sciendo
STUDIA UNIVERSITATIS ECONOMICS SERIES
"Vasile Goldiş" Western University of Arad
SUES
2023 - 33(1) DOI: 10.2478/sues-2023-0002

GLOBAL WARMING AND ATMOSPHERIC CARBON: IS CARBON SEQUESTRATION A MYTH OR REALITY?

Stephen Obinozie Ogwu
Department of Economics, Kingsley Ozumba Mbadiwe University, Ideato, Imo State, Nigeria
Email: stephenobinozie1@gmail.com
https://orcid.org/0000-0002-3427-0426

Afamefuna A. Eze[*]
Department of Economics, University of Nigeria, Nsukka, Nigeria
Email: angus.eze@unn.edu.ng
https://orcid.org/0000-0003-1163-372X

Joshua C. Uzoigwe
Department of Otorhinolaryngology, University of Nigeria Teaching Hospital, Ituku-Ozalla, Enugu, Nigeria
Email: chukwudidc@yahoo.co.uk

Anthony Orji
Department of Economics, University of Nigeria, Nsukka, Nigeria
Email: anthony.orji@unn.edu.ng

Anne Chinonye Maduka
Department of Economics, Chukwuemeka Odumegwu Ojukwu University, Igbariam, Nigeria
Email: annymaduka@gmail.com

Joshua Chukwuma Onwe
Department of Economics, University of Nigeria, Nsukka, Nigeria
Email: onwelink@gmail.com
https://orcid.org/0000-0002-2703-8071

(Received: March 2022; Accepted: May 2022; Published: January 2023)

Abstract: Biotic and abiotic carbon sequestration currently seems to be the only viable tools at the disposal of mankind for mitigating greenhouse gas (GHG) emissions and thus a remedy for tackling global warming challenges. This study accesses the global carbon capture and storage (CCS) programme: the level of success in its implementation and its impact using

[*] Corresponding author: Afamefuna A. Eze. *E-mail:* E-mail: angus.eze@unn.edu.ng

panel data from eight countries, the majority of which have begun one or more operational CCS facilities. To achieve this objective, fifteen years period time series data was sourced for the eight selected countries based on data availability, namely the United States (US), the United Kingdom (UK), Canada, China, Australia, Norway, South Africa, and Nigeria; ranging from 1990 to 2015. The panel ARDL results show that the explanatory variables, global industrial production (LIP), Electricity production (LEP), Agricultural production (LAP), transportation (LTR), and energy supply (LES) have a long-run relationship with the dependent variable (LGHG emissions). While the short-run results show that none of the variables have a significant contribution to LGHG emissions. In the long-run results, LIP and LTR significantly contribute to the reduction of LGHG courtesy of the CCS programme while LEP, LAP, and LES contribute to a rise in the LGHG emission. The cross-sectional results show that all the variables have significant impacts on LGHG in all the sampled countries except Australia. Suggesting that, the CCS programme is viable for mitigating global warming and climate change and therefore should be considered by the various countries of the world.

Keywords: CO_2 Capture; Industrial production; Electricity production; Agriculture production; Global Warming; Panel ARDL.

JEL code: Q53, L7, L94, N5, Q54, C23.

1. Introduction

Environmental issues bordering on greenhouse gas emissions amongst other things and their severe impact on the planet and in turn on the well-being of all lives (both plant and animal) on earth have formed the center of global debate in recent literature. This concern has been made one of the priorities in the United Nations global goals (SDGs). It is a stylized fact that this degradation of the environment ensues from human activities which include energy production, industrial production with consumption activities (Fawzy, et al., 2020; Gajić et al., 2018; Edenhofer et al., 2014). According to Medlock (2009), the process of achieving economic growth comes with a prize and that is environmental degradation which is at its maximum at the take-off and industrialization stages but drops at the advanced stage of development (which is service-oriented activities). This claim is further supported by the environmental Kuznets theory (Uchiyama, 2016).

Studies have it that the bulk of the environmental degradation comes from the production and consumption of energy commodities (Orji, Ogbuabor, Ogwu and Anthony-Orji, 2021; Fawzy, et al., 2020). This is obvious in many countries such as Nigeria with the huge mineral endowment, where according to the Earth Trend Country Profile (2003) report, about 2.5 billion cubic feet of gas is flared annually from energy production activities, this amount to 40% of the overall gas consumption in the entire African continent and thereby making it one of the single largest sources of greenhouse gas emission in the world (Kankara, 2013). From the angle of consumption, the majority of literature on greenhouse gas emissions posits that the transportation sector followed by the industrial sector and then the household are the key users of energy commodities from which comes the bulk of CO_2 which is the main greenhouse gas (Orji, Ogwu, Mba,& Anthony-Orji, 2021; Oyedepo, 2012).

Being faced with numerous disasters on the planet earth which are attributed to the large tons of CO_2gases in the atmosphere, the direction of the environmental debate is now on how to reduce the amount of CO_2 gas in the atmosphere, seeing that reducing energy consumption and regulating exploration activities to minimize the release of harmful substances is not a cure but a preventive measure (Fawzy, et al., 2020).

Recent research on measures to reduce the CO_2 concentration in the atmosphere has come up with findings and recommendations for the capturing of CO_2 and then storing them: a concept referred to as carbon sequestration (Fawzy, et al. (2020); Leung, Caramanna &Maroto-Valer, 2014). In the view of Herzog and Golomb (2004), carbon sequestration is the capturing, securing, and storage of carbon that ordinarily would have been emitted into the atmosphere and remain there. The goal of carbon sequestration is to mitigate global climate change and global warming while still having uninterrupted fossil fuel usage. This is because carbon sequestrations help to reduce the emission of CO_2 into the atmosphere by capturing either directly from industrial or utility plants and storing them in a reservoir (Ontl & Schulte, 2012). According to Lal (2013), there are two main types of carbon sequestration strategies: the Biotic and Abiotic strategies. The biotic strategies are natural processes that are based on photosynthesis where CO_2 is transferred from the atmosphere to the green vegetations, pedologic, and aquatic pools using green plants as a channel (Jacobson, 2019; Ontl & Schulte, 2012). The abiotic strategies use engineering approaches to separate, capture, compress, and transport CO_2 from power plant flue gases and effluent of industrial processes and inject them into the deep ocean and geologic strata (Jacobson, 2019; Gajić et al., 2018).

According to International Energy Agency for Greenhouse Gas, the idea of capturing and storing CO_2 often referred to as CCS began in the 1920s when the CO_2 capturing technology was used in separating CO_2 from the saleable methane gas in the then gas reservoir but became pronounced in 1977 as a formal way of capturing CO_2 and preventing it from being released into the atmosphere. In the early 1970s, some captured CO_2 from a USA gas processing facility was piped to a close-by oil field to help boost oil recovery, a process known as EOR (Enhanced Oil Recovery) (Nikolova & Gutierrez, 2020**)**. The EOR since then has shown a high level of success as millions of tons of CO_2 have now been captured from industrial activities from both natural stock and underground rocks and piped into oil fields in the USA and across annually. Normally, when CO_2 has been used to recover oil in the oil field and separated from the oil it is finally injected into the empty/depleted oil field (Fawzy et al., 2020; Vinca et al., 2018). It is kept there (store) to permanently prevent it from being released into the atmosphere thereby contributing to the reduction of greenhouse gas effects (Bui, et al., 2018). CCS is also an important process in the exploration of natural gas because the gas in its crude state comes with CO_2 during extraction and can only be saleable when the CO_2 has been removed (Bui, et al., 2018). Toward the end of 2012, there was about 5 CCS large-scale project that is operational across the globe, with three full scales operational pilot project in progress. There are other twenty-three large-scale projects under construction having secured funding (IEAGHG).

In the US, the Department of Energy (DOE) carbon sequestration program commenced in 1997 been a small-scale research effort seeking to determine the technical viability of CCS. The program has expanded to multi-facet research development and deployment initiative, seeking the continuous use of fossil fuels while limiting CO_2 emission in a carbon-constraint world (Miller, 2011). The Carbon sequestration program over time has aided the development of technologies used for safe capturing, separating, and storage of $CO_2$to reduce GHG emissions and at the same time not hampering energy use and economic growth. The vision of the DOE is to build CCS capacity through the development of technologies that are safe, cost-effective, able to mitigate CO_2 emission, and available for commercial deployment by 2020 (Miller, 2011).

According to Lal (2013), carbon sequestration could briefly hold for the short run by influencing the global carbon cycle and thus reducing the level of atmospheric CO_2 until the perfect substitute for fossil fuel takes effect. This, therefore, becomes rational for examining the extent to which the countries of the world have gone in adopting and successfully mitigating the greenhouse gas effect through carbon sequestration and to ascertain if a long-run relationship exists between carbon sequestration and GHG. This study intends to evaluate the impact of carbon sequestration programs on GHG across the world using a panel ARDL which also allows for cross-sectional or country-specific analysis. This will be done using selected countries including the US, UK, Canada, China, Australia, Saudi Arabia, South Africa, and Nigeria; of which the majority have operational CCS facilities.

