7. THE RESOURCE-RICH COUNTRIES' BLUE ECONOMY: PROSPECTS FOR SUSTAINABLE ECONOMIC DEVELOPMENT

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Abstract

As climate change and fossil fuel dependency challenge global development, the blue economy offers a promising route to sustainability. This study examines how agriculture, forestry, and fishing value added (AF), aquaculture production (AP), and fishery production (FP) affect sustainable economic development (GS) in African oil-dependent countries from 1980 to 2023. Using the Panel Nonlinear ARDL model with Driscoll-Kraay standard errors, the analysis captures asymmetric effects. Positive shocks in AF, AP, and FP promote GS through improved food security, employment, and economic diversification. Surprisingly, negative shocks also show positive long-run effects, suggesting adaptive policy responses and institutional reforms play a mediating role. By including institutional quality—measured by control of corruption—the study confirms that good governance strengthens the impact of blue economy sectors on sustainability. Findings underscore the need for targeted investments and strong institutions to transform blue economy potential into long-term development outcomes.

Key words: *blue economy, sustainable economic development, oil-dependent economies, Fisheries*

JEL Classification:

1. Introduction

For the past three decades, international reports and conferences have taken an unusual step to stop opportunities for sustainable development, which causes challenges including climate change, overuse of available resources, and degraded ecosystems. Researchers around the world are increasingly focusing on energy intensity, green growth, and blue growth. In the early days, Kraft (1978) compared energy usage with Gross National Product (GNP) to see their relationship. Because of the growing differences between energy demands and care for the environment, more countries are paying attention to saving energy, reducing emissions, and seeking sustainable ways to expand their economies. It was shown in the "Statistical Review of World Energy 2020" that coal is used in the energy mix by 36% globally; carbon emissions have decreased somewhat, yet are still unfavorably high to reach a sustainable and environmentally friendly economy. The world's environment has suffered from climate change and green growth due to emissions from fossil fuels. With this perspective, another area is now a concern of the United Nations, which it has included in its 2030 meeting agenda. At the same time as the "green economy," the blue economy has made its presence known across the globe. The goal of the

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blue economy model is to help humans and society thrive. Besides, the blue economy offers new markets and helps protect and nurture the non-material resources of the oceans. According to the Commonwealth organization, fisheries play a role in 350 million jobs globally, and by 2050, they should account for 34 % of crude oil production from offshore fields.

The United Nations called for member states to adopt integrated action on the environment, society, and the economy, urging them to aspire to sustainable economic development during the 2015 Rio Summit and set out under Agenda 2030. At the heart of this plan are the 17 Sustainable Development Goals (SDGs), which aim to improve human welfare. But for over fifteen years, SDG 13 has been slowed by high levels of greenhouse gas emissions. The targets for the SDGs depend on a 45% cut in carbon emissions by 2030, and the world still needs to reach net-zero emissions by 2050. Such countries are challenged to cut emissions even as they try to boost their economies. Even though there is a clear need for change, fossil fuels are still major sources of energy in these countries, and very little renewable energy is being integrated (Ahmad, 2025). Most of these countries have low levels of energy efficiency, largely due to the fact that little has been invested in sustainable energy innovation and projects. Present information reveals that renewable power from water, wind, and solar supplies only 14.5% of total energy in countries with large oil reserves, showing a missed chance for economic growth and danger to the environment (International Energy Agency, 2022).

People across the globe are becoming more interested in the blue economy since it could play a big role in sustainable development. To become less dependent on familiar resources, countries are counting on sustainable jobs in the ocean economy. In particular, oil-reliant countries find the blue economy attractive, as it creates opportunities for economic diversification in fishing, aquaculture, marine trade, and tourism along the coastlines. Oil-dependent countries do not see many clear advances in sustainability from the blue economy. Knowing about these differences helps policymakers create targeted and successful interventions. Studies on the sustainable blue economy are rare in oil-rich developing countries, despite overall growth in academic work. We still lack research on how oil dependence impacts a country's ability to transition to a blue economic model. The importance of this gap arises because oil dependence plays a big role in the selected countries, thus making the blue economy a better alternative. For instance, aquaculture production in Africa represents only 2.7% of global output, with Nigeria and Egypt being top producers among African oil-exporting nations (Xu & Gao, 2022). However, both countries still rely heavily on imports to satisfy domestic fish consumption needs, highlighting underdevelopment in their fisheries and aquaculture sectors despite having coastlines exceeding 850 km (Li *et al.,* 2021). This illustrates a broader issue: many oil-dependent African countries have vast marine resources yet fail to capitalize on them due to structural constraints, policy inaction, or institutional weaknesses.

Enough studies have looked into how energy intensity relates to initiatives for a green economy and a blue economy, but the challenges remain, largely because undertaking green transitions requires significant investment and advanced technology. Alternatively, the blue economy may offer faster-growing possibilities, with less effort needed, for promoting sustainable growth in regions with fewer resources. For this reason, the study seeks to add to the limited current literature by assessing the potential for fisheries, aquaculture, and agricultural production to support sustainable economic development in African countries that depend on oil. Given these risks, it is urgent to make this shift, as putting it off could increase environmental harm, use up all the resources, and subsequently slow down the UN Sustainable Development Goals (SDGs) (United Nations, 2015).

The main aim of this academic work is to study the asymmetric results between the blue economy and the sustainable economic development in oil-dependent countries. The aim is investigated by examining the nature and degree of the connection between the blue economy and oil-dependent countries' sustainable economic development. It studies how the blue economy contributes to sustainable growth and monitors abrupt changes in that relationship. While analyzing the blue economy, the research uses agriculture, aquaculture production, forestry, and fishing as main areas. These elements are used in the research because they have shown the ability to help many resource-based countries advance economically while developing sustainably. We picked these variables because they represent important economic fields that could help oil-dependent nations stop depending on oil and improve their economies. The variables we examined have two attributes: they are accessible and fit with the economic changes happening in the studied countries. We also selected the sampled countries based on how heavily these countries (Nigeria, Egypt, Algeria, Angola, and Libya) depend on oil. Because the petroleum industry influences their economies highly, the countries show substantial export levels of oil. These countries have been selected as study subjects because they are both typical African oil-dependent nations and supply all the necessary data. The selected countries are ideal for analyzing the different effects the blue economy has on each nation due to their unique economies, systems of government, and regulations. The study period needed for analysis is influenced by how accurately and available the data about the blue economy and sustainable growth are obtained. Examining data from 1980 to 2023 makes it possible to study how various blue economy elements have changed over time. With this specific time frame in mind, researchers can check plenty of marine renewables as well as the rising growth of sustainable fishing. There is a link between the studied era, economic developments worldwide, climate policy, and African priorities regarding sustainability.

The interaction between the blue economy and the energy industry needs to be properly understood to come up with practical and sustainable expansion projections. Where previous researches have mostly depended on their standard estimation approaches, this paper uses more complex methodology to discuss not only linear, but also nonlinear connections between energy-related variables, renewable energy sources, blue economy practices, and sustainable development in oil-dependent nations. In particular, Panel nonlinear ARDL model (PNARDL) is utilized to evaluate asymmetric dynamics which is a vital aspect of the study. The model is also appropriate to reflect the alteration in the relationship between the blue economy and sustainable development in respect to the degree of an individual country in terms of oil dependency, which illustrates both beneficial and adverse impacts. The paper also applies the Driscoll-Kraay standard errors to determine the linear relationships as the study considers both cross-sectional dependence and cross-sectionally common forms of shock. This is more so when addressing the issues pertaining African oil-rich countries, as they tend to have common weaknesses like changes in oil prices and international pledges to climate.

This research offers both theoretical insights and practical relevance. It contributes to the academic discourse on the blue economy by applying a nonlinear approach to reveal asymmetric effects in oil-dependent nations. The study deepens our understanding of how the blue economy can be harnessed to drive sustainable growth under varying economic conditions. Its findings are especially valuable for policymakers in oil-reliant countries seeking to diversify their economies and reduce their dependence on fossil fuels. By presenting actionable insights, the study supports the formulation of targeted policies that can enhance the benefits of the blue economy while ensuring long-term sustainability.

2. Literature review

This part of the study analyzes the conceptual framework and reviews previous research on how elements of the blue economy and the energy sector interact to influence sustainable development.

2.1 Theoretical Framework

According to the Resource Curse Theory (introduced by Auty, 1993), nations that depend heavily on oil and other natural resources will commonly see slowed economic growth, poorly performing government institutions, and damage to the environment. Because commodity prices change often, high demand for rents and less attention to other sectors. About the findings of this study, African nations that depend on oil may experience slow economic progress, become vulnerable to financial crisis, and suffer from the effects of pollution, which together slow down their future growth. It suggests that using blue economy sectors can give countries more ways to earn money and lessen their dependence on pricey and unreliable fossil fuels.

