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Governance, development, and environment: Pathways to a sustainable future

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ABSTRACT

The study aims to explore the relationships among public governance, economic and social development, climate change adaptation, and environmental performance across 149 countries. It seeks to understand how these dimensions interact to promote sustainable development. The methodology is based on Structural Equation Modeling (SEM), utilizing global data from 2022. The variables analyzed include Regulatory Quality, Rule of Law, GDP per capita, Human Development Index (HDI), and Environmental Performance Index (EPI), with data sourced from the World Bank, ND-GAIN, and other reputable institutions. Findings indicate that effective governance drives economic development by attracting investment and fostering institutional stability. This economic progress, in turn, enhances social and environmental indicators, such as HDI and climate adaptation capacity. The interaction among these variables highlights the importance of integrated public policies to achieve sustainability. The originality of the study lies in the presentation of a comprehensive model that integrates governance, economic and social development, and environmental sustainability, providing valuable insights for the formulation of effective public policies. Among the limitations, the study notes the need for a deeper analysis of governance as a catalyst for sustainable development, particularly in light of regional disparities and structural differences among countries. From a practical standpoint, the study suggests integrated policies focused on strengthening governance, reducing regional inequalities, and increasing climate resilience. On a societal level, the research promotes debate on inclusion, social justice, and environmental preservation as essential pillars of global sustainability.

1. Introduction

Public governance and sustainable development have become central to academic and political discourse, driven by the increasing complexity of global challenges such as climate change, social inequalities, and environmental degradation [1–4]. Effective governance plays a pivotal role in fostering economic and social development, positively impacting quality of life, environmental protection, and social justice [5]. Governance that prioritizes inclusion and transparency can significantly reduce inequalities and enhance social and environmental well-being [6]. Conversely, ineffective public policies exacerbate social disparities and environmental degradation, ultimately impeding sustainable development [7].

The relationship between public governance and Economic Development (ED) is intrinsically connected to climate adaptation and environmental performance across nations [8]. Achieving sustainable development requires policies that balance economic growth, social equity, and ecological governance [9]. In the absence of effective governance, economic development often exacerbates climate and social crises, making it increasingly challenging to implement mitigation strategies that reconcile progress with environmental preservation [7,10,11].

These connections also extend to Social Development (SD), as economic growth directly influences resource allocation for education, healthcare, and infrastructure. Such investments are crucial for reducing inequalities and enhancing quality of life [12]. However, when ED occurs without inclusive policies, poverty and exclusion persist, constraining human potential and undermining sustainability goals [13].

Economic development also drives climate adaptation capacity. Stronger economies allocate more resources to green technologies and

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resilient infrastructure, essential for addressing climate pressures. Fragile economies, however, face financial constraints that hinder effective climate policies, increasing vulnerability to extreme events [14]. The relationship between economic development and climate adaptation is interdependent: while ED enhances adaptive capacity, a lack of resilience policies risks growth and societal well-being [15–19].

This interdependence between economic development and climate resilience has prompted recent advances in sustainability modeling. One such innovation is the ECON-ESG concept proposed by Işık et al. [20], which expands the traditional ESG framework by integrating key economic variables. According to Işık, Ongan, and Islam [21], conventional ESG models often overlook the direct role of macroeconomic factors—such as GDP, inflation, and unemployment—creating a disconnect between economic growth and sustainability goals. When applied to G7 and OECD countries, the ECON-ESG model reveals that economic pressures can negatively affect energy efficiency and hinder the energy transition, whereas governance indicators have a positive influence. Grounded in robust analytical methods, this approach underscores the importance of incorporating economic dimensions into sustainability assessments, ultimately supporting the development of more effective and integrated public policies.

The interconnections among governance, economic and social development, climate adaptation, and environmental performance illustrate a complex cycle of challenges and interdependencies. These relationships are not only multidimensional but also deeply intertwined, requiring a comprehensive analytical approach to uncover their dynamics.

In this context, the present study aims to explore the following key research questions:

– What is the relationship between the quality of public governance and the level of economic development across nations?
– How is social development linked to these dimensions, and in what ways does it contribute to the enhancement of climate change adaptation capacity?
– How do these variables, when considered collectively, influence the environmental performance of countries?

2. Theoretical framework

2.1. Interconnections between public governance, economic development, and global sustainability

The interplay between Public Governance, Economic Development (ED), Social Development (SD), Climate Change Adaptation Capacity, and Environmental Performance constitutes a cycle of mutual influences that collectively shape the realization of sustainable development goals [22,23]. Recent studies emphasize the pivotal role of public governance in advancing economic and social progress, acting as a catalyst for policies that harmonize growth with social justice and environmental conservation [5,24,25].

These interactions highlight the necessity of integrated approaches that simultaneously address economic, social, and environmental dimensions in public policy design. Such strategies are essential to ensure that political decisions not only promote economic growth but also uphold human rights and preserve natural resources for future generations [26].

Effective governance promotes economic development by fostering stability, transparency, and inclusivity [25]. These attributes attract investments and encourage the responsible utilization of natural resources, directly influencing nations' environmental performance [3]. In countries with robust governance systems, economic development tends to integrate equity and sustainability, facilitating a more equitable distribution of economic and social benefits [6].

Conversely, countries with weak public governance encounter significant obstacles in addressing inequality, promoting sustainability, and enhancing climate adaptation capacity [13]. These shortcomings often perpetuate cycles of poverty and environmental degradation, undermining the implementation of effective policies for sustainable development and community resilience [27].

Climate adaptation capacity represents another critical factor contingent on both economic development and governance quality [28, 29]. Governments equipped with sufficient resources and adaptive policies are better positioned to respond to extreme climate events while adopting innovative technologies and practices that enhance environmental resilience. In contrast, low-income countries face severe constraints due to scarce resources and ineffective policies, leaving them increasingly vulnerable to environmental and social disasters [14].

These interconnections among public governance, economic and social development, climate adaptation, and environmental performance underscore the imperative for integrated, sustainability-focused approaches. Only through the alignment of these dimensions can sustainable development be realized, effectively balancing environmental challenges with economic and social advancement. The following section will provide theoretical and empirical evidence of the relationships among the variables examined in this research.

2.2. Interconnections between public governance and economic development

Numerous studies employing diverse methodologies underscore the pivotal role governance practices play in fostering sustainable economic growth and ensuring social stability. The existing body of literature highlights that governance quality not only shapes the formulation and implementation of public policies but also exerts a significant influence on economic growth [30,31].

