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Developing climate governance strategies in Nigeria: An emphasis on methane emissions mitigation

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Abstract
In the face of escalating global climate change concerns, nations, including Nigeria, are urged to enhance their climate governance strategies. Nigeria, a key player in Africa and particularly susceptible to climate change, confronts the critical task of addressing and mitigating its greenhouse gas emissions, with a significant focus on methane. This study explores the evolution of Nigeria's climate governance, emphasizing methane emission mitigation. It examines Nigeria's varied emission sources across agriculture, fossil fuel industries, and waste management, underscoring the necessity for sector-specific strategies. The research outlines the methods for identifying emissions, the collaborative efforts with stakeholders, and the resultant action plans. It highlights the pivotal role of the Climate and Clean Air Program (CCAP) and its compliance with the National Climate Change Policy and Response Strategy (NCCPRS) and the Paris Agreement. The paper also stresses the importance of integrating scientific inquiry with practical governance, exploring the benefits of synergistic collaborations. However, it acknowledges the challenges in aligning diverse stakeholder interests. The study reveals Nigeria's proactive and holistic approach to climate governance, particularly concerning methane emissions. It emphasizes that effective climate action requires a blend of policy development, scientific accuracy, and inter-sectoral cooperation. Nigeria's experience offers valuable lessons for other countries in implementing customized climate initiatives, highlighting both the opportunities and complexities involved.
Keywords: Methane emissions, Climate governance, Clean Air Program, Stakeholder collaboration, Sector-specific approaches.

1. Introduction

Climate change refers to any significant and long-term variation in the Earth's climate system, including changes in temperature, precipitation patterns, wind patterns, and other aspects of the climate (Odunola *et al*., 2018). It is primarily caused by human activities, particularly the burning of fossil fuels, deforestation, and industrial processes, which release greenhouse gases into the atmosphere (Gils, 2020). These greenhouse gases, such as carbon dioxide and methane, trap heat from the sun and cause the Earth's temperature to rise, leading to a range of impacts on the environment and human well-being. As the concentrations of greenhouse gases, particularly carbon dioxide (CO_2) and methane (CH_4), continue to rise in the atmosphere, global temperatures are also increasing.

Methane is significantly more effective than CO_2 at heat retention despite its lower atmospheric concentration. The Global Warming Potential (GWP) of CO_2 is established as 1. For methane, the GWP varies between 84 and 87 over a 20-year period and between 27 and 36 over a 100-year timeframe. This variation is due to methane's shorter atmospheric lifespan compared to CO_2. On average, methane emitted today remains in the atmosphere for about a decade, whereas CO_2 persists for a significantly longer duration, typically ranging from 300 to 1000 years (Environmental Protection Agency, 2023). The predominant focus of greenhouse gas (GHG) reduction efforts has been on CO_2, largely due to its higher atmospheric concentration, particularly in industrial sectors. However, the significant and increasing impact of methane emissions on climate change has gained recognition only in recent times. Research indicates that methane is responsible for approximately 0.5°C, which is nearly half, of the current 1.1°C rise in global temperature compared to pre-industrial levels. Consequently, it is now widely acknowledged that, alongside CO_2, targeting methane emissions is essential for effectively slowing down global warming by 2050 (Wang & He, 2023).

Presently, atmospheric methane concentrations are over two and a half times higher than their levels before industrialization (Stein, 2023). In the year 2022, methane emissions, stemming from both natural processes and human activities, reached 589 million metric tons (Mt) (International Energy Agency, 2023). Simultaneously, in July 2023, the average global temperature hit a new record high. This rise in global temperature is linked to more frequent extreme weather events, including heat waves, heavy rainfall, droughts, and tropical cyclones, which have increasingly severe impacts on human lives. Consequently, there is an immediate necessity to reduce greenhouse gas emissions, with a particular emphasis on short-term mitigation strategies.

The impacts of climate change are wide-ranging and include rising global temperatures, melting ice caps and glaciers, sea-level rise, more frequent and severe extreme weather events (such as hurricanes, droughts, and heatwaves), changes in precipitation patterns, and shifts in ecosystems and biodiversity (Botta *et al*., 2019). These changes have significant implications for various sectors, including agriculture, water resources, public health, and infrastructure (Abera & Tesema, 2019). Observable impacts of climate change are already evident in the form of extreme weather events, including heatwaves, excessive rainfall, and coastal flooding (Eckstein *et al*., 2018). Climate change stands as one of the most formidable challenges confronting humanity. Its complexity and ever-changing nature demand multifaceted and cross-sectoral mitigation and adaptation measures, all operating within an agile policy framework for effective management.

Governance is universally acknowledged as a crucial element for successful environmental management (Ogunkan, 2022). Climate governance refers to the processes and mechanisms through which decisions are made and actions are taken to address climate change at various levels, including local, national, and international (González & Numer, 2020). It involves the coordination and collaboration of multiple actors, including governments, businesses, and civil society organizations, to develop and implement policies and strategies to mitigate greenhouse gas emissions and adapt to the impacts of climate change (Rahman & Huang, 2019). Climate governance embodies the framework and actions that ensure the priorities of communities most impacted by climate change are addressed (Dubash, 2021). It encompasses the methods by which

various entities within national and international spheres manage climate-related initiatives, fulfil their commitments, make informed decisions, and maintain accountability. These governance structures include a spectrum of strategies, policies, and procedures established by both the government and its citizens to effectively confront climate change. Adom *et al*. (2023) elaborated on this concept, advocating for climate governance that promotes inclusivity and transparency, ensuring that all stakeholders—including civil society, the business sector, and government entities—have an equitable say in the distribution of power and responsibilities.

