

Carbon Sequestration: A Dependable Ally In The Fight Against Climate Change

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ABSTRACT

This research paper provides an in-depth analysis of carbon sequestration – an approach to climate mitigation. The paper provides an overview of carbon, its forms, and impact on the environment (emission of greenhouse gases (GHG)) and climate (global warming), and how it is affecting Nigerian communities – which form the foundation of which is paper is structured. At the Crux of this paper, carbon sequestration was discussed, its forms (terrestrial, ocean, and geological) were discussed, and also supporting its explanation with figures. It further explains each form of sequestration with experiments. The paper concluded by enumerating how carbon sequestration reduces the impact of climate change events in Nigeria.

Keywords: Carbon, Climate change, GHG, global warming, mitigation, and sequestration.

1.0. INTRODUCTION

1.1. Background of The Study

In 1789, an element was discovered. It is known for its transparency, opaqueness, blackness, softness, fullerenes, diverse binding, and unique ability to form polymers. That element is called “Carbon”. According to Ethan (2020), carbon is the fourth most common element in the universe, the twelfth most common element in the earth’s crust (Nicholas, 2021), the third most common element in humans by mass (12%) (Shraga, 2020), third most common element in animals by mass (Frieden, n.d), and the most common element in plants (Tony and Mark, n.d). Carbon exists in the atmosphere, on the land, and inside the water. Carbon is everywhere.

Carbon, when combined with other elements forms compounds and mixtures that are both nutritious and toxic to humans, plants, animals, and the environment. In humans, carbon combines with oxygen (inlet) gas to produce carbon dioxide (CO₂) (outlet) gas – which forms the basis for breathing in and breathing out. The outlet [CO₂] forms the basic nutrient for plants during photosynthesis. Conversely, the combination of carbon from burning fossil fuels and other volatile materials, and oxygen produces toxic substances like CO₂ that are harmful to the ecosystem. Tamara (2018) adds that carbon contributes to the main causes of a destructive ecosystem. For example, CO₂ and methane (CH₄) account for 79% and 11% of gases contributing to Greenhouse gases (GHG) respectively (U.S. Environmental Protection Agency (EPA), 2020). Obviously, in recent times, carbon is regarded as the pivot for climate change events – which forms the cornerstone of this paper.

1.2. Problem Statement

In 1896, Svante Arrhenius – a Swedish Scientist discovered that CO₂ is being released from the earth from the burning of fossil fuels such as coal, wood, and during combustion into the atmosphere through a warming effect. Also, almost 100 years later, James Hasen – an American scientist confirmed that the CO₂ trapped in the atmosphere is already causing a change in the climate (National Geographic, n.d). In other words, the carbon trapped in the atmosphere has caused an unbalance in the carbon cycle. The carbon cycle – which involves an equilibrium interaction of carbon energy between animals, air, water, land, plants, and the rest of the environment, is being destabilized by the excess emission of CO₂ from burning of fossil fuels. The U.S. EPA (2020) reveals that CO₂ is the primary source of GHG emissions from human activities such as transportation, electricity, and industries.

Global warming – is an end product of CO₂ and other air pollutants accumulated in the atmosphere, and absorbs sunlight and solar radiation that had bounced off the earth's surface (Amanda and Jeff, 2021). The impact – known as the greenhouse effect – which makes the earth inhabitable, has over the years, continued to threaten human activities, animals, plants adaptation, and the environment as a result of the excessive emissions. Also, in recent times, global warming has resulted in rising sea levels, disappearing glaciers, disruption of habitats such as alpine meadows and coral reefs, increased flooding, extreme drought, wildfire, intense heat, and even animal extinction.

Economically, it is capable of destroying valuable properties and consuming the gross domestic product (GDP) of the affected nations. For example, the GDP in African nations exposed to extreme climate events is projected to increase from \$895 billion in 2018 to approximately \$1.4 trillion in 2023 – which is an estimated 50% of the continent's GDP (Okonjo-Iweala, 2020). In 2019, the National Emergency Management Agency (NEMA) revealed that the flood events has displaced about two million Nigerians (Future-Learn, 2019). Adekunle et al. (2011) add that storm surges, ocean surges, and loss of forest resources are all results of climate change events. Also, Ayodele (2016) published that Lagos experienced three weeks of heavy rainfall to herald the impact of climate change in the state. Ayodele further analyzed that a sea level rise of 200 mm might displace about 740,000 people from their homes. And a one-meter rise in sea level would affect 900,000 people. A study in selected Lagos communities (Apapa, Bariga, Makoko, Oloye) reveals how commuters suffer from deterioration of buildings, flooded rooms, and prevalence of malaria (Adelekan, 2016) all being a result of climate change events.

In plants, extreme weather conditions precipitate the growth of climate-based pests and weeds which in turn, suppress and stress plants, and then reduce the quality and quantity of yields from the plants. Consequently, it increases famine, food scarcity, and less-nutritional food production.

Humans and plants are not the only species affected by climate disasters. Animals too face climate-driven threats. As a result of extreme weather conditions leading to food scarcity and drought, the ecosystem becomes unbearable and uncomfortable – which drives animals to migrate to an unusual pole in search of survival. Animals who cannot survive in the new environment go into extinction. A continual habitats loss, fragmentation, human development, and global warming would increase animal extinction in the next 40 years. For

example, the bushfire that happened between 2019 and 2020 burned over 180,000 kilometers square of animal habitats and killed or displaced about three billion animals (Ifaw, 2022).

Ultimately, the Inter-governmental Panel on Climate Change (IPCC) (2022) predicts that the world, and particularly developing countries like Nigeria and others would experience several climate change events over the next two decades with global warming of 1.5°C (2.7°F). Additionally, exceeding this temperature will result in more severe impacts, some of which will cause permanent damages, and risks for societies will increase, especially in low-lying settlements.

1.3. The objective of The Study

The objective of this research paper is to explore carbon sequestration as an option for tackling climate change.

1.4. Scope of The Study

The research focuses on the technical know-how on carbon sequestration as an approach to achieving climate mitigation. The paper bases its research on the threats and problems posed by climate change. The research aims at recommending carbon sequestration as a sustainable option for tackling climate-driven events.