Effective governance practices are essential for promoting transparency, accountability, and citizen participation-key elements that cultivate trust in institutions and create an environment conducive to economic development [32]. The analysis presented in Table 1 illustrates the direct impact of various governance quality factors on economic development, reinforcing the necessity of robust governance practices in diverse socio-economic contexts.

Table 1 underscores the influence of public governance on economic development, emphasizing the critical roles of transparency, inclusion, and regulatory quality in achieving sustainable and equitable growth. Scholars such as Chanda et al. [5], Croft et al. [3], Liashenko et al. [9], Lîsenco [9], and Ma et al. [24] contend that well-structured policies and governance mechanisms are indispensable for fostering enduring and equitable economic progress.

Effective governance cultivates trust, mitigates corruption, and attracts investment, thereby driving economic growth [5]. In the context of the blue economy, equity-based governance prevents the concentration of power and wealth, fostering inclusive development. While blue economy initiatives often prioritize social equity, neoliberal agendas have occasionally exacerbated disparities. Prioritizing equity can realign governance systems to ensure the fair distribution of benefits [3].

Regulatory quality and corruption control are essential for fostering social and economic progress, particularly within politically stable environments [40]. Lîsenco [9] emphasizes that integrating governance with green technologies not only balances economic growth with environmental protection but also aligns economic incentives with ecological goals, fostering innovation.

Institutional trust and perceptions of justice enhance social cohesion, which, in turn, drives economic stability [24]. Furthermore, Tom [41] highlights the transformative impact of inclusive governance in Africa, demonstrating that social policies aimed at addressing inequality play a pivotal role in supporting sustainable growth.

These findings highlight that public governance is not merely a facilitator of economic development but a foundational driver of sustainability and equity. Accordingly, this study posits the following hypothesis (H1): there is a positive and statistically significant relationship

Table 1
Theoretical and empirical evidence on the relationship between public governance and economic development.

Author and Year	Construct	—>	Construct	Method	Observations on the Relationship Between Public Governance and Economic Development
Chanda et al. (2024) [5]	Public Governance	—>	Economic Development	Mixed methods (questionnaires and thematic interviews); analysis with SPSS and Excel	Good governance, characterized by transparency and inclusion, is essential for sustainable economic development, building trust in public institutions.
Croft et al. (2024) [3]	Public Governance	—>	Economic Development	Participatory approach; implementation of an equity model in blue economy governance	Equity in governance prevents power and wealth concentration, fostering more equitable and sustainable development.
Liashenko et al. (2024) [6]	Public Governance	—>	Economic Development	Discriminant analysis and empirical functions; use of SPI and WGI for governance data	Governance effectiveness directly impacts economic development by increasing efficiency and social progress, particularly in politically stable environments.
Lîsenco (2024) [9]	Public Governance	—>	Economic Development	Comparative analysis of environmental governance practices and sustainable economies across countries	Well-structured public governance is crucial to balancing economic development with environmental protection, fostering a green and sustainable economy.
Ma et al. (2024) [24]	Public Governance	—>	Economic Development	Structural Equation Modeling (SEM); analysis of trust in government and social justice as mediators	The quality of public governance strengthens trust and perceptions of social justice, promoting a more prosperous and stable economic environment.
Vilas-Boas (2024) [33]	Public Governance	—>	Economic Development	Reflective and analytical approach; theoretical and practical examples from administrative law	Public governance must adopt a resilient and inclusive model to address vulnerabilities, enabling sustainable economic development that respects citizens' rights and dignity.
Source: Own Elaboration (2024)					

between Public Governance and Economic Development.

2.3. *Interconnections between economic development and social development*

Table 2 underscores the interplay between economic and social development, presenting both benefits and challenges [36,37,42]. Economic growth generates income, employment, and progress in health, education, and well-being [43–47].

Table 2 underscores the analyzing the impact of official business activity on economic growth in China reveals that more developed regions often serve as catalysts for the growth of neighboring areas. However, the persistence of regional disparities underscores the need for targeted policies aimed at achieving balanced and inclusive development, ensuring that all areas benefit equally from economic progress [34]. Complementary research shows that less developed cities in China struggle to fully harness the potential of economic growth, highlighting the need for strategies to reduce social inequalities and ensure a more equitable distribution of prosperity across regions [37].

The adoption of sustainable energy technologies and eco-innovation emerges as a critical strategy that not only supports economic growth but also promotes social sustainability. These approaches mitigate environmental impacts while fostering a development model that is responsible and inclusive, laying the foundation for long-term stability, social equity, and growth [35]. In related analyses, global supply chains are identified as major factors affecting worker health and safety, particularly in low- and middle-income countries. Economic pressures often compromise these conditions, necessitating the implementation of regulatory frameworks that balance economic growth with social welfare [36].

Social protection systems are vital in addressing the limitations of economic growth. Research demonstrates that economic growth alone is often insufficient to reduce child poverty, particularly in low- and middle-income countries. Well-designed policies, such as income transfer programs, social safety nets, and targeted support, can amplify the positive effects of growth, making it more inclusive and effective in

Table 2
Theoretical and empirical evidence on the relationship between economic development and social development.

Author and Year	Construct	—>	Construct	Methodology	Relationship Between Economic Development and Social Development
Gu (2024) [34]	Economic Development	—>	Social Development	Spatial Panel Simultaneous Equation Model	Economic growth in one city increases official business activity in nearby cities, promoting social development through greater economic stability.
Chien, Chau & Huang (2024) [35]	Economic Development	—>	Social Development	Dynamic Auto-regressive Distributed Lags (DARDL) model and correlation matrix	Identified that social sustainability is driven by economic growth when green technologies and innovation are integrated, reinforcing social development through sustainable practices.
Walters, James & Johnstone (2024) [36]	Economic Development	—>	Social Development	Critical narrative review and interviews with key informants	Observed that economic pressures in global supply chains hinder social development for workers in low-income countries, highlighting the need for improved regulatory practices.
Lian, Fan & Lu (2024) [37]	Economic Development	—>	Social Development	TOPSIS entropy weight method and spatial analysis	Found that economic development advances social development in more developed regions, while underprivileged areas lag behind, perpetuating regional inequalities.
Meng & Gray (2024) [28]	Economic Development	—>	Social Development	Qualitative analysis based on case studies	Observed that economic development policies lacking a social focus constrain social development, particularly in the social work sector, where autonomy is limited by government oversight.
Sirén (2024) [38]	Economic Development	—>	Social Development	Multivariate regression analysis using Luxembourg Income Study data	Found that economic growth is more effective in reducing child poverty when accompanied by social policies and social protection, fostering inclusive social development.
Gatawa (2022) [39]	Economic Development	—>	Social Development	Quantitative time series analysis (2014–2018)	Observed that economic development driven by social investments in health and education results in higher quality of life and enhanced social development.

