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RESEARCH ARTICLE

The Spatial Spillover Effects of Public Sector Transparency on Advancing Africa's Sustainable Development Goals

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Received: 14 September 2025 | **Revised:** 2 December 2025 | **Accepted:** 12 December 2025

Keywords: Africa | public sector transparency | rule of law | SDG-13 | SDG-16 | spatial analysis

ABSTRACT

Africa faces significant challenges in achieving the Sustainable Development Goals (SDGs), particularly SDG 13 (climate action) and SDG 16 (Peace, Justice, and Strong Institutions), amid widespread corruption, weak governance, and political instability. This study innovatively explores the spatial spillover effects of public sector transparency—proxied by the corruption perceptions index (CPI)—alongside rule of law and political stability, on key sustainable development metrics, including the sustainable development index (SDI), CO_2 emissions, and ecological footprint. By highlighting these interconnections in Africa's SDG context, it addresses a critical gap in understanding how governance reforms can propagate across borders to foster regional progress. Drawing on panel data from 42 African countries spanning 2012 to 2022, the analysis employs spatial econometric models to capture spatial dependencies. Key findings reveal that the rule of law exerts a significant positive direct effect on SDI (0.024% total increase per 1% improvement) but insignificant spillovers. Enhanced public sector transparency (CPI) elevates CO_2 emissions primarily through spillovers, while the rule of law reduces ecological footprint via indirect effects. Income and population growth positively drive SDI with stronger spillovers yet exhibit mixed environmental impacts. These results underscore the interconnected governance-sustainability nexus in Africa, advocating regional anti-corruption and institutional reforms to harness positive spillovers for equitable green growth and SDG attainment.

1 | Introduction

Over the past three decades, global efforts to combat climate change have been intensified with international organizations and governments pursuing ambitious net-zero strategies (Kocak and Alnour 2024). However, realizing climate resilience requires profound shifts in production processes, consumption patterns, and energy behaviors (World Bank 2024). Despite annual investments exceeding a trillion dollars by governments and corporations to mitigate environmental degradation, these amounts fall short of the United Nations' estimates for effective mitigation and adaptation. A critical barrier exacerbating this shortfall is corruption, which diverts resources intended for emission reductions and climate protection. This interplay between governance and sustainable development is explicitly recognized in Sustainable Development Goal (SDG) 16, which prioritizes "peace, justice, and strong institutions" by addressing political stability, institutional strengthening, and anti-corruption measures. Beyond SDG 16, these governance elements influence parallel goals, particularly SDG 13 on "climate action," as weak institutions and ineffective rule of law (RLW) hinder the enforcement of climate policies, the equitable distribution of green climate funds, and long-term sustainable planning free from political disruptions (García-Sánchez et al. 2024). This underscores the urgent need to examine how corruption and the RLW intersect with climate trajectories and progress towards the pathways for achieving SDGs.

Environmental protection encompasses multifaceted dimensions, yet countries scoring higher on the corruption perceptions index (CPI) consistently demonstrate superior environmental outcomes. In the Global North, where historical emissions are highest, powerful industries lobby to weaken climate legislation and influence international negotiations, often prioritizing fossil fuel interests through disinformation campaigns (Gverdtsiteli and Roberto Martinez 2024). Conversely, in the Global South, particularly Sub-Saharan Africa, inadequate oversight leads to the embezzlement of climate finance meant for sustainable transitions and adaptation. These systemic failures highlight the imperative for governance reforms emphasizing transparency, accountability, and equitable representation in climate governance.

In the context of Africa's holistic development and green growth, the continent's persistent decline in CPI scores to an average of 24 out of 100 in 2024, well below the global average of 43, severely hampers climate action (Transparency International 2025). Corruption not only accelerates environmental degradation but also amplifies climate vulnerabilities, such as irregular rainfall, frequent droughts, desertification, and rising temperatures. Despite contributing less than 4% of global carbon emissions, Africa faces disproportionate impacts, incurring $8.5 billion in economic losses in 2022 and affecting over 100 million people (UNDP 2024). At COP29, developed nations pledged US$300 billion annually by 2035 to support vulnerable countries, signaling increased climate funding for Africa. By 2020, however, African nations received only $29.5 billion, representing just 11% of their total needs (UNDP 2024). Given Africa's low CPI rankings, robust anti-corruption mechanisms are essential to ensure these funds benefit communities and ecosystems rather than corrupt elites (Transparency International 2025). Compounding this, the RLW plays a pivotal role in environmental sustainability by integrating legal frameworks with governance principles, enabling effective enforcement of environmental laws, empowering institutions, and promoting accountability, justice, and community participation (Arthur et al. 2025; Atta and Sharifi 2025). Yet, the World Bank's Worldwide Governance Indicators reveal poor performance in the "RLW" dimension across many African nations, leading to inconsistent environmental law enforcement, unchecked illegal deforestation, land grabbing, and pollution, all of which derail SDG progress (World Bank 2024).

The research problem lies in the pervasive leakage of climate funds due to corruption, compounded by the weak RLW and political instability, which collectively obstruct Africa's path to SDGs, including reduced carbon emissions and minimized environmental footprints. This not only perpetuates vulnerability but also risks squandering international commitments, undermining global efforts to achieve net-zero targets. To address this, the study poses the following research questions:

RQ1. How does public sector transparency (corruption perceptions index) influence sustainable development outcomes in African nations, and what are its spatial spillover effects?

RQ2. What role does the rule of law play in mediating SDGs, environmental sustainability, and climate action in Africa?

RQ3. How does political stability shape pathways toward SDGs, carbon reduction, and ecological preservation?

Africa's context is particularly relevant due to its acute climate vulnerabilities, stagnant anti-corruption progress, and governance deficits, making it a critical case for studying these dynamics. Despite global pledges, the continent's low governance indicators amplify the risks of fund mismanagement, highlighting the need for region-specific insights to inform effective interventions.

This study fills significant gaps and contributes to the current literature in several ways. First, while corruption's environmental impacts are acknowledged, no prior research has empirically investigated fund leakages' effects on Africa's overall sustainable development, providing novel evidence on how corruption hinders SDG attainment. Second, although the RLW is foundational to institutional frameworks, existing studies overlook its specific influence on environmental sustainability in African contexts. Third, by incorporating political stability as a standalone variable, this research reveals its composite effects on green growth pathways, a dimension absent from current scholarship. Fourth, employing a spatial panel model captures spillover effects across African nations, offering more robust, policy-oriented recommendations than traditional approaches.

The remaining portion of the article is arranged as follows: Section 2 presents the literature review and theoretical framework. Section 3 discusses the data and methodology. Section 4 introduces empirical findings and discussions. Section 5 concludes with policy recommendations.

2 | Literature Review

2.1 | Theoretical Underpinnings

This study is grounded in a multifaceted theoretical framework that integrates institutional theory, good governance principles, and spatial econometrics to examine the interplay between public sector transparency, RLW, political stability, and sustainable development in Africa. By drawing on these theories, we elucidate how institutional quality influences environmental sustainability outcomes, such as the SDI, CO_2 emissions, and ecological footprint while accounting for spatial spillovers across geographically interdependent countries. This framework not only addresses the direct effects of governance on SDGs but also highlights cross-border dynamics, which are particularly salient in Africa's context of shared resources, migration flows, and regional vulnerabilities.

Institutional theory posits that formal and informal institutions shape economic, social, and environmental behaviors by reducing transaction costs, enforcing rules, and fostering trust (North 1990). In the realm of sustainable development, strong institutions are essential for aligning human activities with planetary boundaries, as emphasized in SDG 16 (Peace, Justice, and Strong Institutions). High-quality institutions promote efficient resource allocation, innovation in green technologies, and equitable distribution of environmental benefits, thereby enhancing ecological efficiency (Hickel 2019). Corruption, as a manifestation of institutional weakness, erodes these mechanisms by diverting climate funds, enabling illegal resource exploitation, and delaying policy implementation, leading to higher emissions and ecological overshoot (Forson 2024). Conversely, public sector transparency, proxied by the CPI, facilitates accountability, reducing rent-seeking behaviors and ensuring that environmental investments yield sustainable outcomes.

The RLW, a core pillar of institutional theory, provides a stable legal framework for environmental governance. It encompasses formal (predictable laws), procedural (fair enforcement), and substantive (rights-based) dimensions, which collectively support SDGs by safeguarding access to justice, protecting ecosystems, and balancing intergenerational equity (Kreilhuber and Kariuki 2019). In Africa, where a weak RLW often results in selective enforcement of environmental regulations, this theory underscores the need for robust institutions to curb deforestation, pollution, and land grabbing (Atta and Sharifi 2025). Political stability, intertwined with institutional quality, mitigates violence and disruptions that hinder long-term sustainability planning. Stable governance fosters investor confidence, enabling transitions to low-carbon economies and resilient infrastructure (Barbier and Burgess 2021). Instability exacerbates corruption and weakens the RLW, creating a vicious cycle that impedes progress toward SDG 13 (climate action) and related goals.

Building on spatial econometric theory (Anselin 1988), this framework accounts for geographical interdependence, where institutional reforms in one country generate spillover effects on neighbors through trade, migration, and shared ecosystems. In environmental economics, spatial dependence implies that corruption or weak governance in adjacent nations can "spill over" via transboundary pollution, resource conflicts, or policy diffusion, amplifying ecological footprints (Kassouri 2021). For instance, improved economic institutions reduce domestic ecological footprints while exerting negative spillovers on neighbors' environmental degradation. In Africa, this is accentuated by regional integration, where institutional quality influences energy efficiency and emissions across borders. This integrated framework hypothesizes that enhanced institutional quality directly boosts SDI and reduces environmental burdens, with spillovers moderated by economic and demographic controls. It justifies the use of spatial panel models to capture these dynamics, providing a policy-relevant lens for Africa's sustainable transition. Figure 1 shows the theoretical framework of this research. The next sections build on this by reviewing empirical literature and testing these relationships.