1.5. Significance and Impact of The Study

Although, there are several climate mitigation strategies like ecological-based adaptation (EBA), nature-based adaptation (NBA), and solar-based strategies. But, this paper – which is based on carbon sequestration, approaches climate change in a clean, and beneficial way. It does not only collect CO₂ from the atmosphere, but also, stores the CO₂ in the soil, water, and geological formations – thereby, enhancing photosynthesis. In Nigeria, the vulnerability to climate disasters is unavoidable. This is a result of excessive burning of Fossil fuels through combustion and agricultural practices. Thus, the practice of carbon sequestration would in a wide range, provide a clean, sustainable, and green Nigeria.

2.0. LITERATURE REVIEW

Agriculture, Carbon, and Climate Change

Agriculture and climate change are two sides of a coin. Agriculture is the major source of livelihood for both plants and animals. It provides the human basic needs like clothing, food,

and shelter. On the other side of the coin, “Climate change” refers to the increasing changes in the measures of climate over a long period – including precipitation, temperature, and wind patterns. An excess of the changes in the climate leads to global warming which has a rapid effect on the environment. That is, the changes happen and the effects are felt within a short period.

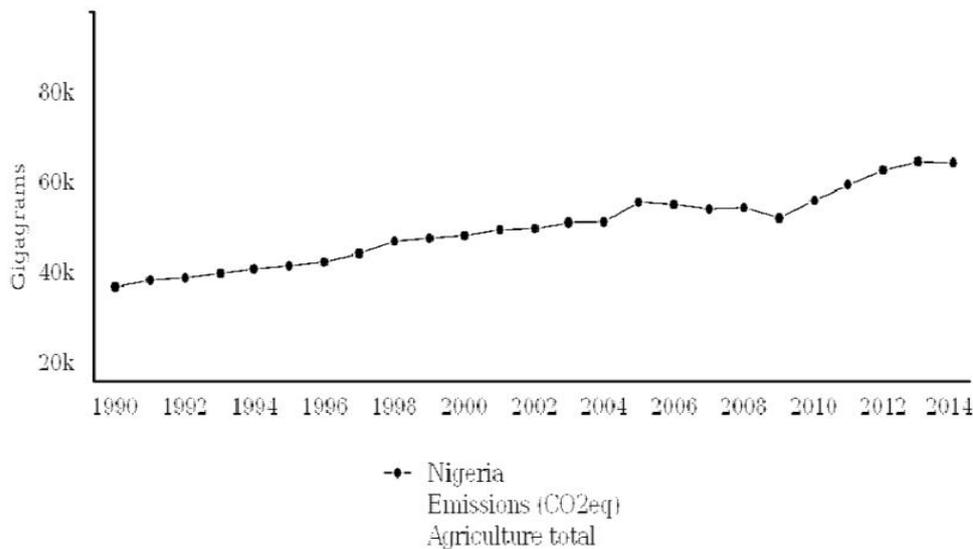
Climate change may be beneficial or detrimental to agriculture. Generally, climate change events like extreme weather conditions affect the growing season of crops and the pattern of crop production. Furthermore, a continuous and severe temperature increase in climate variabilities like heat waves, tornadoes, and thunderstorms adapt to a difficult situation for farmers. According to a survey by Jeff and Holy (2009), the following are the impacts of climate change on agriculture:

- Rapid progress in the life cycle of plants where excess CO₂ and extreme weather conditions exist.
- Higher risk in livestock production.
- The inability to control diseases on crops and animals is a result of the kind of temperature favoring the diseases.
- Oilseeds and grains are more vulnerable to climate change than fruits and vegetables.

According to Future-Learn (2019), climate change events in Nigeria is becoming common as a result of the emission of GHG (sulfur, carbon monoxide, and carbon dioxide) from vehicles, burning of hydrocarbon products, deforestation, and industries' emissions. Consequently, it has caused a reduction in crop yield, public health crisis, reduced livestock production as a result of irregular climatic conditions destroying grasses, farmlands, and animal feed; decrease in power supply from Kanji Dam and other smaller dams due to limited rainfall and drought; and increase food shortage (Ibid).

Conversely, agriculture contributes to GHG. This is evident as agriculture accounted for about 12% of the total GHG in the atmosphere as of 2005 (IPCC, 2007). But Gatesnotes in 2018 revealed an increased emission of GHG (24%) from agriculture (Gatesnotes, 2018). A year ago, the World Bank announced that agriculture's contribution to GHG has already reached 29% (World Bank, 2021) Thus if action [carbon sequestration] is not taken, the percentage will continue to increase. However, the figure below shows the data on CO₂ contributions to agricultural activities.

Fig. 1: Emission of CO₂ from Nigeria's Agricultural Activities



Source: Oreoluwa et al. (2018)

In recent times, the mass (%) of GHG in the atmosphere has increased. Gatesnote (2018) revealed that agriculture contributes about 24% of the GHG in the atmosphere – the second highest after construction (25%). A survey by the Center for Strategic and International Studies (CSIS) (2021) adds that in the past 200 years, the global agricultural sector has released 133 billion metric tons of CO₂ (GtCO₂) from the soil into the atmosphere - compared to three times as less carbon as all human activities emitted in 2019 (43.1 GtCO₂). A closer look at the later statistics shows that agriculture also contributes significantly to toxic carbon emissions.

3.0. THEORETICAL ANALYSIS

3.1. Carbon Sequestration and Climate Mitigation

Climate mitigation refers to the efforts to reduce or prevent the emission of GHG. There are a plethora of climate mitigation strategies, which include adaptation processes and solar-based products. However, carbon sequestration is another strategy used for climate mitigation. Carbon sequestration is the process of removing CO₂ from the atmosphere and then, storing

them in the soil, plants, and the earth's crust. Eric et al. (n.d) described carbon sequestration as the natural or deliberate process by which CO₂ is either moved from the atmosphere or diverted from the emission sources, and stored in the ocean, terrestrial environment, and geologic formation. UC Davis (2022) stated that the percentage by mass of carbon stored in the atmosphere, ocean, and grasslands are 45%, 30%, and 25% respectively.

Skepticism arises about the sustainability of carbon sequestration. Thus, this uncertainty pops the question: How long carbon can be stored in the soil? How much carbon can be sequestered by the different available practices? And how effectively can carbon be sequestered?

3.2. Forms of Carbon Sequestration

Carbon sequestration is basically in three forms: Oceanic carbon sequestration (OCS), terrestrial carbon sequestration (TCS), and geological carbon sequestration (GCS).