Source: Own Elaboration (2024).

addressing social disparities [38]. Furthermore, studies on social work development in China highlight the importance of integrating social concerns into economic planning. Strengthening grassroots social work initiatives is crucial to tackling social challenges and fostering greater inclusion, especially in political environments where the autonomy of social workers may be restricted [28].

The link between health, education, workforce quality, and economic growth is equally critical. Investments in these areas are pivotal for the development of human capital, which is essential for enhancing productivity and ensuring the sustainability of economic growth. Gatawa [39] emphasizes that social investments should be central to economic strategies, thereby contributing to sustainable and inclusive economic development. By prioritizing social development, nations can cultivate a more resilient workforce and strengthen the foundation for long-term economic success.

Collectively, these studies suggest that economic and social development are deeply interconnected and mutually reinforcing. While some research identifies negative relationships or challenges [28,36], the majority of studies [34,35,37,38] consistently support the existence of a positive correlation between economic and social development. Based on this body of evidence, the following hypothesis (H2) is proposed for testing: There is a positive and statistically significant relationship between Economic Development and Social Development.

2.4. Interconnections between economic development and climate change adaptation capacity

The relationship between economic development and climate change adaptation capacity has become a central focus in discussions on sustainability and socio-economic resilience. This connection is crucial, given the growing and undeniable challenges posed by climate change worldwide [48–50]. The evidence presented in Table 3 illustrates how economic development can provide financial resources and technological advancements essential for enhancing societies' capacity to adapt to climate-related challenges. This includes the development of resilient infrastructure, improving disaster preparedness, and fostering innovation in sustainable practices.

This relationship highlights the urgent need for policymakers to integrate economic strategies with climate adaptation policies. Aligning economic development with climate resilience ensures that growth is not only sustainable but also capable of withstanding the environmental pressures brought about by climate change. These insights are vital for shaping policies that balance economic progress with the pressing need for environmental sustainability and social resilience.

Table 3 highlights the link between economic development and climate change adaptation capacity, emphasizing how socioeconomic and institutional factors influence climate vulnerability across countries. Nagy et al. [51] found that, in Latin America, vulnerability to extreme weather events is closely tied to socioeconomic inequality and insufficient infrastructure. The lack of economic development and infrastructure investment diminishes adaptive capacity, exposing vulnerable populations to significant climate risks and affecting human well-being. The authors argue that adaptation policies should not only address the direct impacts of climate change but also promote socioeconomic development to enhance regional resilience [10,30,51].

Countries with lower levels of development are more vulnerable to climate change, as demonstrated by Halkos et al. [10]. Their multilevel analysis revealed that factors such as GDP and institutional quality significantly affect a country's climate adaptation capacity. Developed countries exhibit high adaptive capacity due to substantial investments in technology and infrastructure, which facilitate effective climate adaptation measures [18]. In contrast, developing countries often lack the necessary resources and institutional frameworks, making them more vulnerable to climate impacts [48]. Low-income countries, despite contributing less to global emissions, are the most vulnerable to the effects of climate change [52].

Fuller [52] noted that climate vulnerability negatively affects GDP per capita, making climate adaptation more challenging for these countries due to limited economic resources. He suggests that economic development is crucial not only for improving national economies but also for reducing climate vulnerability. Builds on this by examining the connection between climate vulnerability and fiscal stability. He argues that climate vulnerability can increase fiscal risks, particularly in emerging economies, and that macroeconomic and institutional factors supporting fiscal stability can also help address climate challenges. Thus, economic development and effective governance are key to fostering climate resilience.

Mumtaz & Theophilopoulou [53] explored the relationship between climate shocks and inequality, concluding that low-income countries, particularly those with agricultural economies, are most affected. These shocks not only exacerbate inequality but also hinder adaptation capacity. The authors suggest that balanced and sustainable economic development can mitigate these impacts by strengthening adaptation capacity.

Climate change significantly affects economic challenges and food security worldwide, disrupting agricultural productivity and exacerbating food shortages [55,56]. The interaction between climate variability and food systems results in rising food prices and increased risks

Table 3
Theoretical and empirical evidence of the relationship between economic development and climate change adaptation capacity.

Author and Year	Construct	—>	Construct	Method	Observations on Economic Development and Climate Change Adaptation
Nagy et al., 2018 [51]	Economic Development	—>	Climate Change Adaptation Capacity	Analysis of socioeconomic and climate disaster data	Economic development, infrastructure, and public education are crucial for enhancing resilience and adaptation, particularly in Latin American countries.
Halkos et al., 2020 [10]	Economic Development	—>	Climate Change Adaptation Capacity	Multilevel hierarchical linear modeling	Developed and transitioning countries show greater adaptation capacity, suggesting that economic development is key to reducing vulnerability.
Fuller, 2021 [52]	Economic Development	—>	Climate Change Adaptation Capacity	OLS and time trend regression	High-income countries have greater adaptation capacity, while low-income countries face more challenges due to lower economic capacity.
Mumtaz & Theophilopoulou, 2024 [53]	Economic Development	—>	Climate Change Adaptation Capacity	Panel VAR model	Low economic capacity in poor countries limits adaptation, highlighting the importance of balanced and sustainable development.
Komilov, 2024 [30]	Economic Development	—>	Climate Change Adaptation Capacity	Quantitative and qualitative data collection	Investments in economic security and sustainable development are essential for climate adaptation, particularly in vulnerable economies such as Uzbekistan.
Cardoso, 2024 [54]	Economic Development	—>	Climate Change Adaptation Capacity	Quantitative and discrepancy analysis	Economic development is crucial for adapting to climate change, especially in regions facing financial challenges for climate adaptation.

Source: Own elaboration (2024).

of malnutrition, particularly among vulnerable populations [57,58]. In Uzbekistan, climate change has a severe impact on both economic challenges and food security [30]. However, Komilov [30] emphasizes that investments in local policies and sustainable development can enhance economic resilience and food security. For vulnerable countries like Uzbekistan, economic development is critical to reducing climate risks and fostering adaptation.

Cardoso [54] examined various vulnerability indices and highlighted significant variations in climate vulnerability within developing economies, driven by regional factors. He suggests that economic development plays a pivotal role in implementing effective adaptation policies and proposes the creation of an integrated index to guide public policies and financial decisions, considering regional specifics and economic conditions.