2. Conceptual and empirical review

2.1. Conceptual Review

The US energy information administration (EIA) has stated that by 2050, about 19% of the world's required CO_2 reduction will be achieved through CCS. By their proposition, the sum of 18 functional CCS should be actively operational by the end of 2015; this would need to be expanded to 3,400 by the year 2050. 35% of these projects are to be located in non-OECD countries while the rest is to be located in the OECD countries (Condor, Unatrakarn, Asghari, and Wilson, 2011).

According to the 2017 world report, CCS is the only technology capable of decarbonizing the industrial sector and there are 17 large-scale functional CCS facilities globally with four expected to kick start operation by 2018. These 21 CCS facilities can capture 37 million tons of CO_2 per year. Already a total of 220 million tons of man-made CO_2 have been captured and injected into the deep underground. Therefore, CCS is the key solution to the concept of "energy trilemma" a concept which looks at how to meet up with the commitment of international climate change, keeping the lights on, and reducing the costs of electricity, all at a time (Yap, Gabriola & Herrera, 2021).

2.1.1 Emerging economies

The CCS situation report from China, Brazil, India, Mexico, Russia, and South Africa: countries which are grouped as the major emerging economies in the world, shows that China has a power generating installed capacity of about 700GWe that over 70% of this is from coal. There is the projection that this capacity will increase by almost double in 2020 and will still be dominated by coal. In 2008, China was ranked the number 1 CO_2 emitter in the world (Wang, et al., 2020). China holds the view that the advanced nations would have to take the lead when it comes to CCS. Chinese companies see the CCS as a potential export opportunity and the nation's ministry of science and technology has begun to develop a long-run CCS research and development (R&D) strategy (Condor et al., 2011). Before 2007, China had definite legislation regarding CO_2 but in 2007, the NDRC mapped out a National Climate Change Program for the country, which was meant to last between 2007 and 2010. Among the goal of the program is CO_2 reduction and energy consumption per GDP by 20%. The country has also enacted certain regulations to check for the efficiency of energy and the discharge of water and air pollutants. The NDRC under her medium-term development plan and renewable energy targets to source 10% of her overall energy consumption in 2010 from renewable sources, this was expected to rise to 15% in 2015 (Condor, et al., 2011). The country's agreement with the EU (NZEC, COACH, and $STRACO_2$ projects), Japan, the US (Regulatory Capacity and MOU for cooperation on climate change), and Australia (Joint Coordination Group on Clean Technology) are indications of their activeness in international partnership.

According to Condor et al. (2011), the yearly CO_2 emission by South Africa is estimated at 400 million tonnes thus, making the country one of the largest emitters of GHG in the world. Three factors have been identified as being responsible for this and they include the role of the industrial sector in the GDP growth, the dominance of coal in the country's energy sources, and lower energy efficiency resulting from the low price of energy. The country seeks to reduce emissions by 34% in 2020 and 42% by 2050 in line with the Copenhagen Accord. The strategies include the introduction of renewable energy and demand-side management; the introduction of a carbon tax; the use of CCS in her coal-fired power stations among other things. The country's center for CCS which was launched in 2009 is to saddle the task of driving the CCS initiative.

Brazil is strongly opposed to allowing CCS as a component of the Clean Development Mechanism (CDM) not minding the fact that Petrobras is heavily investing in CCS projects and seeking to override Statoil as the biggest operator of CCS projects (Condor et al., 2011). The reason for this may not be far from the fact that over 80% of electricity in Brazil is generated from hydropower while the rest is altogether from fossil fuel, biomass, and nuclear sources. The bulk of GHG emissions in Brazil comes from burning traceable to the deforestation of the Amazon. Therefore, placing an embargo on the deforestation of the Amazon is the most efficient approach to reducing emissions. For Russia, whose power generation is majorly from fossil fuels to the tune of nearly 90%, she is seen as being relevant for international CCS diffusion (Condor et al., 2011). The Kyoto protocol classified Russia as a transition country and mandated her to maintain her 2008-2012 CO_2 emissions to the level of 1990. Based on the Kyoto protocol, Russia is not committed to investing in any expensive CO2 emission project like the CCS rather, the country is more interested in fuel cell development and H_2 production. What this means is that the existence of any CCS program in Russia must be through a collaborative effort between the government and other international agencies (Condor et al., 2011).

According to Condor et al. (2011), fossil fuels account for 400 million out of the 600 million tons of annual CO_2 emissions in Mexico. The country has a short-term climate change plan and long-term research and development. Although this plan embodied geological CO_2 storage, it is considered an expensive program. They see CCS as a viable means of oil recovery and in turn, could be used to fill up depleted production well-stored. There is currently no specific regulation or legislation applicable to CCS in Mexico only that the country's energy regulating commission and the ministry of energy will likely impose GHG reduction targets on the major players in the energy sector in line with the transition goal. The IEA has predicted that in 2030 that India is likely to be on the list of the top third-largest polluters in terms of total CO_2 emitted annually, in the world. A large percentage of India's electricity supply is sourced from coal-fired generating plants. According to Condor et al. (2011), one-third of these plants emit harmful gases but can reduce the emission of CO_2 to the ton of 10 or 13 million annually if modernized. India currently has no legislation, policy and or regulation regarding the introduction of CCS. The thought of utilizing the available reservoirs for CO_2 storage is far-fetched despite having such potential; this is due to the cost of transporting them to the reservoirs.

According to the 2017 global status report, while the emphasis on emission reduction falls so hard on the OECD economies, more especially in China; emission in many

OECD countries has either declined or plateaued. Almost half of the current global CO_2 emission is traced to China, the US, and India. While emissions in the US have stabilized at about 5Gt per year that of China almost doubled to about 10Gt and India is at just 2Gt. Therefore, it is not surprising to know that the weightier role in the emission reduction efforts rests with the non-OECD economies with china at the forefront accounting for 30% of the overall required reduction (Boden, Marland, and Andres, 2014).

2.1.2 Advantages of Carbon Sequestration through the CCS

The Industry: Industrialization has been the driver of the major economies and this will continue to hold sway, as cities will continue to multiply and expand with infrastructural needs arising. This will require a huge amount of industrial goods like steel, cement, and petrochemicals: the production of which generates and emit CO_2. According to Bui et al. (2018), a significant amount of GHG emissions is linked to the industrial sector as the sector is responsible for 25% of the global CO_2emissions. Therefore, CCS happens to be the only available technology that will make a significant emission cut in the industrial sector. According to the Global Status CCS (2020), the majority of the CCS technology operational around the globe is sited in various industrial facilities.

Power: Currently about forty percent of the world's electricity is sourced from coal, and more than 500 gigawatts of capacity have been added to the existing ones mostly in emerging economies since 2010. These coal plants have the potential to operate for more than 30-40 years, their utilization for electricity generation is projected to increase to about 46% by 2030 (Gajić et al., 2018). Adopting the best available coal technology will not bring about the necessary emission reduction required to meet climate goals nor will it encourage renewable energy sources and or fuel switches. Only by retrofitting carbon capture technology to existing plants do we see the hope of decarbonizing the power sector in many regions Bui et al. (2018). This is where the application of the CCS becomes vital, and many economies are already in it.

Health: An annual premature death of about 3 million resulting from outdoor pollution is recorded with predictions that it will rise to between 6-9million by 2060 and the children are the most vulnerable. Atmospheric carbon causes chronic respiratory diseases such as bronchitis and asthma. Other effects include bone demineralization, kidney calcification, inflammation, oxidative stress, and endothelial dysfunction (Tyler et al., 2019). Being faced with these, the deployment of CCS technologies can cause a significant reduction in conventional atmospheric pollutants-as about 90% of sulfur oxide and over 70% nitrogen oxide emissions reduction can be achieved, and 100% removal of fly ash from electricity generation could be removed and recycled for use in the construction industry (Gajić et al., 2018).

2.1.3 Current Status of CCS across the World

Capture technologies are now widely used at scale across the world. According to the 2017 global status report, there are 17 large-sized CCS facilities across the globe, and this has been capturing CO_2 to the ton of 30 Mtpa and above. There were also 4 large-sized facilities under construction and are expected to be operational by the following year. These 4 large-sized facilities are expected to capture an additional 6 Mtpa of CO_2. There are about 15 small-size CCS facilities globally with some being under construction and others operational. These 15 small-sized capture facilities have their capacity to capture CO_2 ranging from 50,000 to almost 400,000 tonnes yearly. On a cumulative basis, these CCS facilities could capture more than 2 Mtpa of CO_2.