- **Geological carbon sequestration** involves the collection of CO₂ from the exhaust of fossil fuel power plants and injected into the porous rock formation. Morgan and Matthew (2019) defined the geological sequestration of carbon as the capture of CO₂ directly from anthropogenic sources and disposal into geological formations for geologically significant periods.
- **Terrestrial carbon sequestration** is achieved through forest, wetlands, grasslands, and soil conservation strategies in storing CO₂ or reducing the emission of CO₂. It is also meant to say Terrestrial carbon sequestration is the process through which CO₂ from the atmosphere is absorbed by plants through photosynthesis and stored as carbon in soils and biomass (tree trunks, branches, foliage, and roots).
- **Ocean carbon sequestration** is the collection of human-caused CO₂ in the atmosphere and stored in the water body. Aaron (2013) added that ocean carbon sequestration (OCS) is a method that distributes CO₂ more evenly throughout ocean depth and minimizes surface ocean impacts. There are two major methods of OCS – direct injection and ocean fertilization (promoting photosynthetic fixation of CO₂ by ocean organisms).

Carbon sequestration could prove tasking to accomplish because carbon does not only comes from human activities. It also emanates from natural, biological, and geological processes.

Next, this paper discusses the methods involved in the aforementioned forms of carbon sequestration, using case studies, and the chemical or natural approaches to utilize to accomplish carbon sequestration.

4.0. METHODOLOGY

4.1. Terrestrial Carbon Sequestration (TCS): A Case Study of Soil Carbon (SOC)

The method involved in terrestrial carbon sequestration are:

4.1.1. Sample Collection

This is the first stage in carrying out TCS irrespective of the terrestrial ecosystem. The steps involved in collecting the samples are:

- **Identification of Boundary Lines:** This is the process of identifying defined boundaries that make the findings understandable and accurate. Boundary Lines are the range between the maximum and minimum space of the environment that is used for the whole experiment.
- **Establishment of The Baselines:** This involves the state of the environment (treated plots or non-treated plots). Treated plots are terrestrials that have been fumigated from fungi, bacteria, and other soil-based germs. While non-treated plots are in crude forms (not fumigated). Nayak et al., (2019) confirmed that carbon in the environment cannot be sequestered without the contrast between treated plots and non-treated plots. Thus, in establishing a baseline for any terrestrial form of sequestration, both the treated plots and the non-treated plots must be used.
- **Timing:** After the baseline must have been determined, the next is knowing the timeline it will take for any changes to occur. The timing involves considering the changes that would take place, characterized by either a higher or a lower degree of variability. However, the changes also depend on the soil type. For instance in an ecosystem without the presence of clay soil, it will take about ten years to detect only a 15% increase in carbon within the soil (Smith, 2004). Also, the IPCC (2006) adds that it takes SOC about 20 years to reach an equilibrium state. In the case of clay soil, it takes 50-100 years to detect a noticeable percentage of carbon and also, reach an equilibrium state (Sanderman and Buldock, 2010).
- **Sampling Design:** Sampling design is about obtaining unbiased data and drawing an accurate conclusion. To ensure an accurate conclusion, stratification and randomness are recommended. These are performed by dividing the plots into small sizes and sampling the small sizes through an electromagnetic survey, yield map, and remote sensing (Dang et al., 2009). Additionally, a nested or systematic grid design can further improve estimates of the samples.

- **Sampling Method:** The sampling methods include: digging pit, punch core, core drill, core sampling, and excavation. Davis et al., (2018) notified that the 'core' method of sampling is the most appropriate and efficient because it is most times, accurate in heterogeneous sites.
- **Sampling Depth:** Accumulation of SOC in the deeper part of the soil plays an important role in its sequestration. Sequestration on the top layer of the soil results in inaccuracies. Thus, Resende et al.(2006) recommend that samples should be taken from 100cm deep in the layers of the soil, so that accuracy is ensured.
- **Evaluation:** The appropriate approach to evaluate the sequestration rate of SOC is 'equivalent soil mass'. Ellert et al.(2001) defined equivalent soil mass as the reference soil mass per unit area chosen in layers and equivalent mass C is 'C' mass stored in an equivalent soil mass.

4.1.2. Measurements

After addressing all the factors responsible for sample collection, the next is measuring laboratory analysis. This paper focuses on the spectroscopy method and the Eddy covariance method.

- **Spectroscopic Method of SOC sequestration:** This is a time-saving, rapid, and comparative technique used for aerial, laboratory and field SOC sequestration. It works with visible and near-infrared (VNIR) (400 to 1100 nanometers (nm), mid-infrared (MIR) (2500 to 25000 nm), small wave infrared (SWIR) (1100 to 2500 nm), and laser-infrared breakdown spectroscopy (LIBS).

The VNIR according to Wikipedia is the wavelength between 400 and 1100 nm of an electromagnetic spectrum (Wikipedia, 2021). It works with an estimated 100% visible spectrum and partly infrared spectrum. On the other hand, the MIR is a vibrational spectroscopy technique that identifies chemicals (in gas and liquid) on the interaction with electromagnetic vibration in the mid region (400 to 4000 cm^{-1}) (CBRNE, 2018). However, in the laboratory, carrying out SOC sequestration does not depend only on VNIR and MIR. Stevens et al.(2008) also, recommended the SWIR and the difference reflectance spectroscopy (DRS). Amongst these methods, Reeves (2010) confirmed that the MIR gives the most accurate prediction for SOC sequestration.

In field (on-site) analysis, the VNIR proves better when performing SOC sequestration because of its strong water absorption quality (England and Viscara, 2018). For aerial

measurements, the DRS is preferred because of its ability to interpret complex data, reflectance, and data collection (Ben Dor et al., 2009). Stevens et al.(2012) add that to ensure full accuracy in DRS, there must be proper validation and calibration by sensors and imaging devices for scanning and selection processes.

The LIBS is a recent principle focused on atomic emissions and can also, be used for carbon sequestration. To carry out SOC sequestration, calibration models are involved are partial least square regression (PLSR), the project to latent structure (PLS), least absolute shrinkage and selected operator (LASSO), and the multivariate selection regression with covariance estimation (MRCE) (Sirven et al., 2006; World et al., 2001; Tibshirani, 1996; and Rothman et al., 2010). Utilizing the LIBS method for carbon (total carbon, organic carbon, and inorganic carbon) segregation can be performed without pre-estimation. The LIBS is recommended to be better than the other methods because of its accuracy and precision. Although LIBS has not been accepted globally because of a few limitations like interaction with the environment, plasma formation, and moisture formation ability. When these limitations are solved, then, LIBS would become the most appropriate method for carrying out spectroscopic SOC sequestration.