Collectively, these studies reinforce the notion that economic development is central to climate change adaptation. Countries with more robust economic and institutional conditions demonstrate greater resilience, while low-income countries with limited adaptive capacity face more substantial challenges. Therefore, based on the evidence [10,30,51–54], the following hypothesis is proposed for testing (H3): There is a positive and statistically significant relationship between Economic Development and Climate Change Adaptation Capacity.

2.5. *Interconnections between economic development and environmental performance*

The relationship between economic development and environmental performance has become a central topic in contemporary discussions on sustainability and resilience in the context of climate change [59–61] This relationship is bidirectional, as economic growth can both foster environmental improvements and contribute to environmental degradation [62].

Table 4 presents an overview of the studies analyzed, offering a broad perspective on the complex relationship between economic development, often measured by GDP, and environmental performance, which is influenced by economic, cultural, and institutional factors. In resource-dependent countries such as Iraq, GDP is associated with economic challenges that hinder sustainability and limit diversification [26]. Al-Husseini [26] underscores that petroleum-dependent economies face significant difficulties in achieving sustainable growth without implementing necessary reforms.

Wang et al. [4] propose that strong governance positively impacts environmental protection, with higher levels of GDP and education contributing to improved environmental practices. However, extreme climate events may weaken this effect, demonstrating that economic prosperity alone does not ensure sustainability. Silva et al. [12] also find that in high-GDP countries, urbanization and the protection of individual rights increase the likelihood of achieving high environmental performance, suggesting that quality of life complements economic growth as a key factor for fostering a healthy environment.

While high GDP is often associated with negative environmental effects, particularly in resource-dependent economies, information and communication technology (ICT) development can help mitigate these impacts [13,64]. Kartal et al. [64] further emphasize that GDP per capita is a key determinant of environmental performance, with wealthier economies being better positioned to invest in sustainable technologies.

However, Stolbov & Shchepeleva [65] argue that financial development, linked to GDP, may harm environmental performance, as the expansion of financial markets does not always align with sustainability goals. This creates a paradox between economic growth and environmental quality, particularly in uncertain economic contexts.

In the European Union, Drăcea et al. [66] find that energy efficiency, which correlates with GDP per capita, plays a crucial role in enhancing environmental performance. This suggests that economic development can align with sustainability when energy and governance policies are integrated effectively.

Finally, in developing countries, increasing GDP tends to lead to higher CO_2 emissions [18]. However, the adoption of renewable energy and sound governance practices can mitigate this impact, demonstrating that economic growth can be managed in a way that promotes sustainability, particularly in low- and middle-income nations [18].

Recent studies reveal strong thematic coherence in addressing

Table 4
Theoretical and empirical evidence of the relationship between economic development and environmental performance.

Author and Year	Construct	—>	Construct	Method	Relationship Between GDP and Environmental Performance
Al-Husseini, 2024 [26]	Economic Growth	—>	Environmental Performance	Econometric analysis of data from 1980 to 2021	GDP is linked to oil dependency, negatively affecting economic diversification and sustainable growth.
Wang et al., 2024 [63]	Economic Growth	—>	Environmental Performance	Generalized Method of Moments (GMM) analyzing data from 164 countries	High GDP and improved education are positively associated with environmental protection, although extreme events may reduce this impact.
Silva et al., 2024 [12]	Economic Growth	—>	Environmental Performance	Fuzzy Qualitative Comparative Analysis (FsQCA) in 156 countries	High GDP per capita, associated with low corruption and high individual freedom, is one of the combinations contributing to high environmental performance.
Lv et al., 2024 [13]	Economic Growth	—>	Environmental Performance	Panel data analysis with Generalized Instrumental Variables Method (IV GMM) in 102 countries	GDP in resource-rich countries tends to negatively impact environmental quality, although ICT may mitigate these effects in emerging economies.
Kartal et al., 2024 [64]	Economic Growth	—>	Environmental Performance	Super Learner (SL) algorithm integrating six ML algorithms to model the Environmental Performance Index (EPI)	GDP per capita is the most critical factor in improving environmental performance, suggesting that wealthier economies have more resources to invest in sustainability.
Stolbov & Shchepeleva, 2024 [65]	Economic Growth	—>	Environmental Performance	Local projections in panel and K-Means clustering	Financial development associated with high GDP tends to harm environmental performance, mainly due to the expansion of financial markets at the expense of environmental institutions.
Drăcea et al., 2024 [66]	Economic Growth	—>	Environmental Performance	Gaussian graphical models for Bayesian network analysis	GDP per capita, along with energy efficiency, positively contributes to environmental performance, highlighting synergies between economic development and sustainability in the EU.
Rahman and Sultana, 2024 [18]	Economic Growth	—>	Environmental Performance	Panel data analysis with fixed and random effects, plus GMM, FMOLS, and DOLS for long-term relationships	Higher GDP is associated with increased CO2 emissions, but the use of renewable energy and good governance can moderate this effect, especially in developing countries.
Karahan, Yildirim, and Yildirim, 2025 [67]	Economic Growth	—>	Environmental Performance	PROMETHEE method based on entropy with EPI 2022 data	Turkey has a relatively lower GDP compared to other Eastern European countries, which negatively influences its environmental performance.

Source: Own elaboration (2024).

sustainability through an integrated perspective that combines economic, environmental, social, and governance factors—consolidated under the ECON-ESG framework proposed by Işık, Ongan, Islam, and collaborators [20,40,68]. These works share the premise that traditional ESG-based analyses are insufficient to capture the real dynamics of sustainable development, particularly when they overlook the structural role of macroeconomic variables.

Various studies focus on G7 countries such as Canada, the United States, and Italy, analyzing the relationship among economic, social, environmental, and governance factors and their influence on energy efficiency and sustainability [20,69]. Others concentrate on OECD countries, especially within the context of energy transition mediated by artificial intelligence and ESG metrics [9,40]. Additional research addresses Asia-Pacific countries—including East Asia, the Pacific, and South Asia—exploring how ESG factors impact economic growth and carbon neutrality [70,71]. The BRICS nations have also been studied through the lens of water productivity and fintech innovations [72], while research on Chinese cities highlights the influence of the digital economy on energy conservation and emission reduction [73]. Across these cases, findings consistently show that economic factors—such as GDP, inflation, unemployment, and private sector credit—tend to negatively impact environmental indicators like energy efficiency, energy transition, and load-carrying capacity (LCC) [20]. Conversely, governance indicators exert a positive influence, particularly when associated with institutional quality, corruption control, and public policy effectiveness [43,71].

