Revisiting the Migration-Poverty-Growth Nexus in an Oil-Dependent Economy: Evidence from Nigeria

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Abstract. Sustainable economic growth in developing economies is often constrained by structural inefficiencies, poverty, and migration dynamics, yet empirical evidence linking these factors in Nigeria remains limited. Existing studies have largely examined growth determinants in isolation, neglecting the simultaneous influence of poverty and migration on long-term development. This study addresses this gap by investigating the dynamic interplay among migration, poverty, and sustainable economic growth in Nigeria from 2000 to 2023.

Employing an Autoregressive Distributed Lag (ARDL) model and an Error Correction Mechanism (ECM), the analysis integrates real GDP, gross fixed capital formation, labour force participation, remittance inflows, poverty headcount, and trade openness, using 24 annual observations (n=24) sourced from the World Bank, CBN, and NBS. Unit root and cointegration tests confirmed mixed integration orders and a long-run equilibrium among variables, validating the ARDL approach for both short- and long-term inference.

The findings indicated that in the short run, capital formation significantly boosts GDP ($\beta = 0.0123$, $p < 0.01$), whereas labour and remittance inflows exert weak and insignificant effects. Poverty exhibits a positive short-run association with GDP ($\beta = 9.2966$, $p < 0.01$), reflecting informal coping mechanisms, while trade openness shows a negative but insignificant effect. Long-run estimates confirm capital formation as a growth driver, labour participation as structurally constrained ($\beta = –0.000284$, $p < 0.01$), and remittances as largely unproductive. The Error Correction Model confirms an adjustment speed of 44% annually (ECT = –0.44), with the model explaining 77% of GDP variation ($R^2 = 0.77$).

Based on the findings, it is recommended that there is a need for investment deepening, labour market reforms, productive utilisation of remittances, and inclusive growth policies to align with SDGs 1 and 8, ensuring that economic expansion translates into poverty reduction and sustainable development.

Keywords: migration, poverty, sustainable economic growth, remittances**,** ARDL model.

INTRODUCTION

In recent years, remittances from Nigerians abroad have grown significantly. Hence, policies targeted towards strengthening oversight and refining formal remittance channels are being encouraged. Nigeria's migration and remittance policies have focused on two main goals: controlling unlawful flows through stronger guidelines and creating

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diaspora-oriented financial instruments, such as diaspora bonds, to attract long-term foreign capital. However, challenges remain, including weak implementation, informal channel denseness, and the difficulty of balancing regulatory compliance with financial inclusion (Muse, 2025).

Remittances have the potential to support growth, but only when financial systems can convert them from short-term household consumption into productive investment. Without structured incentives, remittances often focus mainly on consumption, thereby limiting their contribution to long-term growth (Barkat, 2024). Nigeria's institutional framework has made appreciable progress in legal migration channels, diaspora engagement, and remittance facilitation, yet gaps remain in coordination and fiscal instruments. GFMD (2023) emphasised the need for a combination of effective supervisory oversight and dependable diaspora investment frameworks to channel remittances into productive projects (Barkat, 2024; Muse, 2025).

Effective remittance utilisation requires complementary reforms. Digital financial inclusion, through mobile banking, remittance-linked savings, and credit products, reduces transaction costs and encourages the use of formal accounts, allowing recipients to build credit histories and access loans for SMEs (Osabutey et al., 2024). Targeted SME financing, including credit guarantees, diaspora-backed investment funds, matching grants, and blended-finance schemes, helps convert remittances into productive investment while lowering risk (Mbango, 2024). Regulatory reforms, such as simplified Know Your Customer (KYC) for small remittance recipients, interoperable digital IDs, fintech sandboxes, and tax incentives for diaspora investors, further enhance the productive use of funds (Bettin et al., 2024). The combination of financial literacy and market access support interventions creates an ecosystem that is capable of redirecting remittances from consumption to investment (Bettin et al., 2024; Mbango, 2024; Osabutey et al., 2024).

Therefore, to achieve the SDGs, particularly SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), and SDG 10 (Reduced Inequalities), it is necessary to integrate institutional reforms, structural transformation, and inclusive and sustainable policies. Evidence from G20 countries shows that stronger institutions and diversified economies lead to better employment and growth outcomes, underscoring the importance of governance in sustaining growth (Azimi, Rahman & Maraseni, 2025). Similarly, in China, uneven regional development restricts the benefits of national growth. This further underscores that inclusive policies and targeted regional interventions are indispensable for poverty reduction and achieving the SDGs (Ji et al., 2025). In Sub-Saharan Africa, growing inequality undermines poverty reduction. This implies that inclusive growth requires attention to both distribution and aggregate growth (Amponsah, Agbola & Mahmood, 2023).

Institutional quality also affects whether migration and remittances contribute to economic growth. Studies in Sub-Saharan Africa show that weak governance can prevent remittances from translating into GDP growth, as funds are often used for consumption rather than investment. Alamoudi (2024) opined that remittances only positively impact growth when governance indicators, such as regulatory quality, corruption control, and government effectiveness, are high. Studies across emerging and advanced economies also showed that regulatory quality is particularly important in determining whether remittances contribute to real GDP growth. At the same time, general rule-of-law indicators may have ambiguous effects. These findings show that the impact of remittances on the economy depends largely on the quality of governance. When institutions are weak, the money sent home from abroad cannot effectively support sustainable growth.

Sustainable economic growth, therefore, is about expanding productive capacity while ensuring social inclusion and environmental sustainability. Growth that benefits only a few segments of society or harms the environment cannot be considered truly sustainable under the 2030 Agenda for Sustainable Development. Globally, progress on the SDGs is uneven, with many regions lagging in poverty reduction and inclusive growth despite rising GDP (United Nations, 2025a). Migration plays a significant role in this scenario by affecting labour supply, remittance flows, the distribution of human capital, and demographic changes. All these shape the pattern of sustainable growth in the long run.

Migration can equally support and constrain economic growth. On one hand, it improves population pressure, facilitates

knowledge transfer, and generates remittance income for households. On the other hand, large-scale emigration of skilled workers can reduce human capital, raise dependency ratios, and create fiscal pressures. The 2030 Agenda recognises this duality, linking migration to several SDGs and emphasising the need for policies that maximise benefits while reducing its negative impacts (Ofori et al., 2023; Usman et al., 2022).

In West Africa and Nigeria, migration is motivated by economic differences, environmental pressures, insecurity, and governance challenges. Internal and international movements respond to livelihood insecurity and the pursuit of better opportunities, which in turn shape urban labour markets, household strategies, and regional remittance networks. Studies have shown that the effects of migration vary depending on migrants' skills, available opportunities in the countries of destination, and economic conditions in the sending countries. Hence, migration can assist households to escape poverty; it can also leave others stuck in hardship, especially when the sending country is not growing broadly and inclusively (Schürmann et al., 2022).