The research needs to understand the Blue Economy as the central theme. When ocean resources are managed sustainably, it helps the economy, provides jobs, and raises living standards, all while guarding the ocean habitats. In addition to business processes related to fisheries, the blue economy includes marine transport, green energy, and tourism. According to the Blue Economy Framework, adopting a blue approach helps nations to develop sustainably, mainly for those who depend on marine operations and resources along their coasts (Laffoley *et al.,* 2018). The wealthy nations that depend on fishing should open new industries near the sea because there are stable and sustainable sources of income in the ocean.

According to Frank (1966) in Dependency Theory, those countries exposed to industrialized nations, mainly those exporting resources like oil, create their economies through the export of raw materials. Using the theory, countries that rely on oil can find ways to overcome challenges as they build a future free from oil. Continuous changes in the global oil market regularly weaken the economies of oil-exporting countries. According to Environmental Theory, because these countries depend heavily on a single resource, they struggle to set aside money for the blue economy. Dependence on oil makes economic change tougher for some countries because the oil industry also controls politics in that part of the world. The blue economy shows oil-dependent countries how to use more sustainable energy sources. As per the theory, the blue economy helps shield nations from relying too much on the international oil market, allowing them to take many different economic actions. The research looks at how actions in the blue economy help reduce the effects of oil dependence on the environment and economy.

The Environmental Kuznets Curve (EKC) hypothesis is based on the notion that a negative relationship between economic growth and environmental deterioration first get worse before it is remedied once a particular income level is attained. According to this theory, the relationship between economic growth and environment follows an inverted U-shaped curve whereby pollution grows during initial phases of industrialization, progressively decreasing after the achievement of increased rates of income, allowing investment in cleaner forms of technology and practices adopted towards sustainability. In the long run, richer economies are in a better place to initiate policies and other innovations that can curb environmental damages.

The study makes use of these theoretical viewpoints to design a framework that explains how blue economy initiatives can address problems caused by oil dependence, create widespread and lasting opportunities for communities and support the environment. The framework backs the idea that relying on sustainable ocean sectors helps cuts economic risks and at the same time creates positive effects on society and nature.

2.2 Empirical Literature

In this sub-section, we provide the empirical literature review of the concerned variables.

2.2.1 Sustainability in Economic Growth

The main goal in achieving economic growth is to bring about development that remains strong financially and environmentally. But, in many oil-reliant countries in Africa, this ideal is not fully met. While African countries own about 30% of all minerals, 10% of the world's oil, and 8% of its natural gas (according to the African Development Bank Group), their profitable resources have not boosted their economies much. The World Bank reports that Africa experienced economic growth of only 2.6% in 2017, 2.3% in 2018, and 2.8% in 2019, despite having so many natural assets. Wealthier nations often struggle economically more than those that lack similar resources.

Because of having a lot of mineral wealth but little development, countries with this characteristic are often called "rich in resources, yet poor in outcomes" (Appiah *et al.,* 2023).

2.2.2 Blue Economy in Relation to Sustainable Economic Development

The blue economy is a way to use marine resources sustainably to safeguard the environment, encourage economic growth, and enhance life quality. It covers different areas, including aquaculture, shipping, tourism, renewable energy sources, and marine biotechnology. It is particularly important because it boosts growth worldwide and provides work for people living in developing coastal areas. Responsible management of ocean resources gives companies new business opportunities, supporting the growth of different industries along the coast. The blue economy develops strategies that help the marine environment while also ensuring the economy grows. Since the majority of the Earth is covered by water, oceans make up the world's biggest living ecosystem. They are necessary for millions of species because they feed them, help over one billion people earn a living, and lessen climate change (Voyer *et al.,* 2021). Only approximately 7% of the ocean has been investigated so far (Alharthi & Hanif, 2020).

According to Aladejana *et al.* (2024), changes in the SDI in Nigeria are strongly linked to the rate of GDP increase caused by blue economy action. Yet, the blue economy of Nigeria is jeopardized by plastic waste, insufficient legislation, and inefficient systems for controlling waste. Nwafor (2024) underlined that plastic waste hurts fisheries, tourism, and public health, and this results from a lack of strict rules, irregular waste disposal, and not enough education about the problem. The study recommends better ways to handle waste, well-planned campaigns to inform the public, and tighter laws to address these environmental problems.

In South Asia, Alharthi & Hanif (2020) looked at blue economy factors in SAARC countries between 1995 and 2018 and found that aquaculture, fisheries, and agriculture are important for the growth of the regional economy. They stressed that taking care of the ocean's resources ensures enough food for everyone, which encourages further economic growth. A study by Ayilu *et al.* (2022) looked into the Indonesian maritime sector and uncovered the main contributors to growth, such as infrastructure, better trade conditions, and new technology. The analysis showed that pursuing sustainability in fisheries, aquaculture, and marine tourism improves the economy and protects the environment.

In both the EU and Africa, the blue economy is gaining importance as a main development goal through activities carried out by their continental governments. Ayoade & Akinsanya (2021) and Van Niekerk & Nemakonde (2022) found that strong implementation of sustainable blue economy policies in coastal countries boosts job growth and leads to different economic activities. Still, overfishing, pollution, and poor infrastructure are some of the things that prevent fisheries from growing sustainably, the study by Yoshioka *et al.* (2020) notes. Work by Michael (2023) and Martinez-Vasquez *et al.* (2021) also supports the idea that sustainable fisheries and aquaculture can support Nigeria's economy by keeping jobs safe and helping the environment. Pauli points out the importance of a beyond in marine resource regulation to favor sustainable growth.

2.2.3 Energy Factors in Relation to Sustainable Economic Development

Adom *et al.* (2020) stress that giving people in sub-Saharan Africa more access to energy is essential for the region's economic growth and for reducing poverty. The research shows that better access to electricity and clean cooking helps the poor, supports small businesses, improves education and healthcare across communities, and helps drive economic growth in the future. They suggest that renewable solar power, created and used away from a central source, can make energy available to people in rural locations. West African countries are the subject of Ouedraogo *et al.* (2021), where it is revealed that sustainable development is tightly associated with access to energy, affecting education, health, and agriculture. It is found by SamaAfrica and others that where there is more energy access, people enjoy better social services and higher indices of human development.

A lot of research has focused on how energy use, the growth of the economy, and environmental sustainability are connected. Renewable energy systems boost GDP and help lower carbon emissions, Louey (2022) and Khan *et al.* (2022) show. According to Jebli *et al.* (2020), the growth of renewables in energy is more effective when energy efficiency policies are adopted. Renewable energy has yet to be fully adopted because these changes are challenged by weak infrastructure, lack of funds, and changing energy regulations. Akinlo & Dada (2021) suggest that in Nigeria that economic growth is promoted by both financial development and new sources of energy.

2.2.4 Renewable Energy in Relation to Sustainable Economic Development

Recent interest among scholars in the link between sustainable economic growth and greener economies is due to concerns about climate change and the environment. Numerous articles show that an economic policy must support low-carbon actions and saving resources to preserve the environment long into the future (Liu *et al.,* 2024; Zeng *et al.,* 2024). Green technologies and more renewable energy are at the heart of this change. According to Abdul-Mumuni *et al.* (2023), more renewable energy is beneficial for the economy in sub-Saharan Africa, and Adedoyin *et al.* (2023) show that investing in renewable energy aids economic development within the European Union.

Still, some notice that taking environmental action can conflict with boosting the economy at the beginning of a transition. For instance, Islam *et al.* (2024) noted that Turkey's earliest economic growth came with damage to the environment, but this was less noticeable with time. Houssam *et al.* (2023) demonstrate that the green economy boosts GDP and job opportunities and decreases poverty, stressing that consistent policies in this area are necessary for ongoing development. Nguyen *et al.* (2024) also explain that when businesses issue green bonds, it encourages economic progress in countries at all levels of development, while *Wu et al.* (2023) note that green credit rules used by Chinese banks contribute to sustainable development across the economy.

Studies are pointing out that the quality and framework of institutions are crucial for supporting a green economy. Saadaoui & Chtourou (2023) explain that good institutions exaggerate the positive role of renewable energy in fostering economic growth. Shen *et al.* (2023) contend that strong environmental regulations, various market measures, and public-private partnerships are important for reaching sustainable development goals. Even so, certain experts are concerned that environmental policies might add to social and financial inequalities; as a case in point, Grabowski *et al.* (2023) note that green transitions could affect households on a low income more.