- **Eddy Covariance (EC) Method of SOC sequestration:** The EC is a flux system that supports or permits GHG measurement and carbon sequestration between the land and the atmosphere. Burba et al.(2013) and Baldcchi et al.(1996) both agree that EC is the most advanced, appropriate, and reasonable method for terrestrial carbon sequestration. Sequestration using EC helps in converting solar energy into chemical energy – used for photosynthesis and the development of plants and other living organisms within their ecosystems (Baldocchi, 2003).

The rate of carbon sequestration on annual basis is measured using net ecosystem production (NEP). NEP is, however, determined by the balance of carbon in the terrestrial ecosystem – otherwise called net carbon exchange (NCE) can be determined by the difference in two flux which is (1) the respiratory flux at night-time and photosynthesis flux at day-time.

It can be expressed mathematically as:

$$R_f - P_f \tag{1}$$

Where R_f is the Respiratory flux, and P_f is the Photosynthesis flux.

The above equation is also known as the *fundamental for determining the carbon budget*. The annual analysis of the carbon budget can be tagged net ecosystem exchange (NEE). Thus, to measure an accurate NEE between the atmosphere and terrestrial ecosystem, an equilibrium in assimilation by Photosynthesis and the respiration from both dead and living organic matter must be attained (Nayak et al., 2019).

4.2. Ocean Carbon Sequestration (OCS)

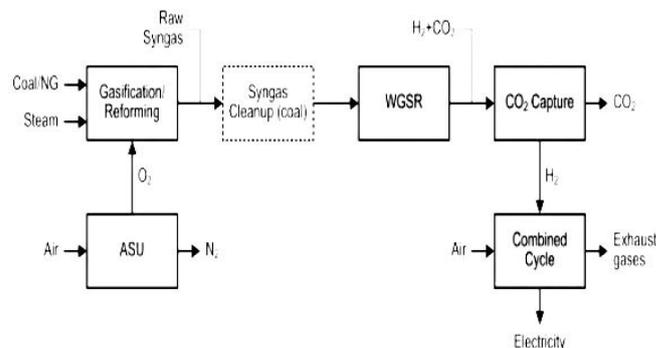
Ocean carbon sequestration (OCS) distributes CO_2 more evenly throughout the depth of the ocean and reduces the impact of CO_2 at the surface (Aaron, 2013). For this paper, direct injection and ocean fertilization shall be focused on as methods involved in OCS.

4.2.1. Direct Injection: This is about injecting gas, liquid, and solid form of CO_2 into the ocean. The processes in carrying out direct injection are:

I. **Capturing of CO_2 From Fossil Fuel Power Plant:** The amount of emission of CO_2 from fossil fuels into the atmosphere is over 11 billion tons yearly – a major cause of climate change (OECD, 2012). Thus, capturing CO_2 is one of the three ways of reducing the amount of toxic carbon in the atmosphere. According to (IEA, 2010), capturing toxic carbon like CO_2 involves three options namely:

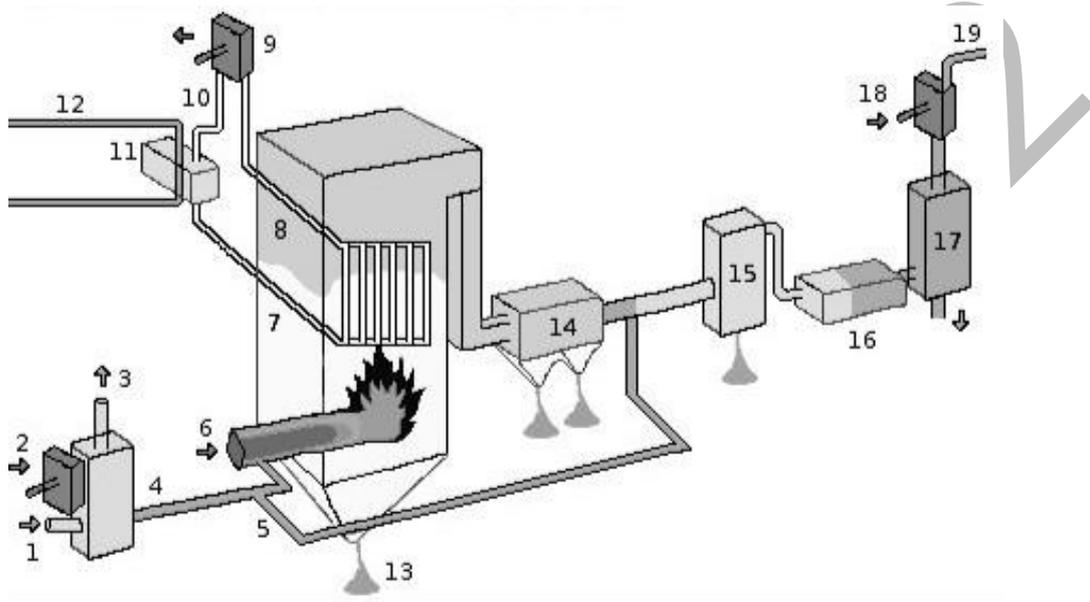
- **Pre-combustion Captures:** Fossil energy and carbon management (FECM) (n.d) described pre-combustion captures as the removal of CO_2 from fossil fuel before combustion is completed. Dumitru and Loana (cited in comprehensive Renewable Energy 2nd Edition, 2022) add that pre-combustion can be displayed for integrated coal gasification combined cycle (IGCC). For example, in the gasification process, coal is partially oxidized in hot air, then it turns into syngas like methane (CH_4), hydrogen, CO_2 , and CO . The syngas faces a process called “*water-gas shift reaction*” – which converts CO and H_2O (water) to H_2 and CO_2 . The CO_2 can then be captured and sequestered.