The 2020 global status report showed that 28 CCS facilities are operationally located in different countries across the globe and installed to capture carbon from industrial and electricity generation plants. This means that 11 more CCS facilities were completed and became operational between 2017 and 2020. Meanwhile, 2 among this number stopped operations as a result of the low demand in the industrial sector most especially in the oil production due to the effect of the coronavirus pandemic.

In the US, the first large-sized CCS facility which is the world's single largest post-combustion capture facility at a power plant became operational in 2016. This was used to capture CO_2 in a parish power plant and can capture at a rate of 1.4 Mtpa while the second which is the first large-size bio-energy CCS facility with a CO_2 capturing capacity of 1Mtpa became operational in 2017 (Beck, 2020). By 2015 the CCS facility in Canada which is operated by Shell and can capture and store over 2 million tonnes of CO_2 was launched into operation. The Santos basin offshore facility has successfully injected more than 4 million tons of CO_2. The first facility project in China and Asia which is a large size CCS located in Yanchang commenced in 2017 with an overall CO_2 capture capacity of 0.4 Mtpa. By 2018, Australia expected the Gorgon Carbon injection facilities with a capacity of 4 Mtpa, to be the best in the world. Canada by 2017 had two new large-sized CCS facilities which by then were at the advanced development stage with other projects in the implementation stage. The Abu Dhabi CCS commenced operation in 2016 making it the first in the Gulf region and can capture up to 800,000 tonnes of CO_2 emitted from the Emirates Steel factory, yearly. In Saudi Arabia, the Uthmaniyah CO_2 capturing facility which is an EOR demonstration facility has progressively operated to a capacity of 800,000 since 2015. In Africa, South Africa is targeting a CCS facility with the capacity to inject, store and monitor about 10,000-50,000 tonnes of CO_2. In Sub-Saharan Africa, the UNFCCC'S CTCN has received a request from the government of Nigeria for technical assistance in laying underground work for the establishment of CCS. For the European Commission, there is strong interest in the shared CO_2 infrastructure approach via its 2017 projects of common interest. As of

2017, there are two CCS facilities in the UK at their early stage of development and one facility at its advanced development stage in Norway with two operational facilities. So far, a total of 31.7 MMtpa of CO_2 has been captured globally through the CCS facilities (Bui, Mac Dowell, and Editors, 2020). Other countries within the region are making a concerted effort to adopt a geologic emission reduction approach also known as the abiotic strategy.

2.1.4 Forest-Based Carbon Sequestration

The efficacy of forest sustainable management in mitigating climate change was recognized in the UN framework convention on climate change (UNFCCC) and the Kyoto protocol which was adopted by the international community in 2005 (Fawzy et al., 2021; Bui et al., 2018; Amano and Sedjo, 2006; & Jindal, Swallow and Kerr, 2006). On the verge of mitigating the negative impact of GHG on the planet, the industrialized nations have realized that the afforestation and reforestation approach is cost-effective and much more in developing nations where it only cost between \$0.10-\$20 to mitigate a ton of carbon (most especially in tropical nations) compared to the developed nation where it cost between \$20-\$100 (IPPC, 2001 & Jindal, Swallow, and Kerr, 2006). In the view of IPPC (2001), a biological sink has the potential to capture about 20% of the excess carbon released in the atmosphere over the first half of the 20th century. According to the Food and Agricultural Organization (FAO, 2004), there were about 30 forestry-based carbon mitigation projects ongoing across the regions of the world inclusive of Africa. However, Jindal, Swallow, and Kerr (2006) recognized 19 forestry-based carbon mitigation projects in Africa alone with each having definite carbon capture capacity and the associated costs. These projects are being financed by various countries: some are by the national government; some by the government of other nations; some by international organizations; and joint partnerships by both the national government and that of the government of other nations. In the case of Africa, the World Bank is the major financer among others (Jindal, Swallow, and Kerr, 2006).

2.2. Empirical Review

Condor et al., (2011) did a study to examine the current status of the main CCS initiatives in the major emerging economies in which they described as a group the available natural resources in these countries, and then on an individual basis by considering the current initiative and current legal and technological status of CCS. They found that CCS is gaining international popularity, and that developed nations are already building government-funded CCS demonstration plants. And those emerging economies have the potential to become essential providers of CCS in the world because of their position as an efficient and large size manufacturers of products and technologies. Furthermore, they found that CCS development in emerging economies still suffers some challenges in the area of technology, finance, health and safety, and the development of healthy international and multi-industry partnerships. The need to meet the growing energy demand and scale up alternative sources of energy requires that CCS has to grow to successfully be able to abate emissions and be the single largest technology for emission abatement by 2050. They found that CCS may not be matured enough to be deployed as a market-based technology and that there is a need to test the technology in industrialized nations before it can be considered for deployment in other nations. And that CO_2 has been successfully used to recover hydrocarbon across the world. Almendra et al. in 2011 did a study on CCS demonstration in developing countries. They found that CCS is a key option in limiting CO_2 emission and that without financial support it will be difficult for the developing nations to adopt CCS technology shortly. They also posited that the advantages of the CCS technology can only be fully assessed when it is first demonstrated in developing nations and possibly developed nations before the possible deployment to nations seeking to pursue CCS policy. In 2008 Jindal, Swallow and Kerr did work to determine how carbon sequestration through forestry and agroforestry can help in mitigating global warming in Africa by discussing ways of overcoming critical challenges to scale up investment in Africa using a comprehensive review of 23 biotic carbon sequestration projects in 14 countries. They found that East Africa is the preferred destination for investors within the continent and that most of the projects are non-Kyoto compliant: representing voluntary emission mitigations. They recommend that governments of African nations need to build the capacity to recognize necessary opportunities to attract more projects. Amano and Sedjo (2006) found that Kyoto has tried to gather international cooperation to mitigate emissions. Furthermore, Kyoto has failed to engage all the developed countries like the USA and more in the process. Bui et al. (2018) recognized that the CCS has the potential to decarbonize the industry, remove CO_2 from the atmosphere, bring about low carbon heat and power and facility the realization of the climate change goals. Jacobson (2019) argued that spending on carbon capture instead of allowing wind to replace bioenergy and fossil fuel will only increase the social cost. Finally, Fawzy, et al. (2020), argued that the existence of carbon dioxide mitigating technologies is not sufficient to meet the target of the Paris agreement and that there is needed to exploit other mitigation technological options.

The outcome of the empirical review shows that while some studies were directional in that they studied a selected group, others focused on a particular sequestration strategy in a given region using pictures, graphs, and tables in presenting the results; and others used analytical tools. But this study will contribute to knowledge by making use of econometrics tools as a purely empirical study in its analysis of the selected countries of the world where the presence of CO_2 sequestration has been felt in any form (either in form of CCS or natural sinks).

3. Methodology and Empirical data

3.1. Theoretical Framework

The theoretical framework of this study will follow the Carbon Dioxide model as was used by Hambel et al. (2019). This model keeps track of CO_2 concentration in the atmosphere. According to the model, the concentration of CO_2 in the air rises anthropologically and through non-man-made CO_2 shocks, and falls as a result of the presence of natural sinks which absorb them. This decrease could also result from the presence of a geologic mitigation strategy. The model denoted the pre-industrial CO_2 concentration in the air as M^{PI} thus; the total current CO_2 in the air is given as:

$$\mathrm{M}_{\mathrm{t}}^{\varepsilon} = \mathrm{M}^{\mathrm{PI}} + \mathrm{M}_{\mathrm{t}} \tag{1}$$

Where $\mathrm{M}_{\mathrm{t}}^{\varepsilon}$ is the total current CO_2 in the air, M_{t} is the atmospheric CO_2 resulting from human activities. Its dynamic is denoted as:

$$dM_t = M_t[g_m(t) - \alpha_t)dt + \sigma_m dW_t^m] \tag{2}$$

Equation (2) becomes the CO_2 dynamics or process. Where dW^m describes the change in shock on CO_2 concentration: $W^m = (W_t^m)t \geq 0$ denotes the standard Brownian motion equation that models unexpected shocks on CO_2 concentration. These environmental shocks could result from natural occurrences like volcano eruptions or earthquakes, or man-made sources. In equation (2), σ_m is the volatility of these shocks and it is constant, g_m represents the expected growth rate of atmospheric CO_2 increase i.e., the normal growth rate of CO_2 in the absence of any reduction actions by the society. Here, g_m is referred to as the business-as-usual (BAU) drift of the carbon process, and it also includes all the past policies implemented to reduce carbon emissions. CO_2 depletion can also be captured here by calibrating g_m, α denotes the abatement policy.

$\alpha = (\alpha_t)t \geq 0$, represents the new CO_2 mitigation policies of the society i.e. it shows how new mitigation policies can change the expected growth rate of CO_2 concentration.