2.2.5 Institutional Quality in Relation to Sustainable Economic Development

The quality of institutions plays a crucial role in fostering sustainable economic development, especially in resource-rich economies and countries prone to volatility. Institutions influence how effectively governments can implement policies, uphold laws, manage public resources, and support long-term growth. According to Acemoglu and Robinson (2012), having inclusive and accountable institutions is essential for achieving sustained economic progress. Recent research backs this up: Iddrisu et al. (2025) and Chien et al. (2023) reveal that countries with stronger institutional quality—evaluated through aspects like corruption control, rule of law, and regulatory effectiveness—perform better in areas such as green investment, infrastructure, and social inclusion. Similarly, Kaufmann and Kraay (2020) and Asongu and Odhiambo (2019) argue that institutional frameworks not only impact economic output but also help mediate the effects of environmental and financial shocks. In resource-rich African countries, for instance, effective institutional mechanisms can help mitigate the risks of resource mismanagement and encourage

Moreover, the quality of institutions plays a pivotal role in steering us towards more sustainable and inclusive growth models. Strong institutions are key to enforcing environmental regulations, attracting climate finance, and establishing trust in green public-private partnerships (Zhang & Duan, 2022; IMF, 2023). Research by Demetriades and James (2011) and Suri and Udry (2022) indicates that nations with robust institutions are more adept at adopting sustainable agricultural practices and developing climate-resilient infrastructure. Additionally, Chang et al. (2024) found that institutional capacity greatly affects how developing economies leverage renewable energy and move away from fossil fuel dependence. Conversely, weak institutions can lead to economic growth that results in environmental degradation and social inequality, rather than genuine development (Auty, 2020; Sachs et al., 2019). This highlights that institutional quality is not just a facilitator of growth; it fundamentally influences the sustainability of that growth. Therefore, enhancing governance—through anti-corruption initiatives, capacity building, and legal reforms—is crucial for achieving the Sustainable Development Goals (Rodrik, 2014; IPCC, 2022).

2.2.6 Conclusion of the Literature Review

Sustainable development is a key goal for African nations, but not everyone agrees on how the different energy, environmental, and maritime economies interact and influence their country's sustainable growth. Many studies have looked at these sectors single-handedly, but it is still hard to find research showing how all of them together affect sustainable development in Africa. Energy transitions, green economic plans, and blue economy approaches are seen by the AU as essential elements of its sustainable development strategy (AU IBAR, 2021). But current research does not fully explain how all of these aspects come together to achieve long-term development. Although both green and blue economies care about environmentally friendly growth and the safety of marine resources, official discussions about them are treated separately. There have been no detailed studies on how these sectors affect one another, particularly in regards to energy and sustainable development in Africa (Tiba & Frikha, 2020; Nagy & Nene, 2021).

Tracing Africa's energy progress is vital, considering that energy use is so closely connected to economic expansion. While the existing literature assumes a simple connection between energy use and the economy, recent findings suggest this model does not accurately represent the true situation in Africa. Simplified models suggesting that GDP growth is solely about increasing energy usage (Alqaralleh & Hatemi, 2024) fail to cover the differing and complex shifts seen in various phases of the economy. The effects of energy on economic growth can change a lot, such as when energy consumption prevents or slows development during slow economic times. Because of these complexities, advanced econometric techniques must be used to help identify these phenomena (Hatemi, 2020).

Sustainable development in African oil-producing countries relies on energy, as well as the green and blue economies, but key sustainability functions are still understudied. Green economy focuses on lowering the impact on the environment by using energy from nature, environmentally friendly farming methods, and building with safe materials (Chuku & Ajayi, 2024). Spotlight on renewable energy is rising; even so, connecting it with sustainable farming and infrastructure is not fully developed. In the same way, the blue economy makes it possible for oil-dependent nations to benefit from their marine and coastal resources, though few researchers have looked at the areas where green and blue economies overlap, particularly around energy changes and using renewable energy. While a few researchers have examined the financial gains of industries such as fisheries and coastal tourism (Zhang *et al.,* 2024), not much is understood about how these sectors relate to the green economy as a whole. For Africa's development to be sustainable, policymakers must understand how the blue and green economies interact.

Not all previous research methods have accurately portrayed the unpredictable and imbalanced ways energy use, environmental sustainability, and economic growth are related. Structural shocks in Africa's oil-dependent economies are not properly represented by the standard cointegration and causality tests. Latest methods, like the nonlinear ARDL approach and tests by Westerlund, help provide better insights into the relationship among energy, growth, and the environment (Ghazouani, 2024). One may also use these approaches to examine how energy use and merging green and blue economies contribute to growth in different parts of the region.

This study tries to fill these gaps by using sophisticated statistical techniques to analyze the nonlinear and asymmetric ways that energy use, the green and blue economies, and economic growth are related in oil-producing African nations. Particularly, using nonlinear ARDL and Driscoll-Kray estimators helps understand how energy, environmental sustainability, and economic development connect in diverse African situations that depend on oil. Other aspects covered in the study focus on the interaction between green and blue economies and whether they can cooperate to achieve sustainable growth. It continues to study how combining green economy principles with blue economy ideas, using more renewable energy as an example, can help achieve sustainable development.

This study is designed to have a big impact on how oil-producing African nations shape their development strategies. The purpose of this study is to address flaws in past methods and look at how different areas connect in order to guide policymakers toward building inclusive and sustainable development in Africa (Estudos, 2011). The Economic Society of Australia (2010) highlighted that concentrating on the AU's strategic areas—green growth, energy shift, and the blue economy—would allow for important insights to help include these elements into a single development plan. In the end, the findings from this study help move the AU's vision for Africa forward by providing more effective and flexible policies that support a solid, shared transition to a continent that is prosperous, productive, and stable.

3. Model and Data

3.1 Sample and Data

The blue economy elements are included in this study to support the move toward a greener economic model. While the green economy helps build sustainability without affecting the environment, the blue economy encourages development by focusing on industries like fisheries, aquaculture, agriculture, and forestry, all in ways that minimize impact on the environment. Strategic development of fisheries on their extensive coastlines gives African countries the potential to grow as leading exporters of aquaculture products and also to support economic diversity.

In this study, sustainable economic development is measured using adjusted net savings, which accounts for particulate emission damages (in current US dollars), following established methodologies from prior studies such as Khan *et al.* (2022) and Usman *et al.* (2021). Indicators of the blue economy include total fisheries production (FP) in metric tons, the value added by agriculture, forestry, and fishing sectors (AF) as a percentage of GDP, and aquaculture production (AP) in metric tons, as also noted by Ahmad *et al*. (2025). Energy variables encompass patterns of consumption: energy intensity (EI), defined as electric power consumption per capita; renewable energy (RE) consumption as a percentage of total final renewable energy use; and overall energy consumption (EC), measured in kilograms of oil equivalent per capita. These measurements align with widely accepted standards in the literature (Waheed *et al.,* 2023). We further used Control of Corruption (CC) as a proxy for institutional quality as widely used by different scholoars (Acemoglu et al., 2001; Farouq & Sulong, 2023) Data spanning 1980 to 2023 for five key oil-dependent African nations (Nigeria, Egypt, Algeria, Angola, and Libya) were obtained from the World Development Indicators and the International Renewable Energy Agency.

3.2 Model Specification

Building on the work of Ahmad *et al. (*2025), the function below is extended to determine how the blue economy indicators, renewable energy, and green energy factors affect sustainable economic development among the 5 African leading oil-dependent countries (Nigeria, Egypt, Algeria, Angola, and Libya). We constructed various econometric models for analysis, with Model 1 representing the growth model, as outlined in equation 1.

$$LGS = f(LFP, LAF, LAP, LRE. LEI, LEC, LIQ) \quad (1)$$

In the present research, GS is the log of the sustainable economic development. The variable LFP represents log of production in fisheries whereas LAF represents log of value added in fisheries, forestry and agriculture. LAP abbreviates to log aquaculture production. LRE reads as a log of renewable energy and the LEI is the energy intensity and the LEC is a log of the total energy. Moreover, LIQ measures the natural logarithm of quality of institutions. The variables will be used to determine the corresponding effects of certain variables on the sustainable growth trend of the chosen economies.

The empirical equations are structured in the following manner

$$LGS_{it} = \beta_0 + \gamma_{1i}LFP_{it} + \gamma_{2i}LAF_{it} + \gamma_{3i}LAP_{it} + \gamma_{4i}LRE_{it} + \gamma_{5i}LEI_{it} + \gamma_{6i}LEC_{it} + \gamma_{7i}LIQ_{it} + u_{it} + e_{it} \quad (2)$$

To deepen the analysis and more accurately reflect the institutional dynamics influencing the connection between blue economy sectors and sustainable economic development, the baseline panel model is expanded to include interaction terms. These terms pair institutional quality (IQ) with key blue economy indicators—namely, agriculture, forestry, and fishing value added (AF), aquaculture production (AP), and fishery production (FP).

$$LGS_{it} = \beta_0 + \gamma_{1i}LFP_{it} + \gamma_{2i}LAF_{it} + \gamma_{3i}LAP_{it} + \gamma_{4i}LRE_{it} + \gamma_{5i}LEI_{it} + \gamma_{6i}LEC_{it} + \gamma_{7i}LIQ_{it} + \gamma_{8i}(LFP_{it} * LIQ_{it}) + \gamma_{9i}(LAF_{it} * LIQ_{it}) + \gamma_{8i}(LAP_{it} * LIQ_{it}) + u_{it} + e_{it} \quad (3)$$

Where FP×IQ, AF×IQ, and AP×IQ are the interaction terms that allow us to test the conditional impact of these sectors under varying levels of institutional strength. By including these interactions, we can identify whether the positive contributions of these sectors to sustainability are enhanced or diminished by institutional capacity.

