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A Review of Carbon Credit Potentials of Tree-Biomass for Telecommunications Applications in Nigeria

***[1]Atsuwe, B. A., [2]Atser, A. R. and [3]Okoh, T.**

[1]Department of Physics Education, Joseph Sarwuan Tarka University, P.M.B 2373, Makurdi, Benue State.
[2]Department of Electrical/Electronics, Joseph Sarwuan Tarka University, P.M.B 2373, Makurdi, Benue State
[3]Department of Botany, Joseph Sarwuan Tarka University, P.M.B 2373, Makurdi, Benue State/

*Corresponding author's email: atsuwe.bernard@uam.edu.ng

ABSTRACT
The telecommunications industry is a significant contributor to greenhouse gas emissions, primarily due to the high energy consumption of its infrastructure. Nigeria, with its rapidly growing telecommunications sector, is not exempt from this challenge. This paper reviews the carbon credit potentials of tree-biomass for telecommunications applications in Nigeria. We examine the current state of the telecommunications industry in Nigeria, the carbon footprint of the sector, and the potential of tree-biomass to mitigate these emissions. Our analysis reveals that tree-biomass has significant carbon credit potential for telecommunications applications in Nigeria, with benefits including reduced greenhouse gas emissions, improved energy security, and enhanced sustainable development. It was Recommendations amongst others that a national policy should be developed by the government to provide a framework for the development of the tree-biomass industry, a significant investment should be made in technology and infrastructure to improve the efficiency and cost-effectiveness of tree-biomass production and processing and a public awareness and education campaigns should be launched to promote the benefits of tree-biomass and encourage its adoption.

Keywords:
Carbon Credit,
Tree,
Biomass,
Telecommunications,
Applications.

INTRODUCTION

The telecommunications industry is a critical component of modern society, enabling communication, commerce, and innovation. However, the industry's energy consumption and associated greenhouse gas (GHG) emissions have significant environmental implications. Around the world, information and communication technologies (ICTs) account for 1.8% to 3.9% of greenhouse gas emissions (IEA 2020). Mobile communication systems form the majority of the ICT sector. This is because it provides people with comfortable communication means that promote efficient and effective business and social interaction, and is essential for the development of business and everyday life spans. Therefore, the demand for mobile communication systems will increase and if more human activities become digital, they will continue to take place in the near future. As a result, greenhouse gas emissions directly connected to ICTs rose twice as fast as global overall emissions between 2002 and 2012. Consequently, when lowering GHG emissions in the ICT sector, attention should be paid to the use of mobile communication systems and should be prioritized as such, approximately 70% of the system's overall energy needs must be met. Base Stations (BSS) are used in mobile communications systems (Holtkamp et al., 2014). As customers continue to expand their services, there is a growing demand for data traffic and mobile communications. As a result, a lot of research has been done on the sources of BS's power, energy consumption, and energy efficiency. For the interdependence of BSS, we have created a linear BS performance model (Rilwan & Mojisola, 2024).

The telecommunications industry in Nigeria is a significant contributor to greenhouse gas emissions, primarily due to the high energy consumption of its infrastructure. The main contributors to these emissions are: Base Stations (BSS): These are the largest energy consumers in the telecommunications sector, accounting for more than 70% of the total energy requirements. The high energy consumption of BSS has to do with the need for continuous power supply to ensure reliable and efficient telecommunications services. Researchers (Lorincz et al., 2012) created a linear BS power consumption model that could be used in situations where BSS are interdependent and demonstrated through measurements a direct correlation between the traffic load of BSS and their power consumptions. The goal of the study in (Goshwe et al., 2015) is BSS power supply with low overhead expenses. Techniques for optimizing BSS power consumption were created and applied in (Faruk et al., 2013) and (Faruk et al., 2012). Currently, the transportation and electrical industries use MIMO (multiple inputs and multiple outputs) and Individual Inputs Used Single Edition (SISO) techniques (Takeshita, 2013; Chan et al., 2013). Most Base Stations in Nigeria rely on diesel generators as a primary source of power, which contributes significantly to greenhouse gas emissions. It's estimated that approximately 4000 tons of CO2 are released daily into the atmosphere due to the operations of BSS in Nigeria and the power consumption patterns of telecommunications infrastructure, including BSS and data centers, also contribute to greenhouse gas emissions. The increasing demand for telecommunications services and the resulting growth in infrastructure have led to higher energy consumption and associated emissions. Table 1 shows the power ratings at a typical 3G/4G BTS consumption in Nigeria.

Table 1: Power ratings of equipment at a typical 3G/4G BTS in Nigeria (Faruk et al., 2013; Faruk et al., 2012; Obinna & Osawuru, 2020)

S/N	Equipment	Power Rating (W)	Quantity	Total Power (kW)
1	Transceiver (3G) (DC)	800	4	3.2
2	GSM Antenna (DC)	20	3	0.06
3	Multiplexer (DC)	240	1	0.24
4	Microwave antenna (DC)	5	5	0.025
5	Baseband unit (DC)	180	1	0.18
6	Router (DC)	330	1	0.33
7	Intermediate frequency links (DC)	20	9	0.18
8	Rectifier (AC)	2400	1	2.4
9	Air conditioner (AC)	1700	2	1.7
10	Indoor light (AC)	60	2	0.12
11	Security light (AC)	100	2	0.20
	Total Power			8.635

Nigeria's telecommunications sector is indeed growing rapidly. This is because the Nigeria telecom market size is estimated to reach USD 11.97 billion by 2030, growing at a Compound Annual Growth Rate (CAGR) of 4.7% from 2025 to 2030 (ITU, 2015), Broadband penetration in Nigeria reached 45.57% as of August 2023, with the government aiming to achieve 70% penetration by 2025 (ITU, 2015) and the country has over 34,862 telecom towers, supporting extensive network coverage across both urban and rural areas. Also, Major telecom operators like MTN Nigeria have already deployed 5G networks across 13 cities, with 700 sites as of May 2023 (ITU, 2015). The smartphone segment dominates the Nigeria telecom market, accounting for approximately 99% of internet device penetration in 2024 (ITU, 2015). Finally, Internet subscriptions in Nigeria have been increasing steadily, with the number of internet subscribers reaching over 150 million as of 2023 (NCC, 2020).

These statistics demonstrate the rapid growth of Nigeria's telecommunications sector, driven by increasing demand for high-speed internet services, expanding network coverage, and growing adoption of digital technologies. To guarantee quality of service, the power supply does not need to be turned off for a full day. Because 38% of Nigerians have access to broadband, the country's telecom sector has expanded quickly. Since 2019, this has worked with more than 72 million subscriptions (NCC, 2020). In 2019, there were 184.7 million active language subscriptions overall, representing a 96.76% mobile penetration rate (NCC, 2020). Nigeria's telecom sector earned over $942 million in 2019 and accounted for 10.6% of the country's GDP in foreign direct investment (NCC, 2020). As a result, the Nigerian economy greatly depends on the telecommunications sector, which has further economic potential as it expands. The most crucial direct and supporting infrastructure is essential to the development and growth of the telecommunications sector. Power or BS is in charge of the direct and support infrastructure. It is crucial to increase the number of BS in order to support better broadband and communication service delivery for more Nigerian subscribers. For a mobile network to function smoothly and continuously with near-perfect availability to maintain a high degree of reliability and quality, power infrastructure is crucial. The effective functioning of MNOS operations is hindered by unreliable and inadequate power supplies to telecommunications BSSs. Infrastructure development in Nigeria's telecom sector comprising 124 microwave gateways, 34,033 BSS, and more than 102,000 km of fiber cable in 2019 (NCC, 2020). However, Nigeria's current sector did not see a corresponding increase in infrastructure. With a daily maximum generation of 5.157 GW and a daily average generation of less than 4.5 GW, the average generation capacity decreased by 7.01% to 6.238 GW in the fourth quarter of 2019 (NERC, 2020). Nigeria had 64% access to electricity between 2018 and 2019, with 91% of its cities and 46% of its rural areas electrified (NBS, 2020). In contrast, during the same time period, the average power availability in places with access to electricity is seven hours (NBS, 2020). This state may have a reliability disadvantage in the Nigerian power sector and the caliber of telecom services in the event that no other options are discovered. As a result, MNOS supplies BSS mostly from diesel generators. According to (Fatokun et al., 2015; GSMA, 2020), 3% of Nigeria's estimated 76% off grid BSS can be attributed to renewable energy. An overview of Nigeria's BSS as a whole and the average daily power supply availability as of 2019 are shown in Table 2.

Table 2: Summary of BSS in Nigeria and Average Daily Power Supply Availability as at 2019

S/N	Total BSS (numbers)	Off-Grid BSS (numbers)		On-Grid BSS (numbers)	Ave. power availability (hrs)
		Diesel generator Powered	Renewable energy powered		
	34,033	25,220	780	8033	7

In the report of (Adepetun, 2015), MNOs in Nigeria use a 15 - 20 KVA power generating set at each of their BSS from diesel as an energy and power source. Each BS receives two of these production sets, which may need to be replaced every two years based on wear and tear (Adepetun, 2015). MNOS has made a significant investment in this. Installation and operation are not cost-effective since production rates are typically not utilized. Ultimately, one of the main effects of a strong depreciation is greenhouse gas emissions to the environment and ultimately the atmosphere. As a result, a significant financial victim was burned at the altar by dependable, effective communications services that released greenhouse gases as smoke.

Each of the BTSS, which are installed worldwide, consumes 25 mWh of electricity on average each year (Lorincz & Bule, 2013; Balogun et al., 2017). With a 25% annual increase in tandem with the growing need for transportation, especially in developing nations, estimates have increased dramatically from the previous year in 2013 (Hassan et al., 2011). Since island generators are mostly utilized when the BTS is operating at full capacity, BTS is the primary energy source that needs a section of the mobile telecommunications network.