Nigeria has experienced periods of strong GDP growth alongside persistent poverty and inequality. This explains why growth alone is insufficient to promote inclusive development. Migration plays a central role in household livelihoods and macroeconomic dynamics. Internal migration supports urban labour supply but often results in informal employment, while international migration generates remittance inflows that can support consumption and investment. Skilled emigration raises concerns about the loss of human capital, particularly in public services and innovation systems. Policy initiatives, including proposals for diaspora funds and bonds, aim to leverage migration-related capital for national development (Ozoh et al., 2025; Reuters, 2024, 2025).

The effects of migration on poverty and growth in Nigeria operate mainly through two channels. First, remittances support household welfare by funding consumption, education, health, and small-scale investment. Their impact on long-term growth depends on the extent to which they are channelled into productive investment and integrated with financial inclusion and trade policies (Mbadiwe & Egesimba, 2024). Second, migration-driven labour reallocation affects domestic production. Rural-urban migration provides labour for services and informal manufacturing, but also increases underemployment where formal jobs are scarce. Skilled emigration (brain drain) reduces institutional capacity and limits productivity gains, particularly if migration is not coupled with investment or trade in higher-value sectors. The balance between remittance flows, skill transmission, and domestic capacity determines whether migration supports sustainable economic growth.

Empirical studies offer mixed evidence. Some Nigerian research shows positive effects of remittances on growth (Abdullahi et al., 2023; Mbadiwe & Egesimba, 2024; Nwokoro, 2024), while others report negative or insignificant impacts of migration on economic output (Ihezie et al., 2025). These variations highlight that migration's contribution to growth is context-dependent, influenced by institutional quality, inequality, sectoral structure, and policy interventions.

Despite growing literature on migration and development, few studies examine the combined relationships among migration, poverty, and sustainable economic growth in Nigeria. Most research focuses on either migration-growth or migration-poverty links in isolation. This study fills this gap by exploring the multidimensional connections among migration, poverty reduction, and sustainable economic growth in Nigeria, offering a more integrated understanding of how mobility, financial flows, and domestic economic structures interact to shape development outcomes.

LITERATURE REVIEW

Migration, poverty, and sustainable economic growth are central to development discourse, reflecting complex interrelations between human mobility, socio-economic structures, and policy environments. Conceptually, migration is understood as a multidimensional phenomenon encompassing both voluntary and involuntary movements, shaped by economic, social, political, and environmental factors. Uchegbulam and Okoronkwo (2025) define migration as cross-border movement motivated by economic opportunities, educational pursuits, and improved living standards, often resulting in the loss of skilled labour in source countries. Schürmann et al. (2022) expand this view,

emphasising that migration is driven by a combination of economic, environmental, social, political, and food security factors, positioning it as both a challenge and a developmental resource. Internal migration, in contrast, refers to movement within national borders, typically from rural to urban centres for employment, education, or better living conditions (Awuse, 2018; Oyeniyi, 2013; Tolorunju et al., 2019). Such movements often involve remittance flows or resource transfers to origin households, underscoring migration's potential as an anti-poverty mechanism.

Poverty, in the literature, is consistently described as multidimensional and dynamic, encompassing material deprivation, limited access to education, healthcare, and basic services, as well as social exclusion. Yameogo and Omojolaibi (2021) operationalise poverty using the headcount ratio of individuals living below the international poverty line, while Zhu et al. (2022) extend this to include human capabilities and social participation. Škare et al. (2016), Balasubramanian et al. (2023), and the United Nations (2025b) emphasise multidimensional poverty encompassing deficits in income, health, education, employment opportunities, and social inclusion, measured through indices such as the Multidimensional Poverty Index (MPI) and the Global Correlation-Sensitive Poverty Index (G-CSPI). These conceptualisations reflect poverty as both a structural and material condition, highlighting deprivation in rights, agency, and capabilities rather than mere income insufficiency (Affandi et al., 2025; Igbokwe-Ibeto et al., 2012).

Sustainable economic growth is similarly defined as a long-term process integrating productive expansion with social equity and environmental stewardship. Adegbuyi et al. (2015) characterise sustainable growth as driven by entrepreneurial innovation and capacity building, generating employment, income, and poverty reduction. Sokunbi et al. (2025) and the United Nations (2025a) emphasise the distribution of opportunities and preservation of social and environmental capital, aligning sustainable growth with the Sustainable Development Goals (SDGs). Chirtoc and Medar (2019) further stress that both qualitative and quantitative expansion of output must be accompanied by structural transformation and improvements in inclusive welfare. Collectively, these conceptual frameworks suggest that migration, through remittances, skill transfer, and reallocation of human capital, can influence poverty alleviation and sustainable economic growth. Yet, its developmental role remains underexplored in the Nigerian context.

Theoretically, this study is anchored on the Sustainability Transitions Theory (STT), which explains long-term societal and economic change as the product of interactions among niche innovations, dominant socio-technical regimes, and broader landscape pressures. Geels (2011) posits that technological, institutional, and cultural shifts co-evolve over time, producing systemic transformation. Adger et al. (2024) extend STT to migration, theorising human mobility as a structural mechanism that redistributes skills, diffuses productive norms and technologies, and modifies consumption and resource patterns. Migration thus operates both as a response to regime failures and as a catalyst for niche innovations, where remittances, knowledge transfers, and entrepreneurial activity can stimulate technological diffusion and institutional learning. When these flows are aligned with effective governance and financial systems, they can foster poverty reduction and sustainable growth. However, meta-analyses reveal that the average growth effect of remittances is modest and highly context-dependent, varying across governance environments and institutional frameworks (Cazachevici et al., 2020; World Bank, 2023). Accordingly, STT reframes migration as an endogenous structural lever whose developmental impact emerges from dynamic interactions among niches, regimes, and landscape pressures that shape sustainable growth trajectories.

Empirical evidence supports the view that migration and remittances influence both poverty and economic growth, though outcomes vary depending on governance, institutional capacity, and policy environments. Globally, Tangpatthamachart and Amornkitvikai (2025), analysing a panel of 180 countries (1950-2010) with system GMM estimators, found that a 1% increase in the working-age population share raised GDP per capita growth by 1.6%, while a 1% decline in child dependency improved income growth by 0.5% and reduced poverty. Affandi et al. (2025), in a semi-systematic review of 149 studies (2008-2024), emphasised that multidimensional poverty cannot be understood in isolation from institutional and environmental contexts, and recommended mixed-method approaches integrating spatial and econometric

analyses. These findings highlight that migration can generate demographic dividends and poverty reduction, although its benefits are conditional on human capital and institutional frameworks (Škare & Pržiklas Družeta, 2016; United Nations, 2025b).

