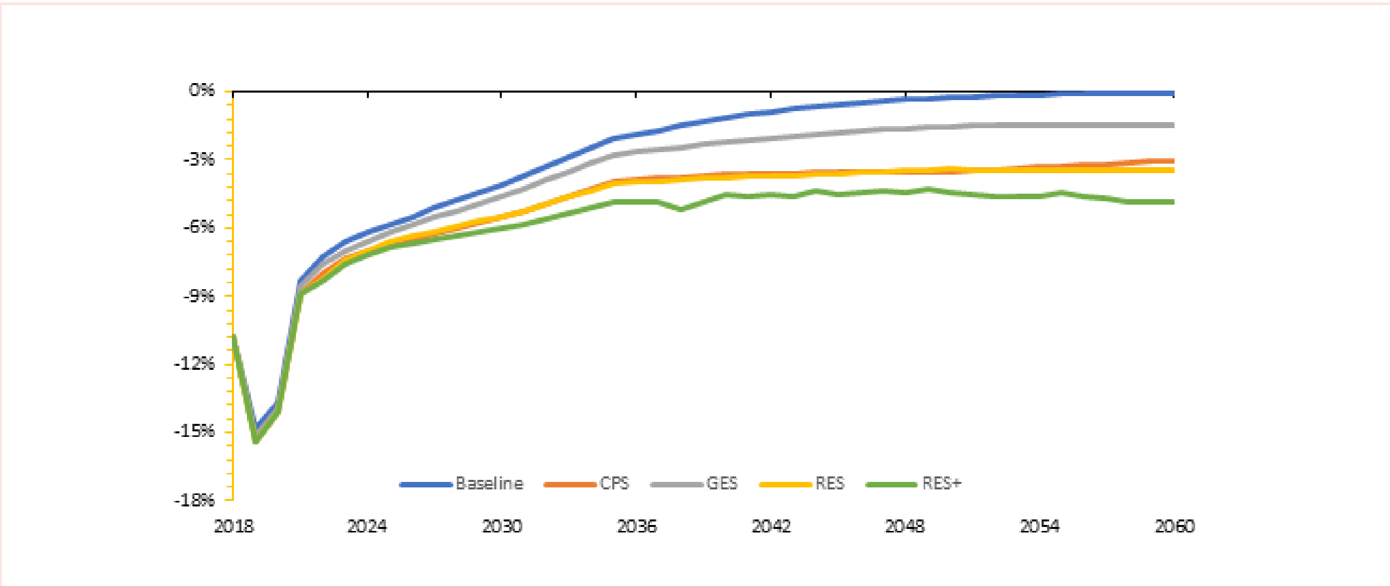
Regarding oil, all scenarios project a drop in oil export revenues by 2060, in line with global shifts towards more sustainable energy sources. Due to differences in oil production and domestic consumption, GES projects the same oil export revenues as Baseline over the 2022-2060 period. Those of the CPS are 0.278 billion USD lower for the 2022-2060 period, due to lower oil production not compensated by the decrease in domestic oil consumption. Conversely, those of RES and RES+ are 5.2 billion USD higher, reflecting a faster move away from domestic oil consumption despite production lower than in Baseline.

Such production levels, facing contrasted trends of domestic energy demand and supply, induce contributions of energy trade (net energy exports) to GDP that decrease at paces differing across scenarios (Figure 37a). In Baseline, the unchecked rise of domestic energy consumptions together with an energy mix highly based on fossil fuels gnaws on the export capacity to the point that Nigeria becomes net energy importer (in money value) in 2042, ending up necessitating 0.9% of its 2060 GDP to cover the incurred net costs. Similarly, GES experiences a rapid decline of its export capacity because of uncontrolled domestic energy demand. However, the development of natural gas extraction and the substitution of domestically extracted gas to imports of refined oil products allow Nigeria to remain a net energy exporter. Lastly, CPS, RES, and RES+ benefit from transitions away from fossil fuels and lower domestic energy demand, allowing Nigeria to remain a net energy exporter. In those scenarios net export revenues, although rapidly declining in early years, remain above 2% of GDP.

The 1% trade deficit objective of Baseline, CPS, GES, and RES warrants that the dynamics of the non-energy trade contributions to GDP compensate those of energy trade (Figure 37b). RES+ stands out as marking the slack on trade deficit allowed by the international aid that differentiates it from RES, explaining their distinct macroeconomic performances. More specifically, the RES+ scenario assumes international financial transfers amounting to an average 1.1% of Nigerian GDP from 2022 to 2060 (under RES+), with fluctuations corresponding to the chronogram of incremental energy supply investment required to shift from CPS to RES. Over the 39-year period, the cumulated international financial aid amounts to 880 billion 2021 USD. This is a rough half of the overall cost of Nigeria's Energy Transition Plan estimated at 1.9 trillion USD (see Introduction).



