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IMPACTS OF ENERGY SYSTEMS (OIL AND GAS) ON SUSTAINABLE ENVIRONMENT: A CASE STUDY OF BAYELSA STATE IN NIGER DELTA REGION, NIGERIA.

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ABSTRACT

This research aims to investigate the effects of existing oil and gas energy systems on the sustainable environment of coastal communities in Bayelsa State, focusing on landscape, water quality, air quality, and aquatic ecosystems, as well as assessing the feasibility of renewable energy alternatives. Bayelsa State is one of the areas in the Niger Delta region that has experienced environmental consequences due to oil production operations. The investigation focused on soil fertility, water quality, and the aquatic habitat in the area. It aimed to understand the effects of oil pollution on important indicators and determine potential solutions for recovery following spill incidents. The fertility profile of the study area impacted by the energy system was compared with the areas without energy system influence as one of the bases for evaluation. The study concluded that the study area is heavily polluted due to ongoing activities of the energy systems (oil and gas), impacting negatively on the quality of water resources, soil fertility, air quality, and aquatic ecosystem. Yet, the key to addressing pollution in Bayelsa state coastal communities in the Niger Delta region is through cost-effective and eco-friendly methods such as regulations, technological advancements, cleanup efforts, decarbonization, and protecting unpolluted areas. This will aid in restoring the soil fertility, water quality, and aquatic habitat back to its original ability to support life.

Keywords: Energy System, Sustainable Environment, Environmental Consequences, Remedy, Bayelsa state, Niger Delta.

I. INTRODUCTION

Sustainable environmental development is now prevalent in both developed and developing societies worldwide. Development is diverse and complex, spanning across various sectors. Development is cross-border in nature, impacting various societies, their environments, and the flora and fauna that reside within them, through systems, processes, costs, and benefits. Human beings, who are at the core of the agenda and process of development, both benefit and suffer greatly from it [1]. The finding and harvesting of natural resources have led to varying outcomes for nations that possess these resources. While a few of these countries have achieved economic strength and independence, others have been pulled into severe economic struggles and disputes. Supporters of the resource curse theory believe that the people in these nations experience extreme poverty, environmental harm, pollution, illness, and lack of education [2]. The Niger Delta region, home to Nigeria's vast oil and gas reserves, is a topic of worldwide interest due to its unifying feature of the Niger Delta. The Niger Delta, with its proximity to the Atlantic Ocean and waterways like the Benue and Niger Rivers, contains significant coastal upwelling sub-ecosystems and is a key hub for marine biodiversity and food production, known for its high productivity in coastal and offshore waters globally [3]. However, pollution from residential and industrial sources, excessive use of Oil and Gas resources, and poorly planned communities, coastal developments, and near-shore activities are leading to the rapid deterioration of fragile land, coastal and offshore habitats, and common marine resources in the region, posing risks to the economies and health of the residents. Communities in the region have recognized the significant transboundary environmental problem caused by activities such as industrial, agricultural, urban, and domestic sewage run-off, eutrophication, and gas flaring which have led to deterioration in water and air quality [3] . Pollution is commonly seen as an unavoidable cost of progress brought about by the petroleum sector. Some claim that oil spillage cannot be eliminated, even with the best oil field practices [4,5]. The advancement of coastal communities in Bayelsa State, Nigeria, is closely connected to the area's energy systems, ensuring long-term sustainability. Bayelsa, located in the canter of the Niger Delta, is abundant in oil and gas reserves, playing a vital role in Nigeria's energy industry. Yet, the utilization of these resources has resulted in significant environmental, economic, and social difficulties. Environmental deterioration in the region is being caused by oil spills, gas flaring, and deforestation, putting the fragile ecosystems at risk. The contamination of water bodies and soil is putting at risk the means of survival for local communities, who rely mostly on fishing and agriculture for their livelihoods. Furthermore, pollution-related diseases are also impacting the health of the population. From an