Regional studies provide additional insights into the structural determinants of migration and growth outcomes. Amar et al. (2020) applied a dynamic GMM model to ASEAN countries (2004-2017), finding that growth reduces poverty, though rising inequality offsets this benefit. In West Sumatra, Amar et al. (2022) used two-stage least squares estimation to demonstrate bidirectional causality between poverty, investment, and growth, with education, health, and unemployment as key determinants. In sub-Saharan Africa, Yameogo and Omojolaibi (2021) employed panel ARDL, VAR, and system-GMM models across 40 countries (1990-2017), showing that trade openness and institutional quality positively impact long-run growth and poverty reduction, while short-run effects are limited.

Within Africa, migration is shaped by both opportunities and constraints. Moyo et al. (2020) found, through a qualitative meta-analysis, that intra-African migration holds significant developmental potential but is constrained by policy fragmentation, securitisation, and xenophobia. Schürmann et al. (2022) demonstrated, using mixed-methods and spatial mapping, that environmental degradation and agricultural limitations drive north-south migration in Ghana, Burkina Faso, and Nigeria, linking mobility to SDGs 1 and 13, and highlighting the need for migration-sensitive climate and development policies.

Empirical research specific to Nigeria presents mixed results. Raimi and Ogunjirin (2012), employing multiple regression (1970-2006), found that GDP was negatively associated with both inflation and remittances, but positively associated with foreign investment and reserves, suggesting that remittances alone are insufficient for growth without macroeconomic stability. Afaha (2013), using the Lagos Migration Survey (2010) and Sub-Saharan panel data, showed that remittances significantly reduce poverty and stimulate household investment. More recent studies reinforce the role of remittances in growth. Mbadiwe and Egesimba (2024) employed ADF, PP, Johansen cointegration, and ECM techniques (1986-2021), finding that remittances and gross fixed capital formation positively affect long-run GDP, with an ECM adjustment speed of 46.1%. Similarly, Nwokoro (2024), using ARDL (1990–2022), found remittances significantly determine long-run growth, adjusting at 31.1% per year, and emphasised the importance of policy reforms to channel inflows productively.

However, contrasting evidence highlights the limits of migration benefits in the absence of supportive structures. Ihezie et al. (2025) used DOLS estimation (1990-2024) and reported that while remittances positively impact growth, migration stock had a negative but statistically insignificant effect. Uchegbulam and Okoronkwo (2025) observed weak, non-significant links between net migration and MSME development (2015-2025). These studies suggest that unregulated emigration, particularly of skilled labour, can induce brain drain and reduce productivity, undermining SDG 8.

Micro-level studies emphasise household welfare effects of internal migration. Awuse (2018), using surveys across six Ghanaian regions, found that internal migration improves access to education, sanitation, and savings, reducing multidimensional poverty. Oyeniyi (2013) documented similar gains in Nigeria, while Tolorunju et al. (2019) demonstrated that internal remittances increase households' probability of escaping poverty, with 58.3% receiving remittances and 80% classified as poor by MPI standards. These findings confirm that internal migration, when supported by welfare systems, can alleviate poverty and promote resilience.

Migration's ecological and sustainability dimensions further enrich the analysis. Li and Wang (2016), using Ningxia ecological migration data, showed that state-led resettlement improves livelihoods and restores degraded ecosystems, though integration and income stability challenges persist. Javid et al. (2012) and Imai et al. (2014) report that remittances reduce poverty and enhance growth in Asian contexts, but volatility can destabilise macroeconomic outcomes. Kurmaiev et al. (2020) and Adger et al. (2024) emphasise governance and institutional quality as key determinants of whether migration contributes positively to sustainable development.

Synthesising across the literature reveals several convergences. Migration and remittances enhance growth (Amar et al., 2020; Imai et al., 2014; Mbadiwe & Egesimba, 2024; Nwokoro, 2024; Tangpatthamachart & Amornkitvikai,

2025), internal migration improves household welfare (Awuse, 2018; Oyeniyi, 2013; Tolorunju et al., 2019), and governance and institutional quality are critical for translating migration into sustained economic development (Kurmaiev et al., 2020; Moyo et al., 2020). However, notable gaps remain. Empirical analyses integrating migration, poverty reduction, and sustainable economic growth within a single framework are limited, especially for Nigeria. Most studies examine either the migration-growth link or the migration-poverty link, often neglecting sustainability outcomes and multidimensional poverty indicators. This study, therefore, seeks to fill these gaps by examining the relationships among migration, poverty, and sustainable economic growth in Nigeria, thereby providing a comprehensive framework that links migration to inclusive and sustainable development and addresses critical empirical and conceptual deficiencies in the existing literature.

METHODOLOGY

This study employs an Autoregressive Distributed Lag (ARDL) framework to examine the dynamic relationship between sustainable economic growth and key macroeconomic indicators in Nigeria. The approach follows the empirical structure of Nwokoro (2024), but extends the specification by integrating poverty and migration-related variables to better reflect contemporary development challenges. Grounded in the Solow growth model and its endogenous extensions, which emphasise capital accumulation, labour dynamics, openness, and external financial flows. The study models real GDP as a function of capital formation, labour force participation, remittance inflows, poverty levels, and trade openness.

Annual time-series data for the period 2000-2023 were sourced from the World Bank's World Development Indicators, the Central Bank of Nigeria (CBN) Statistical Bulletin (2024), and the National Bureau of Statistics (NBS). The functional relationship is specified as:

$$GDPt = f(CAPt, LABt, REMt, POVt, TOt)$$

Which is operationalised econometrically as:

$$GDPt = \beta 0 + \beta 1CAPt + \beta 2LABt + \beta 3REMt + \beta 4POVt + \beta 5Tot + \mu t$$

where real GDP (GDPt) proxies sustainable economic growth; CAPt, denotes gross fixed capital formation; LABt represents the labour force; REMt captures remittance inflows as a migration indicator; POVt denotes the national poverty headcount; TOt measures trade openness; and μt is the stochastic error term. The ARDL approach is selected for its robustness in handling regressors integrated at mixed orders (I(0) and I(1)) and its ability to capture both short-run adjustments and long-run equilibrium relationships.