High operating and maintenance expenses and greenhouse gas emissions (Murthy & Kavitha, 2012). Additionally, when microcell load is present, BTS's increased power requirements may result in subpar quality of service (QOS) (Zhang et al., 2015). In line with this objective, calls for 2.5 billion liters of telecom companies by 2012 have been made in pursuit of this objective. CO2 emissions are greatly decreased as a result (Vincenzo and Sara, 2011, Balogun et al., 2017). Airtel Telecommunication Company 250 BTS in Nigeria has also replaced its diesel generators with greener models, which lowers greenhouse gas emissions and epileptic power in impacted areas (Ani and Nzeako, 2008). The most recent calls for the switch from 4G to 5G mobile applications represent an alternative perspective on this research. In order to satisfy the demands of mobile communications, the fifth generation of telecommunications networks by facilitating the unavoidable rise in mobile data usage. Enhancing capacity, data rates, and incubation times is just one of the fifth-generation network's capabilities. It also addresses the greatest degree of adaptability to deliver a range of services in numerous settings utilizing various technologies in a very effective, reliable, and affordable manner (Brydon, 2014). You will achieve the cost-effectiveness, flexibility, and agility that future mobile networks impacted by size, growth, and age will need (Brydon, 2014).

Therefore, to mitigate these emissions, there is a need to explore alternative energy sources, such as renewable energy solutions, to power telecommunications infrastructure in Nigeria.

Carbon Footprint of the Telecommunications Sector in Nigeria

The telecommunications sector in Nigeria is a significant contributor to GHG emissions, primarily due to the high energy consumption of its infrastructure. A study by the International Telecommunication Union (ITU) estimated that the global telecommunications sector accounted for approximately 2% of global GHG emissions in 2015. In Nigeria, the telecommunications sector is estimated to account for around 1.5% of the country's total GHG emissions. The telecommunications sector is a significant contributor to greenhouse gas (GHG) emissions, primarily due to the high energy consumption of its infrastructure. Nigeria, with its rapidly growing telecommunications sector, is not exempt from this challenge. As a signatory to the Paris Agreement, Nigeria has committed to reducing its GHG emissions and mitigating the effects of climate change (Abubakar et al., 2023; ITU, 2015)

The carbon footprint of the telecommunications sector in Nigeria is significant, primarily due to the high energy consumption of its infrastructure. The sector's carbon footprint can be attributed to several factors, including: Energy Consumption, when the telecommunications sector in Nigeria relies heavily on fossil fuels to power its infrastructure, including base stations, data centers, and network operations centers. Network Infrastructure such that the expansion of telecommunications networks in Nigeria has led to an increase in the number of base stations, data centers, and other network infrastructure, which consume significant amounts of energy and data centers where the centers are a significant contributor to the carbon footprint of the telecommunications sector in Nigeria, as they require large amounts of energy to power servers, cooling systems, and other equipment.

Impact of the Telecommunications Sector's Carbon Footprint on the Environment

The carbon footprint of the telecommunications sector in Nigeria has significant impacts on the environment, in such a way as the GHG emissions from the telecommunications sector contribute to climate change, which has devastating impacts on the environment, including rising temperatures, sea-level rise, and extreme weather events. Also, the combustion of fossil fuels to power telecommunications infrastructure releases air pollutants, including particulate matter, nitrogen oxides, and sulfur dioxide, which have negative impacts on human health and the environment. And the expansion of telecommunications networks in Nigeria has led to the destruction of natural habitats and ecosystems, which has negative impacts on biodiversity and ecosystem services (Abubakar et al., 2023; Adepetun, 2015).

Potential Strategies for Reducing the Carbon Footprint of the Telecommunications Sector in Nigeria

The carbon footprint of the telecommunications sector in Nigeria is significant, primarily due to the high energy consumption of its infrastructure. However, several strategies can be employed to reduce the carbon footprint of the sector, including transitioning to renewable energy sources, implementing energy-efficient technologies and practices, designing and deploying sustainable network infrastructure, and carbon offsetting. Several strategies can be employed to reduce the carbon footprint of the telecommunications sector in Nigeria, when transitioning to renewable energy sources, such as solar and wind power; can significantly reduce the carbon footprint of the telecommunications sector in Nigeria. Energy Efficiency by Implementing energy-efficient technologies and practices, such as reducing energy consumption during peak hours and using energy-efficient equipment, can also reduce the carbon footprint of the telecommunications sector. Sustainable Network Infrastructure when designing and deploying sustainable network infrastructure, such as green data centers and eco-friendly base stations, can also reduce the carbon footprint of the telecommunications sector and Carbon offsetting, which involves offsetting emissions by investing in projects that reduce GHG emissions, can also be employed to reduce the carbon footprint of the telecommunications sector (Dai et al., 2021; Friedlinstein et al., 2020).

Tree-Biomass as a Carbon Mitigation Strategy

Tree-biomass refers to the organic matter produced by trees, including their trunks, branches, leaves, and roots. Tree-biomass is a renewable energy source that can be used to produce heat, electricity, and biofuels. Tree-biomass is defined as the total amount of organic matter produced by trees, including their above-ground and below-ground components. The composition of tree-biomass varies depending on the tree species, age, and growing conditions (Chabot & Goldstein, 2018). Generally, tree-biomass is composed of a complex carbohydrate that provides structure and rigidity to tree cells, Hemicellulose which is a complex carbohydrate that provides energy and nutrients to tree cells, Lignin that is a complex organic compound that provides strength and rigidity to tree cells and Extractives which is a group of compounds that include resins, waxes, and oils (David et al., 2024).

Tree-biomass, derived from sustainably managed forests, has significant carbon credit potential for telecommunications applications in Nigeria. Tree-biomass can be used to generate electricity, heat, or biofuels, providing a low-carbon alternative to fossil fuels. The carbon credit potential of tree-biomass is based on the principle of carbon sequestration, where trees absorb CO2 from the atmosphere during growth, storing it in biomass and soil. Climate change is one of the most pressing global challenges of our time, and Nigeria is not exempt from its impacts. As a signatory to the Paris Agreement, Nigeria has committed to reducing its greenhouse gas (GHG) emissions and mitigating the effects of climate change. One promising strategy for achieving this goal is the use of tree-biomass as a carbon mitigation tool (Arora & Melton, 2018).

Carbon Sequestration Potential of Tree-Biomass

Trees absorb carbon dioxide (CO_2) from the atmosphere through photosynthesis, storing it in their biomass and soil. When tree-biomass is harvested and converted into energy, the carbon stored in the biomass is released, but it is considered carbon neutral because it is part of the natural carbon cycle. Additionally, tree-biomass can be replanted, allowing for continuous carbon sequestration. The escalating concentration of carbon dioxide (CO_2) in the atmosphere, primarily driven by human activities, poses a significant threat to global climate stability (IPCC, 2021). Because of their substantial capacity to reduce carbon emissions, trees, an essential part of terrestrial ecosystems, present promising solutions to mitigate climate change (Pan *et al.*, 2011). In addition to storing carbon in biomass, the photosynthetic CO_2 process enables trees to absorb CO_2 from the atmosphere and transform it into organic matter like trunks, branches, leaves, and roots (IPCC, 2021). By reducing atmospheric CO_2 levels, this carbon design helps to improve air quality and mitigate climate change (Chabot & Goldstein, 2018).

Tree species, age, size, growth rate, and environmental conditions are some of the variables that greatly affect the likelihood of carbon sequestration in trees (Sánchez-Bluemel *et al.*, 2016). Because of their large biomass and quick growth rates, some tree species—like oak, pine, and maple—were found to have high carbon sequestration rates (Bada *et al.*, 2018). According to Phillips et al. (2008), larger, older trees typically follow more carbon than smaller, younger ones. The potential carbon content of hard carbon is also influenced by environmental factors like climate, soil quality, and water availability (IPCC, 2021). Compared to more demanding environments, trees that thrive in favorable conditions with plenty of sunlight, water, and nutrients tend to follow more carbon (Sánchez-Bluemel *et al.*, 2016).

Tree-dominated forests contribute significantly to global carbon sequestration (IPCC, 2021). Particularly well-known for their massive capacity to store carbon are tropical rainforests (Pan *et al.*, 2011). However, significant losses in the forest carbon share were brought about by design and land use changes, which raised the amount of CO_2 in the atmosphere (IPCC, 2021). Trees offer numerous ecosystem services, such as biological diversity, soil erosion prevention, and water filtration preservation, in addition to their function in carbon bonding (FAO, 2020). We can fully utilize trees' potential to slow down climate change while also reaping numerous other ecological and social advantages by preserving and rehabilitating forests. As a result, trees can capture carbon dioxide (CO_2) and save money.

Tree and Carbon Sequestration

The primary method by which trees absorb CO_2 from the atmosphere is photosynthesis. During photosynthesis, plants create glucose, a simple sugar that serves as the tree's primary energy source, using sunlight, water, and CO_2. The structural elements of tree biomass are formed by the conversion of the glucose into cellulose, hemicellulose, and lignin (Taiz & Zeiger, 2010). Numerous environmental elements, such as temperature, light intensity, water availability, and nutrition availability, affect photosynthesis. Different tree species have different ideal conditions for photosynthesis, and these conditions may change as a result of evolutionary adaptations to a given environment (IPCC, 2021). Despite the fact that respiratory CO_2 has been documented, it is also essential for the decomposition of organic matter, which eventually results in the creation of new tissue and wood biomass's capacity to store carbon (Taiz & Zeiger, 2010). The net floor in the wood is determined by the equilibrium between respiration and photosynthesis. The tree looks for carbon when photosynthesis outpaces respiration. On the other hand, the tree releases carbon when respiration surpasses photosynthesis. This balance may be impacted by elements like the type, age, and environmental conditions of the construction (IPCC, 2021). Carbon bonds from the trees are influenced by a number of additional factors besides photosynthesis. Tree species differ in their ability to form carbon bonds. According to (Piao *et al.*, 2008), some species are better at acquiring and storing carbon than others. Carbon sequestration may be impacted by forest structures such as tree density, age distribution, and biodiversity. Although resilient, forests with a wide variety of species and age groups may deteriorate more quickly (IPCC, 2021). Tree growth and carbon bonds can be impacted by climate variables like temperature, precipitation, and wind patterns. Warm temperatures, for instance, can boost photosynthesis but also raise the possibility of forest fires, which can release carbon that has been stored (IPCC, 2021).