2.2 | Institutional Quality and Environmental Outcomes

Conceptually, institutional quality refers to the capacity of a state and its public institutions to manage decision-making processes in a transparent, accountable, and effective manner. Specifically, transparency in public sector practices serves as a vital remedy for reducing public doubt about the government's capacity to achieve SDGs. Such transparency is not only essential for enhancing social welfare but also plays a critical role in protecting the environment (Hope Kempe Ronald 2022). Public sector transparency supports the achievement of environmental sustainability goals by ensuring the efficient and equitable allocation of public resources for

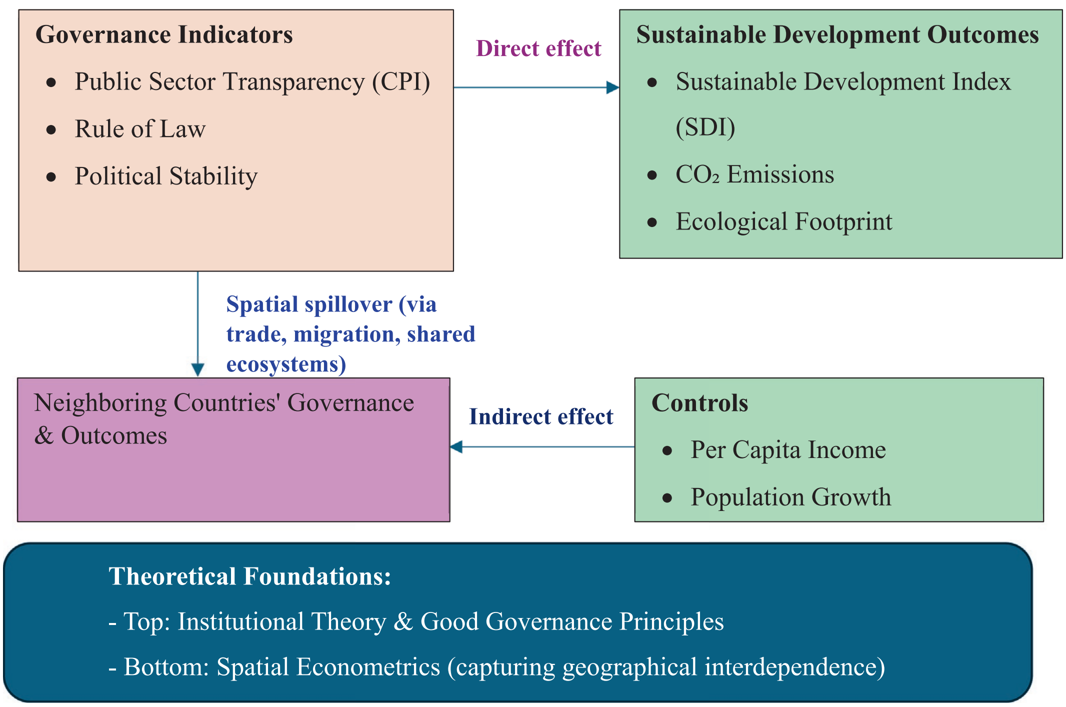

FIGURE 1 | Theoretical framework of this research.

environmental protection, preventing corruption, and fostering public trust (Erin et al. 2024). Therefore, countries with strong institutional quality tend to demonstrate superior performance in the implementation of environmental policies. For instance, the executive power, one of the three branches of the state, occupies a central position in the planning and implementation of environmental policies. The supervision of administrative actions by law enforcement agencies, along with their ability to impose administrative sanctions, makes significant contributions to achieving the objectives of environmental law.

Scholars have extensively discussed the complex connection between institutional quality and environmental outcomes. However, empirical research offers inconclusive findings, largely depending on specific indicators used, the time period examined, the geographical focus, and the methodological approach applied. Among various institutional quality measures, government transparency is widely recognized as playing a crucial role in advancing the 2030 Agenda for sustainable development. Public sector transparency strengthens the quality of legislation and reduces political corruption, which can significantly improve environmental sustainability performance (Guerrero-Gómez et al. 2021). Moreover, transparent and accountable governance facilitates the implementation of environmental policies by increasing public acceptance and enhancing their effectiveness through greater citizen participation (Alcaraz-Quiles et al. 2014).

The efficiency of climate change policies and regulatory initiatives depends on the legal framework and on how laws aimed at mitigating environmental damage are enforced by public institutions (Stef et al. 2023). Such institutions can enhance political stability and the RLW, reduce violence, improve government effectiveness, strengthen voice and accountability, curb the proliferation of corruption, and promote regulatory quality. Together, these factors increase the effectiveness of sustainability policies such as clean energy adoption, ultimately resulting in higher environmental quality (Khan et al. 2022). In a similar context, Maji et al. (2022) argue that strengthening institutional quality is a necessary policy instrument for reducing environmental degradation in the long term in Sub-Saharan Africa. The authors add that sound institutional quality can play an important role in enabling countries to adopt renewable technologies, which in turn contributes to CO_2 emissions mitigation. Mann et al. (2018) further highlighted the critical role of transparent and multi-stakeholder governance systems in mitigating environmental disputes at the local level and ensuring ecosystem protection. The authors argued that the development of resilient environmental sustainability policies largely depends on inter-institutional collaboration and strong governance transparency. Recently, Meschede (2019) and Irtyshcheva et al. (2022) emphasized that the transparent dissemination of sustainable development information enhances the effectiveness of environmental policy implementation and increases citizen participation. Regarding the accountability dimension of institutional quality, Karlsson-Vinkhuyzen et al. (2018) evaluated the potential of emerging accountability regimes for the Sustainable Development Goals, particularly in the context of environmental policy. The authors concluded that some accountability mechanisms may be counterproductive for integrative policy-making. Moreover, at the national level, hierarchical accountability mechanisms with sanctioning powers may discourage policy integration.

The involvement of institutions in climate change governance is associated with improved environmental quality. Strict institutional rules and a robust RLW can compel businesses to reduce CO_2 emissions (Ahmad et al. 2021). Moreover, institutional engagement in a country's structural transformation and in efforts to reduce environmental degradation is critical, as it enables policymakers to effectively enforce and monitor environmental policies. Ren et al. (2022) evaluated the impact of green innovation and institutional quality on energy efficiency using the parametric SFA method. Their study found that in developed countries, institutional quality significantly enhances the positive effect of green innovation on energy efficiency, underscoring the critical role of governance quality in the widespread adoption of environmentally friendly technologies. Similarly, Adolphus et al. (2025) applied the Method of Moments on Quantile Regression to examine the influence of institutional quality on environmental quality. The author uncovered that the influence of institutional quality on environmental outcomes varies depending on a country's income level and investment profile.

2.3 | Spatial Dependence in Sustainability

Despite the extensive research on the nexus between institutional quality reforms and the sustainability agenda, which has substantially enhanced our understanding of the complex and multidimensional transition toward sustainable societies and economies, the empirical literature has largely ignored the spatial dimensions of environmental sustainability policies. A more explicit spatial perspective on the sustainable environment can significantly contribute to contextualizing the territorial sensitivity and the diversity of environmental sustainability processes, which stem from the natural variation in institutional qualities, networks, national strategies, and resource allocation across countries (Coenen et al. 2012). This is because sustainable development is not only about environmental protection but also about creating an inclusive and socially equitable society. In this regard, economic activities in one territory have been shown to affect the environment not only within the same territory but also in neighboring countries. These spillover effects occur due to factors such as institutional linkages, policy diffusion, international network, and societal behaviors (Naqvi et al. 2025; Nikou 2025). Vagnini et al. (2025) further emphasized that socio-economic integration and physical proximity play essential roles in explaining decarbonization outcomes, particularly in industrial sectors.

Empirical studies have largely emphasized that sustainability policies diffuse significantly across countries through structured spatial–temporal dynamics, reflecting governance capacities and the replicability of successful innovations. For instance, the development of environmentally sound technologies in one country can spill over through global value chains, joint R&D programs, and cross-border investment channels, highlighting the importance of spatial dependence in shaping environmental outcomes (Naqvi et al. 2025). Similarly, Tang et al. (2025) found that in West African countries, industrial activities and population density significantly affect environmental degradation in the long run at the local level, and these effects also spill over into neighboring countries. The authors further clarified that spatial dependencies in this region fall within clusters of low-low, low-high, and high-low.

Recently, Arogundade and Hassan (2025) employed the spatial Durbin model (SDM) to examine the spatial spillover effects of the digital economy on environmental quality across 36 African countries between 1995 and 2020. Their findings provide evidence of significant spatial spillovers in the relationship between the digital economy and environmental quality in Africa. The authors further explained that these spillover effects may be attributed to interconnected ecosystems, shared natural resources, and transboundary environmental factors such as air and water pollution. Similarly, Jeetoo and Chinyanga (2023) demonstrated that natural resource depletion exhibits positive spatial spillovers among neighboring countries, whereas carbon dioxide emissions display negative spatial spillovers among geographically proximate countries in the Sub-Saharan African region.

2.4 | Research Gaps

Despite the extensive research on institutional quality and the sustainable development agenda, several gaps remain. (i) The spatial transmission of institutional quality is often overlooked in the existing literature, as prior research has largely relied on traditional analytical frameworks that fail to capture spillover and dynamic effects. (ii) Previous studies have primarily focused on country-specific data, neglecting regional-level analyses, and regional data have not been sufficiently explored. (iii) The limited panel data analyses on institutional quality and sustainable development pathways have largely concentrated on organizational classifications such as the OECD, G7, and BRICS. To address these gaps, this study employs data from 42 African countries and applies three spatial panel regression models: the SDM, the spatial autoregressive model (SAR), and the spatial error model (SEM).

3 | Estimation Strategy and Data

This study examines the spatial spillover effects of public sector transparency—proxied by CPI, RLW, and political stability on SDGs, with a focus on environmental indices across 42 African countries (Table A1), while controlling for economic and population growth. To this end, the study employs several spatial panel regression models, including the SDM, SAR, and SEM. In this part, we explain the estimation process of spatial panel regressions. In doing so, this study utilizes the QGIS program for map extraction. Meanwhile, the GeoDa software was used for creating a spatial weight matrix and a spatial autocorrelation test using Moran's I Index. At the final step, the Stata software version 15 is used to estimate the spatial panel region (SDM, SAR, SEM). The rationale for applying spatial spillover models lies in the geographical interdependence of African countries in economic, social, political, and environmental aspects. Such interdependencies increase these countries' vulnerability to external influences, particularly in areas of environmental sustainability regarding carbon emissions and ecological footprint. Therefore, spatial modeling serves as a vital tool for capturing the patterns and magnitudes of spatial dependencies among African countries. Figures 2–4 illustrate the spatial distribution of the SDI, ecological footprint, and carbon dioxide emissions across African countries in 2022, respectively. Additionally, the spatial distribution of the other variables is presented in Figures A1–A4.

3.1 | Spatial Weight Matrix

To estimate spatial regression, it is crucial to construct a spatial weight matrix. This matrix is an exogenous parameter, used to quantify the degree of spatial interdependence between countries i and j within the study sample. This study follows the widely used Queen contiguity spatial weight matrix to define spatial linkage and assign corresponding weights. This

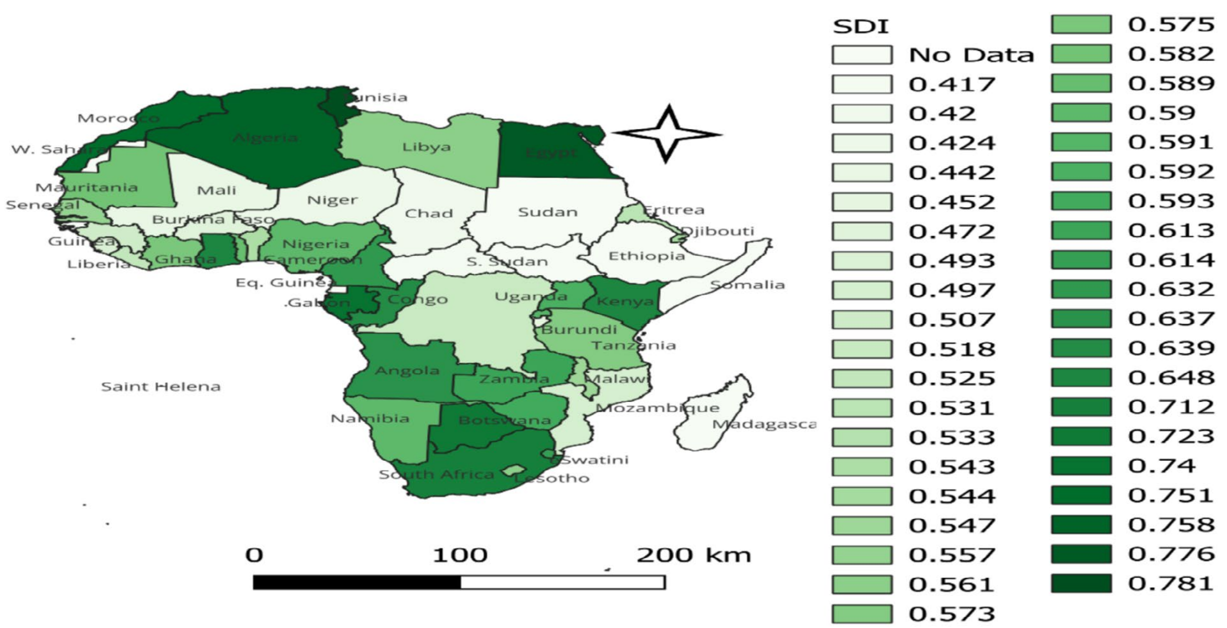

FIGURE 2 | Spatial distribution of sustainable development index across African countries in 2022. *Source:* Authors' own illustration.