(a) Contribution of energy trade to GDP



(b) Contribution of non-energy trade to GDP

Figure 37 Contribution of (net) energy and non-energy trade to GDP, five scenarios

04
SYNTHESIS FOR POLICYMAKERS

4.1 | Oil and Gas Sector

The oil and gas sector needs to adopt technologies, practices, and strategies aimed at reducing environmental impact, minimize GHGs emissions, and enhance overall sustainability. While the long-term goal may be to transition away from fossil fuels, climate-smart practices within the oil and gas sector should focus on improving efficiency, reducing emissions, and mitigating environmental risks. The following are key elements to reduce emissions in oil and gas production.

Carbon Capture, Utilization, and Storage (CCUS):

Exploring policies that encourage the implementation of technologies that capture GHGs emissions produced during oil and gas extraction and processing by not less than 60% by 2060. In addition, deliberate policies should be in place to commit oil and gas companies to utilise the captured emissions (e.g., CO2) in industry process or to enhance oil recovery for improved efficiency of oil and gas extraction.

Methane Emission Reduction:

Exploring policies and technologies that can prevent and reduce methane emission by at least 85% by 2050, and progressively to 98%, throughout the oil and gas value chain.

Flaring and Venting Reduction:

Prioritise stringent policy measures to end gas flaring and venting by 2030.

Institutionalisation of Measurement, Reporting and Verification (MRV):

Enabling policies that mandate all oil and gas companies to present annually verifiable Measurement, Reporting, and Verification (MRV) showing the greenhouse emissions from their organisation

Research and Innovation:

Institutionalisation of research and innovation hubs to support the local development and advancement of low-carbon and efficient technologies within the oil and gas industry.

Energy Diversification Strategies:

Prioritise policies that explore and invest at least 50% in cleaner energy alternatives and technologies to support the energy mix used in the oil and gas supply chain as part of a broader strategy for transitioning away from traditional fossil fuels.

4.2 | Power Sector

The power sector needs to adopt technologies and practices in the power sector that contribute to mitigating climate change, enhancing resilience to its impacts, and promoting sustainable development. Plans and policies targeting the power sector should aim to generate power in a way that minimizes greenhouse gas emissions, reduces environmental impact, and supports the transition to a low-carbon and resilient energy systems. The following are the key elements to reduce emissions in the power sector.

Exploration and Utilisation of Renewable Energy Sources and other Clean Energy Sources:

Prioritisation of renewable energy sources in the energy mix of the country by at least 60% in 2060. Specifically, solar power, wind power, hydropower, bioenergy and nuclear power should be prioritised.

Smart Grids and Demand Response:

Deploying intelligent grid systems, with maximum transmissions and distribution losses of 5%, that enable better integration of renewable energy, improve grid reliability, and allow for real-time monitoring and management and prioritising energy policies that encourage consumers to adjust their electricity usage in response to peak demand or low availability of renewable energy.

Carbon Capture and Storage (CCS):

Prioritise the integration of carbon capture and storage technologies to capture and store at least 58% of carbon dioxide emissions produced during the combustion of fossil fuels in power generation.

Energy Efficiency Measures:

Accelerating the adoption of energy efficiency and energy management measures across all sectors.

Decentralised Power Generation:

There should be deliberate stringent policies to regulate and promote decentralised and distributed power generation to enhance energy access and resilience of the energy grid against disruptions.

Research and Development:

Institutionalisation of research and innovation hubs to support local development and advancement of low-carbon, and efficient technologies within the power sector.

4.3 | AFOLU Sector

The government should prioritise policies that drive the practices and strategies within the agricultural and forestry systems that aim to simultaneously address climate change mitigation, adaptation, and sustainable development goals. The following are the key elements to reduce emissions in the AFOLU sector.

Afforestation and Reforestation:

There should be deliberate and stringent policies to promote afforestation and reforestation activities to increase Nigeria's forest cover to 25 % by 2060.

Precision Agriculture and Urban Farming:

Prioritise the use of technology and data-driven approaches to optimise resource use, reduce waste, and improve efficiency of agricultural practices within rural and urban environments.

Improved Livestock Management:

There should be deliberate and stringent policies targeting rotational grazing and other sustainable livestock management practices to reduce emissions from enteric fermentation and manure by at least 40% by 2050 and progressively to 60%.