Studies conducted by Friedlingstein et al. (2020), Ciais et al. (2019), and Ballantyne et al. (2017) according to the Global Netland-CO_2 sink, it has grown during the previous 60 years. According to Friedlingstein et al. (the 1960s), the global netland-CO_2 sink, which is the difference between fossil CO2 emissions and atmospheric CO_2 growth, was 0.3 ± 0.6 pgc yr in the 1960s (2020). Reversal of the atmosphere by Pylin et al. (2013) It has continuously backed this upward trend in global net-Land-CO_2-senke since the 1980s. Boreal and medium forests play a significant role in this increase, with the Northern Hemisphere contributing more than the Southern Hemisphere (Ciais et al., 2019; Tagesson *et al.*, 2020).

The network's terrestrial CO2 sinks are mostly controlled by photosynthesis in the vegetation. Evidence of increased photosynthesis in vegetation in recent decades has been presented by (Anav et al. 2015; Mao et al. 2016; Badgley et al. 2017; Campbell et al. 2017; Cheng et al. 2017 and Zhang et al. 2018). The fertilization effect is caused by elevated atmospheric CO2 concentrations (2020 and Walker et al., 2021).

There are significant differences in how climate change affects the world's Netland-CO2 sink alone; some dynamic global vegetation models (DGVMs) even predict the opposite effect (Huntzinger et al., 2017). Global net-land CO2 sinks have increased in recent decades due to a decrease in global combustion areas, which has decreased CO2 fire emissions and improved vegetation carbon records (Arora and Melton 2018 and Yin *et al.*, 2020). Satellite observations have revealed a global decline in combustion regions of about 20% over the past 20 years (Andela *et al.*, 2017; and Forkel *et al.*, 2019), especially in regions like North Africa and

Mediterranean Europe (Turco *et al.,* 2016; Forkel *et al.,* 2019 and Bowman *et al.,* 2020). The Amazon basin and Australia experienced record-breaking fires in 2019 and 2020 (Boer *et al.,* 2020) and the long-term impact of these events on burned area trends remains to be assessed are both human-induced as shown in Figure 1.

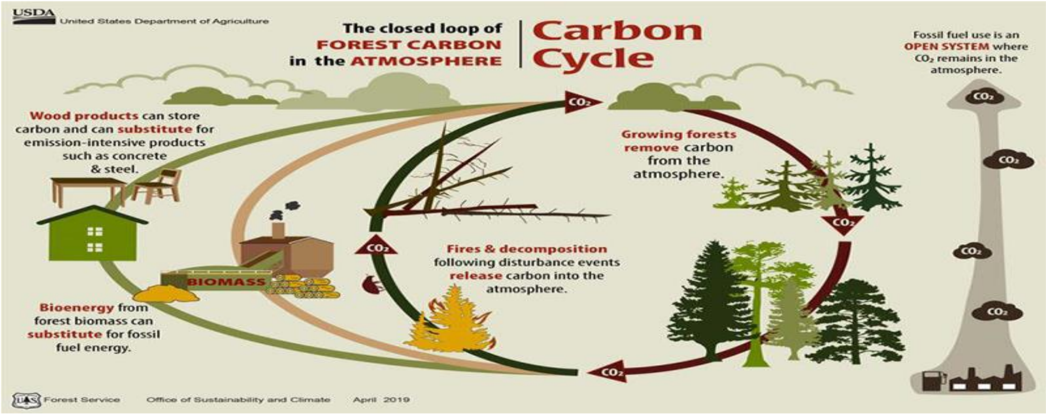

Figure 1: Closed Loop of Forest Carbon. Source: Carbon and Forests (ct.gov)

Global forest Carbon Sequestration Potentials

The carbon sequestration potential of an ecosystem is measured by its ability to increase net carbon sequestration beyond baseline levels through natural or human-induced factors (Wang *et al.,* 2017). Different tree species exhibit varying carbon sequestration potentials, making their selection crucial for effective carbon sequestration projects and optimized forest management (Wang *et al.,* 2017). By lowering the buildup of greenhouse gases in the atmosphere, trees contribute significantly to the reduction of global warming (Hisano *et al.,* 2018). In China's south, In the 1980s, the country's forests absorbed over 65% of its CO2 emissions, surpassing northern China's absorption rates (Chen *et al.,* 2020). Understanding the forest ecosystems' function in the carbon cycle, data on forest management choices, and quantification of their influence on global warming are all necessary for an accurate evaluation of their capacity to sequester carbon (Dai *et al.,* 2021: Ishaq et al., 2014).

According to satellite observations, between 2001 and 2019, carbon dioxide (CO2) and 8.1±2.5 GTCO2E Yra 1 were caused by satellites and other forest disorders (Hariss *et al.,* 2021). Forest fires, drained organic soil, and methane (CH4) and laughter gas (N2O) sustain around 1.1% (0.088 GTCO2E YRA 1) of total emissions. The total carbon loss in the Wald ecosystem during this time was 15.6 ± 49 GTCO2E YR 1. The global net gas forest is 7.6 ± 49 GTCO2E YR 1 when comparing rivers of total emissions and total denials (Hariss *et al.,* 2021). With 78% of total emissions (6.3±2.4 GTCO2EYRâ1) and 55% of total removal (55% of GTCO2E YR 8.6±7.6±7.6 of GTCO2E YR), tropical and subtropical forests make up the majority of global flows (Hariss *et al.,* 2021). Although only 30% of the netfloors in medium subtropical forests had sinks, they extracted more carbon dioxide from the atmosphere (8.6 vs. 4.4 and 2.5 GTCO2E YR). Medium-sized forests were home to 47% of the world's nets and North Sea forests (21%), particularly because their overall emissions are substantially lower than those of subtropical and tropical forests (0.87 and 0.88) (Hariss *et al.,* 2021). Global forest related Green House Gas Fluxes by Climate Domain and Forest Type effect on the environment as shown in Figure 2.

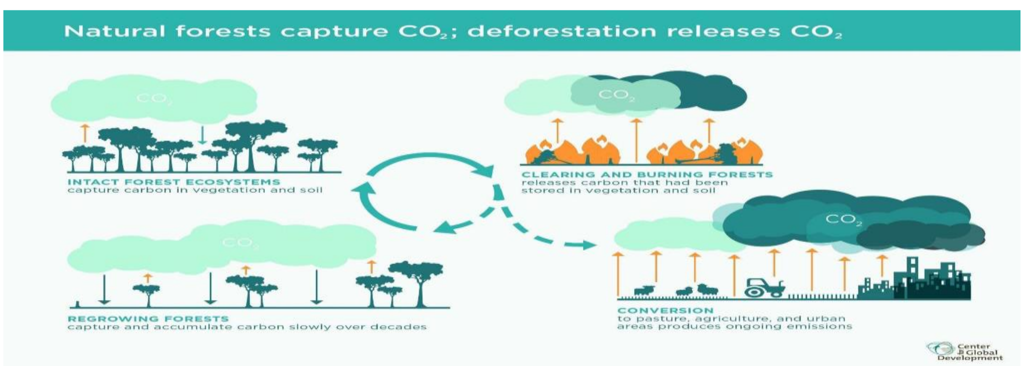

Figure 2: Effect of Deforestation on the Environment

The capacity of a tree to sequester carbon can also be influenced by its age, size and growth type. Generally speaking, older trees have more biomass and store more carbon than younger ones. Furthermore, because of their thicker trunks and larger root systems, large trees are able to absorb more carbon than small trees (IPCC, 2021). The type of development of the tree can also affect its capacity to store carbon. Tall, thin trees, including those that are contaminated, have a higher leaf surface index and can absorb more CO-CO2 from the atmosphere. Figure 3 shows how tree's reduce the amount of carbon dioxde in the atmosphere.

Several techniques were used to estimate the potential for carbon sequestration (Kamalu et al. 2024). Average ratios (MRM) are used to estimate the carbon stock in this area (Turner *et al.*, 1995). Determining the ratio of forest volume to biomass is thought to be a fairly accurate method of evaluating the carbon stock of biomass expansion coefficient (BEF) (Sun & Liu 2019). Allometric equations were more accurate for the aforementioned estimation of ground biomass levels (Agbelade and Lawal 2021; Agbelade and Adeagbo 2020; Adekunle *et al.*, 2013). LiDAR, satellite imagery, and aerial photography are remote sensing methods used to evaluate the possibility of carbon sequestration (Dossa and Miassi, 2024).

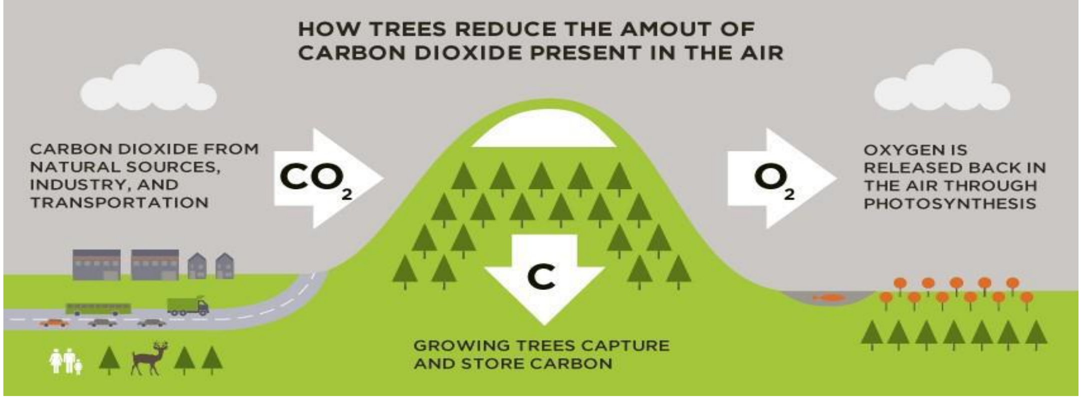

Figure 3: How trees reduce the amount of carbon dioxide in the air.
(Source: http://kingcounty.gov/services/environment/stewardship/one-million-trees/why.aspx)