economic perspective, although the oil industry offers certain job prospects, the adverse effects on conventional ways of earning a living and the absence of economic variety expose communities to risks. In the face of these difficulties, there exists substantial promise for clean and sustainable energy options like solar, wind, and small-scale hydropower. Utilizing renewable energy sources can lower environmental harm, improve economic prospects, and foster social cohesion. Public concern has increased regarding environmental pollution, particularly of water sources [6]. The production of oil faces significant environmental obstacles, especially as the issue of climate change and its adverse effects gain worldwide attention from environmentalists and experts who consider the region within the broader framework of globalization [7]. The importance of environmental sustainability in the Niger Delta cannot be emphasized enough as it is vital for the future generation's wellbeing, a key element in environmental economics [8]. Rural communities in the Niger-Delta region rely completely on the natural environment for their basic needs. Over 70% of individuals rely on the natural environment for their both living and nonliving means of sustenance [9]. Low-income individuals are at risk from environmental changes as they are marginalized socially, politically, and economically, restricting their options for housing locations [10]. Therefore, they experience the negative consequences of natural disasters, loss of biodiversity and deforestation, pollution, and the detrimental effects of industrialization related to oil exploration. Sadly, many individuals in developing nations lack access to clean drinking water due to widespread contamination from oil spills. Ensuring the sufficient provision of high-quality drinking water is essential, and maintaining a sustainable, long-term supply is a matter of both national and international importance [11].

This study seeks to investigate how the current energy systems affect the sustainable environment of coastal communities in Bayelsa State, as well as to assess the viability of renewable energy options. By grasping these interactions, decision-makers, interested parties, and residents can collaborate on achieving a more durable and adaptable future for the area.

II. THE NIGER DELTA

The Niger Delta area is located at the tip of the Gulf of Guinea on the western side of Africa in South-South Nigeria. Approximately 31 million individuals reside there, comprising 7.5% of Nigeria's total land area [13]. Approximately 1,182 exploration wells have been drilled in the delta basin, and around 400 oil and gas fields of different sizes have been recorded [14]. This area spans across more than 800 communities that produce oil, with a vast network of over 900 oil wells and various petroleum production facilities [15]. The geology of the Niger Delta petroleum systems includes Lower Cretaceous (lacustrine) and Upper sections.[16] states that a substantial amount of the global oil and gas reserves can be found in tertiary terrigenous passive continental margins, which contributes to the abundant hydrocarbon resources in Nigeria's Niger Delta.The ecological regions are divided into tropical rainforest in the north of the Delta and mangrove forest along the warm southern coastlines. Mangrove forests and swamps, known for their frequent saltwater flooding, are crucial to the local economy and support a diverse range of plants and animals within an intricate ecosystem [17]. Based on the World B classification, freshwater swamp forests are located inland, separate from mangrove forests, and are characterized by numerous swamps and ponds that fill with floodwater, saturating the soil for a minimum of the rainy season. Two additional ecological regions exist: lowland rainforests and barrier island forests, both of which are in decline. The Niger Delta, Africa's largest mangrove forest and the world's third largest, boasts a diverse range of fauna and flora such as mona monkey, speckle-throated otter, marsh mongoose, and barracuda. The region is home to many of Nigeria's endemic species [18], holding a significant percentage of plant and animal species, yet lacks a coastal/marine protected area.

III. THE STUDY AREA

Bayelsa State is located between latitudes 4°15'N and 5°23'N and longitudes 5°22'E and 6°45'E. These coordinates place it in the heart of the Niger Delta, one of the world's largest and most intricate delta systems (Figure 1). Its geographical positioning is crucial for its climatic conditions, ecological diversity, and economic activities, particularly in the oil and gas sector. The landscape of Bayelsa State is predominantly shaped by its deltaic environment. It features extensive swamps, both freshwater and saltwater, dominated by lush mangrove forests. These mangroves are not only vital for protecting coastal areas from erosion but also serve as breeding grounds for various fish species, supporting local fisheries. Numerous creeks and rivers, including the prominent Nun and Forcados Rivers, crisscross the state. These waterways are essential for transportation and the livelihood of many communities, providing routes for boats and facilitating trade. Additionally, the state's landscape is characterized by low-lying floodplains prone to seasonal flooding, which enriches the soil and supports agriculture. The presence of several islands and deltaic plains, formed by sediment deposition from the Niger River, adds to the state's geographical complexity. These areas are often rich in nutrients, supporting diverse plant and animal life and contributing to the region's high biodiversity. The geology of Bayelsa is marked by extensive deltaic deposits from the Niger River, including alluvial, fluvial, and marine sediments. These deposits have created a complex subsurface structure, which, combined with the high organic content of the sediments, has led to the formation of significant oil and natural gas reserves. These hydrocarbon reserves are a cornerstone of Nigeria's petroleum industry, contributing substantially to the nation's economy