Integrated Water Resource Management:

Implementing practices that improve water use efficiency, reduce erosion, and protect water quality in agricultural and forestry activities.

Supportive Policies and Incentives:

Implementing policies that incentivize climate-smart practices, including financial incentives, subsidies, and regulations that promote sustainable land use.

Knowledge Transfer and Capacity Building:

Providing training and capacity-building programs to farmers, foresters, and other stakeholders to enhance their understanding and adoption of climate-smart practices.

4.4 | Building and Residential Sector

There should be deliberate implementation of sustainable and environmentally friendly practices in the design, construction, and operation of residential homes and buildings, which aim to reduce the environmental impact of buildings, enhance energy efficiency, and contribute to climate change mitigation and adaptation. The following are the key elements to reduce emissions in the building and residential sector of the country.

Access to Energy Efficient Buildings:

Prioritising the implementation of sustainable building codes that encourage energy-efficient building envelopes with well-insulated walls, roofs, and windows to reduce heat gain or loss. In addition, incorporating passive design elements, such as orientation, shading, and natural ventilation, to optimize indoor comfort and reduce the need for mechanical cooling.

Deployment of Efficient Home Appliances:

There should be deliberate policies targeting the promotion of smart homes and replacement of all inefficient home appliance and lighting systems with energy star rated energy efficient appliances by 2060.

Modern Energy Cooking Services:

There should be aggressive utilisation of modern energy clean cooking services like LPG, electric, biogas and improved cookstoves across the urban and rural homes and business with a share of 50% by 2030 and 95% by 2060.

Renewable Energy Integration:

There should be policy that encourages the integration of renewable energy systems to generate renewable energy electricity for residential and commercial building with financial incentives through feed-in-tariff and subsidies programs.

Community Engagement:

Provision of enabling educational programs to citizenries about energy conversation, waste reduction, and sustainable living practices.

4.5 | Transport Sector

There should be deliberate efforts to promote transportation systems and practices that are designed and implemented with the goal of minimizing their impact on climate and enhancing resilience to climate change. The key strategies to support climate-smart transport are presented as follows.

Wide Adoption of Electric Vehicles and Ethanol Vehicles:

Encouraging and promoting use of electric and ethanol vehicles by at least 55 % and 45 %, respectively, of light-duty vehicles by 2060. In addition, promotion of at least 40% of fully electric buses, about 80% of the remaining road passenger vehicles electrified, and 40% of buses powered by ethanol before 2060.

Adoption of CNG Buses:

Encouraging and promoting the use of CNG buses and freight vehicles by at most 45% by 2040.

Public Transportation:

Investment in public mass transit to enhance and expand public transportation systems by shifting 50% of road passenger cars to buses and trains to encourage people use more sustainable modes of transport, reducing reliance on individual car travel.

Active Transportation:

Encourage well-intended policy to promote walking and cycling as modes of transportation to help reduce emissions, improve health, and decrease traffic congestion.

Intelligent Transportation Systems (ITS) and Freight Efficiency:

Encouraging and promoting the implementation of ITS, including smart traffic management systems to reduce congestion and improve overall transportation efficiency. In addition, implementing sustainable freight practices, including efficient logistics, routing, and use of eco-friendly transport modes.

4.6 | Industry Sector

The following are the key measures to support the decarbonisation pathways for the industry sector of the country.

Promotion of Energy Efficiency Measures:

Promotion and adoption of energy management strategies and technologies to eliminate inefficient energy uses in the manufacturing and industrial operations. In addition, introducing and adopting EURO IV efficiency standards for all road vehicles.

Renewable Energy Integration:

Promoting and encouraging integration of renewable energy sources, such as solar and biomass, to generate clean energy for industrial processes.

Carbon Capture and Storage (CCS):

There should be deliberate policies to promote the deployment of carbon capture and storage technologies to capture and store carbon dioxide emissions from industrial processes. Specifically, the cement industry should adopt CCS by at least 58% by 2060.

Green Materials and Circular Economy Practices:

Encouraging and promoting implementation of circular economy principles by minimising waste, reusing materials, and promoting recycling within the industrial processes. In addition, formulating policies to encourage use of environmentally friendly and sustainable materials in manufacturing processes, blending material substitutes to reduce clinker-to-cement ration.

Promotion of Smart Supply Chain:

Prioritising policies that create micro-distribution systems by establishing clusters within areas for accessible and straightforward energy and material utilisation.

