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National innovation systems and sustainable development goal performance in Sub-Saharan Africa

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Abstract. Progress toward the Sustainable Development Goals (SDGs) remains uneven across Sub-Saharan Africa despite sustained policy emphasis on innovation-led development. Although national innovation systems are widely regarded as drivers of long-term growth and sustainability, empirical evidence on how innovation system performance translates into multidimensional development outcomes in the region remains limited. The aim of this study was to examine the effect of national innovation system performance on SDG achievement in Sub-Saharan Africa using a balanced panel of 43 countries over the period 2005-2023. National innovation system performance was measured using a composite index constructed from research and development expenditure, public spending on education, labour force participation, and institutional quality. Panel econometric techniques were employed to account for heterogeneity, endogeneity, and dynamic relationships. The static random-effects results indicated a positive and statistically significant association between innovation system inputs and SDG performance ($\beta = 2.431$, $p < 0.01$), while gross domestic product per capita exhibits a strong positive effect ($\beta = 4.210$, $p < 0.01$). However, the fixed-effects estimates showed that within-country changes in innovation inputs were not statistically significant ($\beta = 2.680$, $p = 0.101$), suggesting that cross-country structural differences largely drive the observed association. After correcting for endogeneity using instrumental variables, innovation inputs remained statistically insignificant ($\beta = 0.240$, $p = 0.489$), whereas institutional quality ($\beta = 2.737$, $p < 0.01$) and gross domestic product per capita ($\beta = 3.004$, $p < 0.01$) emerged as robust determinants of SDG performance. The results of the dynamic system Generalised Method of Moments (GMM) estimation further revealed strong persistence in SDG outcomes (lag coefficient = 0.968, $p < 0.01$), while innovation inputs exhibited only weak short-run effects ($\beta = 1.259$, $p < 0.10$). The findings suggested that innovation systems influence sustainable development primarily through

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institutional and structural channels rather than through direct and immediate effects. Strengthening governance capacity and aligning innovation investments with institutional reforms therefore appear essential for accelerating progress toward the Sustainable Development Goals in Sub-Saharan Africa

Keywords: institutional quality; innovation governance; sustainable development policy; endogenous growth; panel data econometrics; structural equation modelling; development heterogeneity

Introduction

Sustainable development outcomes across Sub-Saharan Africa remain persistently uneven, despite sustained policy commitments to economic transformation, social inclusion, and environmental sustainability. Some countries in the region continue to experience slow structural change, limited industrial upgrading, weak productivity growth, and high vulnerability to social and environmental shocks. Progress toward multidimensional development goals has been constrained by fragmented policy implementation, low innovation capacity, and institutional weaknesses that limit the effectiveness of public investment. As a result, development strategies have struggled to translate economic growth into durable improvements in welfare, resilience, and environmental sustainability. These challenges have intensified the need to identify system-level mechanisms capable of supporting coordinated, long-term development progress across economic, social, and environmental dimensions.

A number of studies have examined the role of innovation systems and related institutional factors in shaping development and sustainability outcomes. According to S. Yigit (2021) and D. Abrol (2025), innovation capacity plays a critical role in determining whether economic growth contributes to sustainable development, particularly in developing regions where institutional quality varies widely. S. Yigit (2021) concluded that innovation-driven growth can support social and environmental outcomes only when supported by effective governance frameworks. R.H. Machado *et al.* (2024) investigated the relationship between innovation, economic development, and environmental performance in developing economies and found that innovation contributes positively to sustainability outcomes, although the strength of these effects depends on institutional and regulatory conditions.

M. Akhtar-Schuster *et al.* (2024) analysed national institutional arrangements for accelerating Sustainable Development Goal (SDG) implementation and emphasised that innovation systems function most effectively when embedded within coherent governance structures. Their findings showed that weak coordination between innovation policy and development planning undermines Sustainable Development Goals progress, particularly in low-income and institutionally fragile countries. M.E. Nenni *et al.* (2024) explored the complex relationship between innovation and sustainability and demonstrated that innovation does not automatically lead to sustainable outcomes, as trade-offs often emerge between economic expansion and environmental protection in contexts with weak regulatory capacity.

A. Haldar *et al.* (2023) examined governance and renewable energy deployment in Sub-Saharan Africa and concluded that innovation investments in clean energy yield limited sustainability benefits in the absence of strong institutional support. Their study highlighted governance quality as a key mediating factor linking innovation inputs to sustainable development outcomes. S. Diop & S.A. Asongu (2024) analysed the role of information and communication technologies in advancing Sustainable Development Goals in African countries and found that technological innovation improves development performance only when complemented by institutional reforms and inclusive policy frameworks.

Despite these contributions, important gaps remain in the existing literature. Most studies focus on specific innovation inputs, sectors, or technologies rather than assessing innovation systems as integrated national structures. In addition, limited attention has been given to how national innovation system performance translates into progress across multiple Sustainable Development Goal dimensions simultaneously. Cross-country empirical evidence linking innovation systems to comprehensive Sustainable Development Goals performance in Sub-Saharan Africa remains scarce, particularly evidence that accounts for institutional quality, economic capacity, and potential threshold effects. As a result, policymakers lack clear guidance on whether innovation systems function as effective engines of sustainable development across diverse institutional contexts in the region. This study aimed to assess how the performance of national innovation systems influences the achievement of Sustainable Development Goals in Sub-Saharan Africa.

Materials and Methods

This study employed a quantitative panel data design to examine the effect of national innovation system (NIS) performance on SDG outcomes in Sub-Saharan Africa. The analysis was based on a balanced panel dataset covering 43 countries observed annually over the period 2005-2023. The dependent variable was the Sustainable Development Goal Index obtained from the Sustainable Development Report (Sachs *et al.*, 2024). The index provided a composite measure of progress across the seventeen SDGs and allowed comparability across countries and over time.The explanatory variables were drawn from the World Development Indicators (WDI) and the Worldwide Governance Indicators (WGI) (World Bank, 2024a; 2024b). Research and development expenditure (% of GDP), public spending on education (% of GDP), labour force participation rate, and GDP per capita were obtained from WDI, while institutional quality indicators were obtained from WGI. GDP per capita was transformed using the natural logarithm. Institutional quality and labour force participation were standardised using z-score transformations.