Fig 1. Geographic location of the study area on Nigeria Map

IV. IMPLICATIONS OF THE ENERGY SYSTEMS ON ENVIRONMENTAL SUSTAINABILITY

4.1 Impact on Air Quality

There is no atmospheric condition that is devoid of environmental pollutants. Good air quality is achieved when there are acceptable levels of solid particles and other pollutants in the atmospheric composition, despite the impossibility of achieving perfect atmospheric conditions due to human activities resulting from advanced technology. The level of atmospheric pollution could rise above the acceptable limit because of the release of air pollutants, as well as the direction of the wind and temperature in the atmosphere [19]. The existence of air pollutants causes the subsequent environmental worries. Most of the time, the atmosphere in Bayelsa State (Niger Delta) is filled with smog and soot (Figure 2). Smog and particulate matter are common forms of air pollution. Ground level ozone, known as smog, forms when the waste products from burning fossil fuels react with sunlight. Soot, which is made up of minuscule particles of chemicals, soil, smoke, dust, or allergens, whether in gas or solid form, enters the atmosphere. Air pollution consists of tiny particles that are 10 micrometers (μm) or less in diameter, known as PM10, and even smaller particles with diameters typically 2.5 micrometers (μm) or less, known as PM2.5. Particulate matter consists of minuscule liquid or solid droplets that can be breathed in and result in severe health impacts [20]. Particles measuring less than 10 micrometers in diameter (PM10) can enter the lungs through inhalation and potentially enter the bloodstream. Tiny particles, also known as PM2.5, present a higher likelihood of causing health problems [21, 22].

Fig 2. Smog and soot pollution in the study area

4.2 Impact on Groundwater and Surface Water

The quality of groundwater and surface water, crucial sources of drinking water, is at risk from excessive usage and contamination by chemicals (such as oil and grease) and microorganisms. Shallow groundwater is easily contaminated by a mix of point and diffuse sources [11]. The degradation of the environment is a significant concern for communities in Bayelsa State in the Niger Delta due to its negative impact on productivity [23]. The main reason for this is the harmful effects of oil and gas extraction, which is primarily responsible for the declining quality of groundwater and surface water in the region. Initial findings of groundwater quality assessment near the WRPC indicate increased levels of BTEX in shallow boreholes and dug well water [24]. This situation is fascinating because, despite being an oil town for over forty years and considered the primary industrial hub in southwestern Nigeria. Some communities in Bayelsa state lacks a dependable public water supply system, forcing residents to depend on private sources such as shallow boreholes and hand-dug wells. This is indeed the case in most of the polluted communities in Bayelsa State. Due to the high-water table, the depth to water is usually less than one meter during the wet season, and the flat topography allows spills and effluent to directly impact groundwater [13]. The lack of water quality surveillance and monitoring systems in the region makes the situation even worse. It is common knowledge that spilled hydrocarbons that are not cleaned up could be trapped in the vadose zone and on the phreatic surface for years, acting as a continuous source of contamination in water supplies [13].

According to [25], the evaluation of the risk of petroleum pollution in groundwater revealed that the levels of PAHs varied between 1.92-40.47 µgl-1, with high molecular weight PAHs being found in undetectable quantities due to their poor solubility in water [13]. According to [26], pollution of groundwater is a significant issue in some Bayelsa communities in Niger Delta area caused by leaking of crude oil and processed petroleum products during extraction and processing activities (Figure 3a&b). Groundwater assessment is shifting towards a watershed perspective more and more because of widespread pollution caused by urban expansion, quick population increase, and alterations in land usage [27]. Due to the importance of groundwater in Africa [28], it is necessary to implement sustainable development strategies to reduce risks, understand hydrogeology, and use microbial methods in managing petroleum pollution.