To capture the alternative dynamics of M that were caused by environmental shocks, we write the new equation as:

$$dM_t = \vartheta_e E_t dt - \delta_t(M_t^s)M_t dt + M_t\sigma_m dW_t^m, \tag{3}$$

$$dM_t^s = \delta_m(M_t^s)M_t dt \tag{4}$$

Where the change in M denotes the difference between CO_2 emission and the quantity of carbon absorbed by natural sinks. E_t denotes the time (t) of anthropological CO_2 emission. ϑ_e is a factor converting emissions into concentrations, M_t^s is the measure of total absorbed atmospheric CO_2 by natural sinks, and δ measures the decay rate of CO_2 i.e. the speed at which CO_2 is absorbed from the air.δ_m is assumed to decrease in M^s (Le Quéré et al, 2007; Nabuurs et al., 2013; and Hedin, 2015). The overall change in CO_2 is the difference between

anthropological emissions and natural CO2 sequestration. Equations (2) and (3) could be referred to as a system of equations with two unknowns ($dM\ and\ E$).
We can solve for the anthropological emissions of CO_2 (short-run emissions) that are consistent with both dynamics by equating (2) and (3):

$$E_t = \frac{M_t}{\vartheta_e}[g_m(t) + \delta_m(M_t^s) - \alpha_t \qquad (5)$$

Equation (5) establishes the relationship between the abatement strategy and the anthropological emission under that strategy. To now capture business-as-usual emissions, we write E_t^{BAU} with $\alpha = 0$.
To define the emission concentration, we have:

$$\varepsilon_t = \left(\frac{E^{BAU} - E}{E^{BAU}}\right) = 1 - \frac{M_t}{\vartheta E_t^{BAU}}[g_m(t) + \delta_m(M_t^s) - \alpha_t] \qquad (6)$$

Equation (6) represents the percentage of CO_2 emission prevented from entering the atmosphere via the implementation of mitigation policies. ε is taken as the emission control rate and ranges between 0 and 1. $\varepsilon \geq 0$ assumption excludes strategies that lead to emissions beyond BAU. On the contrary, $\varepsilon\ \leq 1$ implies that emission cannot be negative, a possibility that can be only with a technological breakthrough like direct carbon removal (DCB).
At this point, it is important to note that the restriction $\varepsilon\ \leq 1$ yields the following upper bound on the mitigation policy:

$$\alpha_t \leq g_m(t) + \delta_m(M_t^s) \qquad (7)$$

3.2. Model Specification

This study will make use of annual data sourced from the World Bank Development Indicators (2018): https://wdi.worldbank.org, for the eight selected countries namely the United States of America (US), the United Kingdom (UK), Canada, China, Australia, Norway, South Africa, and Nigeria; ranging from 1990 to 2015. The variables for this study include greenhouse gas (GHG) being the dependent variable; industrial production (IP), electricity and heat production (EP) and agricultural, forestry, and fish production (AP) as dependent variables. Transportation and energy supply were also introduced into the model as control variables. The study will analyze the data for the variables using the pooled mean group (PMG), also known as panel ARDL. The panel ADRL was developed by Pesaran et al. (1999). Its application in this study is to account for both the long-run and the short-run relationship between greenhouse gas and the dependent variables and to investigate the existence of heterogeneous dynamics across countries. The ARDL model can only be feasible if there is a long-run relationship between the variables of interest. The method has been able to remove the constraint in the events of variables being stationary at both I(0) and I(1). Because the sample for our panel has 8 countries and 25 years, it shows that the sampled years are more than the cross-sectional units and

as a result, it is possible that the data for the variables employed may not be stationary at the expected order of cointegration. However, it is expected that at the order of cointegration I(1) that the assumed model becomes probably dynamic. In this study as proposed by Pesaran &Smith (1995) and Pesaran et al. (1999), the panel ARDL model is utilized because it is regarded as the most consistent and appropriate especially when the panel size is considered. Pesaran &Smith (1995) and Pesaran et al. (1999) opined that the panel ARDL has a definite advantage over other dynamic panel estimators such as instrumental variables, fixed effect method, or even the GMM method proposed by (Anderson & Hsiao 1982: Arellano & Bover 1995) because these other estimators can produce inconsistent results over a mean value of the employed parameters except in the case where the coefficients are identical across the various countries. The ARDL model will be used herein in its error correction form to achieve the study's objective of adopting it. The second-generation unit root and cointegration tests will be done using the STATA 15.0 statistical package, while Eviews 10 will be used for the rest of the analysis.
The ARDL model is thus formulated as follows:

$$\begin{aligned}\Delta GHG_{it} = \beta_0 + \beta_1 GHG_{i,t-1} + \beta_2 IP_{i,t-1} + \beta_3 EP_{i,t-1} + \beta_4 AP_{i,t-1} + \beta_5 TR_{i,t-1} \\ + \beta_6 \\ + \sum_{i=1}^{\rho} \alpha_1 \Delta GHG_{i,t-i} \\ + \sum_{j=0}^{q} \alpha_2 \Delta IP_{i,t-j} + \sum_{k=0}^{r} \alpha_3 \Delta\, EP_{i,t-k} + \sum_{l=0}^{s} \alpha_4 \Delta\, AP_{i,t-l} \\ + \sum_{m=0}^{u} \alpha_5 \Delta TR_{i,t-m} + \sum_{n=0}^{v} \alpha_6 \Delta ES_{i,t-n} \\ + \mu_{it}\end{aligned} \quad (8)$$

Where GHG is greenhouse gas emissions, IP is the industrial production, EP electricity production and AP is the agricultural production. Transportation (TR) and Energy supply (ES) are used as control variables while μ_i is used to indicate the error term. The β's are the long-run parameters of the explanatory variables while β_0 is the intercept of the model. Similarly, the α's is used to denote the short-run parameters of the explanatory variables and the lag of the dependent variable. Furthermore, the notations i and t denote the cross-sections (countries) and periods (year), respectively. The panel can be unbalanced in practice and as such p,q, r, s, u and v which are used to denote the maximum lags may even vary across countries. By parameterizing equation (8), the ECM system is obtained as:

$$\Delta GHG_{it} = \beta_0 + \beta_1 GHG_{i,t-1} + \beta_2 IP_{i,t-1} + \beta_3 EP_{i,t-1} + \beta_4 AP_{i,t-1} + \beta_5 TR_{i,t-1} + \beta_6 ES_{i,t-1} + \sum_{i=1}^{\rho} \alpha_1 \Delta GHG_{i,t-i} + \sum_{j=0}^{q} \alpha_2 \Delta IP_{i,t-j} + \sum_{k=0}^{r} \alpha_3 \Delta EP_{i,t-k} + \sum_{l=0}^{s} \alpha_4 \Delta AP_{i,t-l} + \sum_{m=0}^{u} \alpha_5 \Delta TR_{i,t-m} + \sum_{n=0}^{v} \alpha_6 \Delta ES_{i,t-n} + \theta ECM_{i,t-1} + \mu_{it} \qquad (9)$$

In equation (9), θ represent the error correction parameters while other symbols remain as defined in equation (8). We can further present the country specific short run ECM result for each individual country to be as follows:

$$\Delta GHG_{it} = \alpha_0 + \sum_{i=1}^{\rho} \pi_1 \Delta GHG_{i,t-i} + \sum_{j=0}^{q} \pi_2 \Delta IP_{i,t-j} + \sum_{k=0}^{r} \pi_3 \Delta EP_{i,t-k} + \sum_{l=0}^{s} \pi_4 \Delta AP_{i,t-l} + \sum_{m=0}^{u} \pi_5 \Delta TR_{i,t-m} + \sum_{n=0}^{v} \pi_6 \Delta ES_{i,t-n} + \varphi ECM_{i,t-1} + \mu_{it} \qquad (10)$$

Here, φ is the country-specific ECM parameter measuring the speed of adjustment to long-run equilibrium, α is the intercept for the country-specific short-run result while π is the short-run parameter for the explanatory variables and the lag of the dependent variable.
Equation (10) is therefore estimated to achieve the goal of the study.

3.2.1 Panel Cross-Sectional Dependence test

The problem of Cross-sectional Dependence is usually a serious one when the dataset involved is a macro panel covering a time period of about 30 years and above. When there is the need to check for cross-sectional dependence in a panel just as it is necessary for this study, considering the time span, the Breusch-Pagan (LM) or the Pesaran CD test can be applied depending on whether the sample size (t) is greater than the panel cross-section (n). Because the sample size in this study is greater than the cross-section, the Brusch-Pagan (LM) test becomes the most appropriate to use. The Breusch-Pagan (LM) test is built on the null hypothesis that residuals across entities are not correlated. Going by this, the null hypothesis is rejected if the F-prob. value is < 5% otherwise it will be accepted. Accordingly, the study found significant cross-sectional dependence in the panel and as a result, the first-generation cointegration tests of Pedroni and Kao were no longer suitable for this study; hence the Westerlund test of cointegration was used, which is a second-generation panel test. Just as the presence of cross-sectional dependence in the panel rendered the first-generation cointegration tests unsuitable for this study, the first-generation unit root tests of Levin, Lin & Chu t; Breitung t-stat; Im, Pesaran and Shin W-stat; ADF-Fisher Chi-square; and PP-Fisher Chi-square, were also unfit and as a result of the second generation panel unit root test, Cross-sectional augmented Im, Pesaran and Shin (CIPS) was used in the study.