This work explores how the blue economy, energy intensity, consumption, and renewable energy use affect sustainable economic development in five African oil-producing countries between 1980 to 2023. It was these countries' high dependence on oil that made them good examples, because it creates major sustainability problems and calls for different ways to keep their economies growing. The research studies energy factors, green economic indicators, and blue economic elements. Data on energy intensity, total energy consumption, and adoption of renewable energy are examined as major contributors to the sustainability of the economy. Boosting energy efficiency because of energy intensity means production processes will save money and resources. With these savings, nations can pursue and improve export chances, which promotes wider economic growth and helps to sustain the country's progress.

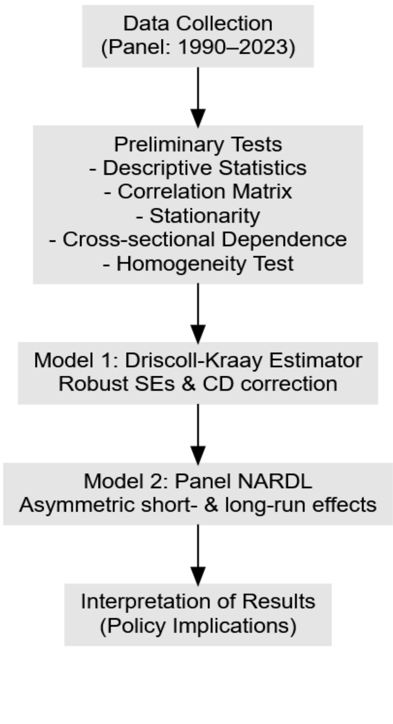
One of the biggest concerns is that various methodologies might overestimate how much influence one type of transaction has over another. The main motivations for blue economy movements in oil-dependent countries are to maintain economic growth and improve activities related to the sea. Such a pattern in causality may lead to biased results and should not be ignored. In response, the research uses the Panel Non-linear Autoregressive Distributed Lag (Panel NARDL) model, as well as Driscoll & Kraay Standard Errors (DKSE) for estimation.

Lagged relationships between the blue economy and sustainable development are captured by this panel NARDL approach, which allows for a better separation of impacts that happen quickly or gradually. In addition, the DKSE method addresses differences among countries that are not easy to observe and handles the problem of nations influencing one another's growth through their blue economy performance. Besides, the model includes control variables to deal with missing factors known to affect the dependent and explanatory variables.

4. Methodology

Before conducting the analysis, the study tested for data interdependence across countries and addressed the limitation of assuming identical slope coefficients by applying the Pesaran and Yamagata (2008) slope heterogeneity test. In this study, we adopt a two-stage econometric technique to rigorously investigate the dynamic and structural relationships between the blue economy indicators and sustainable economic development in African oil-rich and dependent countries. The Driscoll and Kraay estimator and the Non-linear panel ARDL estimator. This is chosen based on their respective advantages. Particularly, considering that the Panel NARDL approach is applied to capture the potential asymmetric effects of our concerned independent variables on the explained variable over time, which allows us to check whether positive and negative shocks have differential long-run and short-run impacts. This technique is essentially useful given the possible non-linear effects of resource-based revenues and political instability on sustainable development outcomes. Whereas the Driscoll and Kraay estimator is subsequently used in this study to correct for serial correlation, cross-sectional dependence, and heteroscedasticity in the panel series, and more importantly, to ensure the robustness of the estimated coefficients.

Figure 1. Methodological Sequence



4.1 Unit Root

In order to cope with the problem of cross-sectional dependence and to provide a better estimated result, the present study makes use of the second-generation unit root tests. Specifically, it uses the Cross-sectionally Augmented Im, Pesaran, and Shin (CIPS) test that was suggested by Pesaran (2007), as well as a nonlinear unit-root test that was proposed by Ucar and Omay (2009) for heterogeneous panels. These approaches are particularly designed in order to manage the complexity of nonlinearity and the integration of cross-panel unit interdependencies. The theory of the CIPS test is based on the work by Pesaran (2007), improving the method of traditionally testing unit roots by integrating time-averages across the cross-section to allow adjusting for common effects on a group of countries or regions.

4.2 Panel Co-integration

In this study, we use advanced panel cointegration tests by Westerlund (2007) to find out if the variables meet in a long-term equilibrium. Unlike earlier research, these recent statistical models are designed to deal with cross-sectional dependence (CSD), since this forms a major part of the data used in macroeconomics. If traditional tests for cointegration assume cross-sectional independence, they may give results that are biased and cannot be trusted. Moving forward, Westerlund's method gets rid of the balanced assumption and leads to better results because it considers CSD (Eibinger *et al.,* 2024). Through the use of asymptotic theory, this method permits tight statistics and powerful testing of cointegration in panels affected by various interactions, sudden breaks in structure, and unequal variances for different countries at different times.

Thanks to this advanced technique, the study carefully analyzes how long-term equilibrium links between energy use, renewable sources, the blue economy, and sustainable growth work together. In addition, Westerlund & Edgerton (2007) designed their cointegration test by applying the initial Lagrange multiplier unit root tests from Schmidt & Phillips (1992), Ahn (1993), and Amsler & Lee (1995). The range of models examined through this framework consists of the following:

$$\delta i(L)\Delta y_{it} = y2_{it} + \beta_i(y_{it} - 1 - \delta_i x_{it}) + \aleph_i(L)V_{it} + \varphi_i \qquad (4)$$

The test statistics of this technique are given below:

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\delta_i}{SE(\delta_i)} \qquad (5)$$

$$G_\delta = \frac{1}{N}\sum_{i-1}^{N}\frac{Y\delta_i}{\delta_i(1)} \qquad (6)$$

$$P_r = \frac{\delta}{SE(\delta)} \qquad (7)$$

$$P_\delta = Y\delta \qquad (8)$$

Eqs. Eight and 9 indicate the group-mean statistics for Ga and Gt, respectively. equations 10 and 11 provide the panel statistics for Pa and Pt. This approach includes both null and alternative hypotheses of "no cointegration" and "cointegration," as appropriate.

4.3 Estimation

Widespread regional and global shocks that include oil price changes and financial crises, and policy transformations affect the economic indicators of financial development and inflation. The analysis shows that appropriate analytical techniques need attention for accurate results. The research employs the Driscoll & Kraay (1998) method to solve this issue. The authors' approach demonstrates great utility in situations where time series data collection has a big T dimension because it enables standard nonparametric time series covariance estimators to handle diverse spatial and temporal correlation patterns. A Newey-West-style correction applied across cross-sectional averages enables Driscoll and Kraay's technique to provide improved standard error estimates. The correction method maintains strong covariance matrix estimations under large cross-sectional sample sizes (N). This methodology functions as a reliable substitute to the Parks-Kmenta or Panel-Corrected Standard Errors (PCSE) method because it performs better in settings with big cross-sectional datasets, especially when used in micro-panel data analysis. In addition, DKSE is suitable for our panel structure and offers robustness to heteroskedasticity, autocorrelation, and cross-sectional dependence in panels with small N and large T.

The Driscoll and Kraay standard errors (DKSE) operate across both balanced and unbalanced panel data structures to analyze datasets containing missing observations. The method deals with time series of any length while simultaneously managing complex error patterns. This method demonstrates particular strength because it yields robust covariance estimates that withstand different forms of time-dependent and cross-sectional dependency patterns. This estimator generates consistent standard errors even when heteroscedasticity exists during situations where both the time (T) dimension and the cross-sectional (N) dimension become large. Spatial as well as serial correlation receive effective resolution from the DKSE estimator.

The following panel data model consists of an error term that displays heteroscedasticity and both autocorrelation and cross-sectional dependence:

$$Y_{it} = \beta X_{it} + u_{it} \qquad (9)$$

Under these conditions, consistent parameter estimation can still be achieved using the pooled least squares method, as demonstrated by Driscoll & Kraay (1998: 551) and further discussed by Tatoglu (2016: 276).

$$\hat{\beta} = (X\acute{X})^{-1}XY \qquad (10)$$

The Driscoll & Kraay standard errors of the parameter estimates are also obtained from the square roots of the diagonal elements of the asymptotic (robust) covariance matrix.

$$V(\hat{\beta}) = (X\acute{X})^{-1}\hat{S}_T(X\acute{X})^{-1} \qquad (11)$$

where $\hat{S}T$ is defined as follows:

$$\hat{S}_T = \hat{\cap}_0 + \sum_{J=1}^{m(T)} w(j.m)\left[\hat{\cap}_j + \hat{\cap}'_j\right] \qquad (12)$$

m(T) shows the lag length for autocorrelation. Bartlett weights, revealed as w(j.m(T)) =1-j/(m(T)+1), ensure that $\hat{S}_T$ is positive definite and allows higher order lags in the sample autocovariance function to receive lower weights. Cross-sectional means of $hit(\beta)$, which is robust in the presence of heteroscedasticity and autocorrelation. The method makes use of cross-sectional averages to achieve standard error consistency across any number of cross-sectional units (N). According to Driscoll and Kraay (1998), consistency remains true when the number of cross-sectional units N becomes infinite. Various spatial and temporal correlations do not affect the robustness of standard errors derived from the analysis of their covariance matrix estimates (Driscoll & Kraay, 1998: 552; Tatoglu, 2016).