Resources from Biomass Plants, animals, lifestyle, and industrial waste that can be converted into energy for beneficial uses are all considered biomass. These resources come in a variety of forms, including forest facilities and residues, production waste, animal feces and waste, agricultural plants and residues, and more (Ojo et al., 2020; Mohammed et al., 2013). Biomass is regarded as the most prevalent and sustainable revival in the world in terms of sustainability. Every day, plants use sunlight to grow through a process called photosynthesis, and animals eat plants and other materials that provide a steady supply of biomass. This is thought to be roughly five times the amount of energy that the world needs. Worldwide, biomass is growing, if not very effectively. According to reports, it supplies about 14% of the world's energy, with developing nations accounting for about 38% of total consumption in the Rural areas above all (Sertolli et al. 2022). Nigeria is essential to sustainable rural development and offers a multitude of biomass tours. Since it is accessible in these areas. According to estimates, domestic biomass can provide about 9.1×1012 MJ of energy per year (Sambo, 2009). About 2.18 × 106 MJ of the raw energy comes from dried grasses and shrubs (Ozoegwu et al., 2017). Every year, about 43.4 million tons of fuel wood are used for home heating and other uses (Oyedepo, 2012). Charcoal and fire are primarily utilized by rural regions and the majority of city dwellers who have low incomes for cooking. An enormous amount of energy is wasted because the majority of this use is a conventional oven with an efficiency of less than 10%. By increasing conversion efficiency by over 20%, improved cooking stoves can mitigate some of the negative effects of burning biomass, including particle pollution and excessive smoke (Obada et al., 2014, 2016, 2022).

Biomass Technology Different types of biomass can be transformed into fuels that are simple to use, process, store, or transport, or into electricity or other useful energy. The need to slow down the rate of global warming is the main factor driving the use of biomass for energy generation because, its carbon emissions or nets are low. The development of domestic autonomous energy generation was another factor contributing to the increased introduction of energy derived from biomass (Mohammed et al., 2017). Many rural areas of Nigeria typically contain plant biomass, such as waste, residues, and other shapes, which can be used in medium-sized power plants to generate electricity for these communities. Utilizing biomass for energy eliminates the need to store agricultural waste, frees up the nation for waste, and lowers the likelihood of an incalculable methane release into the atmosphere. Many of the conversion technologies needed for biomass conversion are still in the early stages of development. But a lot of them are already mature and already in use for producing energy efficiently. There are two main categories into which available biomass conversion methods can be separated. Thermochemical conversion methods for dry biomass and biochemical conversion methods like anaerobic digestion, which work better for wet biomass (Obada et al., 2023; Adams et al., 2018). Combustion, pyrolysis, and gasification are frequently used thermochemical processes. Biomass is either utilized alone or in conjunction with another fossil fuel power source material in conventional biomass power plants. To run its operations and equipment, the Nigerian telecom industry currently depends on fossil fuels like diesel (Amole et al., 2023; Tebepa, 2015). Carbon emissions from this activity have the potential to harm the environment (Ayompe et al., 2021). Climate change, biological diversity loss, rising sea levels, and worsened air quality are some adverse effects (Roy et al., 2023; Steiner, 2019; David et al. 2024).

Nigeria's Biomass Resources

Nigeria has various biomass resources, including:

i. Forest Reserves: Covering about 10% of the country's land mass, with 36 states having forest reserves.
ii. Forest Plantations: Found in 13 states, with species like Gmelina arborea, Tectona grandis, Eucalyptus spp, Acacia spp, and Neem.
iii. Agricultural Residues: Significant amounts generated from crops like cassava, maize, oil palm, plantain, rice, and sorghum (Akinbowale et al., 2022; Ukoba et al., 2024).

Nigeria has significant tree-biomass potential, with various sources contributing to its overall energy mix. Forest Reserves and Plantations cover about 10% of the country's total land mass, with 36 states having forest reserves and 13 having forest plantations. In terms of specific biomass resources, wood and woody biomass are substantial contributors. Nigeria's forest products industry generates various products, including wood pulp, wood fuel, wood charcoal, paperboard, and particleboard, with annual production rates ranging from 10,000 to 100,000 metric tons. The energy potential of these resources is notable. For instance, the total energy derivable from forest residues in Nigeria is estimated to be around 8.3 petajoules (PJ). Additionally, the country's agricultural sector generates significant amounts of agricultural residues, such as cassava, maize, oil palm, plantain, rice, and sorghum, which can be utilized for energy production (Ojekunle et al., 2023; Yohannes & Sewnet, 2024).

Nigeria's biomass resources and their estimated energy potentials are presented as:

i. Agricultural Residues: 1.09 exajoules (EJ)
ii. Animal Wastes: 0.65 EJ
iii. Municipal Solid Waste: 0.11 EJ
iv. Forest Residues: 0.05 EJ
v. Wood Fuel: 0.38 EJ
vi. Charcoal: 0.05 EJ

Overall, Nigeria's tree-biomass potential is substantial, with various resources available for energy production. Harnessing these resources can contribute significantly to the country's energy mix and help mitigate climate change. Nigeria has a total of 36 states with forest reserves and 13 states with forest plantations, covering about 10% of the country's total land mass. Unfortunately, the specific states with forest reserves and plantations are not explicitly listed in the available data which can provide one with some comprehensive statistics on Nigeria's forest and plantation cover (Simeon et al., 2020)

Nigeria has Forest Reserves with a total area of approximately 10,762,702 hectares that is Located in the 36 states across the country with some types of the forests as; Post-extraction secondary forests with 10,508,429 hectares: Swidden fallow secondary forests with land area of 7,570,700 hectares: Rehabilitated secondary forests with a land area of 793 hectares: Post-abandonment secondary forests with 42,268 hectares and Post-fire secondary forests with an un-estimated land area. While the Forest Plantations in Nigeria cover a total land area of approximately 216,072 hectares which is located in 13 states across the country. Again, there are various species found in Nigeria, they are;

i. Gmelina arborea
ii. Tectona grandis
iii. Eucalyptus spp
iv. Acacia spp
v. Neem
vi. Indigenous tree species

The Land Use Categories on the other hand cover a total agricultural land area of 78.5 million hectares, the Arable cropland are 28.2 million hectares, Permanent cropland are 2.5 million hectares, Pasture land is 28.3 million hectares, Forest and woodland is about 10 million hectares, the Fadama is 2 million hectares and other land occupying 7.5 million hectares. Nigeria's tree-biomass potential varies across its 36 states. While I couldn't find a comprehensive breakdown of each state's potential, I can provide some insights into the country's overall biomass resources and highlight a few states with notable forest reserves and plantations. States with Notable Forest Reserves and Plantations Some states with notable forest reserves and plantations include (FAO, 2020):

i. Oyo State: Has significant forest reserves, with the Oyo State Forest Reserve covering an area of approximately 20,000 hectares.

ii. Ogun State: Has several forest reserves, including the Ogun State Forest Reserve, which covers around 15,000 hectares.
iii. Cross River State: Known for its dense forests, with the Cross River National Park covering an area of approximately 4,000 square kilometers.
iv. Taraba State: Has significant forest reserves, including the Taraba State Forest Reserve, which covers around 10,000 hectares (Davidson, 2023).

Tree-Biomass Potential by State

Nigeria, with its vast land area and favorable climate, has significant potential for tree-biomass production. The country has a total forest area of approximately 9.6 million hectares, with a significant portion of this area suitable for tree-biomass production. Also, she has several plantation resources, including eucalyptus, pine, and teak plantations, which can be used for tree-biomass production. Nigeria generates significant amounts of agricultural residues, such as corn stalks, sugarcane bagasse, and rice husks, which can be used for tree-biomass production (Friedlingstein et al., 2020: Forkel et al., 2019).

The tree-biomass potential in Nigeria by state and further broken down into geopolitical zones are looked at from the North-Central States (Geopolitical Zone) which have Benue State with 143,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Kogi State with 120,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Kwara State has 100,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Nasarawa State has 80,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Niger State has 150,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans and Plateau State with 120,000 hectares of forest reserves, with notable agricultural residues from crops like potatoes and maize (Friedlingstein et al., 2020; Forkel et al., 2019).

The North-Eastern States or North-East geopolitical zone has Adamawa State with 100,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans. Bauchi State with 80,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Borno State has 60,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans. Gombe State has 40,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Taraba State has 150,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans and Yobe State with 50,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans.

North-Western States or the north –Western Geopolitical zone houses Jigawa State with 40,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans. Kaduna State with 100,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Kano State with 60,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans. Katsina State has 50,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Kebbi State with 30,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans. Sokoto State with 40,000 hectares of forest reserves, with notable agricultural residues from crops like maize and soybeans. Zamfara State with 20,000 hectares of forest reserves, with significant agricultural residues from crops like maize and soybeans.

South-Eastern States form the geopolitical zone that has Abia State with 20,000 hectares of forest reserves, with notable agricultural residues from crops like cassava and maize. Anambra State has 15,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Ebonyi State with 10,000 hectares of forest reserves, with notable agricultural residues from crops like cassava and maize. Enugu State with 20,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Imo State with 15,000 hectares of forest reserves, with notable agricultural residues from crops like cassava and maize. While the South-South States or geopolitical zone houses Akwa Ibom State with 30,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Bayelsa State has 20,000 hectares of forest reserves, with notable agricultural residues from crops like cassava and maize. Cross River State: with 150,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. Delta State has 25,000 hectares of forest reserves, with notable agricultural residues from crops like cassava and maize and Edo State has 20,000 hectares of forest reserves, with significant agricultural residues from crops like cassava and maize. From the statistics presented above from the six geopolitical zones, one can see the great potential of Biomass that Nigeria has in store.

Benefits of Tree-Biomass

Tree-biomass offers several benefits, including: Renewable Energy Source because tree-biomass is a renewable energy source that can be replenished naturally. Carbon Sequestration means that tree-biomass absorbs carbon dioxide (CO2) from the atmosphere during growth, storing it in biomass and soil. Also, it offers Job Creation and Employment through the production and processing of tree-biomass which creates jobs and employment opportunities in rural areas.