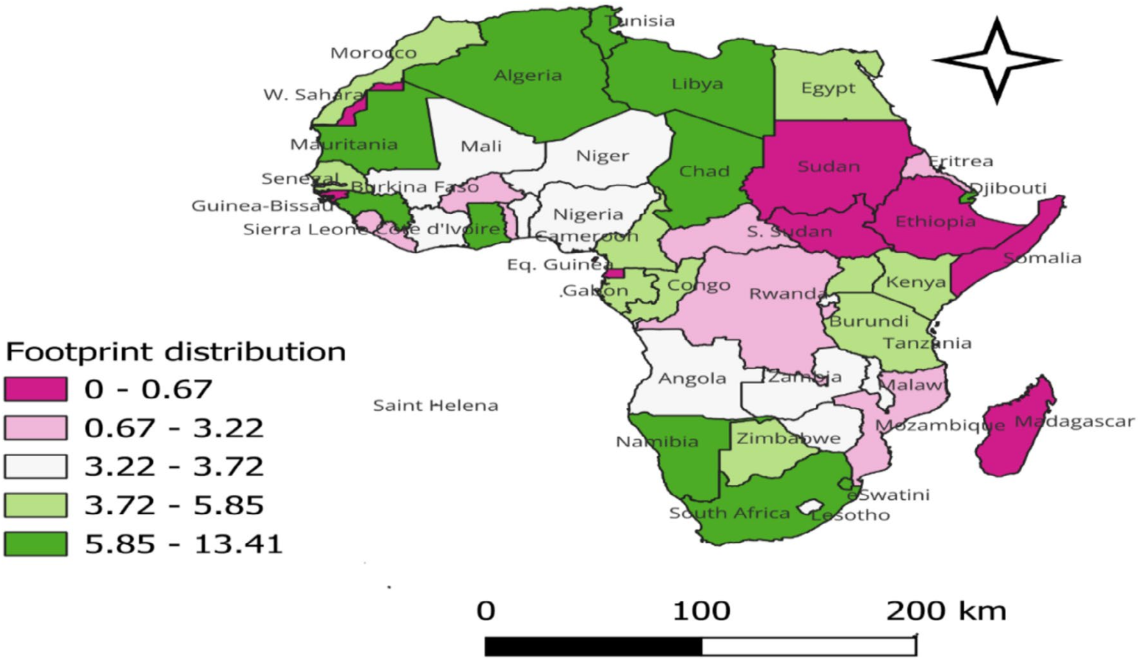

FIGURE 3 | Spatial distribution of ecological footprint in 2022. *Source:* Authors' own illustration.

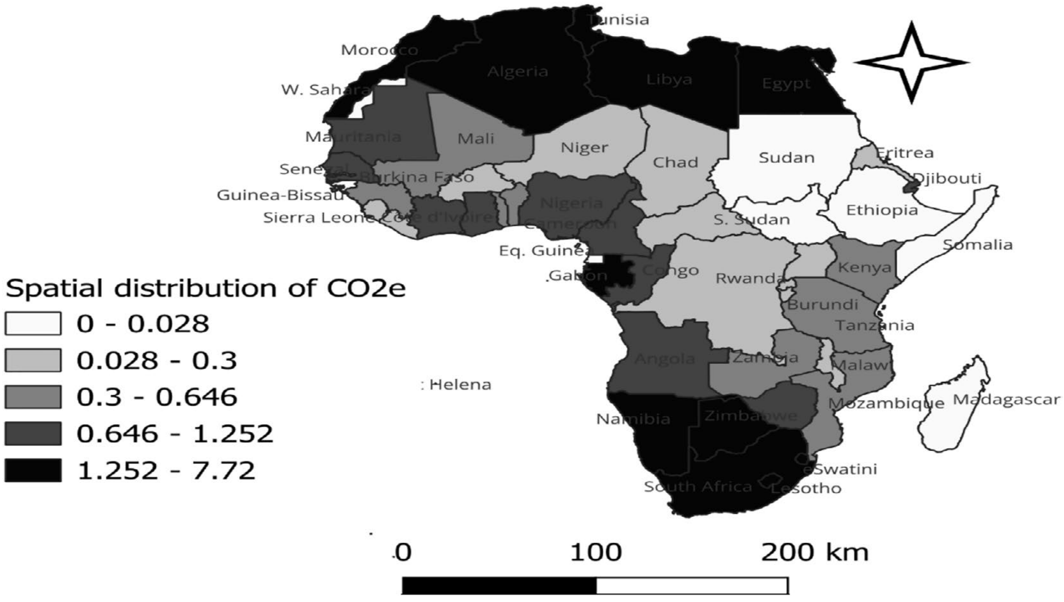

FIGURE 4 | Spatial distribution of carbon emissions in 2022. *Source:* Authors' own illustration.

technique assigns a weight of 1 to countries that are geographically contiguous, sharing either a common boundary or a single point, while assigning a weight of 0 for non-contiguous countries. In the equation below, W is an adjacent order matrix with $n \times n$ spaces. According to Anselin (1988), this approach has the potential to identify a larger number of neighboring units, thereby reflecting broader and more realistic spatial interactions. Consequently, it better captures environmental spillovers, reduces the likelihood of isolated regions, and produces more robust spatial models, particularly when the underlying processes diffuse through both shared borders and points of contact.

$$W_{ij} = \begin{cases} 1, \text{countries } i \text{ and } j \text{ are neighboring countries} \\ 0, \text{countries } i \text{ and } j \text{ are not neighboring countries} \end{cases} \quad (1)$$

3.2 | Spatial Autocorrelation

After constructing a weight matrix, testing the spatial dependency is essential to figure out whether the spatial autocorrelation for the dependent variable is significant. To this end, the Global Moran's Index is used. According to Kassouri (2021), Moran's Index is widely utilized in the literature of spatial research to detect and evaluate the degree of spatial autocorrelation among the observational units in a given spatial dataset. Following the seminal work of Moran (1948), the global Moran's I index is specified as:

$$\text{Moran's } I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\left(u_i-\bar{u}\right)\left(u_j-\bar{u}\right)}{s^2\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}} \quad \forall i=1,\ldots,n \wedge \forall j=1,\ldots,n \tag{2}$$

where

$$\bar{u}=\frac{1}{N}\sum_{i=1}^{n}u_i, s^2=\frac{1}{N}\sum_{i=1}^{n}\left(u_i-\bar{u}\right)^2 \tag{3}$$

where u_i and u_j, correspondingly, indicate the dependent variables (SDI, CO_2, footprint) in the countries i and j. n indicates the number of spatial units in the study sample. W_{ij} represent the factors of spatial weights relating unit i and j such that $W_{ij}=1$ when countries are neighbors, and $W_{ij}=0$ when the spatial units (countries) share no common borders. The magnitude of spatial autocorrelation among the units is determined by the absolute value of Moran's I statistic, with higher values indicating stronger spatial dependence. Moran's I index is explained under the null hypothesis of no spatial autocorrelation. It is computed by the z-score approach within the context of a standard normal distribution with $\mu=0$ and $\sigma=1$ (Kassouri 2021; Kuşkaya et al. 2025). Figures 5–7 present the results of spatial autocorrelation for our models using Moran's I index.

Figure 5 displays diagnostic evidence of spatial autocorrelation for the overall sustainable development index (SDI) across the African region. Moran's I scatter plot (Panel A) shows the standardized regional values of sustainable development on

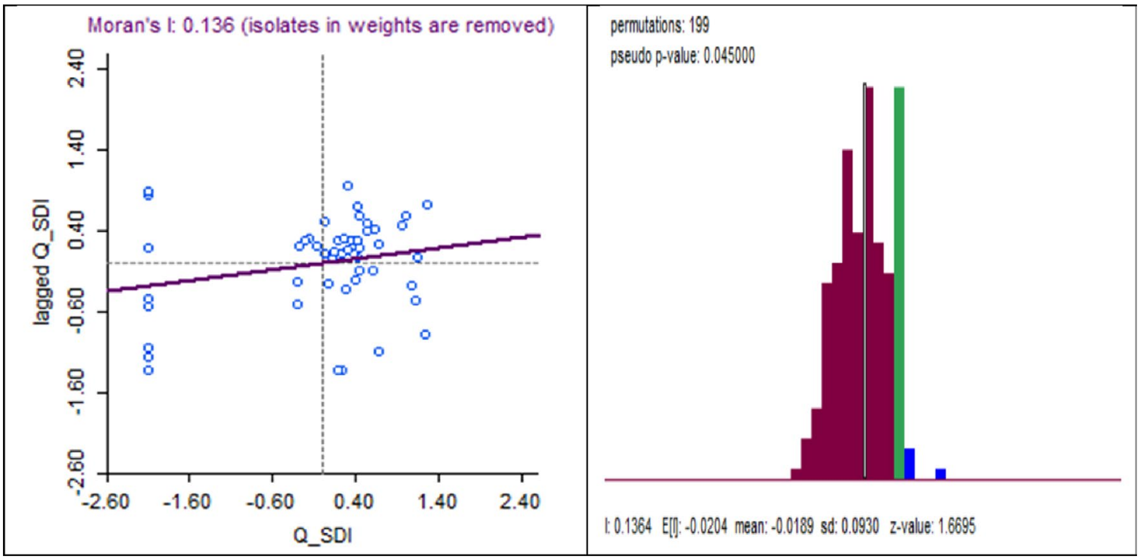

FIGURE 5 | Spatial autocorrelation test for sustainable development index. *Source:* Authors' own illustration.