4.4 Robustness Check

This study uses recent methods from nonlinear panel data modeling to analyze how different variables might impact each other differently. Unlike linear symmetric models, asymmetric modeling expects different effects on the dependent variable depending on whether an explanatory variable is going up or down. Applying the method introduced by Shin *et al.* (2014), the baseline models are modified by introducing the first differences of the regressors, both increasing and decreasing, separately. By separating the disturbances, we can tell if shocks to major predictors lead to separate outcomes. With this kind of approach, the study shows which changes in energy, green economy, and blue economy factors have the biggest effects on sustainable economic development in African countries as time goes on.

The resulting asymmetric equation, formulated by Shin *et al. (*2014), can be expressed as

$$\Delta LGS_{it} = \varphi_{0i} + \varphi_{1i}LGS_{i,t-1} + \varphi_{2i}^{+}LFP_{t-1}^{+} + \varphi_{2i}^{-}LFP_{t-1}^{-} + \varphi_{3i}^{+}LAF_{t-1}^{+} + \varphi_{3i}^{-}LAF_{t-1}^{-} + \varphi_{4i}^{+}LAP_{t-1}^{+} + \varphi_{4i}^{-}LAP_{t-1}^{-} + \varphi_{5i}^{+}LEI_{t-1} + \varphi_{10i}^{+}LEC_{t-1} + \varphi_{11i}^{+}LRE_{t-1} + \sum_{j=1}^{Q}\tau_{ij}LGS_{i,t-1} + \sum_{j=0}^{Q}(\tau_{ij}^{+}LFP_{t-j}^{+} + \tau_{ij}^{-}LFP_{t-j}^{-}) + \sum_{j=0}^{Q}(\tau_{ij}^{+}LAF_{t-j}^{+} + \tau_{ij}^{-}LAF_{t-j}^{-}) + \sum_{j=0}^{Q}(\tau_{ij}^{+}LAP_{t-j}^{+} + \tau_{ij}^{-}LAP_{t-j}^{-}) + \sum_{j=0}^{Q}(\tau_{ij}^{+}LEI_{t-j}) + \sum_{j=0}^{Q}(\tau_{ij}^{+}LEC_{t-j}) + \sum_{j=0}^{Q}(\tau_{ij}^{+}LRE_{t-j}) + z_{it} \quad (13)$$

In this model, φ_{3i}^{+} to φ_{11i}^{+} represent the long-run coefficients associated with positive changes, while φ_{3i}^{-} to φ_{11i}^{-} denote the long-run coefficients for negative changes. Similarly, τ_{ij}^{+} and τ_{ij}^{-} capture the short-run dynamics for positive and negative variations, respectively. The variables LFP_{t-1}^{+} and LFP_{t-1}^{-} refer to the natural logarithms of positive and negative shocks in total fishery production, respectively. Likewise, LAF_{t-1}^{+} and LAF_{t-1}^{-} denote the positive and negative components of the agriculture, forestry, and fishing sector in logarithmic terms. LAP_{t-1}^{+} and LAP_{t-1}^{-} represent the log-transformed values of positive and negative shifts in aquaculture production. The energy-related variables—energy consumption, energy intensity, and renewable energy—are included in their standard logarithmic form without decomposition. The error term is denoted by z_{it}, with i indicating the cross-sectional unit and t the time period.

5. Results and Interpretation

5.1 Preliminary Evidence

This section presents an initial report of our results, presenting preliminary information regarding the relationships between the variables at issue. While these results are not conclusive, they lay the groundwork for more intense analysis and subsequent investigation. The preliminary evidence gathered to this point suggests patterns potentially deserving of investigation in later stages of the study.

5.1.1 Descriptive Statistics

The paper investigates the dynamics of sustainable economic growth in five African oil-dependent countries that existed between 1980 and 2023, which are the relationships between renewable energy, blue economy indicators, energy intensity, and energy consumption. Table 1 (see appendix) shows the descriptive statistics of the variables before their transformation to a log column. Due to the large difference in the nature of the economic events in the chosen countries, the sustainable development variable indicated a mean of 2,589.100 and a high standard deviation of 1,933.247. The indicators of blue economy are quite interesting patterns are observed in total fishery production that averagely amounted to around 1.44 trillion metric tons that highlights the solid maritime potential of these economies. The GDP of the agriculture, forestry, and fishing was an average of 3,226,484, and the aquaculture production was 31.21 metric tons on average. On the energy variables, the average amount of energy being produced by renewable energy was 11.86 gigawatt hours, energy intensity was 14.83, and the average units of energy consumed was 44.25. The skew within the renewable energy is a negative skew which implies a slowly progressive shift to sustainable energy solutions in these oil-dependent countries.

5.1.2 Correlation Analysis and VIFs

The results of the diagnostic of multicollinearity between the variables considered in the present work are provided in Table 2 (see appendix). It provides the correlation matrix and the respective value of Variance Inflation Factor (VIF) to ascertain the soundness of the model specification. The correlation coefficients affirm that there is no pair of variables that can be said to be excessively highly correlated, as it conforms to the selected instruments. More so, VIF values of all the variables are significantly low in comparison to the generally accepted 5 threshold with the highest reported VIF value being 1.96. This implies that there is no multicollinearity in the data and the model has a good variance independence of the predictors.

5.2 Empirical Results

5.2.1 Cross-section Dependence Test

The analysis is started by conducting test of cross-sectional dependence and slope heterogeneity in the panel data. The Cross-Sectional Dependence (CD) test is used to test the independence of residuals of different units, especially of the panel (countries). Table 3 (available online as additional appendix) indicates that the test rejects the null hypothesis at the 1% significance level per all the variables indicating existence of significant interdependencies of the countries. This degree of dependence is also revealed in the mean correlation coefficients (mean and mean |p|), which were significantly reported to be stronger in the case of increasing interconnections according to cross-sectional units.

5.2.2 Slope Homogeneity Result

A summary of the result of the slope homogeneity tests is presented in Table 4 (available online as additional appendix). The outcomes of the delta and adjusted delta statistic and their p-values disagree with the null hypothesis of homogeneity at the 1 percent level. It indicates that regression parameters do not compare across countries. Not only is the Pesaran statistic and the Pesaran and Yamagata (2008) and adjusted 0 beyond the critical value, but they are quite close and could therefore be used to provide evidence that there is indeed a significant difference across the sampled nations in terms of the influence of the explanatory variables on the dependent variable. This sort of variance can be explained by the distinctiveness in the national profiles such as economic organization, governance, and institutional framework (Hsiao & Pesaran, 2008). To adjust to this heterogeneity and already-established dependence across sections, the investigation applies sophisticated panel econometrics technique, which adds the stability and accuracy of empirical results (Skare et al., 2024).

5.2.3 Unit Root Result

Balsalobre-Lorente et al. (2020) conclude that the characteristics of integration of panel variables are important with the purpose of accurately analyzing the associations between them. In linearizing a test, this paper utilizes two unit root tests; the cross-sectional augmented IPS (CIPS) test and the test of non linear heterogenous panel developed by Ucar and Omay (2009). Table 5 (available online as additional appendix) gives the corresponding results with test statistics and at both levels and first differences at p-values. In both tests, the null hypothesis assumes the existence of a unit root that indicates non-stationary whereas the alternative indicates stationary. In few variables, the null was not rejected at 1 and 5 percent level at level form; hence non-stationary behavior. Under the difference, however, the null hypothesis of unit root is strongly rejected meaning the variables shift to stationary variables. This result conforms to accepted economic principles, which assume that macroeconomic and financial time series are generally non-stationary in levels but they turn out to be stationary (at least) on differences. It is an essential difference because using non-stationary data may produce spurious regressions. The existence of stochastic trends and continuous shocks of the level data highlights the importance of differencing, which assists to eliminate the time-related trends, and make the econometric conclusions valid.

5.2.4 Co-integration Test Analysis

This research uses advanced cointegration methods to find long-term connections among the main factors affecting the oil-rich countries' blue economy activities, renewable energy, and related energy sectors over time. The constant and trend models are used to perform panel cointegration tests, and the outcomes can be found in Table 6 (available online as additional appendix). The results never accept the null hypothesis of no cointegration, which means there are stable long-run links among the variables. Although these variables often move in different directions in the short run, there is a clear, lasting correlation between them. Even so, we must be cautious with the results, since cross-sectional dependency and different slopes between series might make cointegration tests unreliable in practice (Bakhsh *et al.,* 2024).