3.2.2 Panel unit root test

After examining the cross-sectional dependence, the next stage in the analysis is to check the order of cointegration of the variables considered in this study. The first-generation panel unit tests may offer spurious and misleading results if cross-sectional dependence and slope homogeneity exist in the data set. The CADF (Cross-sectional augmented Dickey-Fuller) and CIPS (Cross-sectional augmented Im, Pesaran and Shin) tests can counter the cross-sectional dependency and slope heterogeneity in the data, and results are more accurate and robust". The equation for the CADF is written as:

$$\Delta y_{it} = \alpha_i + \pi_i y_{i,t-1} + \varphi_i \bar{y}_{t-1} + \sum_{l=0}^{p} \emptyset_{il} \Delta\bar{y}_{t-1} + \sum_{l=1}^{p} \gamma_{il} \Delta\bar{y}_{i,t-1} + \in_{it} \quad (11)$$

In Eq. (11),$\bar{y}_{t-1}$and $\Delta\ \bar{y}_{t-1}$is averages for lagged and first difference of each cross-section series.

"From CADF, Cross-sectional Augmented Im, Pesaran and Shin (CIPS) statistics are obtained and given as:

$$\text{CIPS}= \frac{1}{N}\sum_{i=1}^{N} CADF_i \quad (12)$$

Where CADF_{i} represents "cross-sectional augmented dickey fuller test" and N is the number of observations".

3.2.3 Panel cointegration test

The present study intends to "study the long-run relationship between variables like greenhouse gas (GHG) being the dependent variable; industrial production (IP); electricity and heat production (EP) and agricultural, forestry, and fish production (AP) as dependent variables. Transportation and energy supply for selected countries. We apply the error correction model (ECM) based cointegration method proposed by Westerlund's (2007) cointegration techniques to fulfil this objective.

This technique deals with the common factor constraint problem that plagued cointegration testing of the first generation. It produces accurate and robust results and helps to handle cross-sectional error term dependence Kapetanios et al. (2011). The test has no restriction for the common factor Khan et al. (2020). In this case, the null hypothesis indicates that cointegration between cross-sectional units does not exist. Besides that, the alternative hypothesis implies the presence of cointegration between considered variables". The expression for the Westerlund cointegration test is as follows:

$$\alpha_i(L)\Delta y_{it} = \delta_{1i} + \delta_{2i}t + \alpha_i\left(y_{i,t-1} - \beta'_1 x_{it} + \lambda_i(L')v_{it} + e_{it}\right) \qquad (4)$$

In this equation, β_i is an error correction coefficient, and α_i is the vector of the cointegration link between x and y.

4. Empirical results

Table 1 Descriptive Statistics

	GHG	IP	EP	AP	TR	ES
Mean	2152706.	30.60493	29.46892	7.060598	26.46875	73.18960
Median	676999.9	27.94768	15.42807	2.261476	28.55334	84.55489
Maximum	12454711	65.36749	99.81727	47.09550	54.46346	95.51006
Minimum	63536.73	17.82977	0.084217	0.550755	4.876900	15.88523
Std. Dev.	3046146.	9.417508	32.13221	10.26918	12.34900	23.16439
Skewness	1.638043	1.114213	1.181925	1.881356	0.089667	-1.461590
Kurtosis	4.654093	3.922482	3.046056	5.427646	2.426106	3.885019
Jarque-Bera	116.7293	50.41271	48.44586	173.7794	3.133131	80.84477
Probability	0.000000	0.000000	0.000000	0.000000	0.208761	0.000000
Sum	4.48E+08	6365.825	6129.536	1468.604	5505.500	15223.44
Sum Sq. Dev.	1.92E+15	18358.72	213723.2	21829.41	31567.06	111073.9
Observations	208	208	208	208	208	208

Source: Own processing.

Table 1 presents the description of initial datasets for the study and reveals that the rate of greenhouse gas emissions (GHG) across the sampled countries varies as the maximum and minimum values of 12454711 and 63536.73 respectively indicate. Similarly, the difference between the maximum industrial production (IP) of 65.36749 and minimum industrial production (IP) of 17.882977connotes that some of the countries in the panel are more industrialized than the others. The wide gap between the maximum and minimum electricity and heat production (EP) across the sampled countries indicates that while some could sufficiently produce the electricity they consume; others may be dependent on other countries for their electricity needs. The scenario in the agricultural, forestry and fish production (AP) is similar to that of EP, most of the sampled countries are agriculturally dependent. This can be seen from the difference between the maximum and minimum AP of 47.09550 and 0.550755, respectively. The transportation and energy supply seems to follow a similar trend of heterogeneity in the rate of activities in the sampled sectors. However, the average value from the data of the sampled variables except for energy supply (ES) indicates that they are accountable for the insignificant proportion of the global percentage of these variables. The descriptive statistic indicates that the entire variable for this study is positively skewed and normal as shown by the skewness and JB probability. The only exception is the TR whose JB result was revealed to be insignificant but will be resolved by logging the data.

Table 2 Result of Pesaran Panel Unit Root Test.

Variable	CIPS @Level	CIPS @First Difference	Decision
LGHG	-2.236*	-5.449***	1(1)
LEP	-1.073	-4.899***	1(1)
LAP	-2.077	-4.478***	1(1)
LTR	-2.039	-5.686***	1(1)
LIP	-2.643***	-----	1(0)
LES	-1.456	-4.579***	1(1)

Source: Own processing.
Note: 1. *******, ****** and ***** denotes significance at 1%, 5% and 10% respectively.
2. Also included in the test equation are the individual intercept and trend.

The unit root results in table 2 show that the variables of the study are all stationary at the order I(1) except for LIP which is stationary at the order I(0). With this, we then proceed with our Panel ARDL result estimation.

Table 3 Result of Westerlund Cointegration Test

Statistic	Value	Z-value	P-value	Robust P-value
Gt	-3.050	-2.367	0.009	0.000
Ga	0.314	4.203	1.000	1.000
Pt	-3.942	1.129	0.871	0.000
Pa	-0.216	2.780	0.997	0.000

Source: Own processing.
Note: bootstrapping critical values under the null hypothesis was used.

The results of the Westerlund cointegration test in the table (3) above show that Gt, Pt, and Pa are cointegrated by observing the Robust P-values. Thus, the H_O of no cointegration is rejected and the alternative hypothesis accepted at the 5%

conventional significance, permitting the use of the Panel ARDL estimation technique.

Table 4 Result of The Panel ARDL Estimation

Dependent Variable: D(LGHG)

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
	Long Run Equation			
LIP	-3.462039***	0.491461	-7.044377	0.0000
LEP	0.136376**	0.064088	2.127950	0.0375
LAP	0.754455***	0.159297	4.736146	0.0000
LTR	-2.505269***	0.525071	-4.771298	0.0000
LES	5.835789***	0.327128	17.83946	0.0000
	Short Run Equation			
ECM(-1)	-0.427596	0.307748	-1.389434	0.1699
ΔLGHG(-1)	-0.201797	0.191316	-1.054781	0.2958
ΔLIP	0.738522	1.419018	0.520446	0.6047
ΔLEP	1.148180	0.716608	1.602242	0.1144
ΔLAP	-0.293679	0.209098	-1.404506	0.1654
ΔLTR	-0.432345	1.173480	-0.368430	0.7139
ΔLES	-0.928728	0.819157	-1.133761	0.2615
C	3.234004	2.373471	1.362563	0.1782
Mean dependent var	0.014094	S.D. dependent var		0.107829
S.E. of regression	0.079119	Akaike info criterion		-2.962774
Sum squared resid	0.369328	Schwarz criterion		-0.571941
Log likelihood	457.1285	Hannan-Quinn criter.		-1.996044

Source: Own processing.