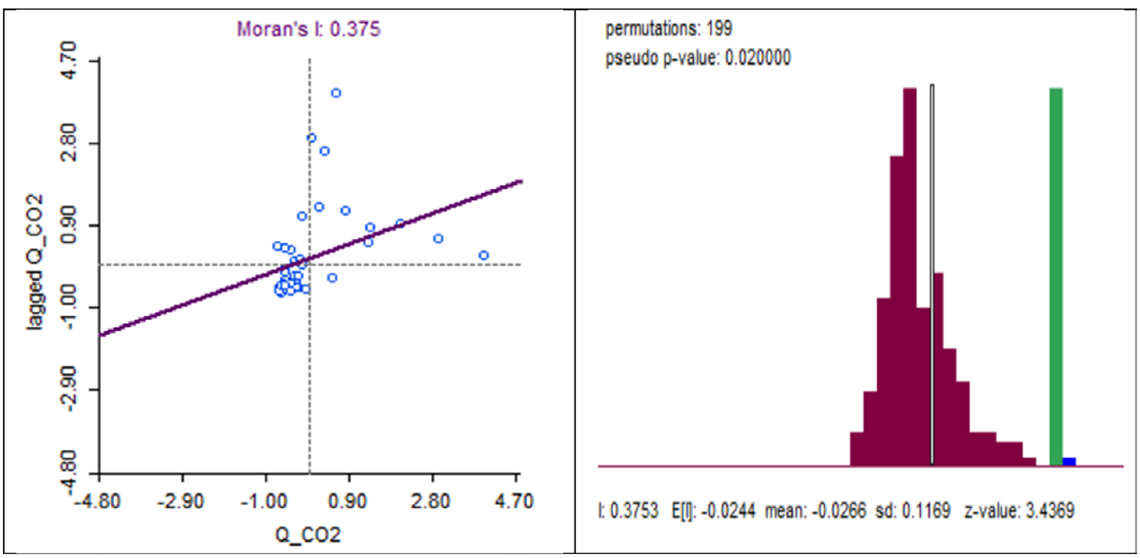

FIGURE 6 | Spatial autocorrelation test for carbon dioxide emissions. *Source:* Authors' own illustration.

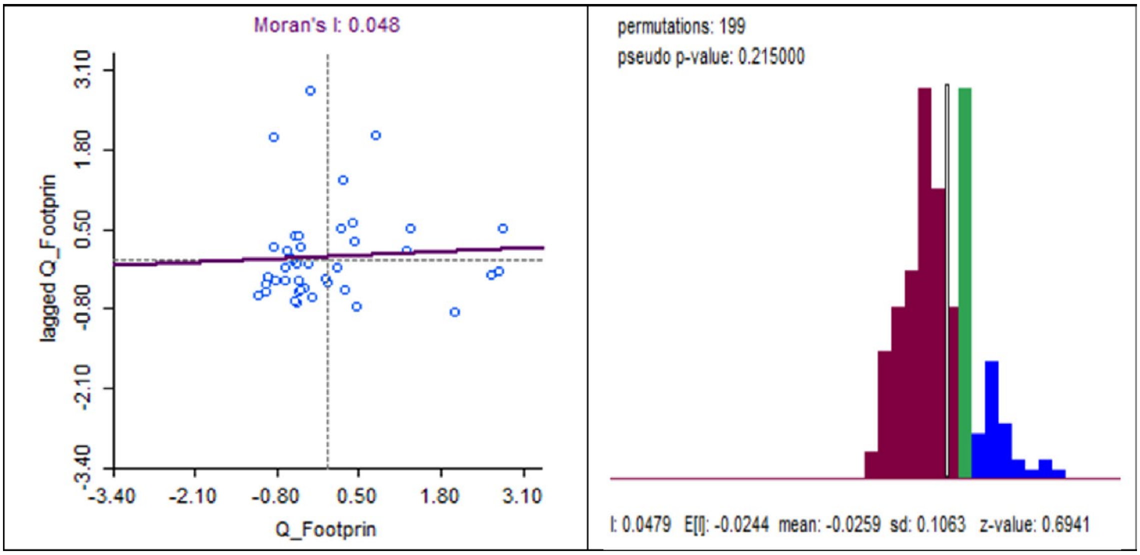

FIGURE 7 | Spatial autocorrelation test for ecological footprint index. *Source:* Authors' own illustration.

the *x*-axis and their spatially lagged averages on the *y*-axis. The positive slope of the fitted regression line indicates clustering of similar values. The calculated Moran's statistic is 0.136, suggesting moderate to strong positive spatial autocorrelation among African countries. In substantive terms, regions with a higher SDI tend to be geographically contiguous, reinforcing the hypothesis that sustainability policies and green infrastructure diffuse spatially. Panel B reports the results of the permutation test (199 permutations), confirming that the observed Moran's *I* is statistically significant. The pseudo *p* value of 0.045 and the *z*-value of 1.669 reject the null hypothesis of spatial randomness at the 5% significance level. The histogram of permuted Moran's *I* statistics illustrates that the empirical value (green bar) lies well to the right of the simulated distribution under the null. Similarly, Figure 6 shows the diagnostic evidence of spatial autocorrelation for CO_2 emissions. The calculated Moran's statistic is 0.375 (pseudo *p* value of 0.02), revealing moderate to strong significant positive spatial autocorrelation. Figure 7, however, indicates the acceptance of the null hypothesis of spatial autocorrelation for ecological footprint (coefficient = 0.048, $p > 0.215$).

3.3 | Spatial Panel Models

In the final step, we estimated the spillover effects of institutional quality on sustainable development with respect to the environmental aspect by employing three spatial panel regressions, including the SAR, SEM, and SDM. It is worth mentioning that, in the spatial analysis, the endogenous variables (carbon emissions and footprint) are influenced not only by changes in the explanatory variables within a given country captured by the direct effects but also by changes in those variables in neighboring countries, which are reflected through the indirect (spillover) effects. Specifically, while the direct impact measures the influence of domestic factors, the indirect impact captures how external factors in adjacent countries affect the local environmental outcomes.

3.3.1 | Spatial Autoregressive Regression

Following (Kassouri 2021), the SAR takes the following form:

$$z_{it} = \alpha + \lambda \Sigma_{j=1} W z_{jt} + \Sigma_k x_{it}^{(k)} \delta_k + \mu_i + \vartheta_t + \varepsilon_{it} \quad (4)$$

where z_{it} is representing the dependent variables for country $i = 1, 2, \ \ldots N$. At time $t = 1, 2, \ \ldots .T$. x_{it} is a $k \times 1$ vector of independent variables. W *is a* row-normalized weight matrix, Wz_{jt} detects the interaction effects of the dependent variables in neighboring countries on the dependent variable z_{it}, and λ represents the strength and direction of spatial interaction between one country and its geographical proximity countries. μ_i and ϑ_t indicate the spatial specific effects and time-period effects.

3.3.2 | Spatial Error Model

In the SEM, the stochastic term of country i is hypothesized to rely on the error terms of neighboring countries j according to the spatial weight matrix (W) and an idiosyncratic component, e_{it}. The specification of the SEM takes the following form:

$$z_{it} = \alpha + \lambda \Sigma_{j=1} W z_{jt} + \Sigma_k x_{it}^{(k)} \delta_k + \mu_i + \vartheta_t + e_{it} \quad (5)$$

where $e_{it} = \phi \Sigma j = 1Wejt + \varepsilon_{it}$. In the above equation, spatial interactions are incorporated in the error term. $Wejt$ indicates the geographical interactions among the disturbances of the different units under examination.

3.3.3 | Spatial Durbin Model

To reflect the spatial interactions in both dependent and independent variables, the SDM was developed. The SDM is specified as follows:

$$z_{it} = \alpha + \lambda \Sigma_{j=1} W z_{jt} + \Sigma_k x_{it}^{(k)} \delta_k + \Sigma_{j=1} W x_{jt}^{(k)} \theta_k + \mu_i + \vartheta_t + \eta_{it} \quad (6)$$

where θ is a $k \times 1$ vector of parameters to be estimated. η_{it} is the disturbance term. Given the inconsistency of fixed effects and random effects models, since it includes spatial interactions, this study utilizes maximum likelihood estimation. For geographic econometric models, the most widely used regression technique is the maximum likelihood methodology (Alnour and Kocak 2025; Kuşkaya et al. 2025). To estimate the spatial spillover effect of institutional quality on sustainable development, this study utilizes annual data extending the period 2012–2022 for 42 African countries selected based on data availability. For the sake of a more effective policy response, this study disaggregated the sustainable environmental indices from the total index (SDI) into CO_2, footprint, as well as tested for the overall measure. Despite the vast resources with which Africa is endowed, the continent continues to face chronic political challenges, governance weaknesses, instability, authoritarian leadership styles, institutional decay, and elite capture, all of which undermine the RLW and public transparency. Effective institutions can enhance public-sector transparency and reduce the likelihood of conflict. Conversely, weak institutional environments erode state legitimacy, foster corruption, and reinforce exclusionary politics (Ackermann et al. 2024). Therefore, this study employs the CPI, RLW, and political stability as proxies for institutional quality. In addition, for the sake of a more policy-relevant outcome, this study considers controlling for population sizes and per capita income. Several African countries are experiencing significant demographic changes, leading to various economic, social, and environmental challenges. Recent studies have emphasized that 56% of global population growth, especially in urban areas, will occur in Africa, accounting for 35% of the world's total increase in urban population between 2018 and 2050. This rapid pace of demographic change has directly or indirectly contributed to major threats such as ecological degradation and biodiversity loss (Kassouri 2021). The following equations reflect the main study objectives:

$$\text{SDI}_{jt} = \alpha_0 + \alpha_1 \text{CPI}_{jt} + \alpha_2 \text{GDPPC}_{jt} + \alpha_3 \text{POP}_{jt} + \alpha_4 \text{RLW}_{jt} + \alpha_4 \text{POL}_{jt} + \varepsilon_{jt} \quad (7)$$

$$\text{CO}_{2jt} = \alpha_0 + \alpha_1 \text{CPI}_{jt} + \alpha_2 \text{GDPPC}_{jt} + \alpha_3 \text{POP}_{jt} + \alpha_4 \text{RLW}_{jt} + \alpha_5 \text{POL}_{jt} + \varepsilon_{jt} \quad (8)$$

$$\text{Footp}_{jt} = \alpha_0 + \alpha_1 \text{CPI}_{jt} + \alpha_2 \text{GDPPC}_{jt} + \alpha_3 \text{POP}_{jt} + \alpha_4 \text{RLW}_{jt} + \alpha_5 \text{POL}_{jt} + \varepsilon_{jt} \quad (9)$$

where the corresponding SDI, carbon emissions, and ecological footprints are represented by SDI_{jt}, CO_{2jt} and Footp_{jt} in country j at time t. α_1, α_2 α_3 α_4 α_5 are the parameters to be estimated. ε_{jt} indicates the stochastic error term. A comprehensive overview of the variables, including their definitions, measurement units, and sources, is provided in Table 1. The SDI evaluates the ecological efficiency of human development by incorporating environmental constraints, acknowledging that progress must occur within the limits of planetary boundaries. It serves as an ecologically informed alternative to the Human Development Index (HDI), adapted for the conditions of the Anthropocene. The SDI is calculated by dividing a country's human development score-based on indicators such as life expectancy, educational attainment, and income, by its ecological overshoot, which reflects the extent to which consumption-based CO_2 emissions and material footprint surpass equitable planetary boundary thresholds. Nations that attain comparatively high levels of human development while maintaining ecological sustainability are ranked higher on the index (SDI 2025).