Furthermore, Tree-Biomass gives Improved Energy Security since tree-biomass can provide energy security by reducing reliance on imported fossil fuels and promoting energy self-sufficiency and Waste Management such that Tree-biomass can help manage waste by utilizing waste wood and other organic materials that would otherwise be discarded.

Tree-biomass is a renewable energy source that can reduce Nigeria's dependence on fossil fuels and lower greenhouse gas emissions. The production and processing of tree-biomass can create jobs and employment opportunities in rural areas. More so, tree-biomass can provide energy security by reducing reliance on imported fossil fuels and promoting energy self-sufficiency. And tree-biomass can further help manage waste by utilizing waste wood and other organic materials that would otherwise be discarded.

There are so many opportunities for Tree-Biomass Development in Nigeria through Government support, the Nigerian government has shown support for the development of the tree-biomass industry through policies and initiatives. The Private sector investment in the tree-biomass industry can provide the necessary funding and expertise for its development and then International cooperation and partnerships can provide access to new technologies, markets, and funding opportunities for the tree-biomass industry.

Production Processes of Tree-Biomass

The production of tree-biomass involves four processes, including: Tree Planting and Cultivation where trees are planted and cultivated in plantations or natural forests: Harvesting where trees are harvested at maturity, typically after 5-10 years: Processing where harvested trees are processed into various products, including wood chips, pellets, and biofuels and Conversion where tree-biomass is converted into energy through various technologies, including combustion, gasification, and anaerobic digestion. While the production processes of tree-biomass include:

Harvesting Tree-biomass production begins with harvesting, which involves cutting and collecting trees from forests or plantations. Harvesting can be done manually or mechanically, depending on the scale and type of operation. After harvesting, the trees are processed into various forms of biomass, including, Wood Chips where the trees are chipped into small pieces to increase their surface area and facilitate drying, the trees are sawn into lumber, and the sawdust is collected as a biomass product, Wood chips or sawdust are compressed into dense pellets, which can be used as fuel and finally the Biomass materials are compressed into briquettes, which can be used as fuel.

Drying is an essential step in tree-biomass production, as it reduces the moisture content of the biomass and makes it more suitable for energy production. Drying can be done using various methods, including: Air Drying where the Biomass is dried using natural air circulation, then the Biomass is dried using machines that blow hot air and then Solar Drying where the Biomass is dried using solar energy. After drying, the tree-biomass is stored in a dry and secure location to maintain its quality. Storage facilities can include: Warehouses, Silos and Outdoor Storage.

Tree-biomass is transported from the production site to the point of use, which can include: Trucks where the Biomass is transported using trucks, which can be equipped with cranes or other loading equipment, Trains: Biomass is transported using trains, which can be more efficient for long-distance transportation or the Biomass is transported using barges, which can be used for transportation over water.

Tree-biomass can be converted into various energy products of heat, electricity and Biofuels. The production processes of tree-biomass involve several steps, from harvesting and processing to drying, storage, transportation, and conversion. Each step is critical to ensuring the quality and efficiency of the biomass product.

Applications of Tree-Biomass

Tree-biomass has several applications, including:

Heat and Electricity Generation where tree-biomass can be used to generate heat and electricity in power plants, industrial processes, and residential heating systems. Biofuels Production: Tree-biomass can be converted into biofuels, including ethanol and biodiesel. Chemicals and Materials Production: Tree-biomass can be used to produce various chemicals and materials, including paper, pulp, and bio-plastics. Soil Erosion Control: Tree-biomass can be used to control soil erosion and promote soil conservation. There are various applications of Tree-biomass across different industries like Heat and Power Generation when the tree-biomass can be burned to produce heat, which can be used for space heating, industrial processes, or to generate electricity. There is also Biofuels where the tree-biomass can be converted into biofuels, such as ethanol, biodiesel, or biogas, which can be used to power vehicles or generate electricity. More so, we have Chemicals and Materials where the tree-biomass can be used to produce various chemicals and materials, such as paper, pulp, bioplastics, and biochemicals. Furthermore, tree-biomass can be used to control soil erosion and promote soil conservation by planting trees and other vegetation. Again, tree-biomass can absorb carbon dioxide from the atmosphere, making it a valuable tool for carbon sequestration and climate change mitigation. Animal Feed where the tree-biomass can be used as animal feed, particularly for ruminant animals like cattle and goats. Tree-biomass can be composted and used as organic fertilizer in agriculture together with Landscaping and Horticulture where the tree-biomass can be used in landscaping and horticulture, such as mulch, compost, or biochar. Tree-biomass can also be used to filter water, particularly in rural areas where access to clean water is limited and it can be used to produce building materials, such as engineered wood products, like plywood and medium-density fiberboard (MDF).

Industrial Applications

Tree-biomass is used to produce pulp and paper products, such as packaging materials, tissue paper, and printing paper, it can also be used to produce textiles, such as rayon, lyocell, and modal fibers. More so, tree-biomass can be used as a source of energy, particularly in the production of food and beverages, and it can be used to produce various pharmaceutical products, such as medicines and supplements.

Energy Applications

Tree-biomass can be used to generate electricity, particularly in rural areas where access to grid electricity is limited. Tree-biomass can be used to produce heat, particularly for space heating and industrial processes and also be converted into biofuels, such as ethanol and biodiesel, which can be used to power vehicles. Therefore, tree-biomass has a wide range of applications across different industries, including energy, chemicals, materials, and pharmaceuticals.

Harnessing Tree-Biomass for Use in Telecommunications in Nigeria

Nigeria's telecommunications sector has experienced rapid growth in recent years, with the number of mobile subscribers increasing from 39 million in 2008 to over 180 million in 2020. However, this growth has been accompanied by a significant increase in energy consumption, primarily due to the high energy requirements of telecommunications infrastructure. This paper discusses the potential for harnessing tree-biomass as a sustainable energy source for telecommunications in Nigeria. The benefits of tree-biomass for telecommunications are numerous and can be summarized as follows (Abubakar et al., 2023; Ajewole et al., 2018).

Renewable Energy Source: Tree-biomass is a renewable energy source that can reduce dependence on fossil fuels and lower greenhouse gas emissions. Energy Security: Tree-biomass can provide energy security by reducing reliance on imported fossil fuels and promoting energy self-sufficiency. Reduced Carbon Footprint: Tree-biomass can help telecommunications companies reduce their carbon footprint and meet their sustainability goals. Cost Savings: Tree-biomass can provide cost savings by reducing energy costs and minimizing the impact of fuel price volatility. Improved Network Reliability: Tree-biomass can improve network reliability by providing a stable and consistent source of energy. Job Creation: The production and processing of tree-biomass can create jobs and employment opportunities in rural areas. Waste Management: Tree-biomass can help manage waste by utilizing waste wood and other organic materials that would otherwise be discarded. Diversified Energy Mix: Tree-biomass can contribute to a diversified energy mix, reducing dependence on a single energy source. Enhanced Energy Independence: Tree-biomass can enhance energy independence by providing a local source of energy. Also, tree-biomass supports sustainable development by promoting the use of renewable energy sources and reducing greenhouse gas emissions. Enhanced Brand Reputation: Telecommunications companies that adopt tree-biomass can enhance their brand reputation by demonstrating their commitment to sustainability. Compliance with Regulations: Tree-biomass can help telecommunications companies comply with regulations and meet their sustainability goals and Increased Energy Independence: Tree-biomass can enhance energy independence by providing a local source of energy (Ani & Nzea, 2008: Forkel et al., 2019)

Benefits for Rural Communities

Job Creation: The production and processing of tree-biomass can create jobs and employment opportunities in rural areas. Improved Energy Access: Tree-biomass can provide energy access to rural communities, promoting economic development and improving living standards. Enhanced Energy Security by providing a local source of energy and reducing reliance on imported fossil fuels. It can also support sustainable development by promoting the use of renewable energy sources and reducing greenhouse gas emissions. As such, we can say that tree-biomass offers numerous benefits for telecommunications, including renewable energy, energy security, cost savings, and job creation. Telecommunications companies, rural communities, and the environment can all benefit from the adoption of tree-biomass.

Technologies for Harnessing Tree-Biomass (Davidson, 2023; Obada et al., 2024)

Combustion Technology: Combustion technology involves burning tree-biomass to produce heat or electricity. This technology is widely used in power plants, industrial processes, and residential heating systems.

Gasification Technology: Gasification technology involves converting tree-biomass into a synthesis gas (syngas), which can be used to produce electricity, heat, or biofuels.

Anaerobic Digestion Technology: Anaerobic digestion technology involves breaking down tree-biomass in the absence of oxygen to produce biogas, which can be used to produce electricity, heat, or biofuels.

Pyrolysis Technology: Pyrolysis technology involves heating tree-biomass in the absence of oxygen to produce bio-oil, biochar, and syngas.
Pelletization Technology: Pelletization technology involves compressing tree-biomass into dense pellets, which can be used as fuel for power plants, industrial processes, and residential heating systems.
Torrefaction Technology: Torrefaction technology involves heating tree-biomass in the absence of oxygen to produce a high-energy-density fuel that can be used in power plants and industrial processes.
Biochemical Conversion Technology: Biochemical conversion technology involves using microorganisms to convert tree-biomass into biofuels, such as ethanol and butanol.
Thermochemical Conversion Technology: Thermochemical conversion technology involves using heat and chemicals to convert tree-biomass into biofuels, such as bio-oil and syngas (Adams et al., 2018).

Challenges of Tree-Biomass Technologies

High Upfront Costs: Tree-biomass technologies require significant upfront investments in equipment and infrastructure. Tree-biomass technologies have varying energy efficiency rates, which can affect their overall performance. Feedstock Quality: The quality of tree-biomass feedstock can affect the performance and efficiency of tree-biomass technologies. Scalability: Tree-biomass technologies need to be scalable to meet the demands of large-scale energy production.