Investment in Research and Development:

Promoting research and development targeting local-context industry decarbonisation strategies and technologies, e.g., waste-to-energy technologies.

4.7 | Waste Sector

There should be deliberate efforts to adopt environmentally sustainable and climate-resilient practices in the waste sector aiming at minimising environmental impact of waste disposal, reduce greenhouse gas emissions, and contribute to overall climate change mitigation and adaptation efforts. The following are the key measures to decarbonisation waste sector of the country.

Adoption of Waste Reduction and Minimisation Strategies:

Encouraging practices that reduce the generation of waste at source, such as promoting reusable products and discouraging single-use items. In addition, promoting policies that encourage the design of products with a focus on reduced packaging and increased recyclability.

Adopt Circular Economy Practices:

Prioritisation of policies that encourages adoption of circular economy principles to maximize the reuse and recycling of materials throughout their life cycle.

Adoption of Energy Recovery from Waste:

Promoting and encouraging the utilisation of waste-to-energy technologies to recover energy from non-recyclable and non-compostable waste materials. In addition, consciously promoting anaerobic digestion to convert waste into biogas in the homes and industries.

Improve Waste Management Regulations:

Enforcing and updating regulations to promote sustainable waste management practices, including recycling targets and waste reduction measures. In addition, providing incentives for businesses and communities to adopt climate-smart waste management practises.

Awareness and Education:

The Nigerian Government should increase the awareness and understanding of circular economy coupled with all stakeholders taking responsibility and investing in smart-waste management solutions.

4.8 | Macroeconomic

The key macroeconomic insight to drive the economic transformations necessary to converge Nigeria towards a stabilised growth path in the energy transition landscape are as follows.

4.8.1 Economic Growth (Real GDP)

All scenarios showed minimal impact on Nigerian GDP growth. However, from a purely macroeconomic point of view, the CPS, GES, and RES+ emerge as the most promising. In 2060, the CPS scenario has the highest real GDP at 4,089.61 million 2021 USD with a growth rate of 5.53%, GES shows a real GDP of 4,069.31 million 2021 USD with a growth of 5.52%, while RES+ shows a GDP of 4,067.97 million 2021 USD with a growth rate of 5.52%. Notably, RES+, however, marks the benefits of the surmised international support that differentiates it from RES: its GDP dominates all other scenarios up to 2054, when it roughly falls in line with the CPS and ends up 2.1% below potential GDP (like GES) in 2060. RES real GDP increasingly lags behind all other scenarios from 2032 on, with an average annual growth rate (AAGR).

4.8.2 Unemployment Rate

The unemployment rate decreases in all scenarios until 2035, thanks to successful structural transformation and increased employment in non-energy domestic production. However, CPS, GES, and RES+ are more effective in reducing unemployment, respectively achieving a 5.30%, 5.85%, and 6.00% unemployment rate in 2060. Conversely, RES performs the worst among the scenarios—8.16%—, reflecting its lower competitiveness due to higher energy costs.

4.8.3 Economic and Environmental Sustainability Dilemma

The CPS and RES scenarios illustrate the classic dilemma between economic and environmental performance. Additionally, the RES+ variant of the RES stands out by combining robust economic growth and low unemployment with significant environmental benefits, albeit reliant on substantial international financial support.

4.8.4 Energy Efficiency and Costs

All scenarios show improvements in energy efficiency, with RES and RES+ demonstrating the most significant gains. However, these scenarios also face higher energy costs, impacting competitiveness in both domestic and international markets.

4.8.5 Trade Effects

The scenarios have varied impacts on Nigeria's energy trade balance. In Baseline, the unchecked rise of domestic energy consumptions together with an energy mix highly based on fossil fuels indicates that Nigeria will become a net energy importer (in money value) in 2042, ending up necessitating 0.9% of its 2060 GDP to cover the incurred net costs. Similarly, GES experiences a rapid decline of its export capacity because of uncontrolled domestic energy demand. However, the development of natural gas extraction and the substitution of domestically extracted gas to imports of refined oil products allow Nigeria to remain a net energy exporter. Lastly, CPS, RES, and RES+ benefit from transitions away from fossil fuels and lower domestic energy demand, allowing Nigeria to remain a net energy exporter. In those scenarios net export revenues, although rapidly declining in early years, remain above 2% of GDP.