5.2.5 Estimation Result

To address both spatial and temporal unobserved heterogeneity, we employ a Two-Way Fixed Effects Panel Regression with Driscoll Kraay SE, which includes both country and year fixed effects. The model is estimated using Driscoll and Kraay (1998) standard errors to account for heteroskedasticity, autocorrelation, and cross-sectional dependence. Both Table 7 and 8 presents the regression results with both country and time fixed effects. Compared to the one-way fixed effects model, the two-way specification better accounts for unobserved global shocks and institutional heterogeneity. This shows economic growth relationships between blue economy indicators and general energy components among the five top African oil-producing nations. The table presents t-statistics written inside square brackets. The model effectively explains 75% and 77% of all variables found in the sample countries, according to the R^2 values.

First off, let's examine Table 7. The integration of Institutional Quality (IQ) with core blue economy variables—like Fishery Production (FP), Agriculture, Forestry and Fishing Value Added (AF), and Aquaculture Production (AP)—reveals some intriguing insights into the drivers of sustainable economic development (GS) in African countries that are rich in oil. Each of these blue economy indicators shows a positive and statistically significant effect, indicating that progress in these areas is vital for sustainable growth. To break it down, a 1% increase in FP, AF, and AP is linked to approximately 3.6%, 5.2%, and 3.0% increases in GS, respectively, while keeping other factors constant.

Table 7: Two-Way Fixed Effects Regression with Driscoll-Kraay Standard Errors

Variables ($ln\mathrm{EF}_{it}$)	Coefficient	Drisc/Kraay Std-Err	t-statistic	P-value
$\ln\mathrm{FP}_{it}$	0.036	0.014	2.57**	0.006
$\ln\mathrm{AF}_{it}$	0.052	0.019	2.74*	0.003
$\ln\mathrm{AP}_{it}$	0.030	0.012	2.50**	0.028
$\ln\mathrm{RE}_{it}$	0.041	0.017	2.41**	0.019
$\ln\mathrm{EI}_{it}$	-0.051	0.015	-3.40*	0.002
$\ln\mathrm{EC}_{it}$	0.035	0.011	3.18*	0.001
$\ln\mathrm{IQ}_{it}$	0.048	0.016	3.00*	0.003
Country Fixed Effects	Included			
Year Fixed Effects	Included			
Observations	220			
R - squared	0.75			

*Note: * Shows statistical significance at a 1 percent level, while ** signifies the 5 percent significance level. Source: WDI (2024); International Renewable Energy Agency (2024)*

It's crucial to recognize that these effects might indicate a mix of structural contributions rather than just straightforward benefits. For example, ongoing advancements in aquaculture and fisheries can lead to improved food security, increased rural employment, and a more diverse export base—essential components of resilience and sustainability in developing economies. Similarly, the strong performance of the AF sector can be seen as a result of its ability to absorb labor, provide ecosystem services, and encourage green entrepreneurship, particularly when backed by effective institutions. However, the model also accounts for institutional quality, providing more reliable evidence that governance quality plays a significant role in maximizing the benefits of resource-based sectors.

Institutional Quality (IQ) stands out as a crucial element, emphasizing that strong institutions are vital for effectively transforming natural and economic resources into long-term development success. The results also indicate that Energy Intensity (EI) negatively affects sustainability, while Renewable Energy (RE) and Energy Consumption (EC) show a positive correlation with growth and sustainability (GS). This points to the dual significance of transitioning to clean energy and ensuring reliable energy access as fundamental enablers of productive growth.

In Table 8, the extended model introduces interaction terms that link the main blue economy variables—Fishery Production (FP), Agriculture, Forestry, and Fishing Value Added (AF), and Aquaculture Production (AP)—to Institutional Quality (IQ). This allows us to delve into whether the effectiveness of these sectors on sustainable economic development (GS) is influenced by the strength of institutions. The primary effects of FP, AF, and AP continue to be positive and statistically significant, showing that improvements in these areas independently foster sustainable growth. However, by including interaction terms (such as lnFP × IQ, lnAF × IQ, lnAP × IQ), the model makes it clear that the level of impact isn't the same everywhere—it really depends on the institutional conditions.

Table 8: Two-Way Fixed Effects Regression with Driscoll-Kraay Standard Errors with Interaction

Variables ($ln\mathrm{EF}_{\mathrm{it}}$)	Coefficient	Drisc/Kraay Std-Err	t-statistic	P-value
$\ln\mathrm{FP}_{\mathrm{it}}$	0.030	0.013	2.31**	0.022
$\ln\mathrm{AF}_{\mathrm{it}}$	0.045	0.018	2.50**	0.014
$\ln\mathrm{AP}_{\mathrm{it}}$	0.028	0.011	2.55**	0.012
$\ln\mathrm{RE}_{\mathrm{it}}$	0.039	0.016	2.44**	0.015
$\ln\mathrm{EI}_{\mathrm{it}}$	-0.049	0.015	-3.27*	0.000
$\ln\mathrm{EC}_{\mathrm{it}}$	0.034	0.010	3.40*	0.000
$\ln\mathrm{IQ}_{\mathrm{it}}$	0.041	0.017	2.41**	0.016
lnFP*IQ	0.019	0.007	2.71*	0.008
lnAF*IQ	0.025	0.009	2.78*	0.006
lnAP*IQ	0.017	0.006	2.83*	0.005
Country Fixed Effects	Included			
Year Fixed Effects	Included			
Observations	220			
R - squared	0.77			

*Note: * Shows statistical significance at a 1 percent level, while ** signifies the 5 percent significance level. Source: WDI (2024); International Renewable Energy Agency (2024)*

The relationship between fishery production (FP) and institutional quality (IQ) is both positive and significant. This indicates that countries with better institutional quality experience greater sustainability benefits from fishery production. In simpler terms, effective regulations, the enforcement of sustainable fishing practices, and smart resource management are crucial to ensure that growth in this sector doesn't harm the environment or deplete resources.

The interplay between AF and IQ demonstrates a significant positive effect, suggesting that agriculture, forestry, and fishing can greatly enhance sustainable growth when institutions provide support for land rights, agricultural extension services, and climate adaptation measures. However, in environments with weak governance, these sectors may fail to deliver similar benefits and could even inflict long-term damage through mismanagement.

It's quite fascinating that the connection between AP and IQ is only marginally significant, or even weaker than other relationships. This suggests that aquaculture might offer some basic advantages because of its technical nature—like having controlled environments—but its ability to truly transform sustainability is still largely dependent on institutional support. This is especially important for aspects like biosecurity, investment frameworks, and regulatory oversight.

Furthermore, Renewable Energy (RE) remains a strong, positive contributor to GS, while Energy Intensity (EI) continues to have a negative impact, reinforcing that energy efficiency and clean energy transitions are essential for long-run development. Energy Consumption (EC) is positively associated with GS, supporting the view that broader energy access promotes economic activity and rural development—especially when paired with institutional capacity.

However, to account for unobserved time-invariant heterogeneity across countries, we test for the joint significance of the country fixed effects in the regression model (Table 9). An F-test confirmed the joint significance of these fixed effects ($F(4, 210) = 8.06$, p less than 0.01), indicating their relevance in explaining variations in sustainable economic development. This adjustment helps mitigate potential omitted variable bias.

Table 9: F-Test of Country Fixed Effects

Source	Degrees of Freedom (DF)	Sum of Squares	Mean Sq	F-Stat	P-value
Country FE	4	22.86	5.68	8.06	0.000
Residual	210	146.65	0.706		
Total	214	169.51			

5.2.6 Robustness

The Panel NARDL estimation results (Table 10) reveal a consistent pattern of positive long-run and short-run effects from both positive and negative changes in key resource-related variables—namely, fishery production (FP), agriculture-forestry-fishing value-added (AF), and aquaculture production (AP)—on sustainable economic development (GS). The estimation is based on a Panel NARDL framework augmented with country- and time-fixed effects, while using Driscoll-Kraay standard errors to correct for cross-sectional dependence, heteroskedasticity, and autocorrelation. The model also allows for heterogeneous slope coefficients across countries.

Both positive ($FP^{+} = 0.468$, $p < 0.01$) and negative ($FP^{-} = 0.519$, $p < 0.01$) shocks in fishery production are statistically significant and exhibit a positive relationship with sustainable economic development (GS). While the positive impact of favorable shocks is expected—due to enhanced food security, livelihoods, and foreign exchange earnings—the long-run positive effect of negative shocks warrants further interpretation. Rather than viewing this as counterintuitive or speculative, our results align with real-world evidence from the selected oil-dependent African countries, where declines in fishery output have often served as catalysts for institutional reform, policy innovation, and investment in sustainability.