RESULTS AND DISCUSSION

Table 1: Descriptive Statistics

Statistic	GDP	CAP	LAB	REM	POV	TO
Mean	2,179.284	19,274.77	56,777,240	4.478	3.945	4.169
Median	2,354.276	10,089.57	56,263,940	4.648	0.552	3.303
Maximum	2,585.734	82,889.22	73,389,347	8.334	41.800	20.794
Minimum	1,421.680	2,404.816	41,887,859	1.015	0.392	–3.699
Standard Deviation	353.064	21,730.01	9,893,709	1.888	11.660	6.020
Skewness	–0.845	1.717	0.177	–0.262	3.015	1.114
Kurtosis	2.452	4.869	1.841	2.581	10.090	3.820
Jarque-Bera	3.155	15.290	1.468	0.450	86.623	5.634
Probability	0.206	0.001	0.480	0.798	0.0000	0.060

Observations	24	24	24	24	24	24

Source: Authors' computation (2025)

The descriptive statistics in Table 1 reveal that Nigeria's GDP shows moderate dispersion, indicating uneven yet steady growth; gross fixed capital formation displays extreme variability and strong positive skewness, suggesting unstable investment flows largely driven by episodic policy reforms and external shocks. The labour force showed relatively stable expansion, consistent with demographic growth, whereas remittances exhibited low volatility, suggesting that migrant inflows remained a reliable source of income during economic downturns. Poverty exhibited the highest fluctuation and excessive kurtosis, highlighting deep income inequality and recurrent welfare crises. At the same time, trade openness was highly dispersed and positively skewed, reflecting Nigeria's inconsistent trade liberalisation regime. The Jarque-Bera test indicates that GDP, LAB, and REM are approximately normally distributed, whereas CAP, POV, and TO deviate significantly, a common feature of macroeconomic series in developing economies prone to shocks.

Table 2 Correlation Coefficient (Matrix**)**

Variables	***GDP***	***CAP***	***LAB***	***REM***	***POV***	***TO***
GDP	*1.000*					
CAP	*0.434*	*1.000*				
LAB	*0.222*	*0.254*	*1.000*			
REM	*0.446*	*0.146*	*0.303*	*1.000*		
POV	*0.926*	*0.371*	*0.511*	*0.050*	*1.000*	
TO	*–0.502*	*0.494*	*0.323*	*0.321*	*–0.209*	*1.000*

Source: Authors' computation (2025)

The correlation results in Table 2 show that economic growth is positively associated with capital formation, labour force expansion, and remittance inflows, suggesting that investment activity, labour participation, and migrant transfers all move in tandem with Nigeria's output performance. Trade openness exhibits a moderate negative correlation with GDP, indicating that external sector dynamics may exert contractionary tendencies on growth, possibly reflecting import dependence or structural trade imbalances. Poverty is strongly positively correlated with GDP, a pattern likely driven by structural measurement issues or growth episodes that have not translated into welfare improvements.

Table 3: Unit Root Test Results

Variable	ADF Test (Level)	ADF Test (1st Diff.)	PP Test (Level)	PP Test (1st Diff.)	Order of Integration
GDP	–3.1974**	—	–3.1520**	—	I(0)
CAP	–0.2211	–3.7673***	–0.3425	–3.8921***	I(1)
LAB	–2.1562	–4.3014***	–2.4292	–4.5793***	I(1)
REM	–1.2670	–9.1556***	–1.9186	–8.8617***	I(1)
POV	–2.7240	–5.0855***	–1.8254	–5.8651***	I(1)
TO	–2.1924	–6.6386***	–2.1662	–6.7683***	I(1)

Notes: **ADF** denotes Augmented Dickey-Fuller test; **PP** denotes Phillips–Perron test.
***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.
Source: Authors' computation (2025)

The unit root diagnostics in Table 3 from both the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests confirm a mixed order of integration among the variables. Real GDP is stationary at the level under both tests, establishing its I(0) status. Conversely, capital formation, labour force, remittance inflows, poverty headcount, and trade openness are all non-stationary at levels but attain stationarity after first differencing, indicating I(1) behaviour.

The consistency between ADF and PP results reinforces the robustness of the integration pattern and validates the appropriateness of employing the ARDL model.

Table 4: ARDL Bounds Cointegration Test

Test Statistic	Value
F-statistic	6.2898

Table 5: Case 4: Restricted Trend

Critical Bounds (Case 4: Restricted Trend)	I(0)	I(1)
10% level	3.097	4.118
5% level	3.715	4.878
1% level	5.205	6.640

Source: Authors' computation (2025)

The ARDL Bounds cointegration test in Table 4 indicates the presence of a long-run equilibrium relationship among sustainable economic growth, capital formation, labour force, remittances, poverty, and trade openness. The computed F-statistic of 6.2898 exceeds the upper critical bounds at the 10% (4.118), 5% (4.878), and 1% (6.640) significance levels for the selected restricted trend specification. This implies rejecting the null hypothesis of "no level relationship," confirming that the variables are cointegrated despite the relatively small sample size.

Table 6: ARDL Long-Run and Short-Run Estimation Results

Long-Run	Coefficient	Std. Error	t-Statistic	p-Value
D(CAP)	0.0123	0.0040	3.0696	0.0097
D(LAB)	-0.000077	0.000042	-1.8348	0.0914
D(REM)	-6.9787	10.2613	-0.6801	0.5093
CAP(-1)	0.00098	0.002996	0.3270	0.7493
LAB(-1)	-0.000284	0.000084	-3.3701	0.0056
REM(-1)	-14.9631	9.2319	-1.6208	0.1310
Short-Run				
GDP(-1)	0.5631	0.2327	2.4199	0.0323
CAP	0.0123	0.0040	3.0696	0.0097
CAP(-1)	-0.0113	0.0053	-2.1340	0.0542
LAB	-0.000077	0.000042	-1.8348	0.0914
LAB(-1)	-0.000207	0.000054	-3.8478	0.0023
REM	-6.9787	10.2613	-0.6801	0.5093
REM(-1)	-7.9844	7.4925	-1.0656	0.3076
POV	9.2966	2.6344	3.5289	0.0042
TO	-4.5067	3.2667	-1.3796	0.1929

Source: Authors' computation (2025)

The ARDL estimates reveal that capital significantly stimulates output in both the long and short run, confirming its role in enhancing productive capacity. Labour exhibits a negative and statistically significant long-run effect, suggesting structural rigidities or diminishing marginal productivity. Remittances show no meaningful impact on growth, indicating weak transmission into productive investment. In the short run, output displays strong persistence, while the negative lagged capital and labour coefficients highlight adjustment frictions.

Poverty exerts a positive contemporaneous effect on GDP, reflecting short-term inconsistencies in welfare output, whereas trade openness remains insignificant. In summary, the results underscore capital's primacy and structural constraints in the growth process.