The 1% trade deficit objective of Baseline, CPS, GES, and RES ensures that the dynamics of the non-energy trade contributions to GDP compensate those of energy trade. RES+ stands out as marking the slack on trade deficit allowed by the international aid that differentiates it from RES, explaining their distinct macroeconomic performances. More specifically, the RES+ scenario assumes international financial transfers amounting to an average 1.1% of Nigerian GDP from 2022 to 2060 (under RES+). Over the 39-year period, the cumulated international financial aid amounts to 880 billion 2021 USD. This is a rough half of the overall cost of Nigeria's Energy Transition Plan estimated at 1.9 trillion USD (see Introduction).

05 CONCLUSION

The DDP project of Nigeria presents a new set of prospective scenarios and modelling frameworks implemented in high-fidelity modelling methodologies to effectively support Nigeria's effort to strategically decarbonise its economy by 2060. The document presents four different energy system trajectories up to 2060 into a shared macroeconomic context envisaging the successful transformation of the economy allowing its convergence towards a path of stabilised (low trade deficit and unemployment) economic growth, estimated under conservative (Baseline) energy system assumptions. Additionally, it explores one variant (RES+) of the most ambitious carbon emission mitigation scenario (RES) relaxing the 1% trade deficit objective common to all scenarios after 2035, to represent international financial support to Nigeria's energy transition.

The economic transformations necessary to converge Nigeria towards a stabilised growth path are modelled in the form of a positive, non-price competitiveness shock acting symmetrically to increase exports and reduce imports of non-energy goods and services. Besides its impact on growth trends, this transformation of the Nigerian economy also implies a reduction of the short-term volatility risks associated with the country's dependency on fossil fuel exports.

In this context of successful economic diversification, the five explored scenarios have limited impacts on either emission reduction, potential economic growth, or the employment level. From a purely emission perspective, the RES has the potential of leading Nigeria to Net Zero emissions by 2060, whereas on the macroeconomic perspective, GES performs better than explored scenarios. Additionally, the RES+ economic activity appears appealing; its economic real GDP growth rate mirrors those of CPS and Baseline (5.53%), while its unemployment rate performs better than RES (8.16% in RES and 6.00% in RES+). However, the materialisation of RES+ hangs on the benefit of USD 880 billion (2021 USD) international support over the four decades to 2060. Although that level of support may be in line with the annual global USD 100 billion support pledge of developed countries in the framework of UNFCCC, strong uncertainty remains about its concretisation, as ongoing debates testify.

Conclusively, Nigeria's energy transition, when strategically guided by appropriate policies, technologies, and international cooperation, particularly focusing on the Gas Economy and Renewable Energy development, can lead to sustainable economic growth, reduced reliance on fossil fuels, and improved socio-economic wellbeing. The transition presents a unique opportunity for Nigeria to redefine its economic trajectory while contributing to global environmental sustainability. The following are key policy implications of the modelling efforts for Nigeria.

5.1 | Economy-Wide Implications and Recommendations

(I) Aggressive Climate Change Mitigation

Decarbonisation of the Nigeria economy will strongly depend on natural gas as transition fuel and utilisation of renewable energy sources, and other clean energy sources (e.g., nuclear) coupled with climate-smart Sectoral measures (e.g. energy efficiency and energy management).

(II) Holistically Navigate the Climate Change Landscape

Evidence based policies, with implementable plans, should be prioritised for climate change mitigation, adaptation, and resilience to holistically respond to the Paris Agreement without distorting the aim to achieve the Sustainable Development Goals.

(III) Industry Decarbonisation Policies

Enabling industry decarbonisation policies aiming at reducing the carbon footprint of various economic sectors by promoting cleaner and more sustainable practices should be prioritised. The industrial sector is a significant contributor to greenhouse gas emissions due to processes like manufacturing, energy production, and transportation. Implementing policies to decarbonize industries is crucial for achieving climate goals and mitigating the impacts of climate change.

(IV) Waste Sector Decarbonisation

There should be deliberate efforts to adopt environmentally sustainable and climate-resilient practices in the waste sector aiming at minimising the environmental impact of waste disposal, reduce greenhouse gas emissions, and contribute to overall climate change mitigation and adaptation efforts.

(V) Climate-Smart Agriculture and Transport

Enabling policies targeting the adoption of climate-smart agricultural and transport practices helps increase resilience to climate change and climate change mitigation should be highly encouraged since agriculture and transport contribute significantly to the emission profile of the country.

(VI) Technology Assimilation and Transfer

Providing training programs and capacity-building initiatives can help industries adopt new technologies and practices, supporting a skilled workforce in the transition to low-carbon processes.

(VII) Supporting Diversification and Renewable Energy

Policies should prioritize economic diversification and investment in renewable energy, especially considering the balanced benefits offered by the RES+ scenario in terms of economic growth and unemployment reduction.