There is a collective agreement within the scientific and societal spheres on the need to manage climate change effectively. Moreover, public discourse is intensifying around the governance of climate change and its implications for the environment and human well-being. Egeruoh-Adindu (2022) argued that effective governance is crucial in the context of climate change, providing a framework for information sharing, decision-making, and enforcement, including monitoring and reporting mechanisms. Furthermore, Huang *et al*. (2020) was of the opinion that climate governance opens up diverse opportunities for stakeholder engagement. Zhang and Bai (2023) highlighted that climate governance is transitioning from a focus on negotiation to a practice-oriented approach that involves a variety of stakeholders and multi-faceted institutional frameworks. Moreover, Hopkins *et al*. (2016) determined that addressing methane emissions in urban environments necessitates concerted research to pinpoint specific mitigation objectives, the adoption of innovative abatement strategies, and vigilant atmospheric methane monitoring to verify the efficacy of these mitigation actions. The urgency of addressing climate change has prompted nations worldwide to implement comprehensive governance strategies (Santos *et al*., 2022). However, Olczak *et al*. (2023) noted that existing mitigation policies address only about 13% of anthropogenic methane emissions.

Short-lived climate pollutants (SLCPs) are substances, such as methane, that have a relatively short lifespan in the atmosphere but can have significant warming effects and adverse health impacts (Díaz, 2023). Methane possesses a warming potential more than 80 times greater than carbon dioxide within its initial two decades in the atmosphere (Díaz, 2023). Methane emissions significantly contribute to the formation of ground-level ozone, which poses health risks to humans and animals, and hampers photosynthetic processes in plants, leading to decreased plant growth and agricultural productivity. The impact of methane-induced ozone has led to substantial yield reductions, cumulatively amounting to an annual loss of approximately 110 million tons of crops (Díaz, 2023). Therefore, it is imperative for governments to expedite and expand initiatives aimed at significantly curtailing short-lived climate pollutants, with a particular emphasis on methane reduction. Amid this global effort, Nigeria, with its unique environmental and socioeconomic challenges, seeks to establish a tailored response that aligns with international standards yet addresses local exigencies. The aim of this paper is to explore the development of climate governance strategies in Nigeria, with emphasis on mitigating methane emissions. By delving into the interconnectedness of global climate concerns and Nigeria's specific context, we aim to provide insights into the nation's journey toward effective environmental stewardship and its significance in the broader global climate conversation.

2. Literature review

2.1 Global climate governance landscape

The recognition of climate change as a global issue began in the late 20th century. Early conferences and accords, such as the Earth Summit in Rio de Janeiro in 1992, laid the foundation for international cooperation on climate change (Jiang & Li, 2022). The Convention was formulated with the primary objective of instituting an international environmental accord to address the multifaceted challenges presented by climate change, emphasizing its ramifications on both natural and anthropogenically influenced ecosystems and the consequential implications for human health and societal well-being (Lebada & Chasek, 2021). An empirical observation central to the Convention was the notable disparity in per capita emissions between developed and developing nations. However, it also projected a surge in emissions from developing nations, a trajectory that

aligns with their inherent socio-economic and developmental trajectories. In light of these disparities and forecasts, the Convention underscored the imperative for a collaborative international approach. This approach predicates on the principle of 'common but differentiated responsibilities,' taking into account individual national capacities and the socio-economic paradigms within which they operate (Stavi, 2022).

The Earth Summit in Rio de Janeiro in 1992 culminated in the adoption of the United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC is a landmark international agreement that has played a crucial role in global climate change governance (Finlayson, 2018). It has provided a framework for international cooperation and action on climate change, bringing together countries from around the world to address this pressing issue. The convention has facilitated the negotiation and adoption of subsequent agreements, which have further advanced global efforts to combat climate change (Iwueke & Alagoa, 2018). The UNFCCC has also established a platform for ongoing dialogue and collaboration among parties, enabling the sharing of knowledge, experiences, and best practices in climate change mitigation and adaptation (Gonzales-Iwanciw *et al*., 2023). The primary objective of the UNFCCC is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Under the UNFCCC, every Party is obligated to submit their national Greenhouse Gas (GHG) inventories (Ahove & Bankole, 2018). Its annual Conference of the Parties (COP) meetings lead to various agreements, with the Kyoto Protocol and the Paris Agreement being the most notable (Maslin *et al*., 2023).

The Kyoto Protocol is an international agreement that was adopted in 1997 as an extension of the United Nations Framework Convention on Climate Change (UNFCCC) (Mor *et al*., 2023). It aimed to address the issue of greenhouse gas emissions and combat climate change. It placed mandatory targets on industrialized countries, recognizing their role in the current levels of greenhouse gases (Maizland, 2023). The Kyoto Protocol delineates explicit and quantifiable measures for the Parties. One of its most ambitious mandates is the reduction of global GHG emissions by a minimum of 5% during the commitment span of 2008 to 2012. This pivotal accord underscores the imperative of constraining global warming to a range of 1.5–2.0°C relative to pre-industrial benchmarks (Fawzy *et al*., 2020).

The Paris Agreement represents a crucial step in international efforts to combat climate change and promote sustainable development. It is a significant international treaty that aims to address climate change and limit global warming to well below 2 degrees Celsius above pre-industrial levels (Teo, 2023). It includes key provisions such as nationally determined contributions, a global stocktake, a transparency framework, and support for adaptation and finance. The agreement highlights the need for financial resources to support developing countries in their climate actions, including mitigation and adaptation efforts (Denchak, 2021). It sets a goal of mobilizing $100 billion per year by 2020 from a variety of sources (Kozul-Wright, 2023). The agreement has been ratified by 197 countries including Nigeria, demonstrating global commitment to addressing climate change (Akinbusoye *et al*., 2023). Unlike the Kyoto Protocol, the Paris Agreement requires all countries to outline their plans for climate actions (Maizland, 2023).