Fig. 2: A Block Representation of Pre-combustion Capture



- **Oxy-fuel Combustion Captures:** The International Journal of Greenhouse Gases Control (IJGGC) (2015) registered that oxy-fuel combustion for CO₂ capture as the process of burning fuel with nearly pure oxygen instead of Air. Oxy-fuel combustion is one of the leading technologies considered for CO₂ capturing (Bui et al, 2018). Furthermore, it contributes to improving the carbon balance in fossil fuel combustion (Linde, 2022).

Fig. 3: Oxy-fuel Combustion Captures of Fossil Fuel Power Plant Operation



Source: Bui et al.,(2018)

- **Post-combustion Captures:** This method is about the removal of CO₂ (5-15%) from fossil fuel power plants before its compression, transportation, and storage in a proper geological formation. (Wikipedia, 2021). CO₂ when dissolved in ambient seawater that has little or no CO₂ content in it is likely to exist in charges as exhibited by this reaction:

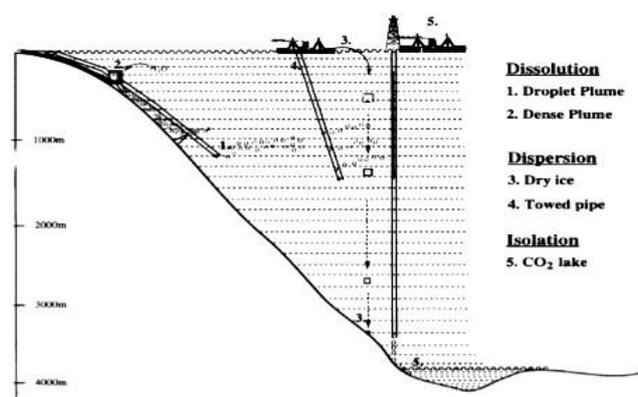


The setup behind the above equations is known as the “carbonate system.”

- II. **Injection of the Captured CO₂ Into the Ocean:** The methods involves in injecting captured CO₂ into the ocean are enumerated below.

- **Dispersion:** This method involves the use of towed pipes and dry ice. The latter is released at the surface of the ocean from a ship. While the former involves injecting liquid CO₂ below 1000 m from a pipe by a moving ship – forming a droplet plume.
- **Dissolution:** This method also involves two other methods: droplet plume and dense plume. Droplet plume is about injecting liquid CO₂ below 1000 m from manifold lying below the ocean. While dense plume is about a dense CO₂ mixture firm below 500-1000 m – forming a sinking gravity current.
- **Isolation:** This involves introducing liquid CO₂ to sea floor at a depth of about 4000 m.

Fig. 4: The Methods of Injecting CO₂ Into Deep sea



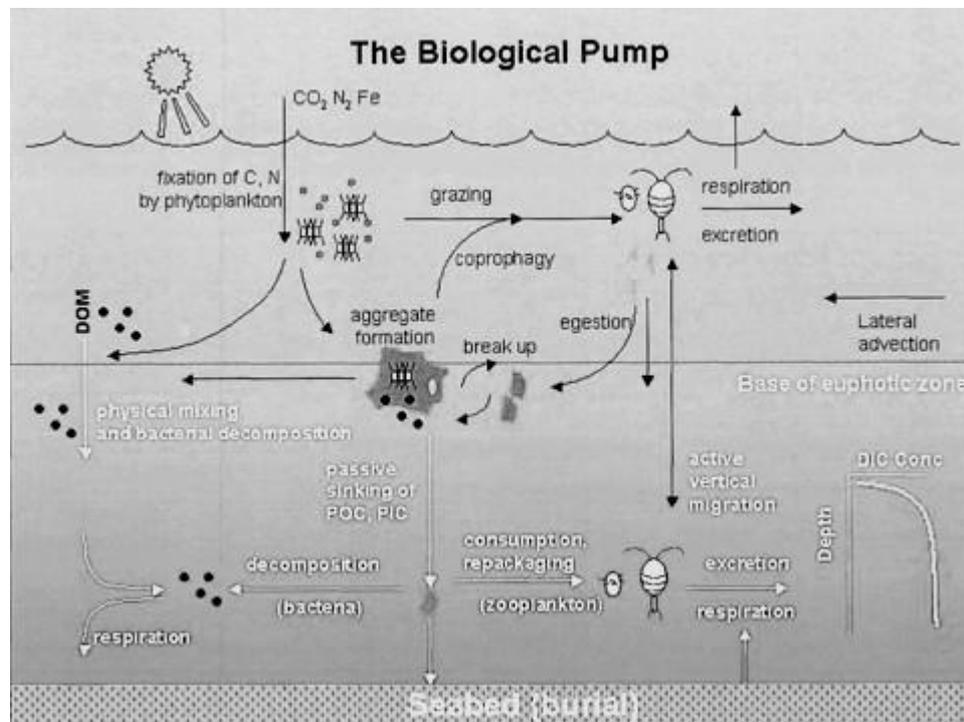
Source: Howard et al., (n.d)

4.2.2. Ocean Fertilization: According to Engineering Monitor (2021), ocean fertilization is a theoretical CO₂ removal technology that refers to dumping large amount of micro- or macro-nutrient (like iron and urea) into ocean areas with low biological productivity – to stimulate the growth of phytoplankton. The approaches involved in carrying out ocean fertilization are through nutrient fixation (dumping nutrient like nitrogen, phosphorus, and iron etc., into area of the ocean where these nutrients are in little amount), pelagic pumping, and the use volcanic ashes. However, this paper focuses on pelagic pumping and volcanic ashes.

- Pelagic Pumping:** This is also called biological pump or Marine carbon pump. Sigma and Hang (2006) refer pelagic pumping as the simplest form of carbon sequestration – where CO₂ is driven from the atmosphere of land runoff to sea floor and sediments. It depends on organic matter that survives degradation in the Euphotic zone and is moved from surface

water to the seafloor. The phytoplankton convert dissolved CO_2 into organic carbon in particles, then consumed by zooplanktons (Lampitt et al., 1990). The biological pump is responsible for taking up and storing of CO_2 from the atmosphere.