Social factors, such as education, digital inclusion, and female labor force participation, also emerge as significant moderators of policy effectiveness. Notably, in studies on BRICS countries, education enhances the impact of financial technologies (fintech) on water productivity [20,69]. Similarly, the digital economy has significantly contributed to lowering carbon emissions and improving energy efficiency in Chinese cities, particularly in regions with greater innovation capacity and stronger environmental governance [73]. In the specific case of the OECD, the authors demonstrate that while technology and artificial intelligence can facilitate the energy transition, they may also introduce economic barriers when implementation costs are high or unevenly distributed [40,68]. On the other hand, institutional strengthening is consistently cited as a critical prerequisite for the success of both environmental and financial inclusion policies [40,68,71]. This perspective aligns with constitutional frameworks that emphasize the rights of future generations in sustainable development, as highlighted by Al-Arbawi [1].

Furthermore, Climate Policy Uncertainty (CPU) is explored in a global study that shows environmental and social factors tend to increase CPU, whereas economic factors help reduce it in the long term - highlighting economic stability as essential for policy predictability [43, 68]. Although diverse in their empirical focus, these studies converge on the notion that sustainability may ultimately rely on the articulation of ECON-ESG factors—an articulation that must account for regional and institutional specificities across countries or groups of countries.

Işık et al. [20] employ a variety of advanced statistical techniques, such as CS-ARDL, the Partial Linear Functional Coefficient (PLFC) model, and panel data models using GMM. In dataset 12, the innovative ECON-ESG framework is introduced, aiming to understand how macroeconomic factors align with ESG criteria to influence energy efficiency. This approach emphasizes specific interactions between macroeconomic and environmental variables. In contrast, the article under review proposes a broader and more integrative model that explores the relationships among governance, economic and social development, environmental performance, and climate adaptation. While Işık's studies provide granular and context-specific explanations, the current article adopts a systemic and structural approach, revealing causal pathways and mediation among latent variables. Both approaches emphasize the integration of economic, social, and environmental dimensions; however, the present study distinguishes itself by employing Structural Equation Modeling (SEM) to test direct and indirect structural relationships—an analytical depth not explicitly achieved in Işık's work.

Rahman et al. [15] apply the XGBoost machine learning algorithm, in conjunction with SHAP analysis, to identify the most influential factors driving climate vulnerability in Bangladesh. Their data-driven approach focuses on identifying variable patterns and relative weights, with a strong emphasis on spatial analysis. In contrast, the SEM-based article builds on a structured theoretical hypothesis and examines relationships among latent constructs with empirical support. Structural equation modeling allows for the estimation of both direct and indirect effects—something not captured by ML algorithms like XGBoost. Nevertheless, both studies share a concern with climate vulnerability and emphasize the need to integrate social and economic variables. Rahman's approach is more exploratory, whereas the SEM-based article is confirmatory and causal.

In Zhang et al. [73], fixed-effects models combined with spatial regressions are used to analyze the impact of the digital economy on energy use and emissions. Like the present article, they assess how structural factors such as innovation and infrastructure influence environmental outcomes. Zhang's [73] innovation lies in the use of spatial models and regional spillover effects, which enrich the geographic dimension of the analysis. While the article "Governance, Development, and Environment" does not incorporate spatialization, it effectively models the structural interdependence between governance and the environment through a robust causal chain (governance → development → environmental performance and climate adaptation). Zhang models direct regional impacts; the present article analyzes global systemic relationships.

Comparatively, [71] employ a dynamic GMM model to investigate the relationship among renewable energy, financial inclusion, and institutional quality, highlighting how institutional effectiveness moderates the positive effects on carbon neutrality. This moderating logic is echoed in the current article, which shows that robust governance is a necessary condition for economic development to translate into environmental and social sustainability. Both studies emphasize conditional and interdependent effects; however, while GMM addresses endogeneity in time series data, the SEM model in this article captures latent relationships between composite constructs by aggregating indicators (e. g., ND-GAIN + EPI for the environment; HDI + life expectancy for the social dimension).

Solangi et al. [74] underscore the role of digital innovation and institutional capacity in improving air quality, using System GMM. As with the current article, they acknowledge that economic development must be coupled with institutional capability to produce positive environmental outcomes. The primary distinction is that Solangi [74] focuses on more specific indicators (e.g., PM2.5), while the article under review employs broader environmental variables such as the EPI and ND-GAIN [75].

The SEM algorithm used in the present study differs significantly from traditional econometric models (e.g., GMM, CS-ARDL, PLFC) and machine learning algorithms (e.g., XGBoost). It offers a structured and multidimensional approach capable of testing causal relationships and estimating indirect effects—an advantage not afforded by models like GMM or XGBoost. While studies by Işık [20,21,40,43,68–70,72,76,77], Ansari [71], and Zhang [73] focus on specific relationships among ESG variables, green finance, digitalization, and energy efficiency, the present article goes further by demonstrating how public governance structures the entire sustainable development system—hierarchically and integratively connecting economic, social, and environmental dimensions.

In conclusion, the analyses demonstrate that the relationship between economic development and environmental performance is complex. While economic growth provides resources for sustainable investments, it also presents challenges, such as increased emissions and resource exploitation. Considering both positive [4,12,64,66] and negative [13,18,26,65,67] relationships between economic development and environmental performance, we propose the following hypothesis (H4): There is a statistically significant relationship between economic development and environmental performance in the countries analyzed.

3. Methodology

This article employs Structural Equation Modeling (SEM) to examine the relationships between governance, economic, social, and environmental variables in a sample of 149 countries, selected based on data availability for 2022. Following the sample selection, multivariate outliers were identified and removed using the Hadi [78] test, which excluded eight countries (Angola, Belize, Ireland, Lebanon, Luxembourg, Norway, Qatar, and Singapore). Fig. 1 presents the conceptual model and the hypotheses to be tested in this research.

The construction and validation of a theoretical model to analyze the determinants of sustainable development require a systematic and methodologically rigorous approach. The first step involves defining the theoretical model itself, which necessitates the identification of the key latent constructs. In this study, five analytical pillars were established: Public Governance, Economic Development, Social Development, Climate Change Adaptation Capacity, and Environmental Performance. These constructs represent complex and interdependent dimensions of development and cannot be directly observed. Therefore, it is essential to select observable indicators that, according to the literature, validly and reliably capture each dimension. Public Governance, for example, can be measured using indicators such as Rule of Law and Regulatory Quality, while Social Development may be represented by the Human Development Index (HDI) and life expectancy. Environmental Performance is captured through the Environmental Performance Index (EPI), which encompasses aspects such as air quality, biodiversity, and sustainable resource use.