(VIII) Support for GES and RES+

Policies should support both the GES and the RES+. While GES shows potential for immediate economic benefits, the RES+ scenario offers a balanced approach, coupling economic growth with sustainability. However, the viability of the RES+ scenario hinges on substantial international financial support, estimated at USD 880 billion over 39 years, accounting for roughly half of the overall cost of Nigeria's Energy Transition Plan (USD 1.9 trillion).

(IX) Invest in Job Creation

Given the higher unemployment rates in the GES and RES scenarios, focus on creating jobs in emerging industries, particularly renewable energy.

(X) Invest in Natural Gas

Position natural gas as a transitional resource to ensure energy security and economic stability.

(XI) International Aid and Long-term Planning

Pursuing international aid is crucial for the RES+ scenario. Policymakers should actively engage in global dialogues to secure this support, aligning with commitments like the UNFCCC's annual USD 100 billion support pledge. Long-term strategic planning is essential, considering the trade-offs between immediate economic needs and sustainable development goals.

(XII) Public Awareness and Education

Creating awareness among the public about climate change and its impacts is essential for building support for mitigation efforts. Education campaigns can encourage sustainable practices and behaviours like energy efficiency across sectors, reducing costs and environmental footprint.

APPENDIX

Appendix 1. Key BAU Assumptions

Key Parameter	Assumption
Study Base Year	2018
Gases Covered	CO_2, CH_4, N_2O, CO, NMVOC, NOX, PM10, PM2.5, BC, OC, SO_2, NH_3
Base Year Population	195.88 million People
Household Size	National = 5.5, Urban = 4.8, Rural = 5.9
Annual Population Growth rate	2030 = 2.5%, 2040 = 2.3%, 2050 = 2.0%, 2060 = 1.7%
Base Year GDP	649.13 billion US$
Sectoral Value Added	Agriculture = 21.4%, Services = 52.6% and Industry = 26.0%
Annual GDP Growth Rate	Stats & Agenda 2050: 2020 = -1.79%, 2021=3.64%, 2025 = 5.2%, 2030 = 5.0%, 2035 = 5.0%, 2040 = 4.7%, 2050 = 4.5%, 2060 = 5.0%
Base Year Urbanisation Rate	43.5%
Electrification Rate	National = 56.5%, Urban = 83.9%, Rural = 25.5%
Existing Generation Plants	**Grid generation (7,228 MW) :** Large Hydro Plants = 1383 MW, Gas Turbines = 5,845 MW **Off-grid generation (25,056 MW) :** Standalone Solar PV (20 to 200W) = 1 MW, Rooftop Solar PV (200W to 20 KW) = 10 MW, Small Hydro = 45 MW, Fossil fuel based self-generation = 25,000 MW

Existing Generation Plants	Cooking :	Lighting :
	Electricity = 1.3% Wood = 65.7% LPG = 4.7% Charcoal = 5.9% Kerosene = 15.6% Vegetable waste = 0.1% Animal waste = 0.1% Coal = 0.5% No cooking = 0.5%	Grid electricity = 44.8% Off-grid electricity = 31.2% Kerosene = 16.6% Wood = 6.6% Natural gas = 0.2%

Key Parameter	Assumption		
Household Appliances	**Stock of appliances (No. Units) :** AC = 5.5 million Fans = 4.7 million Motors = 1.8 million Fridges/freezers = 16.4 million TVs = 15.7 million	**Electricity use (GWh) :** AC = 2,467.7 Fans = 76.7 Motors = 5,145 Fridges/freezers = 557.4 TVs = 190.9 Fridges/freezers = 557.4 TVs = 190.9	**Energy intensities (kWh/Unit) :** AC = 448.67 Fans = 16.32 Motors = 2858.3 Fridges/freezers = 34 TVs = 12.16
Transport	**Road (Number and volumes) :** Number of vehicles = 12.8 million Car = 45.9% | 68 billion pkm Motorcycle = 8.9% | 5.5 billion pkm Bus = 16.2% | 36 billion pkm LDV = 11.5% | 29 billion tkm HDV = 9% | 17 billion tkm	**Rail (volumes)** Passenger = 1,664.9 million pkm Freight = 186.4 million tkm Domestic Air (volumes) Passenger = 9,076.9 million pkm Freight = 19.8 million tkm	
Household and transport demand	Household and Transport demand has been projected based GDP		
Sectoral GVA projections	Agriculture, services, and industry projected based on GDP growth rate		