National innovation system performance was measured using a composite index constructed from four indicators: research and development expenditure, public spending on education, labour force participation, and institutional quality. Each indicator was standardised using a z-score transformation. The standard formulae is indicated in equation (1):

$$z_{it} = \frac{X_{it}-\mu}{\sigma}, \quad (1)$$

where X_{it} represents the value of the variable for country i in year t, μ denotes the sample mean, and σ the standard deviation. This transformation ensures comparability across indicators and prevents variables with larger numerical scales from dominating the composite measure. The National Innovation System index was computed with four standardised indicators and is presented in equation (2):

$$NIS_{it} = \frac{1}{4}[z(R\&D)_{it} + z(Education)_{it} + + z(Labour)i_t + z(InstitutionalQuality)_{it}]. \quad (2)$$

The empirical analysis began with static panel regression models estimated using fixed-effects (FE) and random-effects (RE) specifications. The baseline specification is expressed in equation (3):

$$SDG_{it} = \alpha + \beta_1 NIS_{it} + \beta_2 GDP_{it} + \beta_3 Labour_{it} + + \beta_4 Inst_{it} + \beta_5 Education_{it} + \mu_i + \epsilon_{it}, \quad (3)$$

where SDG_{it} denotes the SDG performance index for country i in year t, NIS_{it} represents the national innovation system index, GDP_{it} is the logarithm of GDP per capita, and μ_i captures time-invariant country-specific effects. Model selection between fixed-effects and random-effects estimators is guided by the Hausman specification test, which evaluates whether country-specific effects are correlated with the explanatory variables. Standard errors were clustered at the country level to account for serial correlation within countries over time.

To address potential endogeneity, an instrumental variables (IV) approach using two-stage least squares (2SLS) estimation was applied. The NIS index was treated as an endogenous variable. External instruments included trade openness, foreign direct investment inflows, and technology imports. Instrument validity was assessed using the first-stage F-statistic, the Sargan–Hansen test of overidentifying restrictions, and the Durbin–Wu–Hausman test. Dynamic panel estimation was conducted using the system Generalised Method of Moments (system GMM) estimator developed by Arellano–Bover and Blundell–Bond. The dynamic specification is expressed in equation (4):

$$SDG_{it} = \alpha + \rho SDG_{it\text{-}1} + \beta NIS_{it} + \gamma X_{it} + \mu_i + \epsilon_{it}, \quad (4)$$

where $SDG_{it\text{-}1}$ represents the lagged dependent variable and denotes the vector of control variables. Estimation employed two-step robust standard errors with finite-sample correction. Model diagnostics included Arellano-Bond tests for serial correlation and the Hansen test for instrument validity.

Quantile regression was applied to capture heterogeneity in the effect of innovation inputs across different levels of SDG performance, particularly where mean-based estimates may mask distributional differences. The quantile regression specification is presented in equation (5):

$$Q_\tau(SDG_{it}) = \alpha_\tau + \beta_\tau NIS_{it} + \gamma_\tau X_{it} + \epsilon_{it}, \quad (5)$$

where $Q_\tau(SDG_{it})$ denotes the conditional quantile of SDG performance at percentile τ. Bootstrapped standard errors were used to ensure robust inference.

Canonical correlation analysis (CCA) was conducted to examine the multivariate association between innovation system variables and SDG indicators. The innovation system vector included research and development expenditure, education spending, labour force participation, and institutional quality. The SDG outcome vector included selected SDG indicators (SDG1, SDG3, SDG4, SDG8, SDG9, SDG11, SDG12, SDG13, and SDG16). As shown in equation (6), the canonical variates are defined as linear combinations of the original variables:

$$U = a'X,\ V = b'Y, \quad (6)$$

where X denotes the vector of NIS variables and Y represents the vector of SDG indicators. The objective, given in equation (7), is to estimate coefficient vectors a and b that maximize the correlation between the canonical variates:

$$\rho = max\ corr\ (U, V). \quad (7)$$

This approach captures the strength and structure of the relationship between innovation system capacity and multidimensional development outcomes.

To account for both direct and indirect relationships, a structural equation model was specified. Equation (8) defines SDG performance as a function of innovation capacity and institutional quality, while equation (9) models institutional quality as an outcome of innovation inputs:

$$SDG_{it} = \beta_1 NIS_{it} + \beta_2 INST_{it} + \epsilon_{it}; \quad (8)$$

$$INST_{it} = \gamma_1 NIS_{it} + \nu_{it}. \quad (9)$$

where SDG_{it} represents SDG performance, NIS_{it} denotes innovation system inputs, and $INST_{it}$ captures institutional quality. This structure allows the identification of mediated effects and system-level interactions. The model was estimated using maximum likelihood with missing values (MLMV).

Finally, to capture dynamic interdependencies and persistence, a vector autoregression model was estimated. As specified in equation (10), each variable is expressed as a function of its own lags and the lags of other variables in the system:

$$Y_t = A_1 Y_{t-1} + \dots + A_p Y_{t-p} + \epsilon_t, \quad (10)$$

where $Y_t = (SDG_t, NIS_t, INST_t, GDP_t)$ is the vector of endogenous variables, A_p are coefficient matrices, and ϵ_t is a vector of error terms. This framework enables the analysis of dynamic feedback effects and the temporal evolution of innovation and development outcomes.

Results

Descriptive statistics and preliminary patterns

This section presents summary statistics and preliminary descriptive patterns for the variables used in the empirical analysis. The objective is to characterize the distributional properties of the data and to assess the extent of cross-country and within-country variation, thereby motivating the choice of panel estimation techniques applied in subsequent sections.

Table 1 reports descriptive statistics for the key variables, covering 817 country-year observations for 43 Sub-Saharan African countries over the period 2005-2023. The SDG Performance Index, obtained from the Sustainable Development Report (Sachs *et al.*, 2024), has a mean value of 53.22 and a standard deviation of 6.30, with values ranging from 39.52 to 70.82. The weighted NIS index, constructed as a standardised composite measure, is centred around zero with a standard deviation of 0.67. Logged GDP per capita exhibits a mean of 7.05. Labour force participation and institutional quality, both standardised variables, display wide ranges. Public spending on education averages 3.78% of GDP.

Table 1. Descriptive statistics

Variable	Number of observations	Mean	Standard deviation	Minimum	Maximum
SDG performance index	817	53.223	6.297	39.515	70.821
NIS index (weighted)	817	-0.003	0.671	-1.148	2.024
GDP per capita (log)	817	7.048	0.898	4.999	9.363
Labour force participation (standardised)	817	0.025	0.998	-2.596	2.134
Institutional quality (standardised)	817	0.000	1.000	-2.584	2.763
Public spending on education (% of GDP)	817	3.783	2.025	0.35	12.33

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Table 2 further decomposes the variation in the two core panel variables, the SDG Performance Index and the weighted NIS index, into between-country and within-country components. For SDG performance, the between-country standard deviation (5.84) substantially exceeds the within-country standard deviation (2.50), indicating that differences in sustainable development outcomes are driven primarily by persistent cross-country factors rather than short-term fluctuations within countries. A similar pattern is observed for innovation system capacity, where between-country variation (0.65) dominates within-country variation (0.19).

Table 2. Descriptive analysis of the key panel variables

Variable	Component	Mean	Standard deviation	Minimum	Maximum
SDG performance index	Overall	53.223	6.297	39.515	70.821
	Between	–	5.844	40.617	69.152
	Within	–	2.500	45.964	60.142
NIS index (weighted)	Overall	-0.003	0.671	-1.148	2.024
	Between	–	0.650	-1.051	1.673
	Within	–	0.194	-0.801	0.984

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Figure 1 illustrates average trends in SDG performance and the innovation index across Sub-Saharan Africa over the sample period. While SDG performance shows a gradual upward trend, the innovation index exhibits stagnation and decline in later years, highlighting a divergence in aggregate trajectories between development outcomes and innovation capacity at the regional level.