Case Studies

MTN Nigeria: MTN Nigeria has launched a biomass-powered base station in Kaduna State, which uses biomass pellets to generate electricity. Also, Airtel Nigeria: Airtel Nigeria has launched a solar-powered base station in Lagos State, which uses solar panels to generate electricity and reduce dependence on fossil fuels (Oliveira et al., 2012).

Challenges of Tree-Biomass Potentials in Nigeria

i. Land Availability: Tree-biomass production requires large areas of land, which can compete with food production and conservation efforts.
ii. Infrastructure: Nigeria's infrastructure for tree-biomass production, processing, and transportation is underdeveloped, making it difficult to harness the potential of tree-biomass.
iii. Technology: The technology for converting tree-biomass into energy is still developing, and the cost of investment is high.
iv. Policy and Regulation: The policy and regulatory framework for tree-biomass development in Nigeria is still evolving and needs to be strengthened.
v. Public Awareness: There is a need to raise public awareness about the benefits of tree-biomass and its potential to contribute to Nigeria's energy mix.
vi. Financing: Access to financing is a major challenge for tree-biomass development in Nigeria, particularly for small-scale producers.
vii. Competition with Food Production: Tree-biomass production may compete with food production for land, water, and other resources.

Strategies to Overcome Challenges and Harness Opportunities

i. Develop a National Tree-Biomass Policy: A national policy should be developed to provide a framework for the development of the tree-biomass industry.
ii. Invest in Infrastructure: Significant investments should be made in infrastructure, including transportation networks, storage facilities, and processing plants.
iii. Promote Public Awareness: Public awareness campaigns should be launched to promote the benefits of tree-biomass and encourage its adoption.
iv. Provide Access to Financing: Access to financing should be provided to small-scale producers and entrepreneurs to support the development of the tree-biomass industry.
v. Develop Local Capacity: Local capacity should be developed to support the development of the tree-biomass industry, including training and capacity-building programs.
vi. Encourage Private Sector Investment: Private sector investment should be encouraged to support the development of the tree-biomass industry.
vii. Foster International Cooperation: International cooperation should be fostered to access new technologies, markets, and funding opportunities.
viii. Provide Incentives for Investment: The government should provide incentives, such as tax breaks and subsidies, to encourage investment in the tree-biomass industry.
ix. Develop Efficient and Cost-Effective Technologies: Research and development should focus on improving the efficiency and cost-effectiveness of tree-biomass conversion technologies.

Future Directions of Tree-Biomass Technologies

i. Research and Development: Continued research and development are needed to improve the efficiency and cost-effectiveness of tree-biomass technologies.
ii. Scaling Up: Tree-biomass technologies need to be scaled up to meet the demands of large-scale energy production.

iii. Integration with Other Technologies: Tree-biomass technologies can be integrated with other technologies, such as solar and wind power, to create hybrid energy systems.
iv. Policy and Regulation: Supportive policies and regulations are needed to encourage the adoption of tree-biomass technologies.

CONCLUSION

Harnessing tree-biomass for use in telecommunications in Nigeria offers several benefits, including renewable energy, energy security, job creation, and waste management. While there are challenges to be addressed, the opportunities presented by tree-biomass make it an attractive option for reducing greenhouse gas emissions and promoting sustainable development in Nigeria. In conclusion, Nigeria has significant potential for tree-biomass production, with benefits including renewable energy, job creation, and improved energy security. However, challenges such as land availability, technology and infrastructure, and policy and regulation must be addressed to realize this potential.

RECOMMENDATIONS

Some of the recommendations will include:
Develop a National Tree-Biomass Policy: A national policy should be developed to provide a framework for the development of the tree-biomass industry.
Invest in Technology and Infrastructure: Significant investments should be made in technology and infrastructure to improve the efficiency and cost-effectiveness of tree-biomass production and processing.
Promote Public Awareness and Education: Public awareness and education campaigns should be launched to promote the benefits of tree-biomass and encourage its adoption.
Encourage Private Sector Investment: Private sector investment in the tree-biomass industry should be encouraged through incentives and supportive policies.
Develop Sustainable Forest Management Practices: Sustainable Forest management practices should be developed and implemented to ensure the long-term sustainability of tree-biomass production.

REFERENCES

Abubakar, S. S., Abdulsalam, S. M., & Nasuru, M. B. (2023). Alternative Clean Energy for Sustainable Growth and Development of Nigerian Telecommunications Sector. Proceedings of the Nigerian Academy of Science, 16 (2), %-17

Adams, P., Bridgwater, T., Lea-Langton, A., Ross, A., & Watson, I. (2018). Biomass conversion technologies, Greenhouse Gas Balances of Bioenergy Systems, 107–39, https://doi.org/10.1016/B978-0-08-101036-5.00008-2.

Adekunle, V.A.J., Nair, N.K., Srivastava, A.K. & Singh, N.K., (2014). Volume yield, tree species diversity and carbon hoard in protected areas of two developing countries, Forest Science and Technology, 10:2, 89-103, https://doi.org/10.1080/21580103.2013.860050

Adepetun, A. (2015) Nigeria: Telecoms Operators Power BTS with 50,000 Gen Sets. The Guardian, Lagos, 22-Jan-2015.

Agbelade A. D. & Adeagbo D. O. (2020). Relationship Between Aboveground Biomass and Tree Species Diversity in Two Protected Forests. Journal of Forestry Research and Management. Vol. 17(1).13-25; 2020, ISSN 0189-8418 www.jfrm.org.ng.

Agbelade A.D. & Lawal A. (2021). Volume Yield and Carbon Hoard In Two Community-Managed Forests Of Ekiti State, Southwest, Nigeria. *Forests and Forest Products Journal 19:127-135.*

Ajewole, M. O., Owolawi, P. A., Ojo, J. S. & Oyedele, M. O. (2018). Hybrid Renewable Energy System for 5G Mobile Telecommunication Applications in Akure. Southwestern Nigeria. Nigeria Journal of Pure and Applied Physics, 8(1), 27-34

Akinbowale, A.S., Meshach, O. A., Adetula, O. I., Arinzechi, C. I., & Jayeola, K. J. (2022). Diversity, Biomass and carbon Storage Potential of Some Tree Species in a Nigerian Natural Forest. Asian Journal of Research in Agriculture and Forestry, 8 (4), 97-108

Amole AO, Oladipo S, Olabode OE, Makinde KA, & Gbadega P (2023). Analysis of grid/solar photovoltaic power generation for improved village Proceedings of the Nigerian Academy of Science PNgAS. Vol 16, No 2, 2023 16 www.nasjournal.org.ng

Anav, A. et al., (2015). Spatiotemporal patterns of terrestrial gross primary production: A review. Reviews of Geophysics, 53(3), 785–818, https://doi.org/10.1002/2015rg000483.

Andela, N., D. C. Morton, L. Giglio, Y. Chen, G. R. van der Werf, P. S. Kasibhatla, R. S. DeFries, G. J. Collatz, S. Hantson, S. Kloster, D. Bachelet, M. Forrest, G. Lasslop, F. Li, S. Mangeon, J. R. Melton, C. Yue, J. T. Randerson. (2017). A human-driven decline in global burned area. Science, 1356, 1356–1362, https://doi.org/10.1126/science.aal4108.

Ani, V.A., & Nzeako, A. N., (2008) Potentials of Optimized Hybrid System in Powering Off-Grid Macro

Base Transmitter Station Site. International Journal of Renewable Energy Research (IJRER) Vol.3, No.4.

Arora, V.K. and J.R. Melton, (2018). Reduction in global area burned and wildfire emissions since 1930s enhances carbon uptake by land. Nature Communications, 9(1), 1326, https://doi.org/10.1038/s41467-018-03838.

Ayompe LM, Davis SJ, & Egoh BN (2021). Trends and drivers of African fossil fuel CO2 emissions 1990–2017. Environmental Research Letters, 15(12), 124039.

Bada, G. O., Utomi, A. O., & Owolabi, O. A. (2018). Assessment of carbon sequestration potential of some tree species in Nigeria. *Journal of Agriculture and Environmental Sciences*, 2(1), 1-9.

Badgley, G., C.B. Field & Berry, J.A. (2017). Canopy near-infrared reflectance and terrestrial photosynthesis. Science Advances, 3(3), e1602244, https://doi.org/10.1126/sciadv.1602244.

Balogun O. E, Owolawi P.A and V.M Strivastrava (2017): Hybrid power systems for GHSM and 4G base stations in South Africa., Proceedings of IEEE AFRICON, 2017, 978-1- 5386-2774-7/17/$31.00©2017IEEE, pp. 1046- 1051

Ballantyne, A., William, S., William, A., P. Kauppi, J. S., Pieter, T., Elena, S., Yude, P., Benjamin, P., Alessandro, A., Pierre, F., Richard, H., & Steven, R., (2017). Accelerating net terrestrial carbon uptake during the warming hiatus due to reduced respiration. Nature Climate Change, 7(2), 148–152, https://doi.org/10.1038/nclimate3204.

Boer, M.M., V. Resco de Dios & R.A. Bradstock, (2020). Unprecedented burn area of Australian mega forest fires. Nature Climate Change, 10(3), 171– 172, https://doi.org/10.1038/s41558-020-0716-1.

Bowman, D. M. J. S., Crystal A. Kolden, John T. Abatzoglou, Fay H. Johnston, Guido R. van der Werf & Mike Flannigan. (2020). Vegetation fires in the Anthropocene. Nature Reviews Earth & Environment, 1(10), 500–515, https://doi.org/10.1038/s43017-020-0085-3.

Brydon Alastair(2014), A report on 5G mobile network features, https://www.unwiredinsight.com/2014/5g-mobilenetwork-features

Campbell, J. E., Berry, J. A., Seibt, U., Smith, S. J., Montzka, S. A., Launois, T., Belviso, S., Bopp, L., & Laine, M. (2017). Large historical growth in global terrestrial gross primary production. Nature, 544(7648), 84–87, https://doi.org/10.1038/nature22030.

Chabot, J. F., & Goldstein, R. A. (2018). *Trees: A guide to their structure, function and ecology*. Academic Press.