Beyond the UNFCCC, a myriad of other organizations actively shaped the global response to climate change, offering diverse perspectives, resources, and expertise. The World Bank, for instance, dedicates substantial financial resources and technical knowledge to aid countries in their adaptation and mitigation efforts. Through funding for infrastructure projects, capacity-building initiatives, and research, the World Bank ensures that nations, especially those most vulnerable, are equipped to address climate-induced challenges (Eisenstadt *et al*., 2021; Michaelowa *et al*., 2021).

The Intergovernmental Panel on Climate Change (IPCC) is another cornerstone in the global climate effort. It consolidates scientific research from around the world to provide objective insights into the state of the climate and potential future scenarios. By offering evidence-based recommendations and drawing attention to critical areas of concern, the IPCC shapes policy decisions at both national and international levels, ensuring they are grounded in the latest scientific understanding (Hermansen *et al*., 2021; North *et al*., 2022).

Meanwhile, non-governmental organizations (NGOs) bring a grassroots dimension to the global climate movement. Through advocacy, research, and on-the-ground projects, NGOs bridge the gap between local concerns and global discussions (Ceesay, 2020). They highlight the voices of those most affected by climate change, ensuring that global strategies are both inclusive and effective (McGregor *et al*., 2018). Furthermore, NGOs often pioneer innovative solutions, collaborate across borders, and act as watchdogs, holding governments and corporations accountable for their environmental commitments (Vu *et al*., 2021). Collectively, these organizations contribute layers of expertise, advocacy, and action, making the global response to climate change multifaceted and robust.

2.2 Nigeria's role and strategies in climate governance

Nigeria has been actively involved in international climate negotiations since 1994 when the country became a party to the United Nations Framework Convention on Climate Change (UNFCCC) (Oramah & Olsen, 2020). The country's engagement in these negotiations is crucial for preparing Nigeria for the impacts of climate change (Ojomo *et al*., 2015). Nigeria has also made efforts to mitigate climate change through the regulation of gas flaring in the Niger Delta (Afinotan, 2022). Nigeria, as part of the African group of negotiators, has been active in international climate negotiations since their inception (Chime, 2022). The nation ratified the Kyoto Protocol in 2004 and the Paris Agreement in 2017 (Chime, 2021). Nigeria is attributed with emitting approximately 48 million tonnes of GHG emissions, surpassing the combined total of the entire sub-Saharan Africa (Afinotan, 2022).

Nigeria ranks among the top ten countries globally for vulnerability to climate change impacts (Edeminam & Akpasoh, 2023). Located in West Africa, Nigeria faces specific climate-related challenges such as rising sea levels affecting its coastal areas, desertification in the north, and increased flooding. In 2022, Nigeria experienced its most severe flooding since 2012, resulting in over 800 fatalities, displacing around 1.5 million residents, injuring 2,407 individuals, and impacting roughly 2.5 million people (Okeke *et al*., 2023). The country's vulnerability to climate change is evident due to its geography, climate, vegetation, soils, economic structure, population, settlement, energy demands, and agricultural activities (Ogunbode, 2021). The combination of high climatic variability, poor infrastructure, and other associated problems pose significant challenges for Nigeria (Okon *et al*., 2021). Nigeria has taken steps to address climate change by establishing agencies and portfolios dedicated to tackling climate change issues (Ayodele *et al*., 2017). These challenges necessitate tailored climate governance strategies.

The Nigerian government, recognizing the imminent threats of climate change, launched several policies and initiatives (Amuda-Kannike *et al*., 2023). The National Climate Change Policy and Response Strategy (NCCPRS) in 2012 was a step towards creating a comprehensive response to climate change. The National Climate Change Policy and Response Strategy (NCCPRS) is a comprehensive framework developed by the Federal Ministry of Environment in Nigeria to guide the country's efforts in addressing climate change. The NCCPRS consists of several key documents, including the National Climate Change Policy, the National Climate Change Response Strategy, Nigeria's Intended Nationally Determined Contributions (INDC) towards the Paris Agreement, the National Adaptation Strategy and Plan of Action on Climate Change for Nigeria, and the National Greenhouse Gas Inventory Report for Nigeria (Federal Ministry of Environment, 2021).

Nigeria, in its proactive approach to addressing climate change, has earnestly sought international partnerships to amplify its climate governance efforts (Nwokolo *et al*., 2023). Recognizing the multifaceted nature of the challenges posed by climate change, the nation understands the need to draw upon the collective intelligence, resources, and experiences of the global community. These collaborations with international bodies, non-governmental organizations (NGOs), and other nations have not only served as platforms for dialogue and knowledge exchange but have also facilitated the transfer of vital technology, mobilization of funds, and the sharing of specialized expertise. Such synergies are invaluable, especially when crafting policies and strategies that are both locally relevant and globally informed. Through these partnerships, Nigeria is

positioning itself to be both a beneficiary and a contributor in the global quest to combat and adapt to the ever-evolving threats of climate change (Ogunkan, 2022).

Nigeria, enriched by a mosaic of cultural diversity and set against the backdrop of varied landscapes, holds a distinct position in the African continent due to its socioeconomic and environmental intricacies. These dynamics, ranging from its expansive economy to its extensive natural resources, give it a unique edge in taking a leadership role in climate governance within the region. Recognizing the delicate interplay between global obligations and localized necessities, Nigeria has continuously sought to harmonize its international commitments with its domestic priorities. This approach not only ensures alignment with the broader goals of international climate conventions but also addresses the pressing needs of its populous and diverse citizenry. By judiciously balancing these global responsibilities with inherent national needs, Nigeria is strategically positioning itself to delineate a future marked by sustainability, resilience, and inclusive growth. As the nation embarks on this journey, its strategies and successes can serve as a template for other African countries aiming to bolster their climate governance frameworks.