4 | Results and Discussion

This part of the study outlines the outcomes of the spatial panel regressions, specifically the SDM, to examine the implications of institutional reforms (CPI, RLW, and political stability) on sustainable development indices (CO_2 index, footprint index, and overall SDI). The main objective of applying spatial spillover analysis is to provide holistic and policy-relevant outcomes by considering not only the effects of the domestic institutional quality reforms but also their spillover impacts on neighboring states across Africa. This Africa-specific analysis offers an important example of spatial dependence, given the high level of cross-national resource corridors, labor mobility, climate disasters, political alliances ethnic ties across the African region. In this vein, we evaluate the direct, indirect (spillover), and total effects of institutional quality on disaggregated sustainable development indices. We started the empirical analysis by examining measures of dispersion and central tendency. Table 2 presents the basic descriptive statistics for the variables under study. On average, per capita income (GDPPC) shows the highest mean value, with a median of 23.411 and a standard deviation of 4.022. The institutional quality measures do not exhibit significant differences in their average values. The CPI has an average of 3.426, while the RLW (3.076) and the political stability index (3.038) display nearly similar averages. Shedding light on sustainable development measures, the SDI (−0.570) and CO_2 emissions (−0.487) indicate nearly the same mean change. However, the ecological footprint shows the highest average among all sustainable development indicators. Population growth in Africa also reveals a considerable change, with an average increase of 16.364, a median of 16.496, and a standard deviation of 1.230. We also examined the correlation matrix for all variables included in the study, as presented in Table A2. The results indicate that there is no evidence of multicollinearity among the variables.

Building on the descriptive statistics, the analysis further examined the order of integration (stationarity) using the Levin–Lin–Chu and Im–Pesaran–Shin unit root tests, accounting for cross-sectional dependence. Table 3 shows that, although the results differ across tests, both indicate that all variables are stationary at first difference, $I(1)$, at the 1% and 5% significance levels. However, some variables (SDI, POL) also exhibit stationarity at the level. In addition, cointegration was tested prior to the spatial panel regression analysis. As reported in Tables 4 and 5, the cointegration test results reject the null hypothesis of no cointegration at the 1% significance level. Subsequently, we analyzed the spatial panel regressions for Equations (7–9) to examine the spillover effects of public sector transparency, proxied by the CPI, RLW, and political

TABLE 1 | Data description.

Variable	Definition	Source
SDI	Sustainable development index, an overall measure that comprises expected years of schooling, mean years of schooling, life expectancy (years), GDP, CO_2 emissions, and footprint indices.	Sustainable Development Organization: https://www.sustainabledevelopmentindex.org/
CO_2	Carbon dioxide emissions per capita (tonnes), disaggregated from the overall SDI.	Sustainable Development Organization: https://www.sustainabledevelopmentindex.org/
Footp	Footprint per capita (tonnes), extracted from the total SDI.	Sustainable Development Organization: https://www.sustainabledevelopmentindex.org/
CPI	Corruption perceptions index. A global ranking measuring the perceived levels of public sector corruption in countries. A country's score is the perceived level of public sector corruption on a scale of 0–100, where 0 means highly corrupt and 100 means very clean.	Transparency International: the global coalition against corruption: https://www.transparency.org/en/cpi/2024
GDPPC	Gross domestic product (constant 2015 US$).	World Bank (World Development Indicators): https://databank.worldbank.org/source/world-development-indicators
POP	Population sizes, total	World Bank (World Development Indicators): https://databank.worldbank.org/source/world-development-indicators
RLW	Rule of law: percentile rank	World Bank (World Development Indicators): https://databank.worldbank.org/source/world-development-indicators
POL	Political stability: percentile rank. It measures perceptions of the likelihood of political instability and/or politically motivated violence, including terrorism.	World Bank (World Development Indicators): https://databank.worldbank.org/source/world-development-indicators

TABLE 2 | Summary of the selected variables.

Variables	Mean	Median	Std. dev.
SDI	−0.570	−0.576	0.172
CO_2	−0.487	−0.511	1.158
Footp	1.499	1.380	0.531
CPI	3.426	3.449	0.374
GDPPC	23.065	23.411	4.022
POP	16.364	16.496	1.230
RLW	3.076	3.335	0.892
POL	3.038	3.218	0.859

stability. Population growth and per capita income were included as control variables.

Tables 6–8 report the estimation results. We first estimated three spatial panel models—SDM, SEM, and SAR—and then performed model selection using the chi-squared statistics (Wald tests) and corresponding p values. We also conducted Spatial Lagrange Multiplier (LM) tests, with detailed results provided in Table A3. The findings show that both the LM-Lag and LM-Error statistics are statistically significant, indicating the presence of simultaneous spatial lag and spatial error dependence. The Robust LM tests also remain significant, confirming that the detected spatial dependence is not spurious. Furthermore, the Wald tests suggest that the SDM cannot be simplified into either the SAR or SEM specification, thereby supporting the SDM as the most appropriate model. These results support the use of the SDM; therefore, we report only the findings from the SDM, which will be the focus of our subsequent discussion. The SDM results are decomposed into direct effects (local), indirect effects (spillover), and total effects (the sum of local and spillover). Notably, the spatial rho tests in Tables 6 and 8, also corroborate the Moran's I index results, indicating significant spatial dependence for sustainable development and institutional quality indicators.

Considering the SDM results in Table 6, the findings indicate that institutional quality, proxied by the RLW, significantly increases the attainment of SDGs. Specifically, promoting institutional quality by 1% results in a 0.023871% increase in SDGs. More importantly, the results reveal that the local effect of institutional quality on SDI is more pronounced (coefficient = 0.040347, $p < 0.000$) compared to the spillover effect, which did not show any significant influence (coefficient = 0−0.01648, $p > 0.105$). This outcome may emphasize that the local institutions are the leading cause for the realization of SDGs. Despite the relatively small estimated effect of the RLW on the SDI (0.0238%), institutional quality typically evolves gradually. Therefore, even modest improvements can generate substantial cumulative impacts over time. Moreover, because the SDI is a composite and relatively stable measure, even a minor enhancement in the RLW can translate

TABLE 3 | Panel unit root test (with CSD).

Variables	Level		1st difference	
	Statistic	*p*	Statistic	*p*
Lim–Pesaran–Shin unit-root				
SDI	−5.083	0.021**	−7.341	0.000*
CO_2	1.872	0.652	−6.080	0.000*
Footp	1.863	0.661	−5.720	0.000*
CPI	2.992	0.762	−7.913	0.000*
GDPPC	3.011	0.627	−7.001	0.000*
POP	1.782	0.887	−9.432	0.000*
RLW	2.912	0.743	−8.091	0.000*
POL	−3.562	0.041**	−5.832	0.000*
Levin–Lin–Chu unit-root				
SDI	−4.909	0.000*	−7.921	0.000*
CO_2	2.763	0.372	−7.091	0.000*
Footp	2.022	0.587	−6.982	0.000*
CPI	2.981	0.712	−5.086	0.000*
GDPPC	1.652	0.981	−4.032	0.000*
POP	1.728	0.974	−3.478	0.033**
RLW	1.591	0.988	−4.782	0.000*
POL	−4.581	0.000*	−7.811	0.000*

Note: Under the null hypothesis of no stationarity. * and ** indicate 1% and 5% levels of significance, respectively.

into meaningful improvements in environmental quality and economic welfare. In line with the prior expectation, the income per capita (coefficient = 0.01237, $p < 0.001$) and population (coefficient = 0.1950, $p < 0.000$) growth are the important driving forces for the attainment of SDGs. More specifically, the spillover effect of income growth (Indirect effect) (coefficient = 0.00693, $p < 0.046$) is slightly stronger than the domestic effect (coefficient = 0.00543, $p < 0.000$). Similarly, the population growth spillover effect (coefficient = 0.130198, $p < 0.000$) is more pronounced than the local effect (direct effect) (coefficient = 0.0648, $p < 0.000$).

Shedding light on the results from Table 7, institutional quality in the form of corruption control significantly impacts carbon emissions. The total effect reveals that an increase in CPI by 1% leads to a 0.21666% increase in carbon emissions. More importantly, the spillover effect of CPI on CO_2 emissions is found to be positive and significant (coefficient = 0.224, $p < 0.022$), while the domestic effect did not reveal any meaningful effect (coefficient = −0.0073, $p < 0.83$). Considering the total effect, while population growth is found to increase CO_2 emissions (coefficient = 0.640904, $p < 0.00$), income per capita significantly reduces carbon emissions (coefficient = −0.0318, $p < 0.081$), although the levels of significance vary. Moving on results of Model 3, the SDM test

TABLE 4 | Cointegration test.

Kao cointegration test	Statistic	*p*
Model 1: sustainable development model		
MDF	−1.3184	0.0937***
DF	−3.2984	0.0005*
ADF	−3.1574	0.0008*
UMDF	−1.9067	0.0283**
UDF	−3.6343	0.0001*
Model 2: carbon emissions model		
MDF	−4.091	0.003*
DF	−3.975	0.021**
ADF	−4.042	0.000*
UMDF	1.202	0.224
UDF	−3.986	0.000*
Model 3: ecological footprint model		
MDF	−6.881	0.000*
DF	0.987	0.766
ADF	−4.662	0.023**
UMDF	−4.516	0.000*
UDF	1.092	0.671

Note: * and ** indicate 1% and 5% levels of significance, respectively.

TABLE 5 | Panel cointegration (Westerlund 2007).

Stat	Values	*z*	Probability	Robust *p*
Model 1				
Gt	−8.811	−8.223	0.000	0.000
Ga	−9.182	−9.119	0.000	0.000
Pt	−10.392	−10.211	0.000	0.000
Pa	−10.824	−10.654	0.000	0.000
Model 2				
Gt	−6.121	−6.191	0.000	0.000
Ga	−7.711	−7.701	0.000	0.000
Pt	−8.191	−8.132	0.000	0.000
Pa	−9.191	−9.181	0.000	0.000
Model 3				
Gt	−5.001	−5.350	0.000	0.000
Ga	−6.101	−6.187	0.000	0.000
Pt	−7.231	−7.129	0.000	0.000
Pa	−10.651	−10.433	0.000	0.000

Note: Null hypothesis: no cointegration; the number of bootstraps replications = 500.

TABLE 6 | Results of the spatial Durbin regression (SDM) analysis—Model 1.