The release of petroleum hydrocarbons and oil-contaminated waste in freshwater areas, as well as the spillover of oily substances in burrow pits during heavy rain, has negatively impacted soil and various sources of controlled water [29]. Research by [30] found that many trace metals exceeded the US EPA Maximum Contaminant Level, indicating water pollution. [31] Study of the Nun River revealed a decline in water quality due to oil production activities, with elevated levels of trace metals, conductivity, and DO compared to baseline data. [32] Analysis of oil residue from the Esi River showed a nickel-vanadium ratio of 1.71 and high Pb concentration, indicating severe pollution

Fig 3. (a) Contaminated groundwater, (b) Contaminated Surface water

4.3 Impacts of Oil and Gas on Landscape

The numerous impacts of oil spills on biota and ecosystem health are diverse. Oil disrupts the operation of different organ systems in plants and animals. It makes environmental conditions not suitable for life, such as, oil floating on the surface of water creates a barrier that stops oxygen from entering water, causing suffocation of some aquatic animals. Toxic substances found in crude oil can lead to death in plants and animals, as well as causing other harmful effects. In most cases, the toxicity level is determined by the kind and type of crude oil, the extent of oil pollution, the environment type, and the varying sensitivity of different organisms [13]. Gas flaring linked to oil production in Bayelsa state in the Niger Delta has a negative impact on

natural ecosystems and biodiversity. Gas flares usually have over 250 toxic substances. The study on the effects of gas flaring on the environment found a nearly 100% decrease in crop yield within 200 meters of the Izombe station, a 45% decrease within 600 meters, and a 10% decrease within one kilometer [22]. Additionally, the evaluation of the PAH compound ratios, such as phenanthrene/ anthracene and fluoranthene/ pyrene, indicated that the high concentration of pyrogenic PAHs in surface soils is a sign that soil contamination is caused by oil leakage and/or gas flaring [34]. As reported by [35], residents view gas flaring as a threat to the health, environment, and overall welfare of communities where oil is produced. Many agricultural lands in the affected communities in Bayelsa state (Niger Delta), known for oil production, are crucial for peasant farming, as they are constantly cultivated and help support the local communities. Reports of crude oil spills in the Niger Delta's farmlands date back to 1971 [36]. Different varieties of crude oil can have a significant impact on soil properties and microorganisms, causing either acute or long-term toxicity (Figure 4). Elevated levels of petroleum hydrocarbon in soil can lead to lack of oxygen, causing soil fauna to die from suffocation. [37] Research has examined how crude oil contamination of soil impacts the germination and growth of certain agricultural crops [38]. The impact of oil-contaminated soil on the seed growth and development of Abelmoschus esculentus, a popular vegetable crop grown in Nigeria, has been documented [38]. As stated in reference [38], the presence of petroleum hydrocarbon in agricultural soil can inhibit germination, impact the agronomic growth of Abelmoschus esculentus L., and ultimately lead to low crop yield.

Figure 4. Contaminated farmland in some affected communities in the study area

4.4 Impact of Aquatic Ecosystem

In the water, the oil slick can float on the surface and be carried to coastlines by wind and waves, ultimately impacting the soil. When there is an oil spill on land or close to the shore, the soil and other parts of the land ecosystem will be impacted without a doubt [39,40].

Oil spills frequently have a fatal impact on fish, shellfish, and other sea creatures, especially when a large number of fish eggs or larvae come into contact with the oil [40]. Shrimp and oyster industries are typically the initial victims of offshore oil spills. Fish stocks usually struggle to recuperate. Fish can be impacted by interacting with oil through their gills, consuming it, or eating prey contaminated with oil. PAHs, found in oil, are the most harmful parts of the substance [Fig 5a&b]. Vapors from oil can harm the central nervous system, liver, and lungs of an organism. Oil spills can lead to lasting reproductive issues in organisms affected by the oil [41]. Fishes are highly vulnerable to the effects of oil spills, as depicted in (Figure 5a&b). The seriousness usually leads to fatalities, disfigurement, and the disappearance of species.