Discussion of Result

The ARDL results present a coherent narrative about the drivers of economic performance. Capital investment consistently emerges as the strongest contributor to growth. Both the short-run and long-run coefficients for gross fixed capital formation are positive and significant, confirming that sustained investment remains central to expanding productive capacity. The significant lagged GDP term also indicates strong output persistence, meaning that growth responds not only to current investment but also to past economic momentum (Topçu et al., 2020).

Labour participation, however, shows weak and sometimes adverse effects. In the short run, it is statistically insignificant, while the lagged long-run coefficient turns negative and significant. This suggests that increases in labour supply alone do not translate into higher output. Such a pattern aligns with conditions in which labour productivity is low, jobs are not expanding in productive sectors, and structural unemployment or a skills mismatch limit the economy's ability to effectively absorb workers (Oyedepo, 2024). Thus, without improvements in human capital and job quality, labour expansion does little to support growth.

Remittances also do not contribute meaningfully to economic expansion. Their coefficients are negative and insignificant across both horizons, suggesting that these flows may be directed more toward consumption smoothing than toward productive investment. In institutional environments with limited financial intermediation or weak investment incentives, remittances often fail to stimulate capital accumulation or enterprise formation, reducing their potential growth impact.

A notable finding is a positive relationship between poverty and GDP in both the short- and long-run. Rather than suggesting inclusive growth, this outcome replicates a structural disconnect; output increases while welfare conditions fail to improve. It may also signal measurement effects, in which rising informal-sector activity boosts GDP without reducing multidimensional poverty (Maune & Matanda, 2022; Ochi, 2023). This contradiction underscores distributional failures, growth concentrated in a few sectors or regions, weak social protection, and inadequate pro-poor public investment.

Overall, the results imply that for growth to become inclusive and sustainable, policymakers must strengthen capital formation, enhance labour productivity, reform labour markets, and create mechanisms that channel remittances into investment. Without these complementary policies, economic expansion will continue to bypass vulnerable groups and reinforce existing inequalities.

Table 7: Error Correction Model (ECM)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
COINTEQ*	-0.436914	0.053763	-8.126650	0.0000
D(CAP)	0.012257	0.002326	5.269713	0.0001
D(LAB)	-0.0000771	0.0000165	-4.676937	0.0002
D(REM)	-6.978741	4.403563	-1.584794	0.1304
C	12316.640	1505.188	8.182789	0.0000

Diagnostic Statistics	Value		
R-squared	0.808819	Mean dependent variable	43.24705
Adjusted R-squared	0.766334	S.D. dependent variable	65.42876
S.E. of regression	31.62762	Akaike info criterion	9.935599
Sum squared resid	18005.52	Schwarz criterion	10.18245
Log likelihood	-109.2594	Hannan-Quinn criterion	9.997680
F-statistic	19.03786	Prob(F-statistic)	0.000003
Durbin-Watson statistic	1.759221	—	—

Source: Authors' computation (2025)

The Error Correction Model results in Table 7 confirm the validity of a long-run adjustment mechanism for the growth model. The error correction term is negative and highly significant, indicating that approximately 44% of deviations from the long-run equilibrium are corrected each year. This magnitude implies a moderately fast speed of adjustment in Nigeria's growth dynamics.

In the short run, capital formation has a positive, statistically significant impact on economic growth, reaffirming the centrality of investment to output expansion. Conversely, the labour force variable shows a negative, significant effect, suggesting structural inefficiencies in labour absorption or productivity constraints in the Nigerian economy. Remittances exhibit a negative, though statistically insignificant, coefficient, implying that migration-related financial inflows do not generate immediate short-term growth effects, likely because remittances are consumed rather than invested.

The constant term is positive and significant, capturing unobserved factors contributing to short-run growth. The diagnostic statistics reveal strong model performance: an adjusted R^2 of 0.77 indicates that approximately 77% of short-run variations in GDP are explained by the regressors. The F-statistic is significant ($p < 0.001$), confirming overall model validity. Information criteria (AIC, SC, HQC) are relatively low, and the Durbin-Watson statistic (1.76) indicates no severe autocorrelation.

Table 8: Diagnostic and Stability Tests

Test	Statistic	Value	df	Probability	Decision
Breusch-Godfrey Serial Correlation LM Test	F-statistic	1.4306	(1, 13)	0.2530	No serial correlation (Fail to reject H_0)
	Obs*R-squared	2.2801	(1)	0.1310	
Breusch-Pagan-Godfrey Heteroskedasticity Test	F-statistic	0.5958	(8, 14)	0.7665	Homoskedasticity (Fail to reject H_0)
	Obs*R-squared	5.8414	(8)	0.6650	
	Scaled explained SS	2.3007	(8)	0.9704	

The diagnostic checks conducted on the ARDL in Table 8 model confirm that the estimated regression satisfies the key assumptions required for valid statistical inference. The Breusch-Godfrey Serial Correlation LM test shows no evidence of serial correlation, as the F-statistic and the Obs*R^2 statistic both fail to reject the null hypothesis. This indicates that the model's residuals are independently distributed and that the dynamic specification is appropriately structured.

Similarly, the Breusch-Pagan-Godfrey test demonstrates that the residuals are homoskedastic. The F-statistic, together with the corresponding Obs*R^2 and Scaled Explained SS statistics confirm the absence of heteroskedasticity, implying that the error variances are stable across observations. This enhances the reliability of the coefficient estimates and ensures that the standard errors are unbiased. These outcomes validate the model's econometric soundness and strengthen confidence in its policy implications.