Together, the descriptive evidence indicates that both SDG performance and innovation system inputs are dominated by long-run cross-country variation. This pattern supports the use of panel estimation techniques that explicitly control for unobserved country-specific heterogeneity and dynamic persistence, such as fixed-effects and system GMM models, in the subsequent empirical analysis.

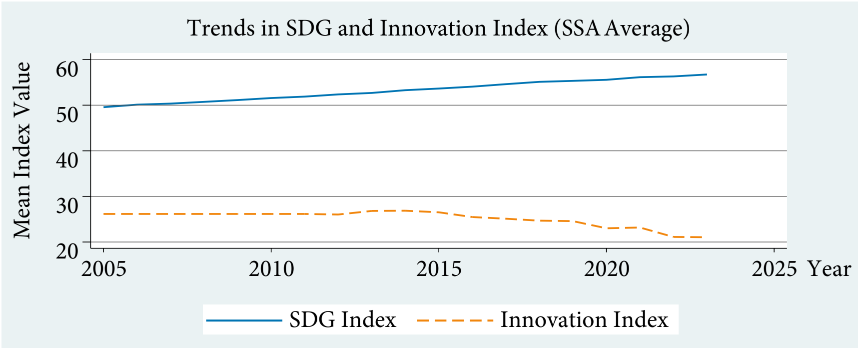

Figure 1. Trends in SDG and innovation index (SSA average)
Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024b)

Baseline results: Static panel models and system-level associations

Static panel models were estimated to examine the average association between national innovation system inputs and Sustainable Development Goal performance, while controlling for observed covariates and unobserved country-specific heterogeneity. Fixed-effects and random-effects specifications were employed to distinguish between within-country variation over time and combined within- and between-country variation across the sample. The fixed-effects results reported in Table 3 indicate that the coefficient on NIS inputs is positive but not statistically significant. This suggests that, after accounting for time-invariant country characteristics, within-country changes in innovation system inputs are not systematically associated with contemporaneous changes in SDG performance. In contrast, GDP per capita exhibits a positive and statistically significant association with SDG outcomes, while labour force participation shows a negative and statistically significant relationship. Institutional quality and public spending on education are not statistically significant in the fixed-effects specification.

Table 3. Regression results – fixed effects

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	2.680	1.601	1.67	0.101	-0.550, 5.910
GDP per capita (log)	4.139***	0.739	5.60	0.000	2.648, 5.629
Labour force participation	-4.636***	1.061	-4.37	0.000	-6.778, -2.494
Institutional quality	-0.929	1.361	-0.68	0.499	-3.676, 1.818
Public spending on education	0.043	0.228	0.19	0.851	-0.417, 0.503
Constant	24.015***	5.375	4.47	0.000	13.168, 34.861
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
R-squared	0.416				
F-statistic	20.674				
Prob > F	0.000				
Akaike Information Criterion (AIC)	3,385.159				
Bayesian Information Criterion (BIC)	3,408.687				

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$
Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

The random-effects estimates presented in Table 4 show a positive and statistically significant association between NIS inputs and SDG performance. This result reflects combined within- and between-country variation and indicates that countries with higher levels of innovation system capacity tend to exhibit higher SDG performance on average. GDP per capita remains positive and highly significant, while labour force participation continues to display a negative and statistically significant association with SDG outcomes. Institutional quality and education spending remained statistically insignificant in the random-effects model. Overall, the random-effects specification explains approximately 42% of the variation in SDG performance, with both within-country and between-country components contributing to model fit.

Table 4. Regression results – random effects

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	2.431***	0.476	5.11	0.000	1.498 , 3.364
GDP per capita (log)	4.210***	0.281	14.98	0.000	3.659 , 4.761
Labour force participation	-2.656***	0.368	-7.21	0.000	-3.379 , -1.934
Institutional quality	-0.364	0.342	-1.07	0.287	-1.034 , 0.305
Public spending on education	0.137	0.092	1.49	0.136	-0.043 , 0.318
Constant	23.103***	2.113	10.94	0.000	18.962 , 27.243
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
Overall R-squared	0.424				
Within R-squared	0.401				
Between R-squared	0.438				
Wald Chi-square	527.460				
Prob > Chi-square	0.000				

Note: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

To complement the regression-based analysis and assess system-level relationships between innovation inputs and sustainable development outcomes, canonical correlation analysis was employed. Using this multivariate approach, the joint association between a vector of SDG indicators and a vector of NIS input variables was examined. Tables 5 and 6 reported the raw canonical coefficients for the SDG set and the NIS input set, respectively, while Table 7 presents tests of significance for the canonical correlations.

Table 5 reports the raw canonical coefficients for the first set of variables, comprising individual Sustainable Development Goal indicators. These coefficients described how each SDG contributed to the respective canonical variates that summarize the SDG outcome space. The first canonical dimension is characterized by relatively stronger positive contributions from SDG 8 (Decent Work and Economic Growth), SDG 16 (Peace, Justice and Strong Institutions), and SDG 17 (Partnerships for the Goals). This pattern suggests that the dominant SDG dimension most closely associated with innovation system inputs is concentrated around economic performance, institutional capacity, and systemic coordination rather than basic social outcomes alone. The contribution of SDG 12 (Responsible Consumption and Production) and SDG 13 (Climate Action) in the first dimension is negative, indicating that environmental sustainability dimensions load differently within the dominant multivariate relationship.

In the second and third canonical dimensions, the coefficients reveal a broader dispersion across SDGs. Education-related and social inclusion goals such as SDG 4 (Quality Education), SDG 5 (Gender Equality), and SDG 11 (Sustainable Cities and Communities) exhibit relatively higher contributions, indicating that these dimensions capture alternative patterns of association between innovation systems and social development outcomes. The fourth canonical dimension shows stronger weights on environmental goals, particularly SDG 12 and SDG 13, reflecting a distinct sustainability-oriented configuration that is less strongly aligned with the dominant innovation–development nexus.