Chan, S., Miranda-Moreno, L. and Patterson, Z. (2013) Analysis of GHG Emissions for City Passenger Trains: Is Electricity an Obvious Option for Montreal Commuter Trains? Journal of Transportation Technologies , 3, 17-29. https://doi.org/10.4236/jtts.2013.32a003

Chen, Z., & Yu, G. (2020). Wang, Q. Effects of Climate and Forest Age on the Ecosystem Carbon Exchange of Afforestation. J. For. Res. 2020, 31, 365–374.

Ciais, P., J. Tan, X. Wang, C. Roedenbeck, F. Chevallier, S.-L. Piao, R. Moriarty, G. Broquet, C. Le Quéré, J. G. Canadell, S. Peng, B. Poulter, Z. Liu & P. Tans. (2019). Five decades of northern land carbon uptake revealed by the interhemispheric CO2 gradient. Nature, 568(7751), 221–225, https://doi.org/10.1038/s41586-019-1078-6.

Dai, L., Zhang, Y., Wang, L., Zheng, S., & Xu, W. (2021). Assessment of Carbon Density in Natural Mountain Forest Ecosystems at Northwest China. Int. J. Environ. Res. Public. Health 2021, 18, 2098.

David, O.O., Mamuda, M., Salihu, B. T., Mkpe, O. K., Simeon, A. A., Shittu, B. A., & Akinlolu, A. (2024). A Review of Rnewable Energy Resources in Nigeria for Climate Change Mitigation. Case Studies In Chemical and Environmental Engineering (ELSEVIER), 9, 1-18.

Davidson, C. O. (2023). Biomass Power: Opportunities and Challenges for Nigeria. World Journal of Advanced Research and Reviews, 20 (02), 001-023

Dossa, K. F., & Yann, E. M. (2024). “Remote Sensing Methods and GIS Approaches for Carbon Sequestration Measurement: A General Review”. International Journal of Environment and Climate Change 14 (7):222- 33. https://doi.org/10.9734/ijecc/2024/v14i74265

FAO. (2020). *The state of the world's forests 2020*. Food and Agriculture Organization of the United Nations.

Fatokun, J. O., Shitu, S., Joseph, E., Bem, A. A., Na-Allah, A. S. & Ekanem, E. (2015). Comparative Analysis of Biogas Yield from Different Biodegradable Substrates in Dutsinma Local Government Area, Katsina State – Nigeria. IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 3 Issue 9, pp. 293-305.
https://ijiset.com/vol3/v3s9/IJISET_V3_I9_44.pdf

Faruk, N., Ayeni, A.A., Muhammad, M.Y., Olawoyin, L.A., Abdulkarim, A., Agbakoba, J. & Olufemi, M.O. (2013) Techniques for Minimizing Power Consumption of Base Transceiver Station in Mobile Cellular Systems. International Journal of Sustainability , 2, 1-11.

Faruk, N., Muhammad, M.Y., Bello, O.W., Abdulkarim, A., John, A. & Gumel, M.I. (2012). Energy Conservation through Site Optimization for Mobile Cellular Systems (Base Transceivers Station Optimization). Epistemics in Science , Engineering and Technology, X, 1-8.

Forkel, M., Wouter, D., Gitta, L., Emilio, C., Stijn, H., Angelika, H., Irene, T., Kirsten, T., & Sandy, P. H. (2019). Recent global and regional trends in burned area and their compensating environmental controls. International Journal of Agriculture and Earth Science (IJAES) E-ISSN 2489-0081 P-ISSN 2695-1894 Vol 10. No. 9 2024 www.iiardjournals.org Online Version

Friedlingstein, P., Michael, O., Matthew, W. J., Robbie, M. A., Judith, H., Are, O., Glen, P. P., Wouter, P., Julia, P., Stephen, S., Corinne, L., Josep, G. C., Philippe, C., Robert, B. J., Simone, A., Luiz, E. O. C., Aragão, A. A., Vivek, A., Nicholas, R., Bates, M. B., Alice, B., Henry, C. B., Laurent, B., Selma, B., Naveen, C., Frédéric, C., Louise, P. C., Wiley, E., Liesbeth, F., Piers, M. F., Thomas, G., Marion, G., Dennis, G., Thanos, G., Luke, G., Nicolas, G., Ian, H., Kerstin, H., Vanessa, H., Richard, A. H., Tatiana, I., Atul, K. J., Emilie, J., Koji, K., Etsushi, K., Vassilis, K., Jan, I. K., Peter, L., Nathalie, L., Andrew, L., Sebastian, L., Zhu, L., Danica, L., Gregg, M., Nicolas, M., David, R. M., Julia, E. M. S., Nabel, S. Nakaoka., Yosuke, Niwa., Kevin, O., Tsuneo, O., Paul, I. P., Denis, P., Benjamin, P., Laure, R., Eddy, R., Christian, R., Jörg, S., Roland, S., Ingunn, S., Adam, J. P., Smith, A. J., Sutton, T. T., Pieter, P. T., Hanqin, T., Bronte, T., Guido, W., Nicolas V., Anthony, P. W., Rik, Wanninkhof, A. J. Watson, D. W., Andrew, J. W., Wenping, Y., Xu, Y., & Sönke, Z., (2020). Global Carbon Budget 2020. Earth System Science Data, 12(4), 3269–3340, https://doi.org/10.5194/essd-12-3269-2020.

Global System for Mobile Communications Association (GSMA) (2020) Renewable Energy for Mobile Towers: Opportunities for Low- and Middle-Income Countries.

Goshwe, N.Y., Kureve, T.D. & Okeleke, A. (2015). Performance Evaluation of Power in GSM BTS in Nigeria Using PV Solar System. Journal of Energy Technologies and Policy , 5, 23-37.

Harris N. L., David A. G., Alessandro, B., Richard A. B., Sytze, d B., Mary, F., Lola, F., Matthew, C. H., Martin, H., Richard, A. H., Peter, V. P., Daniela, R. S., Rosa, M., Roman-Cuesta., Sassan, S. S., Christy, M. S., Svetlana, A T., & Alexandra, T. (2021). Global maps of twenty-first century forest carbon fluxes. Nature Climate Change. https://doi.org/10.1038/s41558-020-00976-6 www.nature.com/natureclimatechange.

Hassan Z, Boostannimehr H, Bharagava B.G, 2011, IEEE Commu Surv, Tut, 13(4), 524-520.

Hisano, M., Searle, E.B., & Chen, H.Y.H. Biodiversity as a Solution to Mitigate Climate Change Impacts on the Functioning of Forest Ecosystems. Biol. Rev. 2018, 93, 439–456.

Holtkamp, H., Auer, G., Bazzi, S. & Haas, H. (2014). Minimizing Base Station Power Consumption. IEEE Journal on Selected Areas in Communications, 32, 297-306. https://doi.org/10.1109/jsac.2014.141210

Huntzinger, D. N., A. M. Michalak, C. Schwalm, P. Ciais, A. W. King, Y. Fang, K. Schaefer, Y. Wei, R. B. Cook, J. B. Fisher, D. Hayes, M. Huang, A. Ito, A. K. Jain, H. Lei, C. Lu, F. Maignan, J. Mao, N. Parazoo, S. Peng, B. Poulter, D. Ricciuto, X. Shi, H. Tian, W. Wang, N. Zeng & F. Zhao. (2017). Uncertainty in the response of terrestrial carbon sink International Journal of Agriculture and Earth Science (IJAES) E-ISSN 2489-0081 P-ISSN 2695-1894 Vol 10. No. 9 2024 www.iiardjournals.org Online Version

Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

International Energy Agency (IEA) (2020) Global CO2 Emissions in 2019.

Ishaq, S. E., Ofoegbu, O., & Azua, E. T. (2014). Sequestration and Carbon Storage Potential of Tropical Forest Reserve and Tree Species Located within Benue State of Nigeria. Journal of Geoscience and Environment protection, 2, 157-166

ITU (2015). ICTs and Climate Change. International Telecommunication Union.

Kamalu, M. A., Amir, A., Musa, Z., & Mohammed, B.G. (2024). An Integrated Review of Potentials and Significance of Carbon Sequestration by Different Trees in Northern Nigeria. International Journal of Agriculture and Earth Science, 10 (9), 1-20.

Lorincz, J., Garma, T. & Petrovic, G. (2012). Measurements and Modelling of Base Station Power

Consumption under Real Traffic Loads. Sensors , 12, 4281-4310. https://doi.org/10.3390/s120404281

Lorincz, J and Bule I (2013), Renewable energy source for power supply of base station sites, Int. J of Bus data Commun, network, 9, 55-74.

Mao, J., Aurélien, R., Binyan, Y., Xiaoying, S., Peter, E. T., Roland, S., Philippe, C., Ranga, B. M., Hervé, D., Shilong, P., Zaichun, Z., Robert, E. D., Yongjiu, D., Daniel, M. R., Mingzhou, J., Forrest, M. H., Bin Wang, M. H., & Xu, L. (2016). Human-induced greening of the northern extratropical land surface. Nature Climate Change, 6(10), 959–963, https://doi.org/10.1038/nclimate3056.

Mohammed, Y.S., Mustafa, M.W., Bashir, N., & Mokhtar, A.S. (2013). Renewable energy resources for distributed power generation in Nigeria: a review of the potential, Renew. Sustain. Energy Rev. 22, 257.

Murthy, C.R., & Kavitha, D.C. (202): A survey of green base stations in cellular networks. IRACST Int. J. Comput. Netw. Wirel. Commun. (IJCNWC). 2012, 2, 232–236.

National Bureau of Statistics (2020) Nigeria Living Standards Survey (2018/2019).

Nigerian Communication Commission (NCC) (2020) 2019 Subscriber/Network Data Report.

NCC (2020). Nigerian Communications Commission Annual Report. Nigerian Communications Commission.
Nigerian Electricity Regulatory Commission (2020) Electricity on Demand: Fourth Quarter 2019.

Obada, D.O., Dauda, M., & Dodoo-Arhin, D. (2016). Flame temperature characteristics and flue gas analysis of an improvised biogas burner, West Indian Journal of Engineering 39, 4.