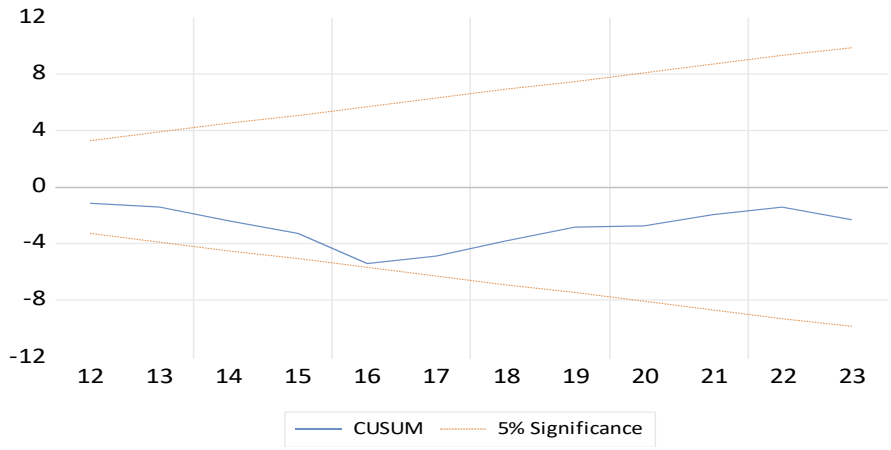

Figure 1: CUSUM TEST

The CUSUM and CUSUM of Squares (CUSUMSQ) (Figure 1, 2) stability tests evaluate the structural stability of the estimated ARDL model over the study period. The CUSUM plot typically indicates whether the model's parameters remain stable by showing if the cumulative sum of recursive residuals stays within the 5% significance boundaries. In this study, the CUSUM test line remained within the critical bounds, implying that the short-run coefficients of the ARDL model are stable and reliable over time. Similarly, the CUSUM of Squares test assesses the constancy of the variance of the residuals. The CUSUMSQ plot also remained within the 5% confidence interval, indicating no structural breaks or parameter instability in the model. Collectively, these results confirm that the estimated ARDL model is structurally stable, and its parameters are consistent and suitable for valid inference.

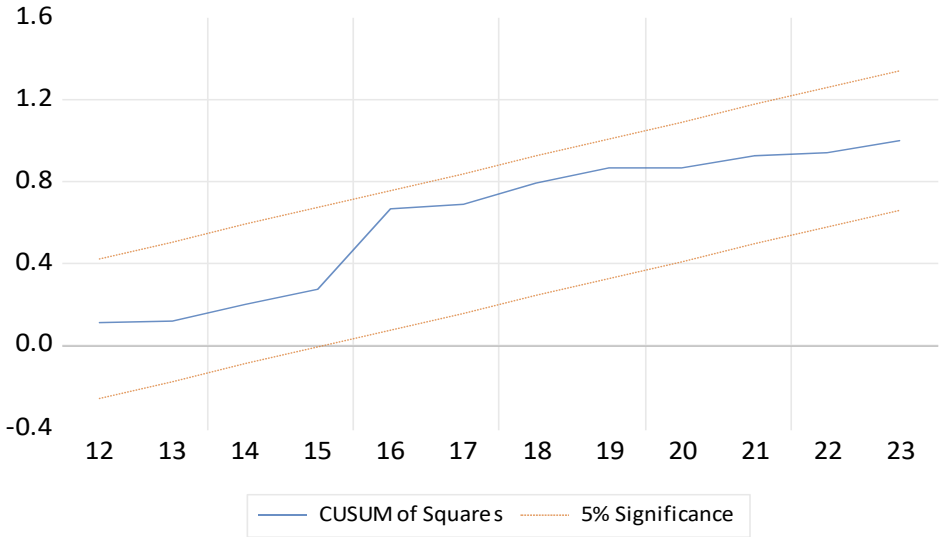

Figure 2: CUSUM SQUARE TEST

Limitations of the Study

The study has some limitations that should be noted. In the first instance, the sample size is relatively small (n=24). Similarly, the study focused solely on one country, Nigeria. The findings, therefore, may not apply to other countries with different economic structures. Third, some variables may be endogenous to one another, raising endogeneity concerns. In another perspective, economic reforms and structural changes over the years could affect outcomes, so the results should be interpreted carefully and not seen as conclusive.

CONCLUSION AND RECOMMENDATION

This study investigates the relationship among migration, poverty, and sustainable economic growth in Nigeria over the period 2000-2023, employing an ARDL framework complemented by an Error Correction Model (ECM). The findings provide robust evidence of both short-run and long-run relationships among capital formation, labour force participation, remittance inflows, poverty levels, trade openness, and GDP growth.

In the short run, capital formation emerges as a significant driver of economic growth, highlighting the importance of investment in productive sectors. Conversely, labour force participation and remittances exhibit weak or negative effects, reflecting structural inefficiencies in labour absorption and the consumption-oriented utilisation of remittance inflows. Poverty demonstrates a positive but contradictory short-run association with GDP, suggesting that informal economic activities by low-income households temporarily expand measured output without delivering inclusive growth. Trade openness appears contractionary in the short term, reflecting Nigeria's import-dependent economic structure and uneven integration into global markets.

In the long run, sustained capital accumulation remains a central pillar of growth. In contrast, labour force participation continues to exert a negative and significant influence, indicative of persistent structural unemployment and low productivity. Remittances do not significantly contribute to long-term growth, suggesting that current channels are inefficient at translating migrant inflows into productive investments. Notably, poverty continues to have a significant positive effect on GDP, underscoring the challenge of non-inclusive growth, in which national output expands without commensurate welfare gains. The bidirectional causality between labour and poverty highlights a reinforcing cycle. Inadequate employment worsens poverty, while poverty constrains productive labour engagement. Similarly, the reciprocal link between trade openness and remittances emphasises the interconnectedness of global migration and trade flows.

In view of the study's findings, the following policy implications arise. First, investment deepening through targeted fiscal incentives, infrastructure development, and public-private partnerships is essential to drive sustainable growth. Second, structural labour market reforms, including vocational training, skill development, and enhanced absorption capacity, are necessary to translate labour force expansion into productivity gains. Third, remittances should be channelled into productive sectors such as small and medium enterprises (SMEs) and agribusiness to enhance their growth impact. Fourth, inclusive growth strategies, including social protection programs and pro-poor investment schemes, are vital to ensure that GDP expansion translates into poverty reduction. Fifth, trade policies should focus on export diversification and value addition to reduce import dependence and maximise employment creation. Finally, integrated migration and trade policies are recommended to harness remittances and diaspora investments for national development.

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Conflict of Interest

None.

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REFERENCE

Abdullahi, S. R., Kwaru, S. M., & Karim, D. I. (2023). Capital structure and financial performance of listed consumer goods firms in Nigeria. *Nigerian Journal of Management Sciences*, *24*(2b), 55–69. https://nigerianjournalofmanagementsciences.com/wp-content/uploads/2023/09/8.-CAPITAL-STRUCTURE-AND-FINANCIAL-PERFORMANCE-OF-LISTED-CONSUMER-GOODS-FIRMS-IN-NIGERIA.pdf

Adegbuyi, A., Fadeyi, O., Oke, A. O., Ajagbe, M. A., & Isiavwe, D. T. (2015). Sustainable economic growth and poverty reduction through entrepreneurship. *International Journal of Academic Research in Economics and Management Sciences*, *4*(2), Pages 62-75. https://doi.org/10.6007/IJAREMS/v4-i2/1675

Adger, W. N., Fransen, S., Safra De Campos, R., & Clark, W. C. (2024). Migration and sustainable development. *Proceedings of the National Academy of Sciences*, *121*(3), Article e2206193121. https://doi.org/10.1073/pnas.2206193121