The second step concerns the selection and treatment of the sample. Countries with available data for all considered indicators were selected, using the year 2022 as a reference. The initial sample included 149 countries. To ensure robustness, the Hadi test was applied to identify multivariate outliers that could distort the results. Excluding these outliers enhanced the consistency of the data and increased the statistical validity of the estimates.

The third step involved data preparation and standardization. Information was collected from internationally recognized sources, such as the World Bank [79,80], ND-GAIN [75,81], and EPI-Yale. As these indicators operate on different scales and units, statistical standardization was applied using the z-score method. This procedure ensured comparability among variables and prevented scale differences from disproportionately influencing the model's estimates.

The fourth step consisted of specifying the structural model. Based on the formulated hypotheses, a Structural Equation Model (SEM) was developed, in which Public Governance directly influences Economic Development, which in turn acts as a mediating variable for the other dimensions: Social Development, Climate Adaptation Capacity (as measured by ND-GAIN), and Environmental Performance (EPI). The constructs were formed using both latent variables and observed indicators. Additionally, covariances were included between theoretically and statistically supported correlated constructs to account for structural interdependencies among the domains analyzed.

In the fifth step, the model was estimated using SEM-specialized software such as AMOS, LISREL, SmartPLS, or the lavaan package in R. The estimation technique applied was Maximum Likelihood (ML), recommended for reasonably sized samples and data that approximate multivariate normality. This approach allows for the simultaneous

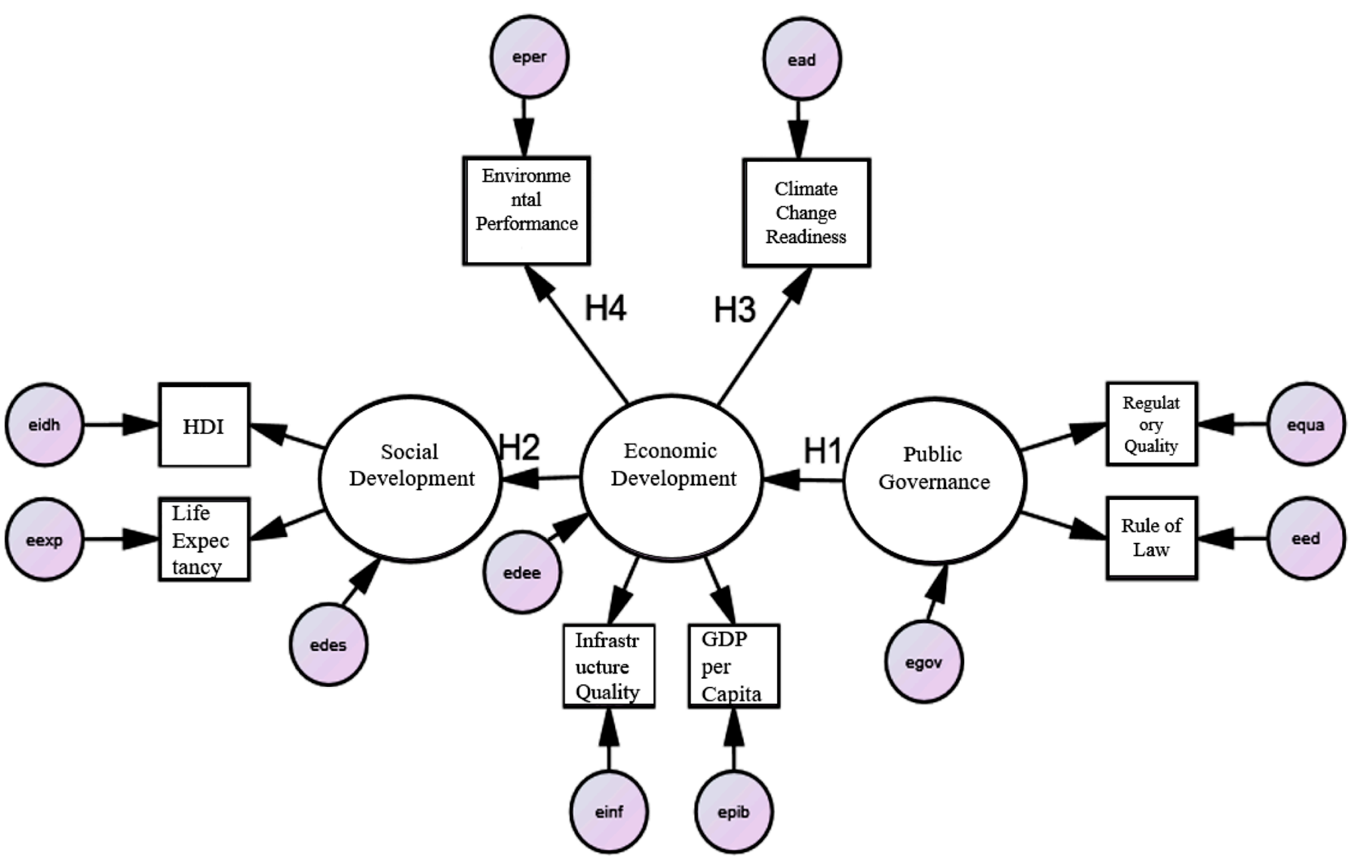

Fig. 1. Theoretical model.
Source: Own elaboration (2024).

estimation of model parameters and the evaluation of the fit of the proposed relationships.

The sixth step focused on assessing the model's goodness-of-fit. Multiple fit indices were calculated, including the chi-square per degrees of freedom (χ^2/df), GFI, CFI, TLI, IFI, RMSEA, and RMSR. These indicators determine whether the proposed theoretical model aligns with the observed empirical data. The literature suggests reference values for each index—typically, GFI, CFI, TLI, and IFI values above 0.95, and RMSEA and RMSR below 0.05, with a χ^2/df below 3 indicating good model fit.

The next stage involved interpreting the results. Standardized factor loadings were analyzed to evaluate the strength of association between observable indicators and their respective latent constructs. Subsequently, standardized regression coefficients between constructs were examined, focusing on the direction, magnitude, and statistical significance of the structural effects. This analysis is essential for understanding the causal paths within the model and identifying direct, indirect, and total effects among variables.