Figure 5. Impacts of oil spillage on aquatic life in the affected communities

V. THE REVERSIBILITY OF THE IDENTIFIED IMPACTS OF THE ENERGY SYSTEMS

Reversing the half-a-century generated negative impact on the Niger Delta requires a three-pronged approach that focuses on not just:(a) Regulatory Measures, (b) Technological Innovations (c) and protecting unpolluted/pristine areas in the Niger Delta.

5.1 Measures of regulation

The process of cleaning and restoring an area contaminated by an oil spill is challenging and usually relies on various elements such as the spilled oil type and the water temperature, which impacts evaporation and biodegradation, and the varieties of coastal areas and sandy shores concerned [42]. This is made worse by the high cost of cleaning up oil spills physically. Microorganisms like Fusobacteria species offer an inexpensive way to clean up oil spills by colonizing and breaking down oil slicks on the ocean's surface [43]. Just like how bacteria are utilized, the bioremediation accelerator utilizes a binder molecule to transfer hydrocarbons from water to gels. The accelerator functions as a gathering agent in both water and on surfaces, bringing molecules like phenol and BTEX to the water's surface, creating clumps that resemble gel. When used on either land or water, the nutrient-packed mixture causes a surge of native, existing bacteria that thrive on hydrocarbons. This group of bacteria decomposes the hydrocarbons into water and carbon dioxide, with EPA studies demonstrating that 98% of alkanes are broken down in 28 days; and aromatics are broken down 200 times faster than in their natural environment [44]. Dispersants have the capability to break up oil slicks [45]. A dispersant is commonly a colloid that is included in a suspension to enhance the dispersion of particles and prevent them from settling or clumping together. The oil is then evenly distributed over a greater amount of water than the original surface area where the oil was released. Nevertheless, studies conducted in labs indicate that dispersants can raise the levels of toxic hydrocarbons in fish by up to 100 times and possibly harm fish eggs [46]. Oil droplets are also dispersed and penetrate deeper into the water has the potential to fatally pollute coral [47]. Solidifying agents made of small dry ice pellets that float and hydrophobic polymers can adsorb and absorb. Solidifiers do not dissolve in water, making it easy to remove the solidified oil without the risk of oil leaching out. Solidifiers are known to have minimal toxicity to aquatic and wildlife, as well as the ability to reduce harmful vapors linked to hydrocarbons like benzene, xylene, and naphthalene.

5.2 Technological Innovations

Decreasing pollution involves utilizing better technologies and methods and implementing industry best practices to lower the likelihood of pollution. One of the main goals of reducing emissions is to tackle flaring and venting, which is responsible for the majority of air pollution. Advancements in valve technology could lower fugitive emissions, and enhanced flare design has boosted combustion efficiency. The process of reinjecting produced water back into the reservoir. It is a common practice in the industry to inject produced water into other formations as a practical solution. However, suitable geological formations in the Niger Delta are becoming scarce, leading to seepage into groundwater during reinjection operations. The use of drill cuttings for brick making and roadbed material, flared gas as fuel, and produced water as wash water promotes the sustainable utilization of waste materials, preventing harm to the environment.

5.3 Protecting pristine/unpolluted areas.

Preventing pristine areas from being affected by oil and gas pollution requires implementing preventive strategies, considering the fragility of the environment and the industry's infrastructure. The Niger Delta contains a vast array of pipelines, flow-lines, gathering systems, tank batteries, and salt-water tanks that traverse regions without E&P operations taking place. Certain areas are not yet polluted but are in danger due to this network system. Although there is a program to inspect and change old pipeline parts in the Niger Delta, the soil's corrosiveness is

causing pipes to deteriorate quicker than anticipated. Regular monitoring is necessary for this preventive measure. Saltwater tanks frequently face the risk of being struck by lightning because of the accumulation of static electricity, leading to oil spills that can spread to nearby lands and waterways. This involves having a second containment system for the tanks, which simplifies the process of cleaning up any spills that occur. During potential severe storms or flooding, it is possible to extract crude oil from tank batteries and replace it with saltwater to avoid tanks tipping over. It is crucial to examine the areas for any damage that occurred post-storm. Ensuring the survival of endemic species and maintaining continuous biodiversity in untouched regions requires establishing protected areas and coastal reserves free from oil and gas development.