Table 5. Canonical correlation; raw coefficients for the first variable set

Number of observations = 817				
SDG	1	2	3	4
goal1	0.000	-0.015	-0.011	0.006
goal2	-0.001	0.031	-0.035	0.047
goal3	0.01	0.007	0.002	-0.03
goal4	-0.002	-0.006	0.012	-0.01
goal5	-0.001	0.046	0.000	0.025
goal6	-0.001	0.011	-0.068	0.006
goal7	-0.001	-0.02	-0.011	0.025
goal8	0.025	0.038	0.019	-0.029
goal9	0.005	0.002	-0.009	-0.044
goal10	-0.001	0.002	0.005	-0.001
goal11	0.005	-0.02	0.068	-0.02
goal12	-0.043	0.03	0.137	-0.161

Continued Table 5

Number of observations = 817				
goal13	-0.021	-0.109	-0.121	0.33
goal14	-0.007	-0.009	0.028	0.006
goal15	-0.007	-0.011	0.005	-0.005
goal16	0.033	0.018	-0.014	-0.002
goal17	0.036	-0.052	0.042	0.066

Source: authors' calculations based on J.D. Sachs *et al.* (2024)

Table 6 presents the raw canonical coefficients for the second set of variables, capturing national innovation system inputs. These coefficients indicated how individual innovation-related factors contributed to each canonical dimension. In the first canonical dimension, institutional quality displays the largest positive coefficient, followed by research and development expenditure. Labour force participation contributes negatively in this dimension, suggesting that labour quantity alone does not align positively with the primary innovation-development configuration without complementary institutional and technological capacity.

The second canonical dimension is dominated by research and development expenditure and labour force participation, implying that this dimension captures a more production- and scale-oriented innovation channel. In contrast, public spending on education contributes more prominently in the third canonical dimension, highlighting a human-capital-driven pathway linking innovation systems to development outcomes. The fourth canonical dimension exhibits a reversal in signs for research and development (R&D) expenditure and a positive contribution from institutional quality and labour force participation, reflecting a distinct configuration where innovation inputs interact differently with sustainability outcomes. The sequence of canonical correlations reported at the bottom of Table 6 shows a declining but still substantial strength of association across dimensions. The first canonical correlation (0.899) indicates a very strong system-level relationship, while the second (0.797) and third (0.737) remain sizeable. Even the fourth canonical correlation (0.539) reflects a moderate degree of multivariate association.

Table 6. Raw coefficients for the second variable set

NIS inputs	1	2	3	4
R&D expenditure	0.168	3.431	-0.034	-5.238
Public spending on education	0.086	-0.083	0.567	-0.018
Labour force	-0.221	0.857	0.179	0.448
Institutional quality	0.879	0.082	-0.724	0.362
Canonical correlations	0.8991	0.7965	0.7365	0.5389

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Table 7 reports multivariate tests of significance for the canonical correlations using Wilks' lambda, Pillai's trace, the Lawley-Hotelling trace, and Roy's largest root. All four test statistics strongly reject the null hypothesis that the sets of canonical correlations are jointly equal to zero. The Wilks' lambda statistic is close to zero and highly significant, indicating that a substantial proportion of variance in one variable set is explained by linear combinations of the other set. Pillai's trace and the Lawley-Hotelling trace further confirm the presence of strong multivariate dependence between innovation system inputs and SDG outcomes. Roy's largest root highlights the dominance of the first canonical dimension, consistent with the very high first canonical correlation reported in Table 6.

Table 7. Tests of significance of all canonical correlations

	Statistic	df1	df2	F	Prob>F
Wilks' lambda	0.0227498	68	3,126.05	74.5788	0.0000 a
Pillai's trace	2.27556	68	3,196	62.021	0.0000 a
Lawley-Hotelling trace	7.54812	68	3,178	88.191	0.0000 a
Roy's largest root	4.21839	17	799	198.264	0.0000 u

Note: a – approximate; e – exact; u – upper bound on F

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Viewed jointly, Tables 5-7 indicate that national innovation systems and SDG outcomes in Sub-Saharan Africa are strongly aligned at the system level, but through multiple canonical dimensions reflecting different development pathways. The dominant canonical relationship is anchored in institutional quality and formal innovation investment and is most closely associated with economic and institutional SDGs, while secondary dimensions capture social and environmental sustainability linkages. This multivariate evidence complements the static panel regression results by demonstrating that, even where within-country regression effects appear weak, innovation systems and sustainable development outcomes remain closely connected through broader structural and institutional configurations.

Results accounting for endogeneity and dynamics

An instrumental variables two-stage least squares (2SLS) model was estimated to address potential endogeneity in the relationship between national innovation system inputs and SDG performance. This specification aims to isolate the exogenous component of innovation system inputs and assess whether the baseline associations observed in static panel models persist once reverse causality and omitted variable bias are accounted for.

The results obtained using the 2SLS estimator, reported in Table 8, indicate that the coefficient on NIS inputs is positive but statistically insignificant. This suggests that, after correcting for endogeneity, innovation system inputs do not exhibit a direct contemporaneous effect on SDG performance. In contrast, GDP per capita remains positive and highly significant, indicating that economic development retains a robust association with SDG outcomes even under endogeneity correction. Institutional quality also emerges as strongly positive and statistically significant, highlighting its independent and substantial contribution to sustainable development performance. Labour force participation is negative but statistically insignificant in the IV specification.

Table 8. Instrumental variables 2SLS regression

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	0.240	0.346	0.69	0.489	-0.439, 0.919
GDP per capita (log)	3.004***	0.205	14.66	0.000	2.602, 3.405
Labour force participation (standardised)	-0.226	0.156	-1.45	0.147	-0.532, 0.079
Institutional quality (standardised)	2.737***	0.242	11.33	0.000	2.264, 3.211
Constant	32.059***	1.452	22.08	0.000	29.213, 34.905
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
R-squared	0.615				
Wald Chi-square	1,303.339				
Prob > Chi-square	0.000				

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.10$

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

To further account for dynamic persistence and potential feedback effects, equation (3) was estimated using a system GMM framework. This approach explicitly incorporates lagged SDG performance and addresses simultaneity and unobserved heterogeneity in a dynamic panel setting. The results obtained using system GMM, presented in Table 9, demonstrated a very strong and statistically significant coefficient on the lagged dependent variable, indicating a high degree of persistence in SDG performance over time. This finding suggests that current SDG outcomes are strongly conditioned by past performance, consistent with path-dependent development trajectories. The coefficient on NIS inputs is positive and weakly significant at the 10% level, indicating a modest dynamic association between innovation system capacity and SDG performance once persistence is taken into account. By contrast, GDP per capita, labour force participation, institutional quality, and public spending on education are not statistically significant in the dynamic specification.

Table 9. Regression results – GMM

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
Lagged SDG performance index	0.968***	0.022	43.90	0.000	0.924, 1.013
NIS index (weighted)	1.259*	0.695	1.81	0.077	-0.143, 2.660
GDP per capita (log)	0.015	0.181	0.09	0.932	-0.349, 0.380
Labour force participation (standardised)	-0.140	0.091	-1.54	0.132	-0.324, 0.044
Institutional quality (standardised)	-0.335	0.285	-1.18	0.246	-0.909, 0.240
Public spending on education (% of GDP)	-0.124	0.089	-1.38	0.173	-0.304, 0.057
Constant	2.452**	0.992	2.47	0.018	0.450, 4.454
Model statistics					
Mean dependent variable	53.426				
Standard deviation (dependent variable)	6.276				

Continued Table 9

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
Number of observations	774				
F-statistic	88,377.477				

Note: ***p < 0.01; **p < 0.05; *p < 0.10

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Together, the IV and GMM results demonstrated that innovation system inputs do not exert a strong or immediate causal effect on SDG performance once endogeneity and dynamic persistence are explicitly modeled. Instead, the results highlight the dominant role of institutional quality in the IV framework and the importance of temporal inertia in shaping sustainable development outcomes in the dynamic context.