Finally, the discussion and hypothesis validation stage sought to confirm or refute the initial propositions based on the estimated coefficients and p-values ($p < 0.05$). The discussion was deepened with insights from the reviewed literature, emphasizing observed causalities and their practical implications. Special attention was given to the direct and indirect effects of Public Governance on the remaining constructs, as well as the institutional and policy implications that emerge from the analysis. The results reinforce the importance of integrated public policies that recognize governance as the foundation for economic development, social justice, climate resilience, and environmental preservation—consistent with findings by Chanda et al. [5] and Ma et al. [24].

The choice to apply Structural Equation Modeling (SEM) in this study is justified by the complex and interdependent nature of the variables under analysis. The primary objective is to understand the relationships among Public Governance, Economic Development, Social Development, Climate Change Adaptation Capacity, and Environmental Performance across 149 countries. These constructs involve both latent and observed dimensions that cannot be adequately examined using univariate methods or traditional regression analysis, which fail to simultaneously account for direct and indirect effects. SEM allows for the testing of complex theoretical models with multiple simultaneous dependencies, which is essential when investigating interconnected systems involving governance, economy, environment, and society. Moreover, this approach enables the incorporation of composite indicators and latent variables, such as Public Governance—measured by Rule of Law and Regulatory Quality—and Social Development—represented by HDI and life expectancy.

Although recent research has employed robust statistical methodologies to assess relationships among socioeconomic, environmental, technological, and governance variables—such as CS-ARDL, GMM, fixed-effects models, and machine learning—these approaches exhibit key limitations compared to SEM. For instance, Işık et al. [20,69] used CS-ARDL, AMG, and CCEMG models to analyze panel data with cross-sectional dependence and to estimate short- and long-term effects between ECON-ESG factors and sustainability outcomes. These methods are well-suited for time-series analysis of observed variables but fall short in capturing latent structures, mediating effects, and complex causal pathways, which SEM effectively models.

Similarly, Ansari et al. [71] employed dynamic GMM models to address endogeneity and heteroskedasticity in analyzing the effects of renewable energy and financial inclusion on carbon neutrality. While GMM is effective in contexts involving autocorrelation and instrumental variables, it does not allow for the simultaneous testing of multiple relationships among latent constructs and observed variables, nor does it clearly identify indirect or mediating effects—elements that are critical in studies on sustainability, governance, and development. Other studies, such as those by Zhang et al. [73] and Rahman et al. [16,17], employed spatial regression models and machine learning algorithms such as XGBoost and SHAP. These methods are powerful in capturing nonlinear patterns and identifying high-performing predictors, especially for spatial and predictive analyses. However, their primary limitation lies in the lack of transparency regarding causal structures among variables, making it difficult to formulate policies based on clear interpretations of underlying mechanisms. Furthermore, machine learning algorithms are fundamentally predictive rather than explanatory, rendering them insufficient for understanding the structural interaction of multiple factors.

By contrast, Structural Equation Modeling (SEM) stands out precisely because it enables the simultaneous analysis of multiple causal relationships among latent and observed variables, offering a comprehensive statistical framework for testing complex hypotheses in multidimensional studies. Variable standardization was also a critical step in ensuring comparability across different measurement scales, facilitating the clear interpretation of factor loadings and regression coefficients. Therefore, the choice of SEM is not only appropriate but necessary, given the complexity of the phenomenon under investigation and the need to capture the interrelations among different domains of sustainable development.

4. Results and discussion

The sample of 149 countries (Fig. 2) encompasses a broad spectrum of capabilities and challenges related to climate change adaptation, economic and social development, environmental performance, and governance. Countries such as Germany, Japan, and the United States, characterized by high levels of economic development, typically possess superior infrastructure and resources for implementing adaptive policies, alongside high standards of social development and environmental performance [60].

In contrast, developing and low-income countries such as Malawi, Burkina Faso, and Haiti face greater challenges in adapting to climate change due to limited resources, lower social development indices, and institutional barriers in governance [82]. These nations often exhibit poorer environmental performance due to their reduced capacity for investing in clean technologies and implementing mitigation policies.

Furthermore, governance varies significantly: while countries like Sweden, New Zealand, and Canada demonstrate stronger governance structures with clear sustainability policies, countries such as Yemen and Syria, affected by political instability, struggle to enforce effective adaptation and environmental protection policies [83].

Overall, this diversity offers a comprehensive analysis of how varying levels of economic, social, environmental, and governance development influence a country's capacity for climate adaptation. Examining the interaction among these variables is essential for understanding the complexity of climate change adaptation.

Table 5 presents descriptive statistics for the variables used in the study, including measures of central tendency (minimum, maximum, mean, median), skewness, and kurtosis. These variables assess economic, social, environmental, and institutional aspects across countries.

The Regulatory Quality variable ranges from 1.42 to 99.53, with a mean of 50.14 and median of 50.00, indicating a symmetric distribution (skewness of 0.06). The negative kurtosis (−1.13) suggests a dispersed data set with fewer extreme values. Rule of Law ranges from 0.47 to 100.00, with a mean of 48.10 and median of 46.70, showing a slight concentration of values below the mean. The positive skewness (0.18) and negative kurtosis (−0.97) indicate a flatter distribution.

Climate Change Readiness has a narrower range (27.16 to 72.94), with a mean of 50.89 and median of 50.21. The skewness of 0.21 shows mild positive tilt, and kurtosis of −0.82 reflects a less concentrated distribution. GDP per capita ranges from \$0.92k to \$90.75k, with a mean of \$26.50k and median of \$19.40k. The positive skewness (0.85) suggests high values raising the mean, and kurtosis of −0.32 indicates a flat distribution.