Table 4 presents the short-run result of the panel ARDL comprising 8 selected countries: US, UK, Canada, China, Australia, Norway, South Africa, and Nigeria; shows that industrial production (LIP) and electricity and heat production (LEP) contribute positively to global greenhouse gas emissions while agricultural, forestry and fish production (LAP), transportation (LTR), and Energy supply (LES) impact negatively on global greenhouse gas emissions. The result for LIP and LEP is in line with the report published by our world data on its website but the result for the rest of the variables fell short of that expectation. However, none of these variables is statistically significant. This is not surprising as the majority of the countries considered in this study are industrial economies, with a mix of hydro and fossil fuels as their major source of electricity generation and heating with some measure of active agricultural policies thereby regulating deforestation, bush burning, and other activities that degrade the forest which are the main ways that greenhouse gas is released from this source. An exception is in the case of natural bush fires which are

common in some of these countries. In some of these economies, the industrial sector still depends on primitive fuels like coal, and fossil fuel-driven machines for their production activities and for electricity generation, of which China, the US south Africa, and Nigeria are typical examples (Condor et al., 2011 and US EIA, 2016). The insignificant results in the short-run may potent that LIP, LEP, LAP, LIP, and LES in the selected countries are not alone are not sufficient to explain global LGHG in the short-run or that current environmental regulations adopted in the respective sector by these countries are slightly yielding result.
In the long run, the result shows that industrial production (LIP), and transportation will reduce greenhouse gas by 346 and 251 percent respectively as shown by the coefficients, -3.462***, and -2.505***. The long-run result for electricity and heat production (LEP), agriculture, forestry, and fish production (LAP), and energy supply (LES)shows that they will increase greenhouse gas by 14, 75 and 584 percent as indicated by their respective coefficient of 0.136**, 0.754*** and 5.835***. Again, this is not surprising because virtually all the countries considered in this study except for Nigeria, have begun to adopt carbon capture and storage technology (CCS) as a measure to mitigate greenhouse gas emissions, majorly in the industrial plants. This shows that increased use of the technology in the industrial production plants and facilities, and the adoption of this CCS technology by other countries will yield fruits in mitigating greenhouse gas emissions in the world. On the other hand, the long-run result for LEP, LAP, and LES will serve as a wake-up call as to the need not to neglect the agricultural and forestry policies as well as majors put in the transportation sector and energy supply aimed at reducing greenhouse gas. Although this agricultural and forestry policy has been relinquished to the third world countries because it is less costly to plant trees in these areas than in first world countries. As recommended by the Kyoto protocol (2005), the need for forestry sequestration policies is not only beneficial to the third world countries, this is because atmospheric carbon has been difficult to capture, is found across the countries of the world and it is only the forest trees and vegetations that serve as the tool for their capture- natural sinks. For transportation, carbon taxing and transition to renewable power (fuel) sources for automobiles may be the most readily available option in the absence of any capture technology.
The ECM-1 is negatively significant as expected, and indicates that a one-unit deviation from equilibrium will be corrected in the next period by approximately 43 percent.

The Cross-Sectional Short-Run Result

Table 5 presents the country-specific results and will be used for country-specific analysis to identify individual countries' uniqueness and policies as well as outcomes.

Table 5 Cross-sectional short-run coefficients (Country Specific Results)

COUNTRY	CONSTANT	ECM (-1)	LIP	LEP	LAP	LTR	LES
US	2.831	-0.327***	1.256***	-0.149***	-0.429***	-0.872***	0.520
UK	0.108***	-0.016***	-0.146**	-0.031***	-0.089***	-0.327)***	1.228***
CANADA	19.695	-2.562***	9.210**	5.831	-1.630**	5.558*	-2.677
CHINA	0.039***	-0.009***	1.133***	0.279***	0.113***	-0.204***	1.513***
AUSTRALIA	1.160	-0.225**	-5.404	0.437	-0.479	-6.821	-2.262
NORWAY	0.158***	-0.019***	-0.089***	2.107	-0.095***	-0.282***	0.247***
SOUTH AFRICA	0.770	-0.187	-0.330***	-0.042***	0.129***	-0.257***	-5.242**
NIGERIA	1.108**	-0.072)***	0.278***	0.753***	0.132**	-0.394**	-0.758***

Source: Own processing.

Note: 1.***, ** and * denotes significance at 1%, 5% and 10% respectively.

5. Discussions

United State of America (US)

The result from the cross-sectional short-run estimate in table 4.5 above shows that the US industrial production LIP significantly contributes to the emission of greenhouse gas to the ton of 126% approximately for every one-unit increase. This is not surprising because it is a well-known fact that the US is a heavily industrialized economy. This calls for invigorated effort in the CCS programme since despite being one of the leading economies in the adoption of the programme the rate of greenhouse gas emissions is still high. The US has 14 operational CCS technologies scattered in the industrial sector although the majority are used for oil recovery purposes while just one is installed in the power generation area. Many of the manufacturing industries in the US depend heavily on other sources of energy for their production, which are big-time LGHG emitters (US EIA, 2020). Electricity and heat production LEP, agricultural, forestry, and fish production LAP, and transportation LTR, individually contribute to the reduction of greenhouse gas in the US at the tonnes of 15, 43, and 87 percent approximately, for every one unit increase, respectively. This is because hydro is the main source of electricity and heat production in the US as revealed by the data for the country. On the other hand, the country has a good environmental policy for agricultural, forestry, and fish production, and has over time maintained good forest vegetation while having adopted tree planting which serves as a natural sink for mitigating greenhouse gas emissions. Again, the CCS facility in these two areas may have been the reason for such a significant reduction in LGHG Global Status of CCS Report (2020). The significance of the constant term suggests that major sectors which are emitters of greenhouse gas are all captured in this study. The result for energy supply (LES) is statistically insignificant. The ECM result shows that the speed of convergence to long-run equilibrium is approximately 33% suggesting that the US economy is sluggish, the possible reason being a market failure.

United Kingdom (UK)

The short-run result for the UK shows that industrial production (LIP), electricity and heat production (LEP), agricultural, forestry, and fish production (LAP), and transportation LTR significantly contributes to the reduction of greenhouse gas emission by approximately 14%, 3%, 9%, and 33%, respectively for every one unit increase. Energy supply LES contributes significantly to greenhouse gas emissions it does so at the ton of 123%. Condor et al. (2011) while comparing China with the developed economies recognized that in terms of per capita emission that the developed economies exceed China. The result for all the variables except for Energy supply LES do not support this claim for the UK, surprisingly, the data for the country showed an upward surge in the adoption and use of other electricity and heat production sources other than hydro, beginning from the year 2000. Furthermore, the result for LIP, LAP, and LTR reveals that the UK is properly managing its industrial, agricultural and forestry, and transportation sectors thus utilizing them to mitigate greenhouse gas. Currently, the UK has no operational CCS facility as shown by the (Global Status of CCS Report, 2020). These results may potent that the UK though a developed economy, is not industrialized like the US and China, and that the use of carbon tax is highly effective in the UK. The significance of the constant term suggests that there are sectors that are emitters of greenhouse gas that are not captured in this study. The ECM showing the speed of convergence in the subsequent period is approximately 2% indicating that the economy is sluggish and may suggest market failure.

Canada

The result for Canada shows that LIP, LEP, and LTR contribute positively to *(LGHG)* while LAP and LES will help to mitigate it. Generally, at the conventional 5% significance level the result for all the variables except for LIP and LAP, is insignificant. The report from the Canadian energy regulatory authority shows that the country's industrial sector is the highest emitter of LGHG while electricity production emits the least amount of LGHG. Canada currently has 4 operational CCS technology with just one located in the electricity production facility (Global Status of CCS Report, 2020) and also operates forestry carbon sequestration that has captured not less than 12 Mt of CO_2 (Amano and Sedjo, 2006). The result of this study seems to suggest that the country has a good environmental management policy operational in the entire sectors considered in this study except for LIP. Implying that the CSS facility installed in the industrial sector is not making any impact at the moment. This could also be due to the data span, meaning that the data may not have captured the period when the CSS facility began operation. The result of the constant indicates that there are no significant LGHG emitting sectors in Canada that were not captured in the study. Finally, the economy converges to long-run equilibrium at the speed of 256% which implies it is not sluggish and is void of any form of market failure.

China

The Chinese LIP, LEP, LAP, and LES are significant emitters of LGHG to the ton of 113, 28, 11, and 151 percent respectively. The LTR sector significantly reduced LGHG emission to the ton of 20 percent. Although China has 3 operational CCS technologies which are located in the industrial production facilities, it has not made any significant impact on LGHG reduction in this sector as the result of this study indicates. China's tremendous economic growth which began in the early part of 2000 stirred up the industrial sector as a result of sky-rocketing demand and thus prompted the demand for coal and other dirty energy for industrial and electricity production because they are cheaper (Condor et al., 2011). The agricultural sector also witnessed a similar trend in growth with increased use of machines and fertilizers. The same is true for the electricity generation and heat production LEP in China; this is because electric power is a driver of industrialization and thus, economic growth. For instance, the 2016 international energy outlook by the US Energy Information Administration showed that China's steel industry utilizes more coal than electricity in its production activities. The chemical industries also followed a similar energy use pattern, with LGHG emitting fuels topping the list of their energy use preference scale. The data span captures the period of supply-incentive for electric mobility hence, the negative result for the transportation sector (Global Climate Tracker, 2021). Conclusively, the fuel use pattern is majorly responsible for this outcome (US EIA, 2016). The significance of the constant term suggests that there are sectors that are emitters of greenhouse gas that are not captured in this study. The economy's speed of convergence to long-run equilibrium is very sluggish at approximately 1% indicating market failure.