Heterogeneity of effects across the SDG distribution

Using quantile regression models, the study examined whether the relationship between innovation system inputs and SDG performance varies across different points of the SDG distribution. This approach allows the effects of innovation and institutional factors to differ between countries with lower, median, and higher levels of SDG performance. The results obtained at the 25th percentile of the SDG distribution, reported in Table 10, indicated that NIS inputs had a positive but statistically insignificant association with SDG performance among lower-performing countries. GDP per capita and institutional quality are both positive and highly significant, suggesting that economic capacity and governance quality are the primary correlates of SDG outcomes at the lower tail of the distribution. Labour force participation and education spending are not statistically significant at this quantile.

Table 10. Quantile regression at the 25th percentile of SDG index

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	0.843	0.542	1.56	0.120	-0.221, 1.906
GDP per capita (log)	2.900***	0.313	9.27	0.000	2.286, 3.514
Labour force participation (standardised)	-0.330	0.238	-1.39	0.166	-0.798, 0.138
Institutional quality (standardised)	2.409***	0.355	6.79	0.000	1.713, 3.105
Public spending on education (% of GDP)	-0.101	0.135	-0.75	0.453	-0.367, 0.164
Constant	30.690***	2.317	13.25	0.000	26.142, 35.238
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
Pseudo R-squared	0.335				

Note: ***p < 0.01; **p < 0.05; *p < 0.10

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

At the median of the SDG distribution, shown in Table 11, the coefficient on NIS inputs remained positive but statistically insignificant. GDP per capita and institutional quality continue to exhibit strong and statistically significant associations with SDG performance, while public spending on education becomes weakly significant. This pattern suggests that human capital investment may begin to play a more visible role at intermediate levels of development, although innovation system inputs still do not exert a statistically robust effect.

Table 11. Quantile regression at the 50th percentile (median) of SDG index

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	0.657	0.479	1.37	0.171	-0.283, 1.597
GDP per capita (log)	3.317***	0.276	12.00	0.000	2.775, 3.860
Labour force participation (standardised)	-0.105	0.211	-0.50	0.619	-0.518, 0.309
Institutional quality (standardised)	2.588***	0.313	8.26	0.000	1.973, 3.203
Public spending on education (% of GDP)	0.226*	0.119	1.89	0.059	-0.008, 0.460
Constant	29.240***	2.048	14.28	0.000	25.221, 33.259
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
Pseudo R-squared	0.366				

Note: ***p < 0.01; **p < 0.05; *p < 0.10

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

In contrast, the results at the 75th percentile of the SDG distribution, presented in Table 12, indicated that NIS inputs were negative and statistically insignificant, while GDP per capita and institutional quality remain positive and highly significant. Public spending on education becomes strongly positive and statistically significant at this upper quantile, indicating that education investment is more closely associated with SDG performance among higher-performing countries. Labour force participation remains statistically insignificant across all quantiles.

Table 12. Quantile regression at the 75th percentile of SDG index

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	-0.408	0.499	-0.82	0.414	-1.388, 0.572
GDP per capita (log)	3.309***	0.288	11.48	0.000	2.744, 3.875
Labour force participation (standardised)	-0.304	0.220	-1.38	0.167	-0.735, 0.128
Institutional quality (standardised)	2.755***	0.327	8.43	0.000	2.113, 3.396
Public spending on education (% of GDP)	0.640***	0.125	5.14	0.000	0.396, 0.885
Constant	30.204***	2.135	14.14	0.000	26.012, 34.395
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
Pseudo R-squared	0.437				

Note: ***$p < 0.01$; **$p < 0.05$; *$p < 0.10$
Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Across all quantiles, institutional quality consistently exhibited a strong and statistically significant association with SDG performance, while the effect of innovation system inputs remains weak and statistically insignificant. The increasing pseudo-R-squared values across quantiles indicate improved explanatory power of the model at higher levels of SDG performance.

Institutional conditioning and interaction effects

An interaction model was estimated to examine whether the effect of NIS inputs on SDG performance depends on institutional quality. Table 13 reported the results from the interaction specification. The results indicated that NIS inputs were positive and highly significant when evaluated at the baseline level of institutional quality. However, the interaction term between NIS inputs and institutional quality is negative and statistically significant. This pattern indicates that the marginal effect of innovation system inputs on SDG performance varies systematically with institutional conditions. GDP per capita and public spending on education remain positive and statistically significant, while labour force participation is not statistically significant in the interaction model.

Table 13. OLS regression of SDG index on NIS inputs, institutional quality interaction, and controls

Variable	Coefficient	Standard error	t-statistic	p-value	95% confidence interval
NIS index (weighted)	4.543***	0.509	8.92	0.000	3.543, 5.543
NIS × institutional quality	-3.555***	0.606	-5.87	0.000	-4.744, -2.366
GDP per capita (log)	3.975***	0.194	20.52	0.000	3.595, 4.355
Labour force participation (standardised)	-0.216	0.166	-1.30	0.195	-0.542, 0.111
Public spending on education (% of GDP)	0.376***	0.092	4.09	0.000	0.196, 0.557
Constant	24.544***	1.439	17.05	0.000	21.719, 27.369
Model statistics					
Mean dependent variable	53.223				
Standard deviation (dependent variable)	6.297				
Number of observations	817				
R-squared	0.589				
F-statistic	232.297				

Note: ***$p < 0.01$, **$p < 0.05$, *$p < 0.10$
Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

Structural and dynamic interrelationships

To further examine the structural linkages between innovation systems and sustainable development outcomes, a SEM (structural equation model) was estimated. The SEM results reported in Table 14 indicated a strong and statistically significant association between NIS inputs and the composite SDG innovation index. The estimated paths from the SDG index to individual SDG indicators are statistically significant for most goals, indicating that overall SDG performance is closely linked to progress across economic, social, and institutional dimensions. However, negative and statistically significant coefficients are observed for environmentally oriented goals, suggesting that improvements in aggregate SDG performance may not translate uniformly into environmental outcomes.

The SEM results further indicated strong and statistically significant relationships between NIS inputs and key innovation system components, including research and development expenditure, public spending on education, institutional quality, and labour force participation. These findings highlight the central role of innovation system inputs in shaping the broader structural configuration of development outcomes, while also revealing heterogeneity across SDG dimensions.