3. Understanding methane emissions in Nigeria

In global discussions about climate change, carbon dioxide often takes centre stage due to its prevalence and long lifespan in the atmosphere. However, methane, though present in smaller quantities, has proven to be a more potent greenhouse gas in the short term. In Nigeria, a nation with diverse environmental and socioeconomic landscapes, understanding and managing methane emissions is imperative. This section delves into the role of methane in climate change and identifies its primary sources within Nigeria.

3.1 Role of methane in climate change

Methane is a greenhouse gas (GHG) that is over 25 times more potent than carbon dioxide (CO_2) in trapping heat in the atmosphere over a 100-year period (Bodunde, 2023). Comprising 85 to 95 percent of natural gas, methane stands as the second most prevalent greenhouse gas, following carbon dioxide (Powell, 2019). Its presence in the atmosphere can be attributed to both natural processes and human activities. Currently, methane emissions resulting from human activities are responsible for approximately 45% of the net global warming experienced today. Additionally, methane acts as a precursor to tropospheric ozone, a significant and potent contributor to climate change at ground level (Díaz, 2023). On a molecular level, methane's potency arises from its ability to efficiently absorb and emit radiation in specific parts of the infrared spectrum, which is where Earth emits energy. Consequently, while methane concentrations are significantly lower than carbon dioxide, the gas can trap an inordinately large amount of heat (Powell, 2019).

Methane has a shorter atmospheric lifespan than CO_2, averaging about a decade. However, its warming impact during that time is considerably more intense as depicted in Table 1. After this, it gets converted into water and carbon dioxide through a series of chemical reactions, which means that its short-term effect on global warming is much greater than its long-term effect (Balcombe *et al*., 2018).

Table 1 – Lifespan and Global Warming Potential (GWP) values for primary greenhouse gases as reported in the IPCC's fifth assessment report (Iwueke & Alagoa, 2018).

GHGs	Lifetime (Years)	Time Horizon	
		20 Years	100 Years
Carbon dioxide (CO_2)	30 - 95	1	1
Methane (CH_4)	12.0	84	28

Nitrous oxide (N_2O)	121.0	264	265

Methane release can set off feedback loops. For instance, as Arctic permafrost melts due to rising temperatures, vast reserves of trapped methane are released. This newly released methane can further amplify global warming, leading to more permafrost melt in a dangerous cycle (Mooney, 2023).

The initiation of the Global Methane Pledge at the COP26 summit in 2021 has heightened international awareness of the risks posed by methane. This collaborative commitment, involving 150 countries, aims to reduce global methane emissions by a minimum of 30% from the levels recorded in 2020 by the year 2030. Despite this pledge, projections indicate that, in the absence of significant reduction efforts, methane emissions could rise by 5% to 16% over the 2020 figures by the end of the decade (Díaz, 2023).

3.2 Major sources of methane in Nigeria

While methane's contribution to Nigeria's overall GHG emissions might be overshadowed by carbon dioxide, its role in accelerating global warming, especially in the short term, cannot be overlooked. Addressing the multifaceted sources of methane emissions in Nigeria requires a comprehensive understanding of its national profile and targeted mitigation strategies across sectors. With global attention shifting towards more encompassing climate strategies, Nigeria's focus on methane can serve as a critical component of its broader climate governance framework.

Global and Nigeria’s methane emissions

In 2022, the total methane emissions amounted to 589 million tonnes (Mt). Of this, natural sources contributed approximately 233 Mt, accounting for around 40% of the total emissions. The remaining 60%, equating to 356 Mt, originated from human activities, also referred to as anthropogenic emissions. The main contributors to these anthropogenic emissions were agriculture (142.3 Mt), the energy sector (133 Mt, encompassing oil, natural gas, coal, and biofuels industries), and waste management (70.8 Mt) (International Energy Agency, 2023). Nigeria's methane emissions profile (Figure 1) is influenced by various sectors, each contributing differently to the national output. In their study, Kulkarni *et al*. (2022) conducted a detailed examination of ground-level methane emissions from human-made sources in two primary Indian cities. They pinpointed three main sources: fossil fuel exploration and energy production, agricultural and livestock activities, and waste processing and disposal.