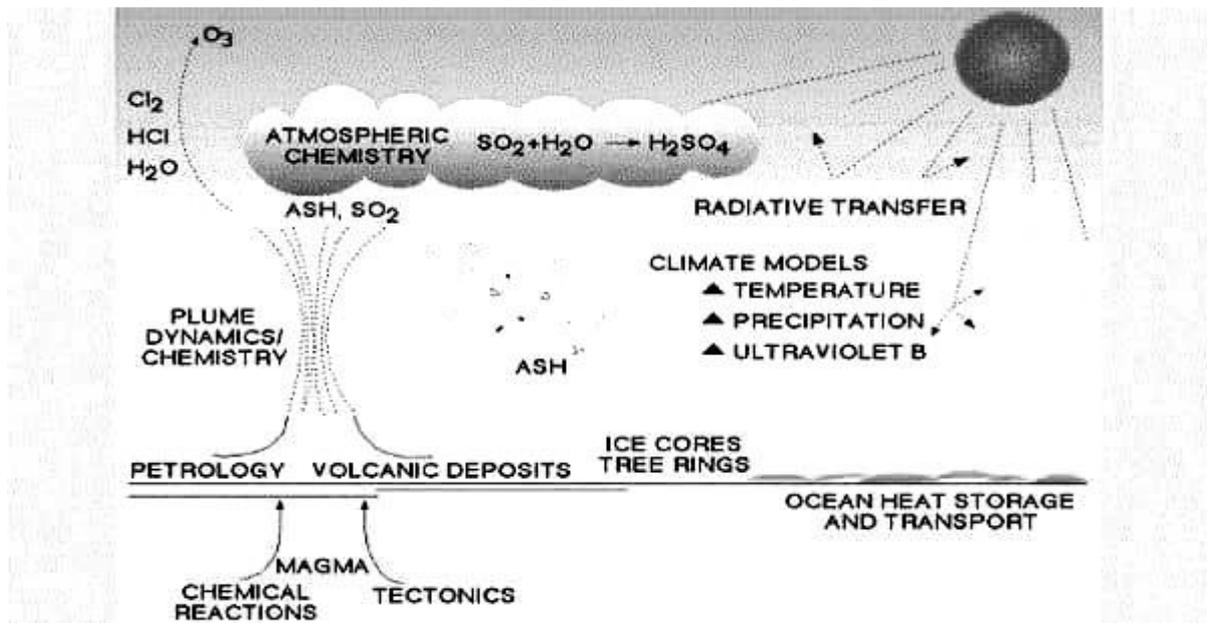
Fig. 5: Processes involved in Pelagic Pumping



Source: Sigma & Haug (2006)

- ii. **Volcanic Ash:** Every volcanoes erupt and lies close to the seas. Annually, millions of tons of volcanic ash falls and settles in seafloors or depth of oceans. When it settled beneath the sea, carbon storage increases and reduces the level of CO_2 in the atmosphere. According to U.S. Geological Survey, 75% of 1500 active volcanoes are settled near the ocean (NatGeo, 2022). Also, researchers predicted that for every 50,000 tons of volcanic ash placed into the sea, and other water bodies, over 2,700 tons of CO_2 can be stored (Tripp, 2021). Although in Africa and particularly Nigeria, volcanoes are not common, and the recent technological innovation may be difficult to acquire and implemented. Thus volcanic ash becomes an option to consider. But, to implement this method, volcanic ash can be imported from different parts of the world where they are common. This in turn, could become a source of income to people.

Fig. 6: How volcanic ash impact climate change



4.3. Geological Carbon Sequestration (GCS)

According to U.S. Geological Survey (USGS) (n.d), GCS is a method of securing CO₂ in deep geological formations to prevent its release from the atmosphere and contributing to global warming and GHG. The USGS also established that there are two main methods for GCS. The two methods are buoyant trapping and residual trapping. Others are solubility trapping and mineral trapping. But only buoyant trapping and residual trapping shall be discussed.

a. Buoyant (Hydrodynamic) Trapping: This is commonly known as hydrodynamic trapping. The method involves trapping CO₂ as “Supercritical Fluid” or “low-permeability caprock”. The CO₂ that is less dense than the formation gas buoyantly rises until it encounters a caprock that has greater pressure than the hydrodynamic force. According to Science Direct (cited in Reservoir Formation Damage 2nd Edition, 2007), hydrodynamic trapping is a time-dependent hydrogeological process where injected CO₂ is effectively trapped by the existence of a very long travel time to the surface.

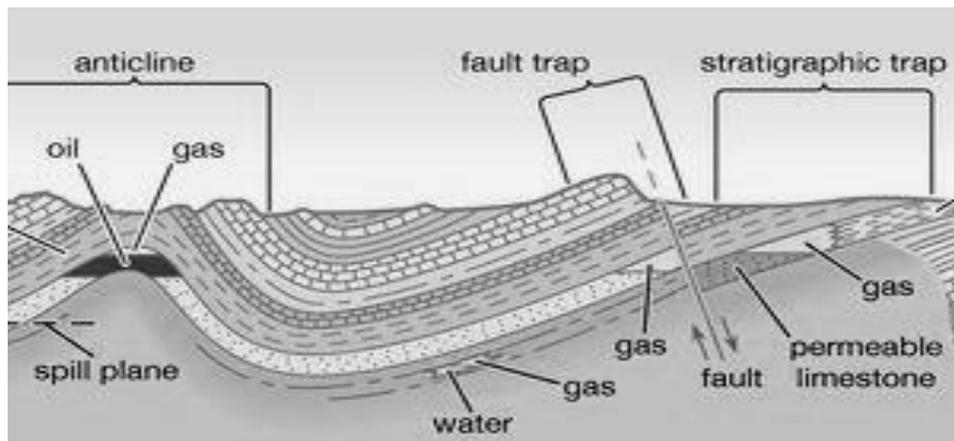


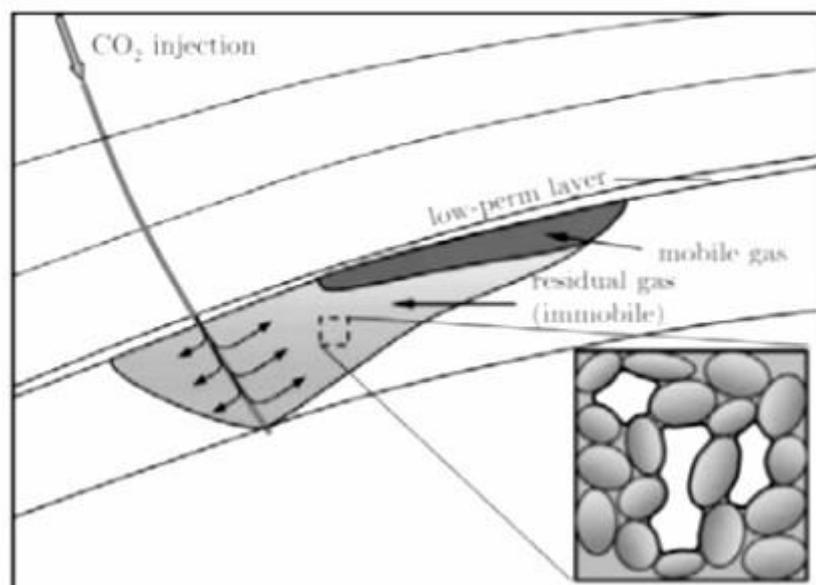
Fig. 7: A example of hydrodynamic trapping for petroleum