Sustainable development index	Coef.	Std. err.	z	$p>z$	95% conf. interval	
Main						
CPI	−0.00154	0.005919	−0.26	0.795	−0.01314	0.010063
GDPPC	0.005243	0.001384	3.79	0.000*	0.002531	0.007955
POP	0.058449	0.01886	3.1	0.002*	0.021483	0.095415
RLW	0.041032	0.005891	6.97	0.000*	0.029487	0.052578
POL	0.006062	0.004871	1.24	0.213	−0.00348	0.015608
_cons	−3.45764	0.434646	−7.96	0.000*	−4.30953	−2.60575
$W(x)$						
CPI	−0.00885	0.016924	−0.52	0.601	−0.04202	0.024325
GDPPC	0.005437	0.003089	1.76	0.078***	−0.00062	0.011491
POP	0.108303	0.026428	4.1	0.000*	0.056505	0.160101
RLW	−0.02035	0.009043	−2.25	0.024**	−0.03807	−0.00262
POL	−0.01179	0.007988	−1.48	0.14	−0.02745	0.003863
Spatial						
rho	0.139739	0.065706	2.13	0.033**	0.010957	0.268521
Variance						
lgt_theta	−3.03933	0.1292	−23.52	0.000*	−3.29256	−2.7861
sigma2_e	0.000821	5.69E-05	14.42	0.000*	0.000709	0.000932
Direct effect						
CPI	−0.0017	0.00617	−0.28	0.783	−0.01379	0.010396
GDPPC	0.005433	0.00134	4.05	0.000*	0.002806	0.008061
POP	0.064897	0.017656	3.68	0.000*	0.030292	0.099502
RLW	0.040347	0.005689	7.09	0.000*	0.029198	0.051496
POL	0.005679	0.004803	1.18	0.237	−0.00374	0.015093
Indirect effect						
CPI	−0.0105	0.020327	−0.52	0.605	−0.05034	0.029336
GDPPC	0.006937	0.003477	2	0.046**	0.000122	0.013751
POP	0.130198	0.025472	5.11	0.000*	0.080275	0.180122
RLW	−0.01648	0.01017	−1.62	0.105	−0.03641	0.003457
POL	−0.01312	0.009465	−1.39	0.166	−0.03168	0.005428
Total effect						
CPI	−0.0122	0.022239	−0.55	0.583	−0.05579	0.031387
GDPPC	0.01237	0.003894	3.18	0.001*	0.004737	0.020002
POP	0.195096	0.024125	8.09	0.000*	0.147811	0.24238
RLW	0.023871	0.011251	2.12	0.034**	0.00182	0.045922
POL	−0.00745	0.011668	−0.64	0.523	−0.03031	0.015423

Note: *, **, *** indicate 1%, 5% and 10% levels of significance, respectively.

in Table 8, among all institutional quality measures, only the RLW demonstrates a significant effect on ecological footprint (coefficient = −0.09946, $p<0.027$). In contrast to our prior expectations, both income (coefficient = −0.02629, $p<0.077$) and population growth (coefficient = −0.15976, $p<0.075$) led to a decline in footprint.

TABLE 7 | Results of the spatial Durbin regression (SDM) analysis—Model 2.

CO_2	Coef.	Std. err.	*z*	*p*>*z*	95% conf. interval	
Main						
CPI	−0.00698	0.033161	−0.21	0.833	−0.07197	0.058016
GDPPC	0.004885	0.007772	0.63	0.53	−0.01035	0.020118
POP	0.375564	0.132783	2.83	0.005*	0.115314	0.635815
RLW	0.008267	0.033078	0.25	0.803	−0.05656	0.073098
POL	0.00253	0.027277	0.09	0.926	−0.05093	0.055992
_cons	−11.3655	1.978038	−5.75	0.000*	−15.2423	−7.48858
W(*x*)						
CPI	0.228909	0.095131	2.41	0.016	0.042457	0.415362
GDPPC	−0.03666	0.017541	−2.09	0.037**	−0.07104	−0.00228
POP	0.281901	0.156632	1.8	0.072***	−0.02509	0.588894
RLW	0.079309	0.04973	1.59	0.111	−0.01816	0.176779
POL	−0.06326	0.044731	−1.41	0.157	−0.15093	0.024411
Spatial						
rho	−0.03052	0.05997	−0.51	0.611	−0.14806	0.087019
Variance						
lgt_theta	−3.26004	0.130906	−24.9	0.000*	−3.51661	−3.00347
sigma2_e	0.02563	0.001786	14.35	0.000*	0.022129	0.029132
Direct effect						
CPI	−0.00735	0.034164	−0.22	0.83	−0.07431	0.059608
GDPPC	0.004807	0.00754	0.64	0.524	−0.00997	0.019585
POP	0.3878	0.128204	3.02	0.002*	0.136524	0.639075
RLW	0.006981	0.032094	0.22	0.828	−0.05592	0.069884
POL	0.003341	0.02645	0.13	0.899	−0.0485	0.055182
Indirect effect						
CPI	0.224011	0.098139	2.28	0.022**	0.031663	0.416359
GDPPC	−0.0366	0.016927	−2.16	0.031**	−0.06978	−0.00343
POP	0.253104	0.151095	1.68	0.094***	−0.04304	0.549244
RLW	0.077676	0.050572	1.54	0.125	−0.02144	0.176794
POL	−0.06625	0.04546	−1.46	0.145	−0.15535	0.022854
Total effect						
CPI	0.21666	0.103062	2.1	0.036**	0.014662	0.418658
GDPPC	−0.0318	0.018248	−1.74	0.081***	−0.06756	0.003968
POP	0.640904	0.109654	5.84	0.000*	0.425986	0.855821
RLW	0.084657	0.052564	1.61	0.107	−0.01837	0.18768
POL	−0.0629	0.054464	−1.15	0.248	−0.16965	0.043842

Note: *, **, *** indicate 1%, 5% and 10% levels of significance, respectively.

This study investigates how institutional quality influences the realization of SDGs in Africa, taking into consideration spatial spillover effects across 42 countries. Using spatial panel analysis, the study offers evidence that both domestic governance and cross-border interdependencies play significant roles in shaping environmental and developmental outcomes. The results

TABLE 8 | Results of the spatial Durbin regression (SDM) analysis—Model 3.

Ecological footprint	Coef.	Std. err.	z	p>z	95% conf. interval	
Main						
CPI	0.004815	0.026034	0.18	0.853	−0.04621	0.05584
GDPPC	0.001019	0.005966	0.17	0.864	−0.01067	0.012713
POP	−0.10526	0.051251	−2.05	0.04**	−0.20571	−0.00481
RLW	0.039723	0.025358	1.57	0.117	−0.00998	0.089424
POL	0.049604	0.021247	2.33	0.02**	0.007962	0.091247
_cons	5.155142	1.287368	4	0.000*	2.631948	7.678336
W(*x*)						
CPI	0.086398	0.073936	1.17	0.243	−0.05851	0.231309
GDPPC	−0.02217	0.013018	−1.7	0.089***	−0.04769	0.003341
POP	−0.1138	0.076679	−1.48	0.138	−0.26409	0.036487
RLW	−0.09187	0.037903	−2.42	0.015*	−0.16616	−0.01758
POL	−0.0606	0.034967	−1.73	0.083***	−0.12914	0.007932
Spatial						
rho	0.178881	0.054275	3.3	0.001*	0.072503	0.285258
Variance						
lgt_theta	−2.40818	0.131701	−18.29	0.000*	−2.66631	−2.15005
sigma2_e	0.016007	0.001116	14.35	0.000*	0.013821	0.018194
Direct effect						
CPI	0.00999	0.027129	0.37	0.713	−0.04318	0.063162
GDPPC	−0.00034	0.005826	−0.06	0.954	−0.01175	0.011083
POP	−0.10649	0.048591	−2.19	0.028**	−0.20173	−0.01126
RLW	0.035065	0.024402	1.44	0.151	−0.01276	0.082893
POL	0.047327	0.021155	2.24	0.025*	0.005863	0.08879
Indirect effect						
CPI	0.100814	0.090689	1.11	0.266	−0.07693	0.278561
GDPPC	−0.02629	0.014859	−1.77	0.077***	−0.05541	0.002836
POP	−0.15976	0.089601	−1.78	0.075**	−0.33537	0.015858
RLW	−0.09946	0.045048	−2.21	0.027**	−0.18775	−0.01116
POL	−0.06446	0.043012	−1.5	0.134	−0.14876	0.019846
Total effect						
CPI	0.110804	0.099528	1.11	0.266	−0.08427	0.305874
GDPPC	−0.02662	0.016798	−1.58	0.113	−0.05955	0.006301
POP	−0.26625	0.097404	−2.73	0.006*	−0.45716	−0.07534
RLW	−0.06439	0.050428	−1.28	0.202	−0.16323	0.034446
POL	−0.01713	0.053114	−0.32	0.747	−0.12123	0.086972

Note: *, **, *** indicate 1%, 5% and 10% levels of significance, respectively.

of Moran's *I* and spatial rho tests reveal that African countries have significant spatial dependences regarding sustainable development and carbon emissions. This particular finding is similar to previous studies that emphasize the interrelation of African economies with regard to their environmental and developmental challenges (Juju et al. 2020; Omisore 2018). On the other hand, CO_2 emissions did not show significant global autocorrelation under Moran's *I*, but the results of spatial rho indicate that countries are influenced by neighboring countries' environmental performance. This strengthens the significant role played by regional cooperation, as autonomous domestic policies could be inadequate to address emissions reduction and environmental sustainability.

One of the most important findings that emerged from this study is the positive and significant influence of institutional quality (measured by the RLW) in progressing SDGs. The outcomes reveal that improvements in domestic institutions result in better gains in terms of a higher value of SDI compared to spillover effects. This outcome suggests that local institutional strength is the primary driver of sustainable development in Africa. These findings resonate with governance literature, which highlights the significance of the RLW and political stability in fostering long-term development outcomes (Adebayo et al. 2025; Barbier and Burgess 2021; Musah 2023; Oppong 2025). The finding of the local effect of institutional quality toward achieving SDGs could be supported by the outcome of (Shabani et al. 2025) that institutional quality lowers CO_2 emissions domestically but increases them in neighboring states. Nonetheless, the limitation of their study to CO_2 emissions hinders the generalizability of the outcomes to other SDGs. Moreover, Bosomtwe (2025) has explored the fiscal impact on SDGs, and the institutional quality was taken into consideration as a moderating factor. The findings uncovered a significant moderating role of the RLW in the fiscal policy-SDGs nexus. However, the absence of strong spillover effects may indicate that the institutional reforms are not easily transferable across borders and that progress depends largely on internal governance reforms. Improvements in the RLW tend to have less diffusion, simply because they depend, for example, on local administrative capacity, national courts, and the behavior/characteristics of public institutions. The institutional changes, such as a better RLW, do not cross borders so quickly. This suggests that the RLW enhances SDI within a country but does not lead to clear effects in its neighboring states, implying that governance quality does not diffuse in a similar manner as economic or demographic factors.

The findings reveal that income and population growth drive the realization of SDGs within countries, as well as generating strong spillover effects across neighboring African states. The fact that spillover effects outweigh local effects suggests that growth dynamics in Africa are inherently regional. Several channels help explain this outcome. First, transboundary trade and resource corridors play a critical role, as economic expansion in one country normally stimulates trade, infrastructure, and investment flows across borders, thereby influencing the development outcomes of neighbors. This connects with earlier studies concerning regional economic integration to development (Dion 2004; Gannon et al. 2022; Tumwebaze and Ijjo 2015; Vamvakidis 1998). Second, labor mobility and relocation are central to Africa's demographic linkages. It is shown that population growth can support labor supply and market expansion in neighboring countries. Also, it can put pressure on other sustainability indicators. These opposing effects reflect the arguments in the demographic transition and sustainable development literature (Fischer et al. 2021). Moreover, climate-related migration due to natural disasters creates demographic relations across border countries, which intensify developmental challenges (Chen and Mueller 2019). Finally, these findings suggest that achieving SDGs cannot be done only as a national project but must be considered in a regional context.