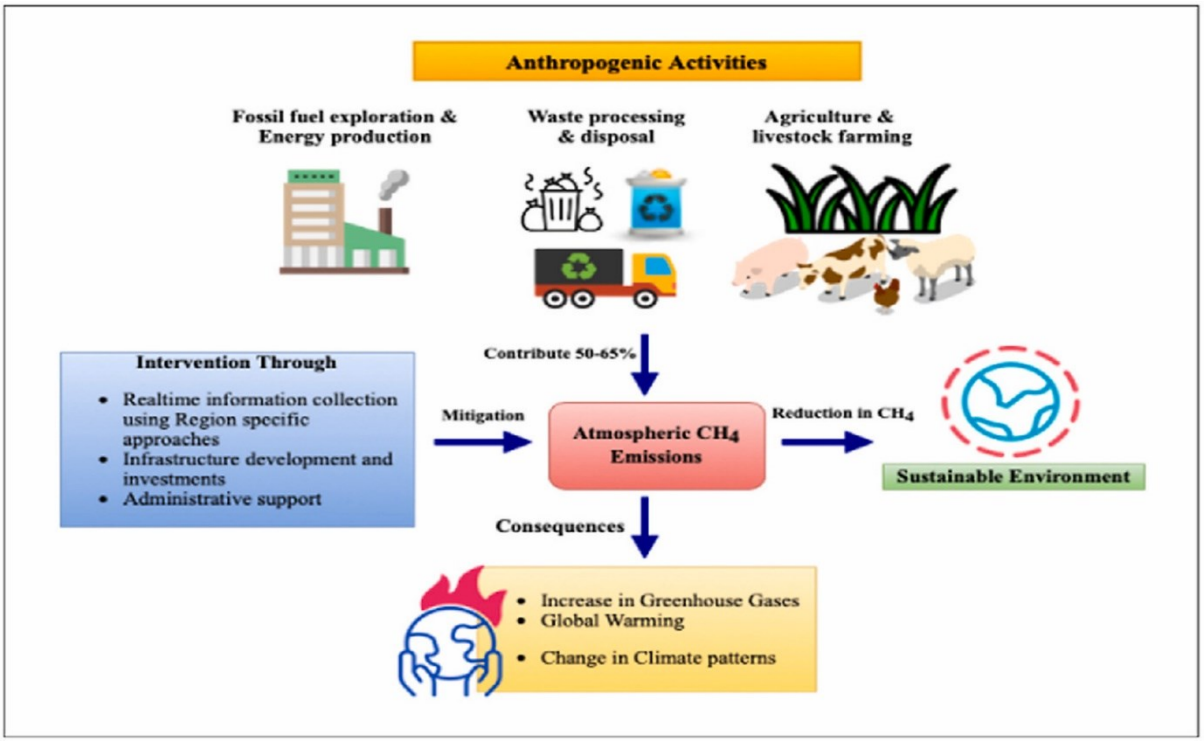

Figure 1 – Nigeria's methane emissions profile.

Sector-specific contributions

Oil and gas: Gas flaring stands as the primary method through which Nigeria adds to the worldwide share of harmful greenhouse gases emitted into the atmosphere (Afinotan, 2022). Nigeria, as a significant oil-producing nation, has considerable methane emissions resulting from the extraction, production, and transportation of oil and natural gas (Odogwu, 2023).

In Nigeria, gas flaring from the petroleum sector significantly contributes to greenhouse gas emissions, driving climate change. This process involves burning the associated gas that emerges during crude oil extraction (Olujobi *et al*., 2022). Flaring and venting during oil extraction are primary contributors. Despite efforts to curb gas flaring with the enactment of the Gas Flare (Prevention of Waste and Pollution) Regulations 2018, the practice remains prevalent, leading to significant methane emissions (Afinotan, 2022).

Agriculture: Nigeria's agricultural sector, with its variety of practices, is a notable contributor to the country's methane emissions. This sector encompasses a wide range of activities, each contributing to methane production in different ways.

In Nigeria, rice is one of the staple crops, and its cultivation often involves flooded paddy fields. These fields, when flooded, create anaerobic (oxygen-free) conditions, ideal for the growth of methanogenic (methane-producing) microbes. These microbes break down organic matter in the soil, releasing methane as a byproduct. The extent of methane emissions from rice paddies is influenced by several factors, including water management practices, the organic content of the soil, and the specific rice cultivars used.

Another significant contributor to methane emissions in Nigeria's agricultural sector is livestock rearing, particularly of ruminant animals like cows. These animals have a unique digestive system that includes a stomach compartment known as the rumen. In the rumen, a complex community of microbes aids in breaking down fibrous plant materials. This process, called enteric fermentation, produces methane as a byproduct, which is then released into the atmosphere when the animals belch. The amount of methane produced depends on various factors, including the animal's diet, breed, and digestion efficiency (Chukwuma *et al*., 2018).

Wetlands: The Niger Delta region, renowned as one of the largest wetland systems globally, plays a significant role as a natural methane emitter. This region, characterized by its extensive river delta and mangrove ecosystems, provides the ideal conditions for methane production. The process is primarily due to the anaerobic (oxygen-free) decomposition of organic matter in the waterlogged soils that typify wetlands. In these oxygen-deprived conditions, specific microorganisms thrive, breaking down organic material in a way that releases methane as a byproduct.

This phenomenon is not unique to the Niger Delta but is a characteristic feature of wetland environments worldwide. Wetlands, including swamps, marshes, and peat bogs, are among the most significant natural sources of methane, a potent greenhouse gas. The methane production in such environments is a part of a natural carbon cycle, but the increasing scale and intensity of these emissions are becoming a concern in the context of global climate change.

Further complicating the situation in the Niger Delta is the region's vulnerability to human activities, such as oil and gas exploration, which can exacerbate the release of methane. Disturbances to the wetland ecosystems, whether through direct physical disruption or pollution, can alter the natural processes and potentially increase methane emissions.

Moreover, climate change impacts such as rising temperatures and changing precipitation patterns can also affect the rate of methane production in wetlands. Warmer temperatures, in particular, can stimulate microbial activity, leading to increased methane emissions. This creates a feedback loop, where increased methane contributes to global warming, which in turn could further enhance methane production from wetlands.

Thus, while the Niger Delta's wetlands are part of a natural process of methane emission, understanding and monitoring these emissions is crucial. This understanding is essential not only for assessing the regional contribution to global greenhouse gas levels but also for managing and mitigating the impacts of human activities on these sensitive ecosystems (American Society of Agronomy, 2019; Wetlands International, 2023).

Waste management: Landfills, wastewater treatment facilities, and other waste management processes, particularly in urban areas, release methane. The decomposition of organic waste in landfills under anaerobic conditions leads to methane generation. The management of landfills is a crucial aspect of waste management due to their potential to emit methane, a potent greenhouse gas. Methane emissions from landfills are a significant contributor to global greenhouse gas emissions.

The Intergovernmental Panel on Climate Change (IPCC) has recognized the importance of mitigating methane emissions from waste in its Fourth Assessment Report. Strategies for mitigating methane emissions from landfills include the implementation of landfill gas collection systems, which capture methane and convert it into energy. The effectiveness of these systems in reducing methane emissions has been demonstrated in various studies.