Table 10 Panel NARDL Estimate

Variables	Coefficients and t-statistics	P-value
Long-run Results		
$lnFP^+$	0.426* [2.91]	0.004
$lnFP^-$	0.481* [3.87]	0.000
$lnAF^+$	0.037** [2.19]	0.012
$lnAF^-$	0.106** [2.53]	0.006
$lnAP^+$	0.041* [3.44]	0.000
$lnAP^-$	0.022** [2.35]	0.021
$lnRE$	0.654* [3.51]	0.000
$lnEI$	-0.683* [4.28]	0.000
$lnEC$	0.017* [4.01]	0.000
$lnIQ$	0.096** [2.18]	0.031
Short-run Results		
ECM(-1)	-0.231* [-3.11]	0.000
$\Delta lnFP^+$	0.398* [3.77]	0.000
$\Delta lnFP^-$	0.328* [3.06]	0.000
$\Delta lnAF^+$	0.128* [3.43]	0.000
$\Delta lnAF^-$	0.297* [2.72]	0.007
$\Delta lnAP^+$	0.142* [2.85]	0.000
$\Delta lnAP^-$	0.693* [3.49]	0.000
$\Delta lnRE$	0.591* [2.72]	0.000
$\Delta lnEI$	-0.311* [4.97]	0.000
$\Delta lnEC$	0.362* [2.89]	0.004
$\Delta lnIQ$	0.063** [2.15]	0.033
Fixed Effects		
Country FE (Joint F)	$F(4, \infty) = 6.74$ 0.000	
Time FE (Joint F)	$F(33, \infty) = 4.17$ 0.000	

Note: ** Shows statistical significance at a 1 percent level, while ** signifies the 5 percent significance level. Source: WDI (2024); International Renewable Energy Agency (2024)*

For instance, Angola experienced a substantial decline in marine fish stocks between 2011 and 2013 due to overfishing and weak regulatory enforcement. In response, the government introduced a revised fisheries law in 2015, including vessel monitoring systems, seasonal closures, and enhanced licensing protocols to restore marine resources (FAO, 2017). Similarly, Egypt faced a drop in wild fish catch around 2007–2009 as a result of pollution and water flow disruptions from Nile-based irrigation practices. This prompted the General Authority for Fish Resources Development (GAFRD) to scale up aquaculture as a strategic alternative, contributing to the sector's long-term recovery and resilience (El-Naggar et al., 2015; World Bank, 2020). In Nigeria, the sharp decline in inland and coastal fisheries between 2012 and 2014—caused by flooding and oil pollution—led to the implementation of climate-smart agricultural and aquaculture initiatives in subsequent years, focusing on sustainability and ecosystem restoration (Adegbite et al., 2019). Algeria's 2010–2012 downturn in marine fisheries spurred the adoption of a national fisheries and aquaculture development strategy (2014–2020), emphasizing sustainable practices and institutional capacity building (FAO, 2016). Likewise, Libya initiated coastal protection programs in partnership with the FAO in 2009, following years of ecosystem degradation and fisheries decline, aiming to restore marine biodiversity and support small-scale fisheries (FAO, 2011).

These country-specific developments provide a plausible explanation for our model's finding that negative shocks can have positive long-term effects. They reflect a pattern where environmental or economic disruptions trigger government and institutional responses that improve governance, resource management, and sectoral sustainability over time. Moreover, the inclusion of institutional quality—proxied by control of corruption—in our model further confirms that the effectiveness of these policy responses is amplified under strong governance structures. This reinforces the importance of institutional resilience and adaptive policymaking in transforming short-term sectoral shocks into long-term gains for sustainable economic development.

The model results further indicate that both positive ($AF^{+} = 0.043$, $p < 0.05$) and negative ($AF^{-} = 0.129$, $p < 0.01$) shocks in agriculture, forestry, and fishing value-added (AF) have statistically significant and positive long-run effects on sustainable economic development (GS). Notably, the coefficient of negative shocks is larger, suggesting that periods of economic stress in this sector can act as catalysts for policy responses and structural adaptation. This result aligns with the theoretical underpinnings of the Panel Nonlinear ARDL framework, which captures asymmetric effects and recognizes that development outcomes are shaped not just by sectoral expansion but also by the nature and effectiveness of institutional responses to shocks.

In the context of African oil-dependent economies, this finding is supported by historical evidence. For example, following agricultural productivity losses during the 2008–2009 food price crisis, Nigeria and Egypt scaled up public investment in climate-resilient agriculture, including seed distribution programs, irrigation infrastructure, and subsidy realignments aimed at improving food security and rural livelihoods (World Bank, 2012; FAO, 2013). In Algeria, drought-induced declines in agricultural output during the early 2000s led to the adoption of a long-term rural renewal policy that emphasized integrated watershed management and ecosystem restoration (UNDP, 2015). Similarly, Angola, after facing a drop in food crop yields in the late 1990s and early 2000s due to civil conflict and climate variability, received targeted donor support and launched the Family Farming Development Plan (PDPA) to improve smallholder productivity and rural incomes (IFAD, 2019). These examples reflect how downturns in the AF sector often provoke multi-layered responses—ranging from donor assistance and institutional reform to investment in climate-smart technologies.

These responses are consistent with the concept of "sustainability through necessity" (Beck et al., 2020; Nguyen, 2021), where crises prompt innovation, policy shifts, and donor engagement that strengthen long-term development trajectories. The model does not imply that sectoral decline is desirable; rather, it highlights how the institutional and policy responses to adversity can generate medium- to long-term benefits. Such responses may include public spending reallocation, implementation of sustainable land and resource management practices, and increased external financing through climate adaptation funds or multilateral support (UNEP, 2020; AfDB, 2021).

Likewise, both positive ($AP^{+} = 0.046$, $p < 0.01$) and negative ($AP^{-} = 0.028$, $p < 0.01$) shocks are tied to beneficial changes in GS. This demonstrates the flexibility of aquaculture systems, where even setbacks can lead to enhanced regulation, better environmental practices, or a pivot towards more efficient and sustainable aquaculture operations. Although this might sound a bit counterintuitive, the PNARDL model effectively captures these self-adjusting processes that follow shocks. This aligns with findings that suggest aquaculture resilience relies on the institutional ability to turn disruptions into sustainable practices (Zhang et al., 2023; Chaturvedi et al., 2024).

A key aspect of this extended specification is the introduction of institutional quality (IQ), which is significantly and positively linked to GS over both the short and long term. This insight reinforces the notion that effective institutions are vital for better policy implementation, upholding environmental regulations, and enhancing resilience, particularly during downturns in various sectors.

In addition to the main variables, this study incorporates renewable energy (RE), energy intensity (EI), and energy consumption (EC) as control variables. RE consistently has a positive and significant effect on GS, emphasizing the benefits of clean energy transitions in oil-rich economies across Africa. On the other hand, EI negatively affects GS, indicating that energy inefficiencies might be a barrier to sustainability. Meanwhile, EC positively influences GS in both the short and long term, supporting the notion that energy access is a key factor in driving productive activities and economic development (Montalbano et al., 2022).

These results confirm that the relationship between blue economy sectors and sustainability is not linear or uniform. Rather than assuming that increases in all components uniformly promote GS, the evidence suggests nuanced, context-specific dynamics, with institutional and policy responses playing a crucial role in mediating both positive and negative shocks. Therefore, policymakers must focus not only on promoting sectoral growth but also on building resilience and responsiveness to downturns. Doing so ensures that both opportunities and disruptions are harnessed for long-term sustainable development (Rodrik, 2014; Dasgupta, 2021).

6. Discussion

This study highlights the complex and dynamic role of the Blue Economy—specifically agriculture, forestry and fishing value added (AF), aquaculture production (AP), and fishery production (FP)—in promoting sustainable economic development (GS) in oil-dependent African countries. The findings suggest that these sectors are not only critical to rural livelihoods and food security but also function as macroeconomic stabilizers in regions highly exposed to oil price volatility.

It's no surprise that positive changes in AF, AP, and FP lead to meaningful improvements in GS. This aligns perfectly with the Sustainable Livelihoods Framework and the Lewis Dual Sector Model (Lewis, 1954), which highlight how crucial natural resource sectors are for developing economies. Agriculture and its related fields not only provide income, jobs, and food but also promote a shift away from reliance on oil. By encouraging resilience through caring for the environment and fostering economic inclusion, these sectors play a vital role in ensuring long-term sustainability.

Interestingly, the model reveals that negative shocks in agriculture, aquaculture, and fishery production (AF, AP, and FP) are associated with positive long-run effects on sustainable economic development (GS). While this may appear counterintuitive, it reflects how adverse events can prompt policy-driven adjustments that ultimately strengthen sectoral performance and institutional resilience. These shocks often trigger targeted public investments, regulatory reforms, and the mobilization of international support, which together help convert short-term disruptions into long-term gains.

This pattern is evident across the five oil-dependent African countries studied. In response to production downturns, Nigeria and Egypt expanded climate-resilient agricultural programs and aquaculture investments to stabilize food systems (World Bank, 2012; El-Naggar et al., 2015). Algeria initiated integrated rural development and land restoration policies after repeated agricultural stress (UNDP, 2015), while Angola and Libya adopted coastal rehabilitation and fishery management initiatives following environmental degradation (FAO, 2011; IFAD, 2019). These actions demonstrate that well-timed interventions—rather than the shocks themselves—drive the observed positive outcomes.

This dynamic supports the idea of "sustainability through necessity" (Beck et al., 2020; Nguyen, 2021), where institutional responsiveness to crises fosters innovation and policy learning.