The results show that institutional quality has an important role in shaping environmental outcomes, especially indicators like CO_2 emissions and ecological footprint. This also suggests that there are spillover effects, because reform in one country can end up affecting neighboring countries. The positive spillover effect of CPI on CO_2 emissions to neighboring countries may sound inconsistent, but it becomes reasonable when considering the regional economic structure on the continent. If a country strengthens its control of corruption, this may help its business environment to improve in the short run, leading to higher emissions due to the boost in productivity, but may also attract cleaner and more regulated industries at home in the long term. However, part of the pollution-intensive industries may shift to bordering countries, especially with weaker environmental regulations. This kind of regulatory asymmetry is in line with studies on the "pollution-haven" hypothesis and matches, to a large extent, the reality of many African areas. For instance, Shabani et al. (2025) reported that institutional quality is linked with renewable energy and CO_2 emissions, supporting the environmental Kuznets curve (EKC) hypothesis. In their case, they noticed that stronger institutions help to lower emissions at the domestic level, but at the same time, they may cause more emissions in nearby countries. In another study, Alvarado et al. (2023) looked at spillovers from institutional quality to energy intensity. The findings show a significant spillover effect of institutional factors on energy intensity, which is vital towards affordable and sustainable energy in Africa. Related to SDG 1, Olaoye (2022) argues that to reduce poverty in sub-Saharan Africa, governments need to adopt spatially segregated policies, which may require cross-border coordination. Overall, these results highlight a paradox; while stronger institutions are expected to reduce environmental stress (Ali et al. 2019; Li et al. 2022), they may also promote industrial expansion, leading to higher emissions if the environmental safety measures are weak. This outcome is consistent with the mixed evidence in the governance-environment literature (Li and Zhang 2025) and underscores the importance of balancing governance reforms with explicit sustainability policies. It is worth noting that the spillover effects may vary across different regions within the African continent. For instance, in West Africa and Eastern and Southern Africa (COMESA), the informal cross-border trade represents approximately 42%, and 40% of the total trade between countries (Asafu-Adjaye 2025), respectively, which may well magnify the spillover of income and population growth. In the East African region, migration flows and labor mobility are higher compared to other regions in Africa (Oucho et al. 2023), which may justify how the population dynamics spillover more easily between the region's countries.

5 | Conclusion and Policy Recommendations

5.1 | Conclusion

Africa faces significant obstacles in achieving the SDGs—particularly climate action (SDG 13) and strong institutions (SDG 16). Widespread corruption, weak RLW, and political instability not only hinder domestic environmental governance but also intensify cross-border vulnerabilities through shared resource systems and transboundary climate risks. Motivated by Africa's persistently low CPI scores, averaging 24 out of 100 in 2024, far below the global average, and its high exposure to climate threats despite minimal emissions, this study examines the spatial spillover effects of institutional quality on environmental sustainability. Using data from 42 African countries, we analyze how public sector transparency (CPI), RLW, and political stability influence the SDI, CO_2 emissions, and ecological footprint, controlling for income and population growth. This study contributes to the literature by being the first to disentangle spatial spillovers of institutional drivers on disaggregated environmental metrics in Africa, addressing gaps in previous research that overlooked the RLW and political stability as distinct determinants. By applying spatial econometric techniques, we offer a robust framework for understanding how governance dynamics across borders shape environmental outcomes in the Anthropocene.

Drawing on annual panel data from 2012 to 2022, we employed spatial panel regression models including the SAR, SEM, and SDM to capture geographical interdependencies. The Queen contiguity spatial weight matrix was used to define neighboring relationships, and Moran's *I* index confirmed significant positive spatial autocorrelation for SDI and CO_2 emissions, underscoring the relevance of spatial modeling in Africa's interconnected context. Model selection tests favored the SDM, which allowed decomposition of effects into direct (local), indirect (spillover), and total impacts.

Our key findings reveal nuanced roles for institutional quality in advancing sustainability. First, the RLW exerts a significant positive direct effect on SDI, enhancing ecological efficiency in human development within countries, though spillover effects were insignificant. This highlights the primacy of domestic institutional reforms in realizing SDGs. Second, higher public sector transparency (CPI) was associated with increased CO_2 emissions, primarily through spillover effects, suggesting that reduced corruption may facilitate cross-border economic activities that inadvertently elevate emissions if not paired with stringent environmental safeguards. Third, the RLW demonstrated a negative spillover effect on ecological footprint, indicating that institutional improvements in one country can reduce resource overshoot in neighbors, potentially through diffused governance practices. Additionally, per capita income and population growth positively influenced SDI with stronger spillover than direct effects, while income reduced CO_2 and footprint, and population exhibited mixed environmental impacts. These results affirm the interconnected nature of Africa's sustainability challenges, where local governance gains can amplify regional outcomes, but also underscore potential trade-offs between institutional quality, economic growth, and environmental integrity.

5.2 | Policy Implications

Based on the empirical findings, several targeted policy recommendations emerge to foster sustainable development in Africa, emphasizing both domestic reforms and regional collaboration to leverage positive spillovers while mitigating adverse ones. These recommendations draw on specific regional platforms and institutions, such as the African Continental Free Trade Area (AfCFTA), the African Union's Agenda 2063, the Economic Community of West African States (ECOWAS), the Southern African Development Community (SADC), the African Development Bank (AfDB), and the African Peer Review Mechanism (APRM), to diffuse governance reforms and achieve measurable outcomes.

First, African governments should prioritize strengthening the RLW by implementing harmonized legal frameworks across borders, such as through ECOWAS and SADC protocols that standardize environmental regulations and enforcement. This could involve establishing regional judicial networks—facilitated by the African Union—to combat cross-border environmental crimes like illegal deforestation and land grabbing, directly addressing selective enforcement issues in low-performing Worldwide Governance Indicators. Investments in judicial independence and institutional capacity building, including digital training platforms for judges, would yield measurable outcomes, such as a 10%–15% reduction in ecological footprint spillovers within 5 years, as tracked via SDG indicators. The APRM could play a key role in monitoring compliance through peer-reviewed. assessments, ensuring reforms translate into improved SDI scores at both local and regional levels.

Second, to counteract the spillover-driven increase in CO_2 emissions linked to enhanced public sector transparency (CPI), policymakers must integrate anti-corruption measures with green transition strategies via specific tools like digital public procurement systems and open climate finance portals. For example, ring-fencing climate finance—such as the at least US$300 billion annual commitment by 2035 agreed at COP29—could be achieved through blockchain-based tracking platforms and independent audits, preventing leakage and ensuring funds support low-carbon projects. The AfDB, in collaboration with ECOWAS and SADC, could lead peer-review mechanisms under the APRM to diffuse best practices in corruption-free investments, particularly in Sub-Saharan Africa. These mechanisms would link reforms to measurable outcomes, such as a 20% improvement in fund utilization efficiency, monitored through transparent dashboards that report on emission reductions and project impacts.

Third, harnessing the positive spillovers from income and population growth on SDI requires coordinated regional economic policies under frameworks like AfCFTA, incorporating sustainability clauses such as carbon border adjustment mechanisms and shared renewable energy infrastructure (e.g., cross-border solar grids). Regional institutions like ECOWAS and SADC could facilitate joint ventures in green industries, while population policies—including education and family planning programs—channel labor mobility toward green jobs in transboundary economic corridors. The APRM could evaluate these initiatives through governance benchmarks, aiming for quantifiable results like a 15% boost in intra-regional trade sustainability indices and reduced demographic pressures on ecological footprints.

Finally, international partners, including the United Nations and developed nations, should support these efforts through capacity-building aid conditioned on governance benchmarks, aligning with SDG 17 (partnerships for the goals). This could involve funding for digital tools and harmonized frameworks via the AfDB, with progress monitored using spatially informed indicators like Moran's I to enable adaptive policymaking and ensure equitable green growth across the continent.

5.3 | Limitations and Future Research Directions

While this study advances understanding of spatial institutional dynamics in African sustainability, several limitations warrant acknowledgment. First, the analysis is constrained by data availability, covering only 42 countries and the 2012–2022 period, potentially overlooking sub-national variations (e.g., city-level heterogeneities) or longer-term trends. Second, the reliance on aggregate indices like CPI and SDI introduces risks of measurement error, such as perceptual biases in CPI or aggregation inconsistencies in SDI, and may mask sector-specific nuances, including corruption in extractive industries. Third, omitted variable bias could arise from unaccounted factors influencing both governance and sustainability, such as cultural or geopolitical elements. Fourth, although spatial models account for interdependence, potential endogeneity between institutional quality and sustainability outcomes, for example, bidirectional or reverse causality, remains a concern, as it is not fully addressed through advanced techniques like instrumental variables or dynamic panel approaches in this study.

Future research could extend this work by addressing these limitations through methodological enhancements and expanded scopes. To mitigate omitted variable bias, incorporating additional variables, such as gender inequality or renewable energy adoption, would allow exploration of moderating effects on spillovers. Subnational analyses using city-level data or dynamic spatial models could reveal finer-grained heterogeneous patterns, while sub-regional comparisons (e.g., West vs. East Africa) might highlight contextual differences. Employing advanced econometric approaches, such as spatial difference GMM or SDM with instrumental variables, would better tackle reverse causality and endogeneity issues. Extending the timeframe or leveraging finer-grained data (e.g., satellite-derived ecological footprints) could enhance robustness. Finally, qualitative case studies on spillover mechanisms, such as through migration or trade, would complement quantitative insights, informing more holistic pathways to SDGs in the Global South.

Author Contributions

Suat Kara: conceptualization, data curation, formal analysis, methodology, writing – original draft. **Yücel Oğurlu:** investigation, software, visualization, writing – review and editing. **Md. Emran Hossain:** resources, validation, supervision, writing – review and editing. **Mohammed Alnour:** data curation, formal analysis, visualization, writing – original draft. **Soumen Rej:** methodology, project administration, writing – original draft. **Abdalla Sirag:** writing – original draft, resource, writing – review and editing.

Data Availability Statement

The sources of data used in this study are included in the main text and are publicly available.

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Appendix A

TABLE A1 | List of African countries with a schematic diagram of the adjacent space weight matrix.