Additionally, the IPCC report highlights the importance of reducing organic waste in landfills through waste reduction, recycling, and composting. These practices can help minimize the amount of organic waste that decomposes and produces methane in landfills. The report also emphasizes the need for proper landfill design and operation to minimize methane emissions. This includes measures such as compacting waste to reduce oxygen availability, which can inhibit methane production.

Furthermore, the IPCC report suggests the use of landfill covers and liners to prevent the release of methane into the atmosphere. The implementation of these strategies requires collaboration between waste management authorities, policymakers, and other stakeholders (Bogner *et al*., 2008). It is important to note that the effectiveness of methane mitigation measures may vary depending on factors such as landfill size, waste composition, and local regulations. Therefore, a comprehensive approach that combines multiple strategies tailored to specific landfill conditions is necessary to effectively reduce methane emissions from landfills.

Lack of Infrastructure: The lack of adequate infrastructure in Nigeria presents a significant challenge in harnessing methane for beneficial use, particularly in sectors like oil extraction and waste management. Methane, a potent greenhouse gas, is often released into the atmosphere as a byproduct of these activities, contributing to climate change. However, with the right infrastructure, this methane could be captured and utilized as a valuable energy source, turning a waste product into an asset.

In the oil extraction process, natural gas, which is primarily composed of methane, is often found alongside crude oil. In Nigeria, the lack of infrastructure to process and transport this natural gas leads to flaring or venting, where the gas is burned off or released directly into the atmosphere. This not only wastes a potential energy source but also releases large amounts of methane and carbon dioxide, exacerbating greenhouse gas emissions. Developing infrastructure to capture this natural gas could transform it into a significant energy resource, providing power for local communities and industries, and reducing environmental impact.

In the waste management sector, landfills and wastewater treatment facilities are major sources of methane emissions. Organic waste decomposes anaerobically in landfills, producing methane. Currently, much of this methane escapes into the atmosphere due to the lack of systems to capture and utilize it. By implementing landfill gas capture technologies, this methane can be collected and used to generate electricity or heat, or even processed into natural gas for use in homes and businesses. Similarly, methane capture from wastewater treatment plants can provide a renewable energy source while reducing emissions.

3.3 Need for enhanced methane emission standards and abatement strategies in Nigeria

There is a pressing imperative for Africa, especially Nigeria, to adopt and enforce heightened methane emission standards and implement comprehensive abatement strategies. Figure 2 indicates that a mere 4% of methane mitigation policies have been implemented in Africa. Olczak *et al*. (2023) posited that Africa requires fresh regional and national policies to capitalize on methane mitigation opportunities. This assertion stems from Africa's significant contribution to global methane emissions, its leading role in global fossil fuel production, and the anticipated rapid economic growth in its emerging economies compared to advanced ones, which could lead to increased consumption. Nigeria plays a pivotal role in global climate change mitigation, given its substantial contribution to Africa's greenhouse gas (GHG) emissions through the uncontrolled release of methane from its oil and gas sector in the Niger Delta (Afinotan, 2022). Furthermore, Dioha and Kumar (2020) believed that by focusing on the reduction of methane emissions in Nigeria, both the local impacts of climate change can be mitigated, and the overall global emission dynamics can be significantly influenced.

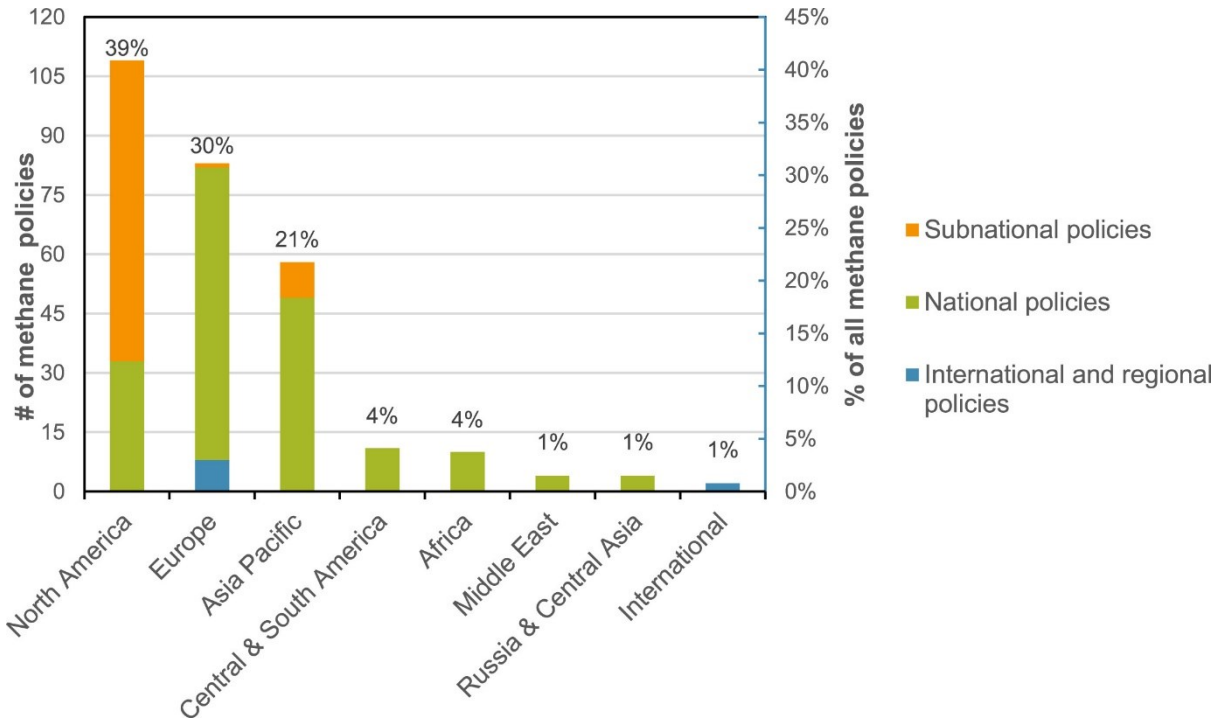

Figure 2 – Overview of methane policies adopted at subnational, national, and regional/international levels by region (Olczak *et al*., 2023).