Source: Britannica (n.d)

b. Residual (Capillary) Trapping): Residual trapping otherwise called capillary trapping was formed by a means of fluid withdrawal test by first, injecting CO_2 and then, withdrawing fluid – leaving behind the immobile fluid (Saba, 2020). The trapping process takes place during the imbibing phase when injected gas migrates upward due to buoyancy and the formation imbibes to reoccupy the pore spaces. Holtz (2022) adds that the processes involved in residual trapping depends on reservoir petro physical characteristics such as porosity and permeability. Capillary trapping here have been used in many studies and researches. For example, Saba (2020) used single-well push-pull- experiment to evaluate residual trapping at the Otway site, Australia. Also Rasmusson et al., (2017) and Krevor et al., (2012) in their studies addressed residual trapping from pore-networks modelling.

Fig. 8: residual of trapped CO_2 after post injection

Source: Zhang & Song (2014)



5.0. EXPERIMENTS AND RESULTS

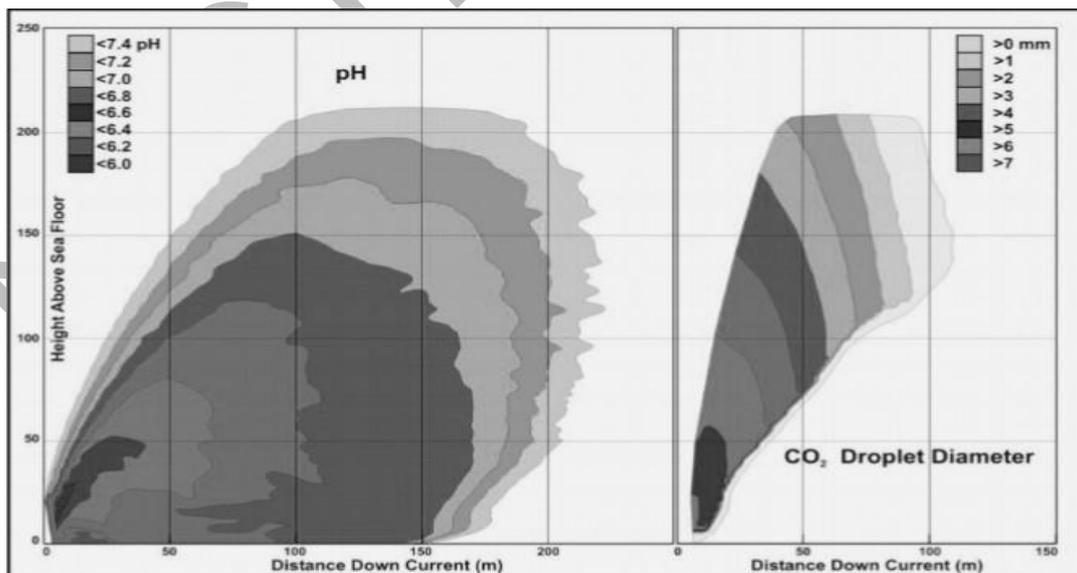
5.1. Experiment and Result For Ocean Carbon Sequestration

Table 1: Field experiment matrix

Duration of Each Test Release (approximate)	Two Hours.
CO ₂ Flow Rates	1.6 and 9.5 gallons per minute (0.1 and 0.6 kg/s)
Number of Nozzle Designs Tested	2
Ambient Conditions	Conduct tests at range of current speeds, if possible
Number of Tests	12 to 20
Total Amount of CO ₂ Released	Approximately 5,000 gallons (20 metric tons)

Source: Pacific International Center for High Technology Research (PICHTR)

Fig.9: Result of a from a sample area used for OCS



Source: Chen et al., 2001 (cited in pacific international center for high technology research (PICHTR), 2001). Legend: Vertical cross-section of plume after completion of 2-hour liquid

CO₂ released. It represents the maximum extent achieved by the plume in a current of 3cm/sec current speed at these water depths.

5.2. Experiment and Result for Terrestrial Carbon Sequestration

The experiment for Terrestrial carbon sequestration in this paper is mirrors the experiment carried out in dumping site in Leadville,

Fig. 10: Experiment carried out at Leadville

Sample	pH	EC	%C	%N	Bulk density (g/cm ³)	C:N ratio	Mg of C/ha	Metric tons CO ₂ /acre
Optimum for soils ¹	5.5 - 8	< 2	--	--	0.5 - 1.4	20 - 40:1	--	--
Biosolids 0-15 cm (LB)	5.23	2.664	5.88	0.36	1.29	11	114	169
Biosolids 15-30 cm (LB)	5.59	2.74	4.81	0.32	1.41	13	102	151
Pellets 0-15 cm (LP)	5.89	2.53	6.37	0.52	1.54	10	147	218
Pellets 15-30 cm (LP)	5.83	2.76	6.25	0.51	1.61	11	151	224
Compost 0-15 cm (LC) ²	5.7	3.08	5.45	0.29	1.2	15	98	146
Compost 15-30 cm (LC) ²	5.46	1.78	4.38	0.29	1.22	14	80	119
Untreated 0-15 cm (LU)	3.72	3.13	3.75	0.24	1.09	17	61	91
Untreated 15-30 cm (LU)	3.67	2.09	4.16	0.26	0.97	16	61	90
Reference 0-15 cm (LR)	5.67	0.48	5.22	0.3	0.79	10	62	92
Reference 15-30 cm (LR)	5.74	0.22	2.9	0.14	1.22	10	53	79

Source: Nyle & Ray (2007) (cited in U.S. EPA, 2011). **Legend:** CO₂ = carbon dioxide C= carbon cm= centimeters EC= electrical conductivity N= Nitrogen mg= mega gram ha= hectares NA= not applicable g/cm³= grams per cubic centimeters.