1	**Botswana**	**9**	**24**	**33**	**39**	**0**	**0**	**0**	**0**
2	Egypt	32	0	0	0	0	0	0	0
3	Dem. Rep. Congo	7	9	12	13	14	15	30	37
4	Chad	7	10	23	32	42	0	0	0
5	Sierra Leone	6	34	0	0	0	0	0	0
6	Guinea	5	18	21	34	38	0	0	0
7	Central African Rep.	3	4	23	30	0	0	0	0
8	Djibouti	31	0	0	0	0	0	0	0
9	Zambia	1	3	14	24	28	29	37	39
10	Nigeria	4	11	23	42	0	0	0	0
11	Benin	10	26	27	42	0	0	0	0
12	Rwanda	3	13	14	15	0	0	0	0
13	Uganda	3	12	14	22	0	0	0	0
14	Tanzania	3	9	12	13	15	22	28	29
15	Burundi	3	12	14	0	0	0	0	0
16	Gabon	23	30	0	0	0	0	0	0
17	Ghana	18	26	27	0	0	0	0	0
18	Côte d'Ivoire	6	17	27	34	38	0	0	0
19	Algeria	20	32	35	36	38	42	0	0
20	Mauritania	19	21	38	0	0	0	0	0
21	Senegal	6	20	25	38	0	0	0	0
22	Kenya	13	14	0	0	0	0	0	0
23	Cameroon	4	7	10	16	30	0	0	0
24	Namibia	1	9	33	37	39	0	0	0
25	Gambia	21	0	0	0	0	0	0	0
26	Togo	11	17	27	0	0	0	0	0
27	Burkina Faso	11	17	18	26	38	42	0	0
28	Malawi	9	14	29	0	0	0	0	0
29	Mozambique	9	14	28	33	39	40	0	0
30	Congo	3	7	16	23	37	0	0	0
31	Eritrea	8	0	0	0	0	0	0	0
32	Libya	2	4	19	36	42	0	0	0
33	South Africa	1	24	29	39	40	41	0	0
34	Liberia	5	6	18	0	0	0	0	0
35	Morocco	19	0	0	0	0	0	0	0
36	Tunisia	19	32	0	0	0	0	0	0
37	Angola	3	9	24	30	0	0	0	0

(Continues)

TABLE A1 | (Continued)

1	Botswana	9	24	33	39	0	0	0	0
38	Mali	6	18	19	20	21	27	42	0
39	Zimbabwe	1	9	24	29	33	0	0	0
40	eSwatini	29	33	0	0	0	0	0	0
41	Lesotho	33	0	0	0	0	0	0	0
42	Niger	4	10	11	19	27	32	38	0

TABLE A2 | Correlation matrix.

Variables	−1	−2	−3	−4	−5	−6	−7	−8
(1) CO_2	1.000							
(2) Footp	0.690	1.000						
(3) SDI	−0.660	−0.453	1.000					
(4) POL	−0.234	−0.150	0.348	1.000				
(5) RLW	−0.340	−0.159	0.437	0.614	1.000			
(6) POP	0.140	0.288	0.108	−0.380	0.008	1.000		
(7) GDPPC	0.241	0.115	0.282	−0.070	0.305	0.457	1.000	
(8) CPI	−0.222	0.037	0.250	0.454	0.619	−0.022	0.160	1.000

TABLE A3 | Model diagnostic checks.

Test	Statistic	*p*	Conclusion
LM (spatial lag)	15.72	0.000	Significant spatial lag dependence detected
LM (spatial error)	13.45	0.000	Significant spatial error dependence detected
Robust LM (spatial lag)	6.81	0.006	Significant, robust to spatial error
Robust LM (spatial error)	5.93	0.015	Significant, robust to spatial lag
Wald test for SDM → SAR	18.42	0.000	SDM cannot be simplified to SAR
Wald test for SDM → SEM	15.33	0.000	SDM cannot be simplified to SEM

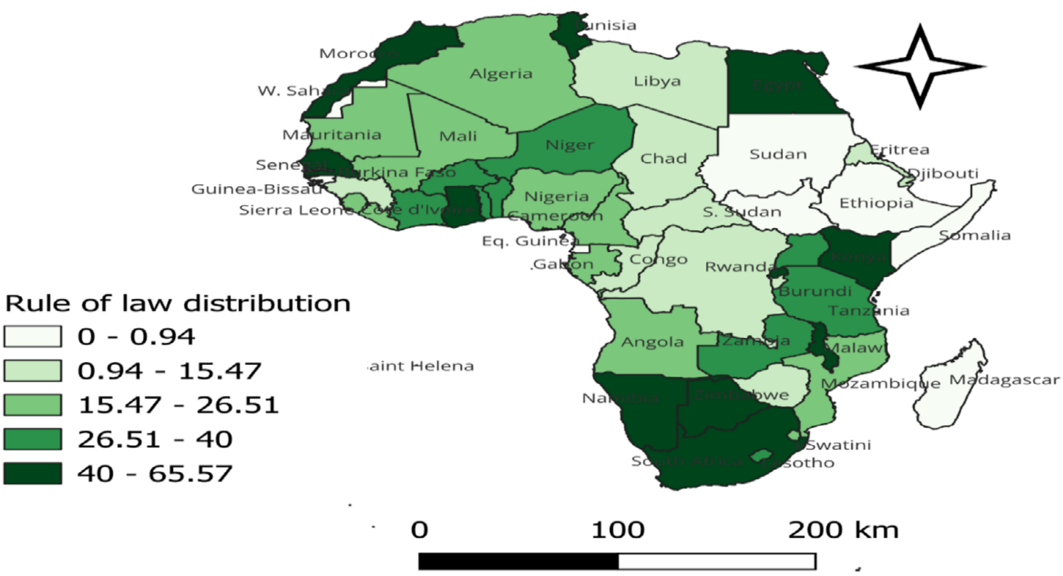

FIGURE A1 | Spatial distribution of the rule of law in 2022. *Source:* Authors' own illustration.

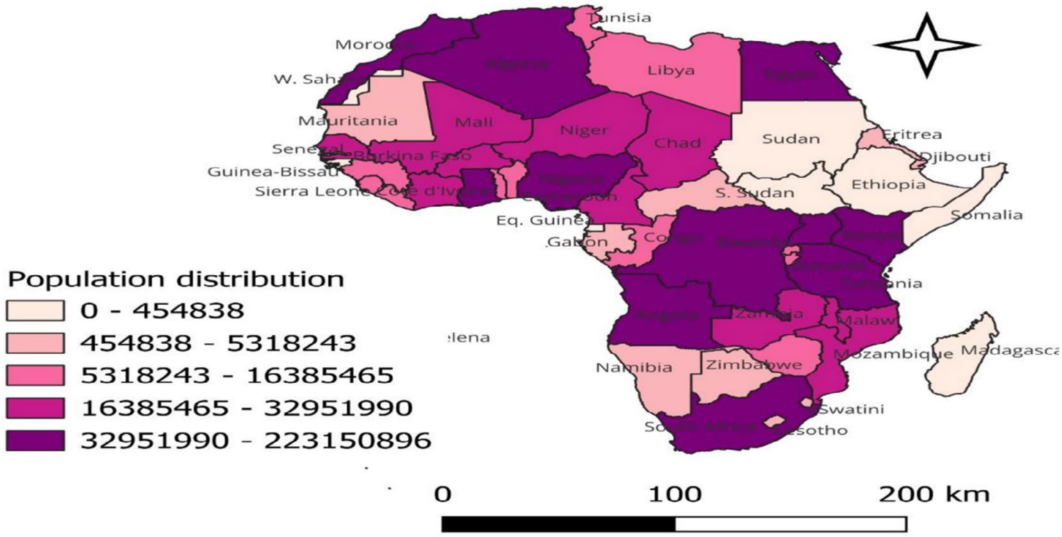

FIGURE A2 | Spatial distribution of population sizes in 2022. *Source:* Authors' own illustration.

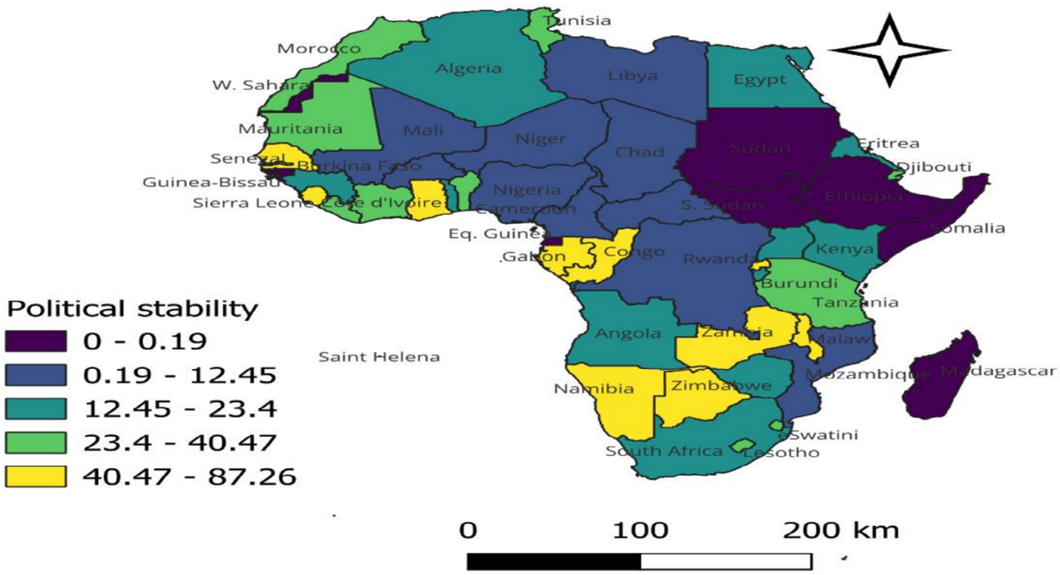

FIGURE A3 | Spatial distribution of political stability in 2022. *Source:* Authors' own illustration.

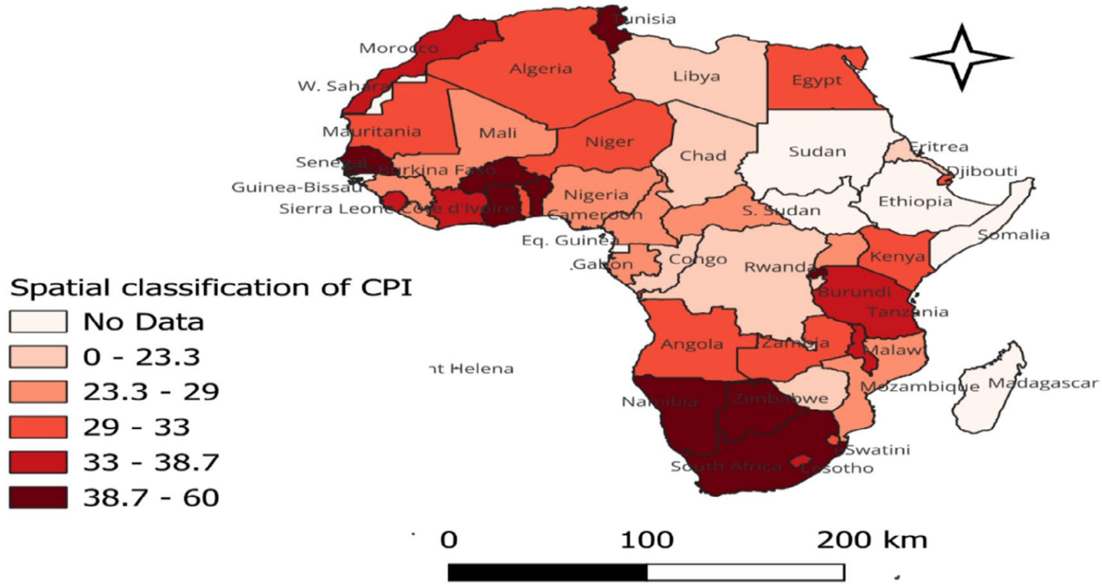

FIGURE A4 | Spatial distribution of corruption perception index in 2022. *Source:* Authors' own illustration.