Obada, D.O. , Obi, A.I., Dauda, M., & Anafi, F.O. (2014). Design and construction of a biogas burner, PTURJ 2, 35.

Obada, D.O., Kekung, M.O., Anafi, F.O. The addition of Nigerian Kankara kaolin improves the ash properties of empty fruit bunches during combustion, MRS Adv 7 (2022) 614–618.

Obada, D.O., Kekung, M.O., Levonyan, T., & Norval, G.W. Palm oil mill derived empty palm fruit bunches as a feed stock for renewable energy applications in Nigeria: a review, Bioresour. Technol. Rep. 24 (2023) 101666, https://doi.org/10.1016/J. BITEB.2023.101666

Obinna, I.N. and Osawaru, O.E. (2020) Modelling of Power Consumption in Two Base Stations, Using Ugbor Station and Benson Idahosa University Station in Benin City as a Case Study. International Journal of Innovative Science and Research Technology, 5, 1153-1165. https://doi.org/10.38124/ijisrt20jun611

Ojekunle, O. O., Oyebanji, N. A., Majolagbe, M. O., & Akinnotimi, J. A. (2023). Assessing Carbon Sequestration Potential of Indigenous Trees among Academic Parks in Federal University of Agriculture, Abeokuta, Nigeria. Journal of Applied Science and Environmental Management, 27 (9), 2021-2027

Ojo, A.A., Awogbemi, O., & Ojo, A.O. An Overview of the Exploitation of Renewable Energy Resources in Nigeria. South Africa, and the United Kingdom, Energy, 2020, p. 10.

Oyedepo, S.O. (2012). On energy for sustainable development in Nigeria, Renew. Sustain. Energy Rev. 16, 2583.
Ozoegwu, C.G., Mgbemene, C.A.,& Ozor, P.A. (2017). The status of solar energy integration and policy in Nigeria, Renew. Sustain. Energy Rev. 70, 457.

Pan, Y., Birdsey, R. A., Fang, J., & Turner, D. P. (2011). *Quantifying global forest carbon sink*. Science, 333(6044), 989-993.

Peylin, P., Law, R. M., Gurney, K. R., Chevallier, F., Jacobson, A. R., Maki, T. , Niwa, Y., Patra, P. K., Peters, W., Rayner, P. J., Rödenbeck, C., van der, L., & Zhang, X. (2013). Global atmospheric carbon budget: results from an ensemble of atmospheric CO2 inversions. Biogeosciences, 10(10), 6699–6720, https://doi.org/10.5194/bg-10-6699-2013.

Phillips Oliver L. , Luiz E. O. C. Aragão, Simon L. Lewis, Joshua B. Fisher, and Armando Torres-Lezama (2008). The Amazon rainforest carbon International Journal of Agriculture and Earth Science (IJAES) E-ISSN 2489-0081 P-ISSN 2695-1894 Vol 10. No. 9 2024 www.iiardjournals.org Online Version

Piao, S., Philippe, C., Yao, H., Zehao, S., Shushi, P., Junsheng, L., Liping, Z., Hongyan, L., Yuecun, M., Yihui, D., Pierre, F., Chunzhen, L., Kun, T., Yongqiang, Y., Tianyi, Z., & Jingyun, F. (2008). The impacts of climate change on global forest ecosystems. Science, 320(5877), 1073-1077.

Rilwan, O. O., & Mojisola, F. O. (2024). Renewable Electricity Generation: Solution to GHG Emmissions in

Nigeria Telecom Industry. World Journal of engineering and technology, 12, 885-894

Roy P, Pal SC, Chakrabortty R, Chowdhuri I, Saha A, & Shit M (2023). Effects of climate change and sea-level rise on coastal habitat: Vulnerability assessment, adaptation strategies and policy recommendations. Journal of Environmental Management, 330, 117187.

Sambo, A.S. Strategic developments in renewable energy in Nigeria, International Association for Energy Economics 16 (2009) 15.

Sánchez-Bluemel, M., (2016). Carbon sequestration potential of forest tree species: A review. *Forests*, 7(10), 248.

Satya, S., Olumide, O. O., Elmira, N. G., & Ahmed, K. I. A. (2017). Impact of Sustainable Energy Savings in Nigeria Telecoms Industry. CSCC

Sertolli, A. , Gabnai, Z., Lengyel, P., & Bai, A. (2022). Biomass potential and utilization in worldwide research trends—a bibliometric analysis, Sustainability 14, 5515, https://doi.org/10.3390/SU14095515 , 5515 2022;14.

Simeon, O. J., Joseph, I. O., & Ralf, P. (2020). Assessment of Potential Resources for Biomass Energy in Nigeria. Resources (MDPI), 9 (92), 1-41

Steiner A (2019). Climate change, environment, and sustainable development in Africa. In African Economic Development (pp. 93-110). Emerald Publishing Limited.

Sun, W., & Liu, X., Review on Carbon Storage Estimation of Forest Ecosystem and Applications in China. For. Ecosyst. 2019, 7, 4.

Tagesson, T., Guy, S., Stéphanie, H., Philippe, C., Feng, T., Martin, B., Anders, A., Jean-Pierre, W., Jonas, A., Stefan, O., Lei, F., Zhendong, W. & Rasmus, F. (2020). Recent divergence in the contributions of tropical and International Journal of Agriculture and Earth Science (IJAES) E-ISSN 2489-0081 P-ISSN 2695-1894 Vol 10. No. 9 2024 www.iiardjournals.org Online Version

Taiz, L., & Zeiger, E. (2017). *Plant physiology*. Sinauer Associates.

Takeshita, T. (2013) Prospects for Renewable and Fossil-Based Electricity Generation in a Carbon-Constrained World. International Journal of Clean Coal and Energy, 2, 35-43. https://doi.org/10.4236/ijcce.2013.22b008

Tebepah, E. (2015). The cost of telecommunications evolution in Nigeria. Journal of Energy Technologies and Policy, 5(10), 17-26.

Turco, M., Joaquín, B., Fabrizio, D. L., Paolo, F., Jost von, H., Nikos, K., Maria-Carmen, L., Fotios, X., & Antonello, P. (2016). Decreasing Fires in Mediterranean Europe. PLOS ONE, 11(3), e0150663, https://doi.org/10.1371/journal.pone.0150663.

Turner, D.P., Koerper, G.J., Harmon, M.E., & Lee, J.J. (1995). A Carbon Budget for Forests of the Conterminous United States. Ecol. Appl. 5, 421–436.

Ukoba, M. O., Dumuodeke, E. O., Briggs, T. A., Ojapah, M. M., Owebor, K., Okkedu, K. E., AKhtar, K., & Ilhami, C. (2024). Using Remote Sensing Techniques to assess Biomass Energy Potentials and appropriate Site Locations in Nigeria. Measurement Sensors (ELSEVIER). 33, 1-25

Vincenzo, M., & Sara, A., (2011) INRIA Sophia Antipolis Mediterranean Reducing Costs and Pollution in Cellular Networks.IEEE Communication Magazine August 2011

Walker, A.P., De Kauwe, M.G., Bastos, A., Belmecheri, S., Georgiou, K., Keeling, R.F., McMahon, S.M., Medlyn, B.E., Moore, D.J.P., Norby, R.J., Zaehle, S., Anderson-Teixeira, K.J., Battipaglia, G., Brienen, R.J.W., Cabugao, K.G., Cailleret, M., Campbell, E., Canadell, J.G., Ciais, P., Craig, M.E., Ellsworth, D.S., Farquhar, G.D., Fatichi, S., Fisher, J.B., Frank, D.C., Graven, H., Gu, L., Haverd, V., Heilman, K., Heimann, M., Hungate, B.A., Iversen, C.M., Joos, F., Jiang, M., Keenan, T.F., Knauer, J., Körner, C., Leshyk, V.O., Leuzinger, S., Liu, Y., MacBean, N., Malhi, Y., McVicar, T.R., Penuelas, J., Pongratz, J., Powell, A.S., Riutta, T., Sabot, M.E.B., Schleucher, J., Sitch, S., Smith, W.K., Sulman, B., Taylor, B., Terrer, C., Torn, M.S., Treseder, K.K., Trugman, A.T., Trumbore, S.E., van Mantgem, P.J., Voelker, S.L., Whelan, M.E., & Zuidema, P.A. (2021). Integrating the evidence for a terrestrial carbon sink caused by increasing atmospheric CO2. New Phytologist, 229(5), 2413–2445, https://doi.org/10.1111/nph.16866.

Wang K., Hu , D., J. Deng, Z. Shangguan & L. Deng (2018). Biomass carbon storages and carbon sequestration potentials of the Grain for Green Program-Covered Forests in China. Ecology and Evolution. 2018;8:7451–7461. www.ecolevol.org

Yin Yi, A. Anthony Bloom, John Worden, Sassan Saatchi, Yan Yang, Mathew Williams, Junjie Liu, Zhe Jiang, Helen Worden, Kevin Bowman, Christian Frankenberg & David Schimel (2020). Fire decline in dry tropical ecosystems enhances decadal land carbon sink.

Nature Communications, 11(1), 1900, https://doi.org/10.1038/s41467-020-15852-2.

Yohannes, G., & Sewnet, G. (2024). A Review of the Carbon Sequestration Potential of Fruit trees and their implications for Climate Change Mitigation: The Case of Ethiopia, Cogent food and Agriculture (Taylor & Francis), 10: 1-16

Zhang, Q., Tezuka, T., & Mclellan, B.C., (2012) Scenario analysis of low-carbon smart electricity systems in Japan in 2030. In: Yao T (ed) Zerocarbon energy Kyoto 2011, Part 1. Springer, Berlin, pp 33–44.

Zhang, Y., Joiner, J., Hamed Alemohammad, S., Zhou, S., & Gentine, P. (2018). A global spatially contiguous solar-induced fluorescence (CSIF) dataset using neural networks. Biogeosciences, 15(19), 5779–5800, https://doi.org/10.5194/bg-15-5779-2018.