5.3. Experiment and Results for Geological Carbon Sequestration

The GCS experiment was carried out using Reactive Infiltration Instability – which focuses on the mineralization of CO₂ dissolve in porous water, for between 10-100 years after Injection of the CO₂ subsurface. The experiment was carried out to achieve (i) the effect of porosity in porous water (ii) the effect of Anorthite concentration and (iii) the effect of reaction rate.

Fig. 11(a): Effect of Anorthite

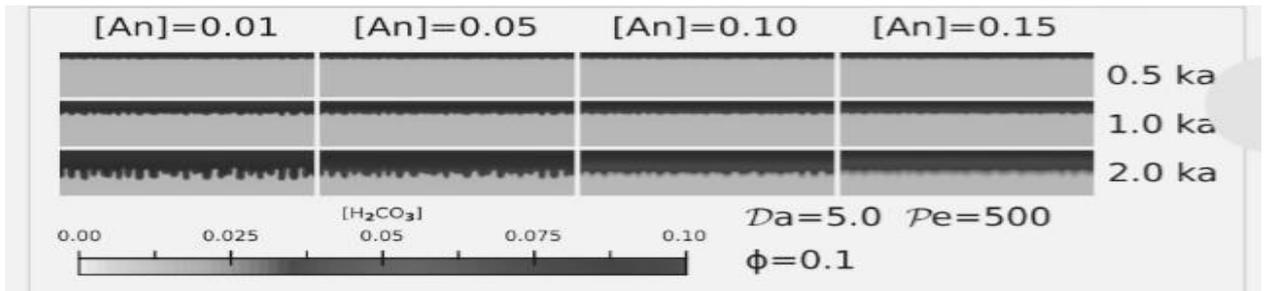


Fig. 11(b): Effect of rate of reaction

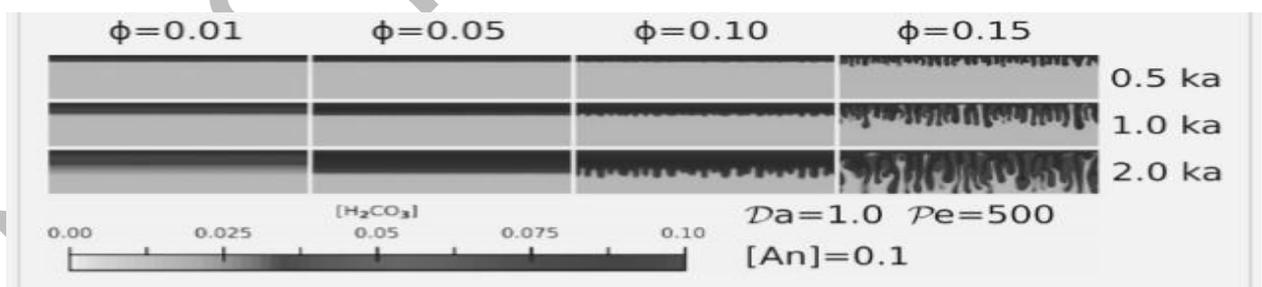
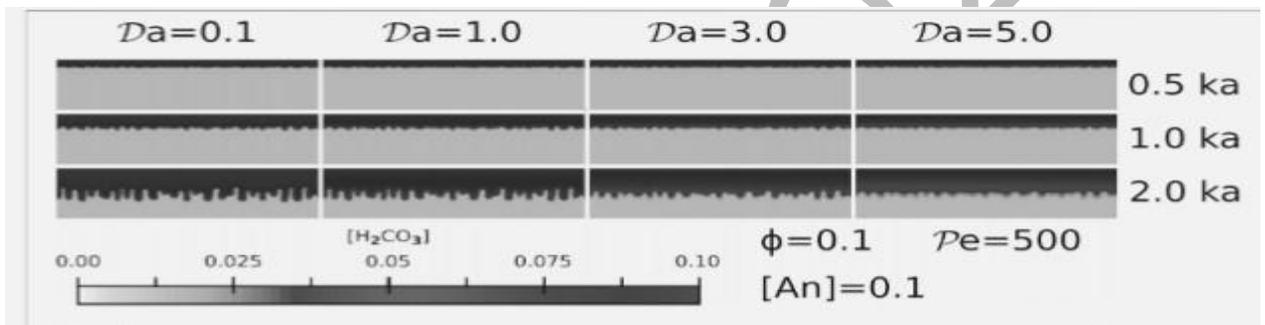


Fig. 11(c): Effect of Porosity

Source for (a), (b)& (c): Frontier In Earth Science (2020).

6.0. DISCUSSION

The results in section 4 of this paper demonstrate how carbon is collected, stored, and sequestered. The results mirror the quality of the region and the aftermath after the experimental processes are carried out and each of the processes used in the experiment makes a tremendous impact within their jurisdictions. In general, the aftermath of carbon sequestration (TCS, OCS, and GCS) involves the following.

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- TCS offers a co-effective strategy to avoid and mitigate CO₂ emissions by increasing the magnitude of the carbon in the trees, soil, and biodiversity.
- In soil, it acts as a resistor to degradation, making the soil healthier – thereby increasing agricultural productivity.
- OCS can also minimize frequent ocean surges – which usually lead to erosion, farmland erosion, landslide, and flooding.
- It is capable of offsetting the annual increase of atmospheric carbon – leading to sea rise, glaciers, storms, winds, etc. by between 25-30%.
- Saturated carbon in the soil and disturbance of soil release captured carbon. Hence proper soil management is required at all times.
- It purifies surface and underground water and offsets emissions due to fossil fuels.
- Through carbon sequestration, carbon dung can be investigated and utilized for converting the methane activities of cattle dung into biogas, rather than depending on fossil fuels and woods.
- Capturing CO₂ captured geologically can be used to extract geothermal heat which can also, be used to produce renewable geothermal energy.

7.0. CONCLUSION

The findings in this paper demonstrate that carbon sequestration is possible irrespective of the environment. Climate change events are destructive and they are gradually dominating human activities. Fortunately, the carbon sequestration approaches discussed in this paper are recommended as the road map to tackling climate change in Nigeria. Thus, this paper is apt for the drive to tackle climate change and global warming.

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