Table 14. Structural equation model analysis

Structural equation model Estimation method: MLMV	**Coefficient**	**OIM std. err.**	**z**	**P>z**	**[95% conf.**	**interval]**
Structural						
SDG Innovation Index						
NIS Inputs (weighted)	5.15	0.274	18.780	0.000	4.612	5.687
_cons	53.236	0.184	289.330	0.000	52.875	53.596
goal1						
sdg_index	2.594	0.093	27.750	0.000	2.411	2.777
_cons	-105.143	5.009	-20.990	0.000	-114.96	-95.326
goal2						
sdg_index	0.775	0.05	15.550	0.000	0.677	0.873
_cons	9.187	2.671	3.440	0.001	3.952	14.422
goal3						
sdg_index	1.769	0.046	38.520	0.000	1.679	1.859
_cons	-55.263	2.461	-22.460	0.000	-60.086	-50.441
goal4						
sdg_index	2.462	0.083	29.600	0.000	2.299	2.625
_cons	-88.296	4.459	-19.8	0.000	-97.035	-79.556
goal5						
sdg_index	1.616	0.076	21.300	0.000	1.468	1.765
_cons	-41.405	4.067	-10.180	0.000	-49.377	-33.434
goal6						
sdg_index	0.965	0.033	29.560	0.000	0.901	1.029
_cons	-0.984	1.749	-0.560	0.574	-4.412	2.445
goal7						
sdg_index	1.784	0.069	25.900	0.000	1.649	1.919
_cons	-62.347	3.691	-16.89	0.000	-69.582	-55.112
goal8						
sdg_index	0.113	0.044	2.560	0.010	0.027	0.2
_cons	58.328	2.371	24.6	0.000	53.682	62.974
goal9						
sdg_index	1.534	0.043	36.06	0.000	1.451	1.617
_cons	-60.249	2.28	-26.43	0.000	-64.717	-55.781
goal10						
sdg_index	0.027	0.132	0.21	0.835	-0.23	0.285
_cons	42.668	7.048	6.05	0.000	28.854	56.482
goal11						
sdg_index	1.612	0.059	27.26	0.000	1.496	1.728
_cons	-29	3.17	-9.15	0.000	-35.212	-22.788
goal12						
sdg_index	-0.454	0.023	-19.57	0.000	-0.499	-0.409
_cons	117.951	1.244	94.84	0.000	115.514	120.389
goal13						
sdg_index	-0.331	0.021	-15.48	0.000	-0.373	-0.289
_cons	114.486	1.146	99.89	0.000	112.239	116.732
goal14						
sdg_index	-0.026	0.047	-0.55	0.580	-0.119	0.067

Continued Table 14

Structural equation model Estimation method: MLMV	Coefficient	OIM std. err.	z	P>z	[95% conf.	interval]
_cons	67.397	2.542	26.52	0.000	62.416	72.379
goal15						
sdg_index	-0.158	0.066	-2.39	0.017	-0.288	-0.028
_cons	76.575	3.543	21.62	0.000	69.632	83.518
goal16						
sdg_index	1.156	0.052	22.14	0.000	1.054	1.258
_cons	-10.57	2.798	-3.78	0.000	-16.054	-5.085
goal17						
sdg_index	1.023	0.051	19.99	0.000	0.922	1.123
_cons	0.002	2.742	0.000	0.999	-5.372	5.376
rd_expgdp						
nis_inputs_weighted	0.185	0.006	32.28	0.000	0.173	0.196
_cons	0.285	0.004	74.17	0.000	0.277	0.292
psegdp						
nis_inputs_weighted	1.934	0.081	23.88	0.000	1.775	2.092
_cons	3.788	0.054	69.71	0.000	3.681	3.894
Inst_quality						
nis_inputs_weighted	1.134	0.034	33.54	0.000	1.067	1.2
_cons	0.003	0.023	0.13	0.897	-0.042	0.047
Labor force						
nis_inputs_weighted	0.213	0.051	4.15	0.000	0.113	0.314
_cons	0.025	0.035	0.74	0.462	-0.042	0.093
var(e.sdg_index)	27.659	1.368			25.103	30.475
var(e.goal1)	282.575	13.981			256.459	311.35
var(e.goal2)	80.356	3.976			72.929	88.539
var(e.goal3)	68.204	3.375			61.901	75.15
var(e.goal4)	223.948	11.08			203.251	246.753
var(e.goal5)	186.322	9.219			169.102	205.295
var(e.goal6)	34.469	1.705			31.283	37.979
var(e.goal7)	153.48	7.594			139.295	169.109
var(e.goal8)	63.299	3.132			57.449	69.745
var(e.goal9)	58.541	2.896			53.13	64.502
var(e.goal10)	559.527	27.684			507.816	616.504
var(e.goal11)	113.163	5.599			102.704	124.686
var(e.goal12)	17.421	0.862			15.811	19.194
var(e.goal13)	14.795	0.732			13.427	16.301
var(e.goal14)	72.767	3.6			66.042	80.177
var(e.goal15)	141.358	6.994			128.293	155.752
var(e.goal16)	88.21	4.364			80.058	97.193
var(e.goal17)	84.675	4.189			76.849	93.297
var(e.rd_expgdp)	0.012	0.001			0.011	0.013
var(e.psegdp)	2.412	0.119			2.189	2.658
var(e.z_inst_quality)	0.42	0.021			0.381	0.463
var(e.z_labor)	0.974	0.048			0.884	1.073
LR test of model vs. saturated: chi2(231) = 37,904.81 Prob > chi2 = 0.0000						

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

To assess dynamic interrelationships and feedback effects, a VAR model was estimated. The VAR results reported in Table 15 indicated strong persistence in SDG performance, as reflected in the statistically significant coefficient on its first lag. Lagged NIS inputs exhibit weak and mixed effects on SDG performance, with evidence of short-run significance at specific lags but no consistent long-run pattern. In contrast, SDG performance does not exert a statistically significant effect on subsequent changes in NIS inputs. The dynamics of NIS inputs themselves display high persistence, indicating gradual adjustment over time.

Table 15. Vector autoregression model of the dynamic interactions between SDG performance and national innovation system inputs

	Coefficient	Std.err	z	P>|z|	[95% conf.	interval]
sdg_index						
sdg_index						
L1.	1.001	0.046	21.83	0	0.911	1.09
L2.	0.014	0.053	0.26	0.796	-0.091	0.119
L3.	-0.036	0.039	-0.91	0.361	-0.113	0.041
NIS						
L1.	0.567	0.304	1.87	0.062	-0.028	1.162
L2.	-0.298	0.141	-2.11	0.035	-0.574	-0.022
L3.	0.181	0.109	1.66	0.097	-0.032	0.394
NIS						
sdg_index						
L1.	-0.012	0.017	-0.68	0.494	-0.045	0.022
L2.	0	0.02	0	0.997	-0.04	0.04
L3.	0.003	0.014	0.24	0.811	-0.024	0.03
NIS						
L1.	0.983	0.122	8.04	0	0.743	1.223
L2.	-0.03	0.099	-0.3	0.763	-0.224	0.164
L3.	0.001	0.054	0.02	0.987	-0.105	0.107

Source: authors' calculations based on J.D. Sachs *et al.* (2024), World Bank (2024a), World Bank (2024b)

The SEM and VAR results indicated that innovation systems and sustainable development outcomes are structurally linked, but that the dynamic transmission from innovation inputs to SDG performance is relatively slow. The weak short-run feedback observed in the VAR results suggests that increases in innovation system inputs do not immediately translate into measurable improvements in SDG outcomes. One explanation is that the impact of innovation investments typically unfolds over longer time horizons, as research spending, education investments, and institutional reforms require time to generate knowledge creation, technology diffusion, and productivity improvements. In addition, many countries in Sub-Saharan Africa face structural constraints such as limited absorptive capacity, weak institutional coordination, and underdeveloped innovation ecosystems, which can slow the translation of innovation inputs into development outcomes. These factors mean that innovation investments tend to influence SDG performance through cumulative and path-dependent processes, where gradual improvements in human capital, institutional quality, and productive capacity eventually reinforce sustainable development trajectories rather than producing immediate feedback effects.