Non-Energy sector	Subsector	
Fugitive Emissions from the Energy Sector	• Fugitive emissions from solid fuels • Fugitive emissions from oil and gas	
Industrial Processes and Product Use (grows with GDP growth rate)	• Cement production • Lime production • Glass production • Other processes • Production of chemicals • Production of metals • Non-Energy Products from fuels and solvent • Refrigeration and air conditioning • Foam blowing	• Fire extinguishers • Aerosols • Solvents • Semiconductor and electronic manufacturing • Electrical equipment • Other F gas use • Other product manufacturer and use

Non-Energy sector	Subsector
Agriculture, Forestry and Other Land Use (grows with population and GDP growth rate)	• Enteric fermentation • Manure management • Manure in pasture range and paddock • Land Use and Land Use Change and Forestry • Direct N20 emissions from managed soils • Other direct soil emissions • Indirect N2O from managed soils • Indirect N2O emissions from manure management • Rice cultivation and other
Waste (grows with the population growth rate)	• waste disposal • Biological treatment of solid waste • Waste incineration & open burning • Wastewater handling
Other	• Indirect N2O emissions from atmospheric deposition of nitrogen in NOx and N • Other

Appendix 2. Sectorial-based Key Policy Assumptions

Sectors	Supporting Program	Detailed Consideration		
		Current Policy Scenario	Gas Economy Scenario	Renewable Energy Scenario
		Universal access to modern energy by 2030		
Power*	National Energy Policy. Mambilla Hydro Project. (3050MW) Energy for all: Solar power strategy (5 million SHS). Sustainable Energy for All Action Agenda.	By 2050, grid power mix consist of CSP (5000MW), nuclear (8000 MW), large hydro (24000 MW), solar PV (150000 MW), wind (20000 MW), biomass (9500 MW). Off grid power mix will be minigrid (10000 MW), standalone (10000 MW), rooftop PV (10000MW), small hydro (3500MW). Total power generation capacity by 2050 is 250 GW (share of grid 86.6%)	Grid power consists of CSP (1000MW), Nuclear (15000MW), Solar PV utility (45000MW), Wind (1000MW), biogas from waste (5000MW), Biomass (1000MW), coal (0 MW), large hydro (24000MW), Gas (15000MW), gas with CCS (130000MW) Off grid power consists of Hybrid solar minigrid (2500MW), Rooftop PV (5000 MW), Standalone PV (2000MW), small hydro (3500 MW) Carbon capture can capture 80% of carbon emissions by 2030, and 100% carbon emissions by 2060. Total power generation capacity by 2060 is 250 GW (58% from Gas CCS)	Grid power consists of CSP (15000MW), Nuclear (20000MW), Solar PV utility (45000MW), Wind (25000MW), biogas from waste (15000MW), Biomass (20000MW), coal (0MW), large hydro (24000MW), Gas (0MW) Off grid power consists of Hybrid solar minigrid (27950MW), Rooftop PV (27500 MW), Standalone PV (27500MW), small hydro (3500 MW) T&D losses: 2030 (8%), 2060 (5%). Total power generation capacity by 2060 is 250 GW (100% renewable with nuclear energy).