Australia

The outcome for Australia looks surprising as the entire result is statistically insignificant. Australia is the world's largest exporter of coal and the world's twentieth largest consumer of energy; hence, her energy needs up to date have been met by fossil fuels. The primary energy consumption in Australia is dominated by coal, followed by oil and then gas (Geoscience Australia, 2020). For the past few years, Australia LGHG has continued to manage its LGHG this success is attributed to certain policies seeking emission reduction both in the electricity production where it is gradually twitting from coal to renewable sources, the case of agriculture and forestry is as a result of the prevailing drought in the country thus reducing the use of fertilizer and as well the number of livestock. Other sectors are in one way or the other witnessing emission cut. Even Australia's transportation sector which is one of the largest emitters of LGHG is statistically insignificant (Australian Government: Department of Industry, Science, Energy and Resources, 2020). The constant term of the results of these countries is not significant and that is an indication that the sectors considered in this study are the key emission sectors in Australia. The speed of convergence to equilibrium, in the long run, is sluggish at approximately 23%, which may suggest market failure.

Norway

Norway's LEP and LES positively impact LGHG but only the *LES* is significantly contributing to Norway's LGHG emission to the ton of approximately 25 percent for anyone unit rise in supply. The result for LIP, LAP and LTR seems to point out that the country has a good and functional agricultural, forestry, and fish production regulatory framework, as the sector contributes to the reduction of LGHG emission to the ton of approximately 10 percent. Norway has 2 operational CCS facilities: the first began operations in 1996 while the second was in 2008 and both are located in the industrial sector for natural gas processing. This may be the reason for the negative LGHG emission from the industrial sector. A possible interpretation of the negative emissions from the transportation sector is the policy of carbon taxation. The significance of the constant term suggests that there are sectors that are emitters of greenhouse gas that are not captured in this study. The ECM shows that the speed of convergence to long-run equilibrium is sluggish at approximately 2 percent and may be due to market failure.

South Africa

The result for South Africa shows that LIP, LEP, LTR, and LES are all contributing significantly to LGHG emissions reduction in South Africa at the ton of 33, 4, 26, and 524 percent, respectively while LAP contributes to emissions increase at the ton of 13 percent. These results have serious implications for the country. Firstly, South

Africa is known for high LGHG emissions due to the growing industrial activities and high energy utilization. The industrial activities in the country are being powered by coal which the country is richly endowed with and thus, making electricity very cheap. While the government has undertaken carbon taxing and placing an embargo on setting up new coal-powered plants as a measure to ensure an emission cut, this no doubt must be responsible for the significant reduction in LGHG emission in the country (Condor et al., 2011). On the contrary, the absence of any regulatory framework for the LAP must be responsible for the significant contribution to LGHG emission. The constant term of the result for South Africa is insignificant, indicating that the sectors considered in this study for the country are the key emitters. The speed of convergence to long-run equilibrium as indicated by the ECM is sluggish at approximately 19 percent suggesting market failure.

Nigeria

The study result shows that Nigeria's LIP, LEP, and LAP contribute significantly to the emission of LGHG to the ton of 28, 75, and 13 percent respectively, while LTR and LES are responsible for LGHG reduction at the ton of 39 and 76, respectively. The result is in tandem with the energy use pattern in the country where there is little or no active and functional regulatory framework. There is high emission in the entire industrial production of Nigeria ranging from gas flare and the use of fossil fuel for powering industrial plants. Nigerians' energy consumption exceeds the installed capacity with the excess consumption generated from private generator sects which run with gasoline and diesel oil. The available supply from hydro is often epileptic (Ogwu et al., 2022). The country is notably transiting from primitive to modern agriculture where there is increased use of machinery and fertilizers. Furthermore, there is a high rate of deforestation and bush burning in the country thus, the result for agricultural, forestry, and fish production shows that it is contributing significantly to the growth of LGHG emissions. To remedy this incidence of rising emissions in the country, there is the need to strengthen the existence but weak institutions charged with the responsibility of regulating the environmental activities. Furthermore, carbon taxation could also be introduced, and then transition to renewable energy speed-up. The constant term for Nigeria just like some other countries used in this study is significant and shows that there are emitting sectors in the country not captured in this study. The speed of convergence to long-run equilibrium is sluggish at 7 percent implying market failure.

6. Conclusions

This study sought to examine the feasibility of carbon-capturing as a measure of reducing greenhouse gas visa vise global warming and climate change, to check if any long-run relationship exists between carbon capture and greenhouse gas emissions, and to use proxies to ascertain the impact of carbon sequestration programmes.

The study found that it is much more difficult to capture carbon in the atmosphere compared to direct capture from industrial and electric facilities. Hence, the CCS facility best fits the direct capture of carbon from industrial and electric plants while forest sequestration is the easiest and best approach for atmospheric carbon capture. Again, the CCS carbon capture approach is ideal for all economies most especially the industrialized economies whereas the forest sequestration approach is most ideal for the poor economies since the cost of planting trees there is low compared to the developed economies.

The study also found that most economies are backward in the adoption of CCS technology especially the third-world countries, with Africa as a typical example, even though some countries in that region are major producers of natural resources which are big-time carbon emitters. On the other hand, the majority of forest sequestration projects is been located in third-world countries.

The short-run result from the regression estimation shows that none of the variables have a significant contribution to global LGHG emissions. These portent two things, firstly, that globally the various environmental policies coupled with the presence of CCS technologies are yet to make a significant impact. Secondly, that the sampled countries are unable to explain the global LGHG emission in the short run.

The long-run result, however, shows that LIP and LTR will significantly lead to LGHG emission reduction at the global level, while LEP, LAP, and LES will significantly increase emission. This means that an increased commitment to the installation of CCS technologies in the various industry across the globe especially in the industrial and oil-producing economies as well as effective agricultural and forest management like tree planting and reduction of deforestation activities will drastically reduce the global LGHG emissions, and help reduce atmospheric carbon. This is true as the cross-sectional short-run result of the economies considered further indicated. The result for the industrialized economies with those of the emerging economies showed significant contribution to LGHG from the LIP, LEP, and LAP in most of the economies. The only exception is Australia which was traced to the effective implementation of environmental policies aimed at LGHG emission reduction. Nigeria being the only developing economy considered showed the same trend of high LGHG emissions from LIP, LEP, and LAP as the developed and emerging economies. The reason is the absence of effective industrial regulation despite being an oil-rich economy. The result of the constant term for most of the countries seems to suggest that there are sectors not considered in this study that are key emitters. However, this is contrary to expectations.

Based on the findings of this study we recommend that the use of CCS technology should be adopted in every carbon-emitting industry across the globe. Forestry carbon sequestration should also be adopted alongside policies that will forestall the degradation of the existing forest vegetation and thus, reduce atmospheric carbon concentration and prevent the release of carbon into the atmosphere. Like in South Africa, the adoption of carbon taxing may work to deter high polluting industries from doing so. Economies should be swift to transit to the use of clean and renewable energy and fuel sources. Finally, there is a need to further research this area which will consider carbon taxing and investigate some of the missing variables in some of the country-specific results.

Acknowledgments
Not applicable.

Funding
This research received no external funding.

Author contributions
Ogwu conceived the topic and wrote the introduction. Dr Uzoigwe and Stephen did the literature. Prof. Maduka and Ogwu did the methodology. Eze provided the data and did the analysis together with Ogwu and Onwe. While Dr. Orji did the editing.

Disclosure Statement
The authors declare no conflict of interest.

References

1. Almendra, F., West, L., Zheng, L., Forbes, S. (2011), CCS Demonstration in Developing Countries: Priorities for a Financing Mechanism for Carbon Dioxide Capture and Storage, WRI Working Paper, World Resources Institute, Washington DC. Available online at www.wri.org/publication/ccs-demonstration-in-developing-countries
2. Amano, M., Sedjo, R.A. (2006), Forest Sequestration: Performance in Selected Countries in the Kyoto Period and the Potential Role of Sequestration in Post-Kyoto Agreements, Resource for the Future Report (2006). Available online at https://media.rff.org/archive/files/sharepoint/WorkImages/Download/RFF-Rpt-ForestSequestrationKyoto.pdf.
3. Australian Government: Department of Industry, Science, Energy and Resources, (2020), Quarterly Update of Australia's National Greenhouse Gas Inventory: June 2020. Available online at https://www.industry.gov.au/data-and-publications/national-greenhouse-gas-inventory-june-2020.
4. Beck, L. (2020), Carbon capture and storage in the USA: the role of US innovation leadership in climate-technology commercialization. Clean Energy, 4(1), 2–11.
5. Boden, T. A., Marland, G., Andres, R.J. (2014), National CO_2 Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2014, Carbon Dioxide Information Analysis Centre, Oak Ridge National Laboratory, US Department of Energy.