Nigeria took decisive steps in 2023 to regulate methane emissions within the oil and gas industry. The nation aims to reduce methane emissions from flaring by 100% by 2030 and cut fugitive methane leaks by 95% by 2050. In 2018, the energy sector emitted 209 million tonnes of CO_2 equivalent, with 33% attributed to the oil and gas sector. These mitigation efforts are integral to Nigeria's NDC targets, aiming for an unconditional 20% reduction and a further 47% with international assistance.

The Climate and Clean Air Program (CCAP) resulted from a strategic partnership being established between the Institute of the Environment Limited, University of Port Harcourt, Nigeria; Chalmers University of Technology, Sweden; and the Government of Nigeria regarding the building of a knowledge platform that will facilitate sustainable atmospheric methane and other volatile organic compounds (VOCs) mitigation measures. The Climate and Clean Air Program (CCAP) was introduced to reduce short-lived climate pollutants (SLCPs) that contribute to both climate change and air pollution (Diaz, 2023). By incorporating short-lived climate pollutants (SLCPs) into national planning and the NDC, Nigeria has facilitated stakeholder engagement across budgeting, development, and investment sectors. This integration, marked by the SLCP National Action Plan, ensures that the 22 SLCP Mitigation Measures are pivotal in achieving Nigeria's NDC objectives (Malley *et al*., 2021).

The Nigeria Upstream Regulatory Petroleum Commission (NURPC) oversees the creation and monitoring of methane mitigation guidelines (NUPRC, 2022). A baseline for fugitive methane was established using the Country Methane Abatement Tool (CoMAT), and a data reporting framework for methane management was developed. By mid-2023, over 70% of oil and gas operators adhered to the regulations, providing a greenhouse gas emissions management plan within six months of its introduction. This plan outlines their operations, emission sources, quantification methods, annual and long-term emission reduction targets, and a commitment to upgrade to combined cycle turbines by 2030.

Operators must provide quarterly fugitive emission and GHG monitoring reports to NUPRC. These rules affect oil and gas production sites, export terminals, and gas processing and gathering stations. Companies are now mandated to conduct yearly greenhouse gas inventories and LDAR

inspections, aiming to phase out pneumatic devices within five years. These norms are integrated into the design, setup, and modification of oil and gas infrastructure, ensuring alignment with emission reduction guidelines. To fortify inspection efficacy, NURPC offers LDAR training, encompassing field visits. Oil and gas entities are invited to partake for a clearer grasp of inspection modalities.

Beyond this sector, Nigeria's SCLP National Action Plan charts ambitious reduction goals. By adopting all 22 stipulated abatement strategies, a projected 61% cut in SLCP emissions is expected by 2030. Key goals include halving methane from landfills and open waste burning, reducing agricultural emissions by 30%, transitioning 25% of buses to natural gas by 2030, and targeting an 80% reduction in HFCs by 2045 (CCAC Secretariat, 2023).

4. Challenges and collaborative solutions

Understanding the gravity and complexity of methane emissions and their mitigation requires a deep dive into both the challenges and the collaborative solutions that have been formed in response. As one of the most potent greenhouse gases, methane's role in global warming is paramount, and efforts to curb its release have been the focus of many national and international strategies.

4.1 Methane emission mitigation strategies

Methane presents unique challenges in the realm of greenhouse gases. While its concentration in the atmosphere is less than that of carbon dioxide, its global warming potential over a 20-year period is significantly higher. Consequently, even small leaks or unintentional emissions can have profound environmental implications.

Several industries, notably agriculture, waste management, and fossil fuels, are significant contributors to methane emissions. The diversity of sources means that a one-size-fits-all approach is ineffective, necessitating tailored strategies for different sectors. Methane abatement efforts extend significant ancillary benefits, notably in enhancing public health and safety by contributing to improved urban air quality through the global diminution of ozone levels (Anenberg *et al*., 2012). Tyner and Johnson (2018) asserted that both the technology and economics for mitigating methane emissions are within reach. Nevertheless, the process of mitigating these emissions has consistently posed challenges. Kohler *et al*. (2022) highlighted a fundamental gap in knowledge regarding the specific locations and temporal dynamics of urban methane emissions at scales appropriate for effective monitoring and management.

<u>Strategies in the agricultural sector:</u>

Agriculture, particularly livestock farming, is a leading source of methane. Enteric fermentation in ruminants, such as cattle, produces methane as part of their digestive process. Strategies here include:

- *Dietary adjustments*: Research has shown that altering livestock feed, incorporating additives like seaweed, can reduce methane production during digestion.
- *Manure management*: Methane is produced during the decomposition of manure. Techniques like anaerobic digestion can be employed to capture this methane and use it as a biogas.

<u>Strategies in the waste management sector:</u>

Landfills are methane hotspots. As organic waste decomposes, methane is released.

- *Landfill gas collection*: Modern landfills are equipped with systems to collect and channel methane emissions, which can then be flared or used as an energy source.
- *Organic waste diversion*: Composting or digesting organic waste separately can reduce methane emissions from landfills.

<u>Strategies in the oil and gas industry:</u>

The extraction, processing, and transport of fossil fuels, especially natural gas, are rife with methane emissions.