Discussion

This study examined whether national innovation systems contributed meaningfully to SDG performance in Sub-Saharan Africa after accounting for institutional quality, economic development, endogeneity, heterogeneity, and dynamic adjustment processes. Across the range of empirical strategies applied, a consistent pattern emerged. Innovation inputs were positively associated with SDG performance in static specifications, but their direct effect weakened substantially once endogeneity and dynamics were addressed. Institutional quality and income levels instead dominated as the primary conditioning factors through which innovation capacity translated into development outcomes. This evidence reframed the innovation-development nexus away from a linear input-output relationship toward a system-level, institutionally mediated process, consistent with the system-oriented perspective supported by R. Jjagwe *et al.* (2024) and advanced by M. Ogwu (2025).

The baseline fixed- and random-effects estimates indicated a positive association between national innovation system inputs and SDG performance, particularly in models capturing both within- and between-country variation. However, the divergence between fixed- and random-effects estimates suggested that innovation effects were not uniform across contexts. This finding was consistent with comparative African evidence reported by L. Mosupye-Semenya (2024), who documented substantial variation in innovation system effectiveness across institutional environments. It also aligned with S. Lukman *et al.* (2023), who found that similar innovation investments produced divergent outcomes depending on governance capacity. While much of the literature treated innovation as a broadly positive driver of development, the present findings indicated that development outcomes were more sensitive to institutional conditions than to innovation inputs alone.

After addressing endogeneity using instrumental variables and system GMM estimators, the estimated effect of innovation inputs weakened further. In the IV specification, innovation inputs lost statistical significance, whereas institutional quality remained strongly positive and statistically significant. The dynamic GMM results reinforced this pattern by revealing strong persistence in SDG performance and only weak short-run effects of innovation inputs. This suggested that innovation investments operated through gradual structural channels rather than generating immediate development gains. Similar conclusions were reported by E. Narayanan *et al.* (2024), who showed that institutional quality and infrastructure determined how effectively countries translated innovation inputs into productive outcomes. Complementary evidence was provided by O. Skorge (2024), who identified structural constraints limiting the translation of innovation inputs into development performance in developing economies.

The dominance of institutional quality across estimation strategies supported recent arguments that Africa's innovation challenge was less related to input scarcity than to institutional alignment. M. Mbaya & J. Ouma-Mugabe (2024) showed that fragmented governance structures weakened innovation outcomes despite the presence of capable actors, while related work emphasised the importance of policy coordination and institutionalised foresight in science, technology, and innovation systems. Although these studies did not explicitly examine SDG performance, the present analysis provided empirical evidence that institutional fragmentation had direct development implications. The structural equation model further indicated that innovation inputs were associated with improvements in institutional quality, although these relationships appeared contingent on broader governance conditions, consistent with the contextual preparedness argument advanced by H. Zvoushe (2024).

The heterogeneity analysis reinforced these findings. Quantile regression results showed that innovation inputs were statistically insignificant across the lower and middle segments of the SDG distribution, while institutional quality remained consistently positive across all quantiles. Only at higher levels of SDG performance did complementary factors such as education spending become significant. This pattern suggested that innovation investments in lower-performing countries were constrained by institutional and structural limitations. Similar heterogeneity in innovation outcomes was documented by S. Ndicu *et al.* (2023), while L. Mosupye-Semenya (2024) reported substantial cross-country variation in innovation system effectiveness. Extending these findings to multidimensional SDG outcomes, the present study indicated that innovation-led development was conditional and context-dependent. The increasing importance of education spending at higher levels of SDG performance was also consistent with the human capital–innovation link emphasised by O.T. Adeosun *et al.* (2024).

Evidence from environmental and sustainability-focused studies further supported these conclusions. R.N. Weerasinghe & K.S.L. Gunawardena (2024) found that innovation contributed to environmental sustainability only under conditions of strong regulatory capacity. J. Chaves-Chaparro *et al.* (2025) argued that sustainability outcomes depended on integrated socio-technical and institutional systems rather than isolated technological inputs. These perspectives were consistent with the heterogeneous and sometimes negative loadings observed for environmental SDGs in the structural equation model. While innovation-driven development appeared to support economic and social dimensions, environmental outcomes lagged where institutional capacity remained limited.

At sub-national levels, E. Lambert & K. Deyganto (2024) reported positive effects of entrepreneurship, education, and R&D on development outcomes. The present study did not contradict these findings but placed them within a broader system-level framework. The structural equation model indicated that national innovation inputs affected SDG performance primarily through institutions, education systems, and labour markets rather than through direct channels. This helped explain why localised innovation successes often failed to scale at the national level in weaker institutional environments. These findings were consistent with the coordinated innovation ecosystem perspective outlined by J.A. Afolabi & F.M. Adeyinka (2024).

The canonical correlation analysis provided further evidence of a strong multivariate association between innovation systems and SDG outcomes, even when direct regression effects appeared weak. The results indicated that innovation capacity and development outcomes were structurally linked, supporting the system-level perspective highlighted by R. Jjagwe *et al.* (2024). However, variation in SDG loadings across canonical dimensions suggested that different goals responded unevenly to innovation inputs, reinforcing the multidimensional nature of sustainable development.

The structural equation model further clarified these relationships. Innovation inputs were strongly associated with institutional quality, education spending, R&D intensity, and labour force participation, which in turn shaped SDG performance and individual goal outcomes. Economic, social, and institutional goals exhibited positive associations, while environmental goals displayed weaker or negative relationships. Similar concerns regarding uneven and potentially inequality-enhancing effects of technological change were raised by C.A. Ouinsou & A.F.C. Chabossou (2024), who showed that technological adoption could exacerbate disparities in the absence of institutional safeguards.