Afaha, J. S. (2013). Migration, remittance and development in origin countries: Evidence from Nigeria. *African Population Studies, 27*(1), 53–66. https://utoronto.scholaris.ca/server/api/core/

bitstreams/8b687634-b610-4b7e-9757-7ab6d303b700/content

Affandi, Purwaningsih, Y., Hakim, L., & Mulyaningsih, T. (2025). Interplay between poverty, poverty eradication and sustainable development: A semi-systematic literature review. *Global Transitions*, *7*, 1–20. https://doi.org/10.1016/j.glt.2024.11.001

Alamoudi, A. (2024). Do governance indicators have a role in remittances-growth nexus in Egypt? *Economic Journal of Emerging Markets*, 164–177. https://doi.org/10.20885/ejem.vol16.iss2.art6

Amar, S., Idris, I., Pratama, I., & Anis, A. (2020). Exploring the link between income inequality, poverty reduction and economic growth: An ASEAN perspective. *International Journal of Innovation, Creativity and Change, 11*(2), 24–41.

Amar, S., Satrianto, A., Ariusni, & Kurniadi, A. P. (2022). Determination of poverty, unemployment, economic growth, and investment in West Sumatra Province. *International Journal of Sustainable Development & Planning, 17*(4), 1237–1248. https://doi.org/10.18280/ijsdp.170422

Amponsah, M., Agbola, F. W., & Mahmood, A. (2023). The relationship between poverty, income inequality and inclusive growth in Sub-Saharan Africa. *Economic Modelling, 126,* Article 106415. https://doi.org/10.1016/j.econmod.2023.106415

Awuse, A. (2018). *The effects of internal migration on poverty reduction in Ghana. African Journal of Applied Research, 4*(2), 65–80. https://ajaronline.com/index.php/AJAR/article/view/272

Azimi, M. N., Rahman, M. M., & Maraseni, T. (2025). Advancing sustainable development goal 8 targets: The role of institutional quality, economic complexity, and state fragility in G20 nations (2000–2023). *Research in Globalisation, 10,* Article 100278. https://doi.org/10.1016/j.resglo.2025.100278

Balasubramanian, P., Burchi, F., & Malerba, D. (2023). Does economic growth reduce multidimensional poverty? Evidence from low- and middle-income countries. *World Development, 161*, 106119. https://doi.org/10.1016/j.worlddev.2022.106119

Barkat, K., Mimouni, K., Alsamara, M., & Mrabet, Z. (2024). Achieving the sustainable development goals in developing countries: The role of remittances and the mediating effect of financial inclusion. *International Review of Economics & Finance, 95*, Article 103460. https://doi.org/10.1016/j.iref.2024.103460

Bettin, G., Massidda, C., & Piras, R. (2024). The intertwined role of social and financial remittances in new firms' creation. *Journal of International Management, 30*(1), 101110. https://doi.org/10.1016/j.intman.2023.101110

Cazachevici, A., Havranek, T., & Horvath, R. (2020). *Remittances and economic growth: A meta-analysis. World Development, 134*, Article 105021. https://doi.org/10.1016/j.worlddev.2020.105021

Chirtoc, I.-E., & Medar, L.-I. (2019). Reducing poverty for sustainable economic growth. *Annals of the "Constantin Brâncuși" University of Târgu Jiu, Economy Series*, (6), 189–193. Academica Brâncuși Publisher. https://www.utgjiu.ro/revista/ec/pdf/2019-06/26_Chirtoc.pdf

Tangpatthamachart, S., & Amornkitvikai, Y. (2025). Demographic shifts and economic growth: A global analysis across ageing and non-ageing economies. *Research in Globalisation*, *11*, Article 100321. https://doi.org/10.1016/j.resglo.2025.100321

Delessa, K., Alemu, T., & Bane, J. (2024). Remittances inflow and economic growth nexus in Sub-Saharan Africa: Do institutional quality and macroeconomic stability matter? *Heliyon, 10*(3), Article e25690. https://doi.org/10.1016/j.heliyon.2024.e25690

Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental Innovation and Societal Transitions, 1*(1), 24–40. https://doi.org/10.1016/j.eist.2011.02.002

Igbokwe-Ibeto, C. J., Akhakpe, I., & Oteh, C. O. (2012). Poverty and sustainable socio-economic development in Africa: The Nigerian experience. *Asian Economic and Financial Review, 2*(2), 367–381. https://www.proquest.com/openview/ded677b31bbeef70a4d7c424402a6781/1?pq-origsite=gscholar&cbl=1786341

Ihezie, U. R., Okoro, E. N., & Chinatu, N. A. (2025). *Impact of migration and remittance on economic growth in Nigeria: Dynamic ordinary least square model. Journal of Advanced Education and Sciences, 5*(2), 15–26. https://dzarc.com/education/article/view/636

Imai, K. S., Gaiha, R., Ali, A., & Kaicker, N. (2014). Remittances, growth and poverty: New evidence from Asian countries. *Journal of*

Policy Modeling, 36(3), 524–538. https://doi.org/10.1016/j.jpolmod.2014.01.009

Javid, M., Arif, U., & Qayyum, A. (2012). *Impact of remittances on economic growth and poverty. Academic Research International*, 2(1), 433–447. http://www.savap.org.pk/journals/ARInt./Vol.2(1)/2012(2.1-44).pdf

Ji, L., Tao, S., Lin, T.-Y., Sun, Y., Chen, M., Chiu, Y.-H., & Hu, W. (2025). Efficiency and regional divergence in China's poverty reduction (SDG 1) and decent work and economic growth (SDG 8). *Technological and Economic Development of Economy*, 1–23. https://doi.org/10.3846/tede.2025.24894

Kurmaiev, P., Seliverstova, L., Husarevych, N., & Kolisnichenko, P. (2020). Migration as a factor of the sustainable economic development. *European Journal of Sustainable Development, 9*(1), 380–390. https://doi.org/10.14207/ejsd.2020.v9n1p380

Li, P., & Wang, X. (2016). *Introduction: Poverty reduction, ecological migration and sustainable development*. In P. Li & X. Wang (Eds.), *Ecological migration, development and transformation* (pp. 1–10). Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-662-47366-5_1

Maune, A., & Matanda, E. (2022). The nexus between gross capital formation and economic growth: Evidence from Zimbabwe. *EuroEconomica, 12*(2), 45–58. https://www.dj.univ-danubius.ro/index.php/JAM/article/view/1891

Mbadiwe, M. M., & Egesimba, C. S. (2024). Remittances and economic growth: A case study of Nigeria. *International Journal of Entrepreneurial Development, Education and Science Research (IJEDESR), 8*(1), 308–322. https://doi.org/10.48028/iiprds/ijedesr.v8.i1.16