Sectors	Supporting Program	Detailed Consideration		
		Current Policy Scenario	Gas Economy Scenario	Renewable Energy Scenario
		Universal access to modern energy by 2030		
Residential and building	Access to Clean and Affordable Energy (SDG 7) National Gas Expansion Project Revised NDC Energy Transition Plan	Efficient household technologies replace 80% of inefficient household technologies by 2050, and 100% replacement by 2060. Clean energy will account for more than 80% of cooking energy by 2050, from 59% in 2030. Urban: Clean fuel share comprises of electricity (23.7%), natural gas (3.3%), solar thermal (8%), and LPG (65%) Rural: Clean fuel share comprises of electricity (22.7%), natural gas (0.1%), LPG (77.2%)	Efficient household technologies will replace 100% of inefficient household technologies by 2060. Share of clean cooking (45.2% in 2030, and 90% in 2060). Urban: Clean fuel share comprises of electricity (47.9%), LPG (52.1%). Mode of lighting: grid (78.6%), off-grid (10.4%), solar (11%). Rural: Clean fuel share comprises of electricity (20%), LPG (79.9%), natural gas (0.1%)	Efficient household technologies will replace 100% of inefficient household technologies by 2060. Share of clean cooking (50% in 2030, and 95% in 2060). Urban: Clean fuel share comprises of electricity (86.6%), LPG (10.4%), natural gas (3%). Mode of lighting: grid (77%), off-grid (1.7%), solar (21%), others (0.3%) Rural: Clean fuel share comprises of electricity (80.4%), LPG (19.5%), natural gas (0.1%)
Services		The share of energy in 2060 comprises of electricity (48%), LPG (49%), kerosene (1%), charcoal (1%), and wood (1%).	The share of energy at 2060 is electricity (40%), LPG 53%, kerosene (2%), charcoal (1%), and wood (4%)	The share of energy at 2060 comprises of grid electricity (60%), off-grid electricity (26%), LPG (8%), kerosene (2%), charcoal (2%), and wood (2%)
Industry		Energy intensive industry (cement) has a share of 94.5% of the industry. Share of natural gas with CCS (48%), electricity (35%), LPG (0.01%), and wood (16.99%) by 2060.	Energy intensive industry (cement) has a share of 94.5% of the industry: Share of natural gas with CCS, electricity, Charcoal, LPG, and wood are 57%, 40%, 0.3%, 0.1% and 2.6%, respectively, by 2060.	Energy intensive industry (cement) has a share of 94.5% of the industry: Energy from grid electricity, off-grid, natural gas, fuel oil and wood are 17, 10, 21, 5, and 47, respectively, by 2030. By 2060, energy share will be 50, 25, 25%, respectively, for grid electricity, off-grid, and natural gas.
Transport	National gas expansion program Revised NDC	passengers shift to buses, while 40% of passengers shift to motorcycles and three-wheelers. Electric vehicles will replace 85% of cars and buses by 2050. 15% of LDV to run on CNG and 85% to run on electricity.	By 2060, 50% and 20% of passenger vehicles to shift to buses and three wheelers, respectively. Electric, CNG and ethanol vehicles to replace 45%, 45% and 10% of gasoline fuel cars and taxis by 2060.	By 2060, 50% and 20% of passenger vehicles to shift to buses and three wheelers, respectively. Electric vehicles account for 80% of all passengers' cars by 2060, while ethanol

Sectors	Supporting Program	Detailed Consideration		
		Current Policy Scenario	Gas Economy Scenario	Renewable Energy Scenario
		Universal access to modern energy by 2030		
Transport	National gas expansion program Revised NDC	15% of HDV will run on LPG and 85% to run on electricity by 2050. 50% of rail to be powered by electricity by 2050.	While 45%, 20%, 25%, and 10% of diesel buses will be replaced with electric, natural gas, ethanol, and hybrid buses, respectively, by 2060. Energy intensity of domestic aviation decreases by 0.1% and share of ethanol (10%). Energy intensity of road vehicles decreases by 0.2% annually. Car sharing, cycling, and walking will reduce passenger kilometers by 16%	powered cars replace 20% of passenger cars. 60% of diesel buses are to be replaced with electric vehicles, and 40% by ethanol buses. Electric and ethanol powered motorcycles and three wheelers to substitute gasoline motorcycles and three wheelers. Road: 20% of cars comply with EURO IV standard. Gasoline powered LDV is replaced by 55% electric and 45% ethanol powered LDV. Rail: 40% electric Car sharing, cycling, and walking will reduce passenger kilometers by 16%
AFOLU	New National Forestry Policy	Enteric fermentation will decrease by 2%, 2.5%, 4%, and4.5% respectively, by 2030, 2040, and 2060. Reforestation with a carbon sink of 7.9 million metric tonnes by 2060	Enteric fermentation will decrease by 3%, 4%, 5%, and 6% respectively, by 2030, 2040, and 2060. Other emissions decrease by 1.5% annually. Reforestation with carbon sink of 35.3 and 126.3 million metric tonne, respectively, by 2030 and 2060.	Enteric fermentation will decrease by 5%, 8% and 10%, respectively, by 2030, 2040, 2050, and 2060. Other emissions decrease by 1.2% annually. Reforestation with carbon sink of 12.5 and 70 million metric tonne, respectively, by 2030 and 2060.
Waste		Emissions from waste decrease by 2%, annually.	Emissions from waste decrease by 2% annually.	Emissions from waste decrease by 5%, 10%, 15%, and 20%, respectively, by 2030, 2040, 2050, and 2060.
Oil and Gas		Gas flaring: 2030 (0%) Fugitive emission reduction (oil) 95% from 2050 Fugitive emission reduction (gas) 81%	Gas flaring: 2030 (0%) Gas process loses: 2060 (5%) Fugitive emission reduction (oil and gas) 98% from 2060	Gas flaring: 2030 (0%) Gas process losses: 2060 (2.5%) Fugitive emission reduction (oil and gas) -10% growth per year

DDP

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