Ultimately, the findings highlight that the developmental trajectory of blue economy sectors depends not only on growth but also on how effectively governments react when those sectors are under stress.

For instance, the positive association between fishery production shocks (FP^- and FP^+) and GS may be explained by enhanced governance measures and marine conservation efforts often initiated during periods of resource depletion or output volatility. Literature supports this view: Pauly et al. (2002) and Asche et al. (2015) show that well-managed fisheries can both recover ecological balance and enhance long-term productivity, while unregulated overfishing leads to economic and environmental losses.

Aquaculture production (AP) significantly contributes to sustainable development, reflected in both its positive and negative shock coefficients. This is in line with the World Bank's Blue Economy Framework (2017), which underscores aquaculture's potential to enhance food security, create jobs in rural communities, and alleviate the burden on wild fisheries. Even in challenging times, investing in sustainable aquaculture can provide long-lasting benefits through improved environmental regulations, technological advancements, and a shift to more efficient production models (FAO, 2020; Zhang et al., 2023).

By including energy-related control variables, we can better appreciate how the blue economy plays a role in sustainability. Renewable energy (RE) consistently has a positive effect on green growth (GS), while energy intensity (EI) tends to drag it down, which aligns with the Environmental Kuznets Curve (EKC) hypothesis (Grossman & Krueger, 1991; Ozturk & Acaravci, 2013). These insights support the notion that moving towards clean energy is vital for achieving sustainable growth (Inglesi-Lotz & Dogan, 2018). Moreover, the positive relationship between energy consumption (EC) and GS highlights the critical importance of having access to modern energy to drive productive sectors and maintain livelihoods.

Overall, this study presents robust evidence that the blue economy can serve as a dual engine of economic and environmental sustainability, provided institutions are responsive and policies are targeted. Rather than viewing negative shocks as beneficial per se, the model captures the resilience and adaptive mechanisms that shape how such shocks influence long-run outcomes. The results underscore the need for proactive, well-governed strategies that convert resource volatility into opportunities for sustainable transformation.

This study contributes to the growing empirical support for Sustainable Development Goal (SDG) 14, demonstrating that sound policies in agriculture, fisheries, and aquaculture can help resource-rich countries reduce fossil fuel dependence and build more inclusive, diversified economies.

6.1 Conclusions and Recommendations

This paper examines the asymmetric linkage of the blue economy to sustainable economic growth in five leading oil-producing economies in Africa over the period 1980 to 2023. It yields important information on the numerous determinants of sustainable economic development in these countries, using state-of-the-art econometrics techniques. The analysis attests that energy dynamics, as well as green and blue economic dimensions, are key drivers of long-term sustainable economic development in the region.

Unit root tests revealed that after first differencing, the variable became stationary, meaning that at the level there were unit roots. The cointegration tests signified the presence of long-run equilibrium relationships among variables. Employing standard error estimation after Driscoll and Kraay, the study established that sustainable economic growth in oil-dependent African countries critically depends on blue economy variables such as fishery production and agriculture, in conjunction with some important energy variables like energy intensity and renewable energy consumption.

The results coming from the Panel NARDL clearly revealed that sustainable development is determined asymmetrically, implying positive and negative changes in explanatory variables that generate different effects. These asymmetries were discernible in both short- and long-run relationships, shedding insight into the inherent complexities that characterize sustainable economic development in Africa. This further implies that positive shocks to fisheries and agriculture have been paramount in fostering long-run sustainable economic development. The institutional quality variable also shows a positive and significant result.

Energy use was seen as a key factor. Renewable energy adoption and improvements in energy intensity positively affected sustainability. On the contrary, total energy consumption affected sustainability negatively, barring this world from the shift to clean and efficient energy sources. This study highlights the importance of sustainable management of resources and green technological innovations that require active government policies to help laboriously facilitate the development of renewable energy systems. At the end of the day, the research pushes for broad policy approaches in African nations that produce oil. These strategies need to mesh economic progress with protecting nature and shaking up the energy sector. Taking this all-encompassing route is absolutely essential to protecting natural assets, keeping the environment healthy, and reaching lasting, sustainable economic advancement.

6.2 Policy Recommendations

Based on these findings, policymakers in African oil-dependent countries will find ways to boost sustainable development by growing the blue economy. The major positive effects of agriculture, forestry, and fishing (AF), along with aquaculture production (AP), indicate that these industries are essential for the country's future growth beyond reliance on oil. It is advised that governments in these oil-dependent African countries set up special funds and insurance to protect producers against risks such as climate change, over-fishing, and market disruptions. Based on the essential contribution of agriculture and aquaculture for sustainable development, governments should give more importance to a varied export base, enhanced industrial processing, and climate-proof technological upgrades. For a sustained fishery production (considered less significant in the analysis), rules should aim to train local groups, protect community resources, and address Illegal, Unreported Unregulated fishing.

Likewise, the asymmetric results of the concerned variables underscore the importance of the blue economy indicators towards sustainable economic development in these sampled countries. The evidence suggests that blue economy areas matter greatly in supporting sustainable development, thereby having stronger long-term effects than the negative shocks. To achieve beneficial growth and more resilient outcomes, policymakers are encouraged to establish financial safety nets to resist shocks, enhance growth in areas resistant to climate change, strengthen regulatory frameworks to protect valuable resources, and integrate approaches from the blue economy in their national plans. These targeted initiatives will help African oil-rich and dependent countries leverage their blue economy sectors for sustainable and inclusive economic growth.

On the other hand, positive changes in blue economy areas make a bigger and sustained impact on growth sustainability than the negative shocks. This underlines the need for both growth-focused and risk awareness in policies. Both national and regional plans are now acknowledging these double challenges. In many African nations and at the regional level, blue economy policies have been developed to prioritize ecological growth, presently emphasizing aquaculture, fishing management, and the development of the agricultural sector. These efforts align with this study's finding that positive sectoral growth drives long-term sustainability.

The insights of the study can be used by policymakers and regional leaders to develop policies that would foster viable developments among the oil-rich countries of Africa. The results are indicative of the fact that directing investments into renewable energy and innovation in the sectors of the blue and green economy constitutes a strong direction towards stable economy in the long-run. Initiatives that will enhance such sectors should be given priority since they have been useful to African countries that rely on oil. The report raises another point, which is the necessity of considering energy issues both in terms of consumption and efficiency. In this respect, managers are advised to adopt policies that will reduce their energy requirements and enhance performance without diminishing their requirement of renewable energy whose contributions now go beyond the national development but global sustainability and environmental outcomes.

This research contributes deeper to the subject by analyzing the synergies between the energy consumption, green economy and blue economy sectors that determine sustainable economic growth in African countries. The use of hidden cointegration methods with nonlinear ARDL models guarantees better and sounder results. The asymmetric effects are also included which adds new information about how positive and negative shocks create dissimilar results, what it means to their significance on sustainability. The results can be applied to the better explanation of the theoretical concepts and the prediction of further studies in this area. The paper also proposes evidence-based policy guidelines to policymakers and stakeholders in Africa oil-rich states highlighting the need of various sectors including agriculture, forestry, fisheries, aquaculture, innovation and renewable energy. The knowledge shared would guide governments and international bodies to develop policies that would encourage sustainability, enhance speed on innovation, and focus on clean energy as a long-term development agenda.

This analytical work has a great impact on societal growth in terms of how the incorporation of sustainable growth strategies affect the well-being of the society. The research underlines the importance of the energy, green, and blue economy sectors supported through sustainable initiatives that can create employment, enhance livelihoods, and social welfare of people in African countries. By shifting toward renewable energy and making energy more efficient, not only would a company contribute to the stability of the economy but also alleviate the environmental issues that tend to impact vulnerable communities disproportionately. Solutions to these challenges are very critical towards social equity and general living standards throughout the area. In addition, the blue economy model focuses on sustainable utilization of marine and coastal resources, maintaining a cultural heritage, and promoting the inclusiveness of coastal populations..

6.3 Limitations of the Study

This research provides some crucial learnings about how the blue economy links to sustainable growth in these African countries that are heavily dependent on oil exports. But that doesn't mean it's not without its limitations. The data is only current up to a certain point (based on the availability), thus, it may not give the complete picture of the current happenings. Plus, since the study focuses on just five of the largest oil-producing countries, it's difficult to extrapolate from the findings to the whole of Africa; the economies of these countries vary so much from the rest of the continent. excluding other countries, which also have potential in blue economy development and their sustainability challenges, the scale becomes even wider.

6.4 Future Research Avenues

While this study provides important insights into the blue economy-sustainable development dynamics in African oil-dependent countries, several avenues for future research can further capitalize on the findings and address the limitations noted. Future research can delve into the following areas to further provide a richer and fuller understanding of these dynamics. Future studies must expand the time frame of the data to include post-2023 data to allow for the inclusion of newer trends such as the impact of the Paris Agreement, climate adaptation measures, and the use of alternative energy sources in Africa. Future studies can involve a comparative study to compare oil-dependent countries with non-oil-dependent countries.

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