- *Leak detection and repair*: Regular monitoring and timely repair of leaks in drilling sites, pipelines, and processing plants can significantly reduce emissions.
- *Flaring*: In instances where capturing methane is not viable, flaring can convert methane to CO_2, a less potent greenhouse gas.

Promoting technological innovations:

Across all sectors, technology plays a pivotal role. Innovations like drone-based methane detectors and bio-engineered feed for livestock can elevate the efficiency of mitigation efforts. Table 2 encapsulates the foremost mitigation strategies deployed across various sectors as.

Table 2 – Compilation of key methane mitigation approaches by sector (Adapted from Ocko *et al*., 2021).

Sector	Methane mitigation measures
Livestock	Incorporation of methane inhibitors, use of electron sinks, integration of oils and oilseeds into feed, adoption of intensive grazing practices, enhancement of feed conversion efficiency, systems for manure coverage and digestion, selective breeding programs; exclusion of dietary changes in humans.
Rice cultivation	Enhancement of irrigation systems, implementation of advanced cropping techniques, optimization of fertilization levels such as the use of rice straw compost prior to transplanting, intermittent irrigation practices, introduction of alternative rice hybrids, and soil amendments.
Oil and gas industry	Upstream leak detection and repair, replacement of inefficient pumps, transition to instrument air systems, installation of vapour recovery units, capture of blowdown gases, substitution with electric motors, proactive replacement of faulty devices, upgrades to compressor seals or rods, installation of flares, implementation of plunger systems, downstream leak detection and repair.
Coal mining	Deployment of pre-mining degasification techniques, coal bed drying, inundation of abandoned mine shafts, enhancement of ventilation systems and methane capture through oxidation, implementation of open flaring methods.
Landfills	Generation of electricity via reciprocating engines, gas turbines, combined heat and power (CHP) systems, or microturbines combined with landfill gas recovery, segregation at source with recycling or waste treatment with energy capture for municipal wastes, similar recycling or treatment strategies for industrial wastes; elimination of organic waste landfilling.

4.2 Stakeholder collaboration and potential hurdles

Challenges in methane emission mitigation are manifold, and the solutions are equally diverse. However, with a collaborative spirit, embracing both technological innovations and global partnerships, these challenges can be surmounted. As the world stands at an environmental precipice, it is these collective efforts that will determine the sustainability of our shared future. Methane mitigation is not solely the responsibility of any single entity. Governments, industries, NGOs, and the general public have roles to play. Collaborative action is necessary not only to pool resources but also to ensure that mitigation efforts are holistic and effective.

Private-Public Partnerships:

Industries, especially those in the fossil fuel sector, are often better equipped in terms of technology and logistics to handle methane mitigation. Governments, on the other hand, can provide policy support, incentives, and regulatory frameworks. Collaborations between the two can yield scalable and sustainable solutions.

NGOs and grassroots movements:

While top-down approaches are vital, bottom-up movements led by NGOs and community groups can address localized issues effectively. They can also play a pivotal role in awareness campaigns, ensuring that the public remains informed and involved.

International collaborations:

Methane mitigation is a global challenge. Collaborations, in the form of shared research, technology transfer, and policy harmonization, can accelerate efforts. International agreements, like the Paris Agreement, also offer a framework for nations to collectively address the challenge.

Potential hurdles:

Collaborative efforts, while essential, are not without challenges:

- *Differing priorities*: Industries might prioritize profitability over environmental considerations, leading to potential conflicts with regulatory bodies.
- *Regulatory gaps*: Inconsistencies in regulations, especially across nations, can hinder effective mitigation.
- *Economic constraints*: Methane mitigation, in the short term, can be capital-intensive, potentially dissuading industries from adopting necessary measures.
- *Public perception*: Misinformation or a lack of awareness can hinder public support for necessary initiatives.

5. Conclusion

Throughout our exploration of methane emissions and its implications for Nigeria, several key findings have emerged. Firstly, methane's potency as a greenhouse gas cannot be understated; even though its atmospheric concentration is less than carbon dioxide, its impact on global warming is substantial. Different sectors in Nigeria, especially agriculture, waste management, and the fossil fuel industry, have been identified as significant contributors to methane emissions. Addressing these emissions requires tailored, sector-specific approaches. Collaborative efforts, bringing together public and private entities, grassroots movements, and international partners, are crucial in devising and implementing these strategies. However, such collaborations come with their own set of challenges, including differing priorities and potential regulatory gaps.

Proposed steps for future climate governance in Nigeria:

1. *Policy harmonization*: Nigeria should work towards creating a cohesive policy framework that unifies efforts across sectors and aligns with international best practices.
2. *Strengthening regulatory bodies*: Agencies like the Nigeria Upstream Regulatory Petroleum Commission (NURPC) need further strengthening, ensuring they have the necessary tools and authority to monitor and enforce methane mitigation measures.
3. *Investment in research & development*: Encourage investments in technological innovations that specifically address Nigeria's unique challenges in methane emission mitigation.
4. *Public awareness campaigns*: An informed public is an empowered one. Launching comprehensive awareness campaigns about methane's impact and the measures being taken can foster public support and involvement.
5. *Private sector incentives*: Provide incentives, such as tax breaks or grants, to industries that adopt and exceed methane mitigation standards.

6. *Collaborative international initiatives*: Nigeria should actively engage in, and potentially lead, regional initiatives in Africa focused on methane mitigation, sharing knowledge, resources, and best practices.
7. *Continuous review*: As the climate crisis evolves, so should the strategies to combat it. Regular reviews of methane mitigation efforts should be conducted, adapting to new research findings and technological advancements.

In conclusion, while the challenges Nigeria faces in mitigating methane emissions are multifaceted, they are not insurmountable. With a blend of robust policies, collaborative efforts, and an emphasis on innovation, Nigeria can not only address its methane emission challenges but also position itself as a leader in climate governance in the African region.

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