5.4 Decarbonation mechanisms

Decarbonization involves reducing the quantity of carbon (or CO_2) released for each unit of primary energy consumed. Transformations in the energy supply resulted in decarbonization as the emission factors differ between various fuels, with wood emitting 1.25 tons of elemental carbon (tC) per ton oil equivalent (toe). 08 tons of coal for every ton of oil, zero. 84 is the price for oil, and 0.64 is the price for natural gas [49]. Renewable energy and carbon sequestration are the two primary methods for decarbonization of energy systems (Figure 6 and 7). These methods work to manage the emission of greenhouse gases in the air by substituting the current fossil fuel energy sources like coal, oil, and natural gas, which are big producers of greenhouse gases like CH_4, CO_2, N_2, with renewable energy sources such as wind, solar, and nuclear energy that release much fewer greenhouse gases. Moreover, the process of carbon sequestration entails the retention and containment of CO_2 in geological sites like empty oil and gas reservoirs, as well as saline aquifers, to prevent its emission into the air for an extended period [50].

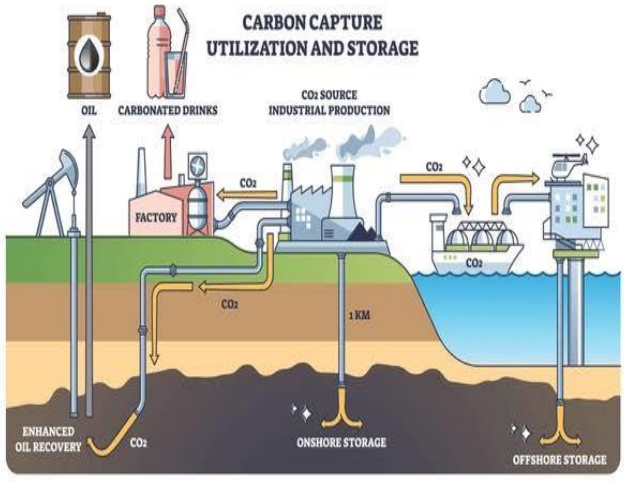

Fig 6. Schematic diagram of carbon sequestration

Fig 7. Some of the renewable energy

VI. CONCLUSION

The harm has already been caused, some communities in Bayelsa which is part of the Niger Delta is steadily declining because of the failure of main contributors. The scenery is visually unattractive and not productive. The extensive impacts are evident in assessments done on both marine and terrestrial ecosystems. With, implementing short-term solutions like the remediation techniques mentioned in Section 1.4 will produce positive results. Additional suggestions involve creating and sustaining a fundamental data collection system on the present conditions of the Niger Delta, which covers the physical and chemical characteristics of areas directly affected by pollution, such as land, water, air, and wildlife. Truly, there is existing literature and research that is currently spread out and simply needs to be organized into a database. Likewise, it is important to make the environmental data of oil and gas exploration and production multinational corporations available to the public. This can legally be mandated in order to enhance transparency.

In the future, improved collaboration among the Government, Multinationals, and Nigeria will result in greater productivity. Delta must be started. An emphasis should be placed on committing to the remediation and reclamation of the Niger Delta over a 20 to 50-year period; (a) The people of the Niger Delta must play a greater role in protecting their own communities, prioritizing a sustainable future over short-term gains, (b) Multinational companies should not only adopt best practices in their operations but also focus on economically empowering their host communities by providing job opportunities to lift them out of poverty and deter them from engaging in sabotage, (c) The government must act as the mediator between the two parties while upholding regulations to protect the environment, (d) Addressing corruption by empowering NGOs to hold all parties accountable can help combat the challenges faced in these efforts.

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