6. Bruce, G., Miller, D. (2011), US and International Activities for Near-zero Emissions during Electricity Generation. Clean Coal Engineering Technology (2011).
7. Bui et al. (2018), Carbon Capture and Storage: The Way Forward. Energy and Environmental Science, 11(5), pp. 1062-1176.
8. Bui, M, Mac Dowell, N. (2020), Carbon Capture and Storage, Royal Society of Chemistry, UK. Available online at https://doi.org/10.1039/9781788012744
9. Condor, J., Unatrakarn, D., Asghari, K., Wilson, M. (2011), Current Status of CCS Initiatives in the Major Emerging Economies. Energy Procedia, 4, 6125–6132. Available online at http://dx.doi.org/10.1016/j.egypro.2011.02.620
10. Edenhofer, O.R.P.M., Sokona, Y., Kadner, S., Minx, J.C., Brunner, S., Agrawala, S., Baiocchi, G., Bashmakov, I.A., Blanco, G., Broome, J., Bruckner, T., Bustamante, M., Clarke, L., Conte Grand, M., Creutzig, F., Cruz-Núñez, X., Dhakal, S., Dubash, N.K., Eickemeier, P., Farahani, E., Fischedick, M., Fleurbaey, M., Gerlagh, R., Gómez-Echeverri, L., Gupta, S., Harnisch, J., Jiang, K., Jotzo, F., Kartha, S., Klasen, S., Kolstad, C., Krey, V., Kunreuther, H., Lucon, O., Masera, O., Mulugetta, Y., Norgaard, R.B., Patt, A., Ravindranath, N.H., Riahi, K., Roy, J., Sagar, A., Schaeffer, R., Schlömer, S., Seto, K.C., Seyboth, K., Sims, R., Smith, P., Somanathan, E., Stavins, R., von Stechow, C., Sterner, T., Sugiyama, T., Suh, S., Ürge-Vorsatz, D., Urama, K., Venables, A., Victor, D.G., Weber, E., Zhou, D., Zou, J., Zwickel, T. (2014), Technical summary. In: Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T., Minx, J.C. (eds), Climate change 2014: mitigation of climate change. Contribution of working group III to the fifth assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available online at https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_technical-summary.pdf.
11. Fawzy, S., Osman, A.I., Doran, J., et al. (2020), Strategies for mitigation of climate change: a review. Environmental Chemistry Letters, 18, 2069–2094.
12. Gajić, G., Djurdjević, L., Kostić, O., Jarić, S., et al. (2018), Ecological Potential of Plants for Phytoremediation and Ecorestoration of Fly Ash Deposits and Mine Wastes, Front. Environ. Sci., 13.
13. Geoscience Australia (2020), Australia's Energy Production, Consumption and export. Available online at https;//ga.gov.au/scientific-topics/energy/basics.
14. Global CCS Institute (2017), The Global Status of CCS. Available online at https://www.globalccsinstitute.com/wp-content/uploads/2018/12/2017-Global-Status-Report.pdf.
15. Global CCS Institute (2020), The Global Status of CCS. Available online at https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Global-Status-of-CCS-Report-English.pdf.
16. Hambel, C., Kraft, H., Schwartz, E. (2019), Optimal Abatement in a Stochastic Equilibrium Model with Climate Change, National Bureau of Economic Research (NBER) Working Paper No: 21044. Available online at http://www.nber.org/papers/w21044.

17. Herzog, H., Golomb, D. (2004), Carbon Capture and Storage from Fossil Fuel Use. Encyclopedia of Energy. Available online at https://sequestration.mit.edu/pdf/enclyclopedia_of_energy_article.pdf.
18. International Energy Administration Green House Gas. A brief History of CCS and Current Status: CCS information sheet. Available online at https://ieaghg.org/docs/General_Docs/Publications/Information_Sheets_for_CCS_2.pdf.
19. Jacobson, M. Z. (2019), The health and climate impacts of carbon capture and direct air capture. Energy & Environmental Science,12, 3567-3574.
20. Jacobson, T. A., J. S., Kler, M., Herke, T., et al. (2019), Direct Human Health Risk of Increased Atmospheric Carbon. Nature Sustainability, 2, 691-701.
21. Jindal, R., Swallow, B., Kerr, J. (2008), Forestry-based carbon sequestration projects in Africa: Potential benefits and challenges. Natural Resources Forum*,* 32(2), 116–130.
22. Kankara, A. I. (2013), Examining Environmental Policies and Law in Nigeria, International Journal of Environment Engineering and Management, 4(3), 165-170 Available online at http://www.ripublication.com/.
23. Lal, R. (2010), Carbon Sequestration in Saline Soils, Journal of Soil Salinity and Water Quality, 1(1 and 2), 30-40. Available online at http://tinread.usarb.md:8888/jspui/bitstream/123456789/1024/1/carbon_saline.pdf.
24. Lal, R. (2013), Carbon Sequestration, Terrestrial, (Ed.) Reference Module in Earth System and Environmental Sciences.
25. Leung, D. Y.C., Caramanna, G., Maroto-Valer, M. M. (2014), An overview of current status of carbon dioxide capture and storage technologies. Renewable and Sustainable Energy Reviews, 39, 426-443.
26. Mcpherson, W.J. B. (2019), Multiple Flow Associated with Geological CO2 Storage, (Ed.) Science of Carbon Storage in Deep Saline Formation.
27. Nikolova, C., Gutierrez, T. (2020), Use of Microorganisms in the Recovery of Oil From Recalcitrant Oil Reservoirs: Current State of Knowledge, Technological Advances and Future Perspectives, Frontiers in Microbiology.
28. Ontl, T. A., Schulte, L.A. (2012), Soil Carbon Storage. Nature Education Knowledge*,* 3(10), 35. Available online at https://www.nature.com/scitable/knowledge/library/soil-carbon-storage-84223790/.
29. Ogwu, S. O., Orji, A., Ogbuabor, J.E., Anthony-Orji, O.I. (2022), Multiple Cooking Energy Patterns and the Environment in Nigeria: An Empirical Evidence from ARDL. Journal of Social and Economic Statistics (Unpublished).
30. Orji, A., Ogwu, S.O., Mba, P.N., Anthony-Orji, O.I. (2021), Energy Demand and Cooking Energy Cost in An Oil-Rich Economy: A New Evidence from Nigeria. Studia Universitatis "Vasile Goldis" Arad-Economic Series*,* 31(1), 1-21. Available online at https://publictii.uvvg.ro/index.php/studiaeconomia.
31. Oyedepo, S. O. (2012), Energy and sustainable development in Nigeria: the way forward, Energy. Sustainability and Society, 2(1),15-24.
32. Rafindadi, A.A., Yosuf, Z. (2013), An Application of Panel ARDL in Analysing the Dynamics of Financial Development and Economic Growth in 38 Sub-Saharan African, Preceding-Kuala Lumpur International Business, Economics, and Law Conference 2, December 2-3. Available online at

https://www.academia.edu/5473419/AN_APPLICATION_OF_PANEL_ARDL_IN_ANALYSING_THE_DYNAMICS_OF_FINANCIAL_DEVELOPMENT_AND_ECONOMIC_GROWTH_IN_38_SUB_SAHARAN_AFRICAN_CONTINENTS
33. Uchiyama, K. (2016), Environmental Kuznets Curve Hypothesis and Carbon Dioxide Emissions, Development Bank of Japan Research Series.
34. US Department of Energy (1999), Carbon Sequestration: Research and Development. US DOE, Springfield, VA, National Technical Information Service. Available online at http://www.ornl.gov/carbon_sequestration/.
35. US Energy Information Administration (2016), International Energy Outlook. Available online at https://www.eia.gov/outlooks/ieo/pdf/0484(2016).pdf.
36. US Energy Information Administration (2020) Use of Energy Explained: energy use in industry. Available online at https://eia.gov/energyexplined/use-of-energy-in/industry.php.
37. Vinca, A., et al. (2018), The role of carbon capture and storage electricity in attaining 1.5 and 2 °C. International Journal of Greenhouse Gas Control, 78, 148–159.
38. Wang, J., Feng, L., Palmer, P.I. et al. (2020), Large Chinese land carbon sink estimated from atmospheric carbon dioxide data. Nature*,* 586, 720–723.
39. Yap, J.T., Gabriola, A.J.P., Herrera, C.F. (2021), Managing the energy trilemma in the Philippines. Energy, Sustainability & Society, 11**(**34).