Dynamic interrelationships estimated using the vector autoregression model highlighted the path-dependent nature of development processes. SDG performance exhibited strong autoregressive persistence, while innovation inputs showed delayed and less stable effects. This finding was consistent with the framework developed by D. Acemoglu *et al.* (2005) and suggested that innovation policies should be evaluated over longer time horizons. While M. Zhang *et al.* (2024) emphasised the role of institutional diversity and interactive learning in shaping innovation outcomes, the present results indicated that innovation capacity did not automatically translate into sustainable development without supportive institutional conditions. Broader structural factors, including international linkages and absorptive capacity, also appeared to shape long-term outcomes, as argued by I. Dominguez Lacasa & M. Molina Vogelsang (2024).

Methodologically, the use of multiple empirical approaches provided a consistent picture of the innovation–

development relationship. Previous work by S. Hamidi & A. Berrado (2024) emphasised the importance of multivariate and dynamic methods for analysing national innovation systems. By combining panel regressions, canonical correlation analysis, structural equation modelling, and vector autoregression, this study provided a comprehensive assessment of how innovation systems interacted with sustainable development outcomes over time. The results suggested that innovation policy in Sub-Saharan Africa required a shift from input expansion toward institutional coordination and sequencing. Investments in R&D, education, and technology were necessary but not sufficient. Without institutional coherence and regulatory capacity, innovation systems generated limited SDG gains.

In contrast to studies that treated innovation as an autonomous driver of development, the present analysis positioned governance quality and economic structure as foundational conditions for innovation-led sustainability. This reframing had implications for both research and policy. It highlighted the importance of integrating institutional, heterogeneity, and dynamic perspectives into empirical models of innovation and development, and it suggested that strengthening institutional capacity was central to achieving the Sustainable Development Goals in Sub-Saharan Africa.

Conclusions

This study examined whether national innovation systems function as effective engines of Sustainable Development Goal achievement in Sub-Saharan Africa after accounting for institutional quality, economic development, endogeneity, heterogeneity, and dynamic adjustment. Using a combination of static panel models, instrumental variable estimation, system GMM, quantile regressions, and multivariate techniques, the results show that innovation inputs alone do not generate uniform development gains. Instead, the impact of innovation systems on sustainable development is conditional and strongly mediated by institutional quality.

The static panel estimates suggest a positive association between innovation inputs and SDG performance. For example, the fixed-effects results indicate a positive but statistically weak coefficient for the NIS index ($\beta = 2.68$, $p = 0.101$), while GDP per capita shows a strong and significant effect ($\beta = 4.14$, $p < 0.01$). Institutional quality becomes more influential in the instrumental variable models, where its coefficient remains large and highly significant ($\beta = 2.74$, $p < 0.01$), while the NIS index becomes statistically insignificant ($\beta = 0.24$, $p = 0.489$). Dynamic system GMM estimates further confirm strong persistence in development outcomes, with the lagged SDG index displaying a coefficient close to unity ($\beta = 0.968$, $p < 0.01$), indicating substantial path dependence in SDG trajectories.

Distributional analysis using quantile regressions reveals similar patterns. Across the SDG distribution, institutional quality remains consistently positive and significant ($\beta \approx 2.4$-2.8, $p < 0.01$), whereas the effect of innovation inputs is statistically weak and unstable. Interaction models show that institutional quality significantly moderates the effect of innovation systems, with the interaction coefficient ($\beta = -3.56$, $p < 0.01$) indicating that the effectiveness of innovation investments depends strongly on governance conditions. Multivariate results from structural equation modelling and vector autoregression further suggest that innovation systems influence SDG outcomes primarily through indirect and gradual channels rather than immediate feedback effects.

The findings indicate that innovation-led development strategies in Sub-Saharan Africa are constrained less by the quantity of innovation investment than by the institutional capacity required to translate innovation into sustainable development outcomes. Strengthening governance, regulatory capacity, and policy coordination therefore appears essential for innovation systems to generate meaningful SDG progress. Future research could extend this analysis using sector-level or micro-level innovation indicators to better capture the channels through which innovation influences development outcomes. Comparative studies across developing regions may also help identify institutional thresholds that determine when innovation investments translate into sustainable development gains.

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Національні інноваційні системи та результати досягнення Цілей сталого розвитку в Африці на південь від Сахари

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Анотація. Прогрес у досягненні Цілей сталого розвитку (ЦСР) залишається нерівномірним у країнах Африки на південь від Сахари, попри сталий акцент державної політики на інноваційно орієнтованому розвитку. Хоча національні інноваційні системи широко розглядаються як рушії довгострокового зростання та сталості, емпіричні докази того, яким чином ефективність інноваційних систем трансформується у багатовимірні результати розвитку в регіоні, залишаються обмеженими. Метою цього дослідження було проаналізувати вплив ефективності національних інноваційних систем на досягнення ЦСР у країнах Африки на південь від Сахари на основі збалансованої панельної вибірки з 43 країн за період 2005-2023 років. Ефективність національних інноваційних систем вимірювалася за допомогою композитного індексу, сформованого з показників витрат на дослідження і розробки, державних витрат на освіту, рівня участі робочої сили та якості інституцій. Для врахування гетерогенності, ендогенності та динамічних взаємозв'язків застосовано панельні економетричні методи. Результати моделі випадкових ефектів засвідчили позитивний і статистично значущий зв'язок між інноваційними ресурсами та показниками досягнення ЦСР ($\beta = 2{,}431$, $p < 0{,}01$), тоді як ВВП на душу населення продемонстрував сильний позитивний вплив ($\beta = 4{,}210$, $p < 0{,}01$). Водночас оцінки моделі фіксованих ефектів показали, що внутрішньокраїнові зміни інноваційних ресурсів не є статистично значущими ($\beta = 2{,}680$, $p = 0{,}101$), що засвідчило визначальну роль міжкраїнових структурних відмінностей у формуванні виявленого зв'язку. Після корекції на ендогенність за допомогою інструментальних змінних інноваційні ресурси залишилися статистично незначущими ($\beta = 0{,}240$, $p = 0{,}489$), тоді як якість інституцій ($\beta = 2{,}737$, $p < 0{,}01$) і ВВП на душу населення ($\beta = 3{,}004$, $p < 0{,}01$) виступили стійкими детермінантами результатів ЦСР. Результати динамічної оцінки за методом узагальнених моментів (GMM) також виявили сильну інерційність результатів ЦСР (коефіцієнт лагу = 0,968, $p < 0{,}01$), тоді як інноваційні ресурси продемонстрували лише слабкі короткострокові ефекти ($\beta = 1{,}259$, $p < 0{,}10$). Отримані результати підтвердили, що інноваційні системи впливають на сталий розвиток переважно через інституційні та структурні канали, а не через прямі й негайні ефекти. Відтак, зміцнення управлінської спроможності та узгодження інноваційних інвестицій з інституційними реформами є ключовими умовами прискорення прогресу у досягненні ЦСР у країнах Африки на південь від Сахари

Ключові слова: якість інституцій; управління інноваціями; політика сталого розвитку; ендогенне зростання; панельна економетрика; структурне моделювання рівнянь; гетерогенність розвитку