Mbango Ngea, R. G. (2024). *Effect of remittances on access to financing by small and medium enterprises: The role of financial development* (Afreximbank Policy Research Working Paper Series, APRWPS/2024/04). African Export-Import Bank. https://media.afreximbank.com/afrexim/APRWPS202404_Effect-of-Remittances-on-Access-to-Financing-by-Small-and-Medium-Enterprises-3.pdf

Moyo, I., Nshimbi, C. C., & Laine, J. P. (Eds.). (2020). *Migration conundrums, regional integration and development: Africa–Europe relations in a changing global order*. Palgrave Macmillan. https://doi.org/10.1007/978-981-15-2478-3

Muse, M. A. (2025). The ambiguity, opaqueness and consequences of FATF's remittance regulatory strategies: The case studies of Somalia and Nigeria. *Journal of Economic Criminology,* 8, Article 100156. https://doi.org/10.1016/j.jeconc.2025.100156

Nwokoro, A. N. (2024). Globalization, migration, and economic growth in Nigeria. *Lapai Journal of Economics, 8*(1), 165–171. https://dx.doi.org/10.4314/lje.v8i1.11

Ochi, A. (2023). Inequality and the impact of growth on poverty in sub-Saharan Africa: A GMM estimator in a dynamic panel threshold model. *Regional Science Policy & Practice, 15*(6), 1373–1395. https://doi.org/10.1111/rsp3.12707

Ofori, I. K., Gbolonyo, E. Y., Toyo Dossou, M. A., Nkrumah, R. K., & Nkansah, E. (2023). Towards inclusive growth in Africa: Remittances, and financial development interactive effects and thresholds. *Journal of Multinational Financial Management, 68*, Article 100798. https://doi.org/10.1016/j.mulfin.2023.100798

Osabutey, E. L. C., & Jackson, T. (2024). Mobile money and financial inclusion in Africa: Emerging themes, challenges and policy implications. *Technological Forecasting and Social Change, 202,* Article 123339. https://doi.org/10.1016/j.techfore.2024.123339

Oyedepo, E. O. (2024). Labor force dynamics and economic performance: A case of Nigeria, India, and China. *Journal of Economics & Management, 46*, 143–170. https://doi.org/10.22367/jem.2024.46.06

Oyeniyi, B. A. (2013). *Internal migration in Nigeria: A positive contribution to human development*. ACP Observatory on Migration Research Report (ACPOBS/2013/PUB01). International Organisation for Migration (IOM)

Ozoh, J. N., Madueke, C. M., Onwka, I. N., Ezeife, A. O., & Edeh, C. C. (2025). Migrant remittances and economic growth in Nigeria: Evidence from ARDL analysis (1990–2023). *Journal of Economics, Management and Trade, 31* (9), 1–13. https://doi.org/10.9734/jemt/2025/v31i91346

Raimi, L., & Ogunjirin, O. D. (2012). Fast-tracking sustainable economic growth and development in Nigeria through international migration and remittances. *Humanomics, 28*(3), 209–219. https://doi.org/10.1108/08288661211258101

Reuters. (2024, April 26). *Nigeria seeks managers for planned $10 billion diaspora fund*. Reuters. https://www.reuters.com/world/africa/nigeria-seeks-managers-planned-10-billion-diaspora-fund-2024-04-26/

Reuters. (2025, May 12). *Nigeria's economy grows strongly amid high inflation, World Bank says*. Reuters. https://www.reuters.com/world/africa/nigerias-economy-grows-strongly-amid-high-inflation-world-bank-says-2025-05-12/

Schürmann, A., Kleemann, J., Teucher, M., Fürst, C., & Conrad, C. (2022). Migration in West Africa: A visual analysis of motivation, causes, and routes. *Ecology and Society, 27*(3), Article 16. https://doi.org/10.5751/ES-13489-270316

Škare, M., & Pržiklas Družeta, R. (2016). Poverty and economic growth: A review. *Journal of Business Economics and Management, 17*(2), 156–175. https://doi.org/10.3846/20294913.2015.1125965

Sokunbi, G. M., Maku, O. E., & Adelowokan, O. A. (2025). Panel analysis of the impact of unemployment on sustainable Economic Growth in West Africa. *Ekonomista*, 1–20. https://doi.org/10.52335/ekon/207390

Tolorunju, E. T., Dipeolu, A. O., Sanusi, R. A., & Akerele, D. (2019). Effects of the reward of internal migration on poverty status of rural households left behind in Ogun and Osun States, Nigeria. *Agricultura Tropica et Subtropica, 52*(3–4), 129–138. https://doi.org/10.2478/ats-2019-0015

Topcu, E., Altinoz, B., & Aslan, A. (2020). Global evidence from the link between economic growth, natural resources, energy consumption, and gross capital formation. *Resources Policy, 66,* Aricle 101622. https://doi.org/10.1016/j.resourpol.2020.101622

Uchegbulam, J. C., & Okoronkwo, S. (2025). Migration, MSMEs and economic development in Nigeria. *Journal of Economics and Allied Research*, *10*(2), 178–189.

United Nations. (2025a). *Goal 1: End poverty in all its forms everywhere*. In *The Sustainable Development Goals Report 2025*. United Nations Department of Economic and Social Affairs (UN DESA). Retrieved from https://sdgs.un.org/goals/goal1

United Nations. (2025b). *The Sustainable Development Goals report 2025*. United Nations Department of Economic and Social Affairs (UN DESA). https://unstats.un.org/sdgs/report/2025/

Usman, M. A. M., Ozdeser, H., Çavuşoğlu, B., & Aliyu, U. S. (2022). On the sustainable economic growth in Sub-Saharan Africa: Do remittances, human capital flight, and brain drain matter? *Sustainability, 14*(4), Article 2117. https://doi.org/10.3390/su14042117

World Bank. (2023, May 2). *Migration: Overview*. The World Bank. https://www.worldbank.org/en/topic/migration/overview

Yameogo, C. E. W., & Omojolaibi, J. A. (2021). Trade liberalisation, economic growth and poverty level in sub-Saharan Africa (SSA). *Economic Research–Ekonomska Istraživanja, 34*(1), 754–774. https://doi.org/10.1080/1331677X.2020.1804428

Zhu, Y., Bashir, S., & Marie, M. (2022). Assessing the relationship between poverty and economic growth: Does Sustainable Development Goal can be achieved? *Environmental Science and Pollution Research*, 29(19), 27613–27623. https://doi.org/10.1007/s11356-021-18240-5