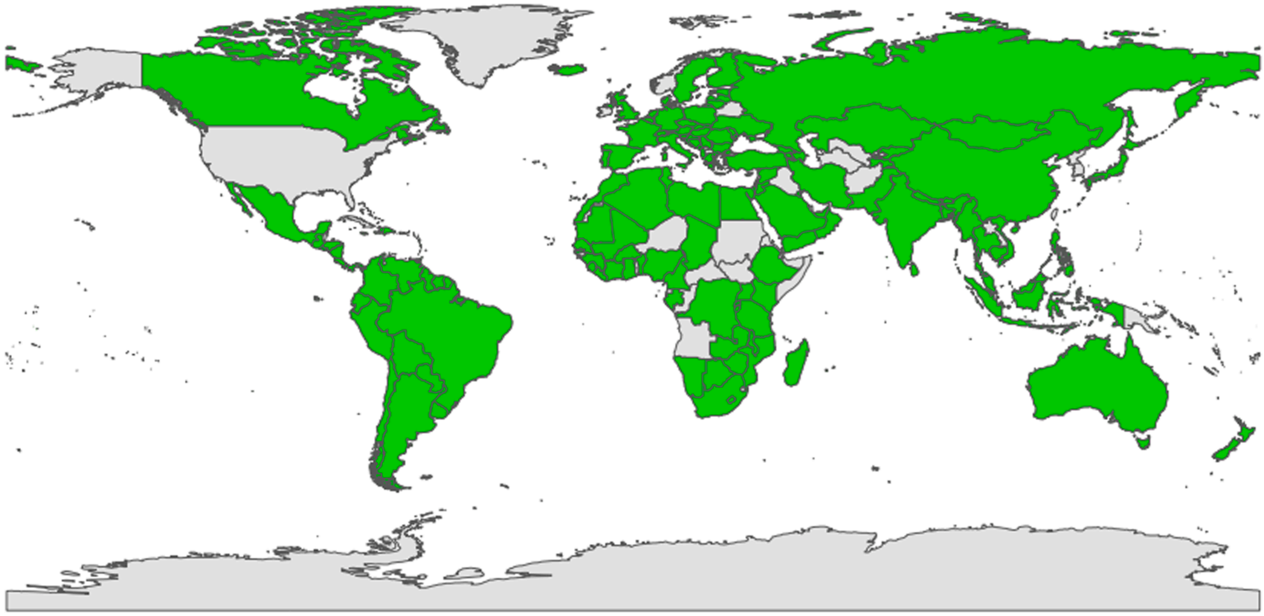

Fig. 2. Relationship of the countries analyzed in the research.
Source: Own elaboration (2024).

Table 5
Minimum, maximum, mean, median, skewness, and kurtosis of the variables used in the research.

Variable	Min.	Max.	Mean	Median	Skewness	Kurtosis *
Regulatory Quality	1.42	99.53	50.14	50.00	0.06	−1.13
Rule of Law	0.47	100.00	48.10	46.70	0.18	−0.97
Climate Change Readiness (ND-GAIN)	27.16	72.94	50.89	50.21	0.21	−0.82
GDP per capita (in thousands US$)	0.92	90.75	26.50	19.40	0.85	−0.32
Human Development Index (HDI)	0.39	0.97	0.73	0.76	−0.40	−0.87
Overall Infrastructure Quality	1.79	6.44	3.97	3.97	0.07	−0.73
Life Expectancy (in years)	48.87	83.84	71.80	74.41	−0.79	−0.03
Environmental Performance Index (EPI)	18.90	77.90	43.11	40.90	0.58	−0.07

* indicates excess kurtosis. Source: author's own elaboration (2024).

HDI ranges from 0.39 to 0.97, with a mean of 0.73 and a median of 0.76. The negative skewness (−0.40) indicates a concentration of values above the mean, while the kurtosis of −0.87 suggests a low concentration of extreme values.

Infrastructure Quality ranges from 1.79 to 6.44, with both the mean and median equal to 3.97, indicating symmetry (skewness of 0.07). The negative kurtosis (−0.73) reflects moderate dispersion.

Life Expectancy spans from 48.87 to 83.84 years, with a mean of 71.80 years and a median of 74.41. The negative skewness (−0.79) suggests that higher values are more prevalent, while the kurtosis near zero (−0.03) indicates an almost normal distribution.

Environmental Performance (EPI) ranges from 18.90 to 77.90, with a mean of 43.11 and a median of 40.90. The positive skewness (0.58) suggests the presence of extreme values, while the kurtosis near zero (−0.07) indicates a balanced distribution.

Overall, the statistics reveal varying degrees of dispersion and symmetry, with some variables being more concentrated around the mean and others being more dispersed. Skewness and kurtosis offer valuable insights into the distribution of the data for further analysis. Understanding the interactions between economic and environmental factors is essential for addressing climate change challenges. Structural equation modeling was employed in this study to assess these interrelationships. Table 6 presents the fit indices, along with reference values proposed in the study.

When analyzing Table 6, all fit indices fall within the reference values suggested by the literature. The chi-square ratio to degrees of freedom (1.04) is well below the 3.00 threshold, indicating an excellent model fit. GFI (0.97), CFI (1.00), TLI (1.00), and IFI (1.00) all exceed the minimum expected values, confirming the adequacy of the model.

Regarding error indices, RMSEA (0.02) is significantly below the 0.10 threshold, indicating minimal discrepancy between the estimated and observed data. RMSR (0.03) also meets the acceptable limits, remaining within the fit range.

These results confirm that the adjusted model meets all quality criteria, reinforcing the robustness of its interpretations. The achieved values validate the reliability of the measurements and their consistency in representing the underlying relationships among the analyzed variables.

Table 7 presents the standardized direct loadings of the model, illustrating the dynamics of mutual influences between variables. This

Table 6
Fit index values, reference authors, and reference values.

Fit Index	Reference Author	Reference Value	Value
Chi-square Ratio*	Carmines & Mciver (1981) [45]	<3.00	1.04
GFI	Byrne (2013) [84]	>0.95	0.97
CFI	Byrne (2013) [84]	>0.95	1.00
TLI	Hu & Bentler (1999) [85]	>0.95	1.00
IFI	Bollen (1989) [86]	>0.90	1.00
RMSEA	Steiger (2007) [87]	<0.10	0.02
RMSR	Hooper, Coughlan & Mullen (2008) [88]	<0.05	0.03

* Chi-square ratio by degrees of freedom (df).

Table 7
Estimated (standardized) direct loadings of the model.

Variable	Direction	Variable	Loading	Prob.
Economic Development	<—	Public Governance	0.931	0.000
Social Development	<—	Economic Development	0.879	0.000
Environmental Performance (EPI)	<—	Economic Development	0.772	0.000
Climate Change Readiness (ND-GAIN)	<—	Economic Development	0.969	0.000
Regulatory Quality	<—	Public Governance	0.969	0.000
Rule of Law	<—	Public Governance	0.959	0.000
GDP per Capita (in USD)	<—	Economic Development	0.907	0.000
Overall Infrastructure Quality	<—	Economic Development	0.927	0.000
Life Expectancy (in years)	<—	Social Development	0.884	0.000
Human Development Index (HDI)	<—	Social Development	1.000	0.000
eepi	<—>	epib	0.223	0.000
edes	<—>	edee	0.673	0.000

Source: Author's elaboration (2024).

analysis enhances the understanding of interaction mechanisms and informs policies for sustainable, adaptive development.

The flow depicted in Fig. 1 and Table 7 begins with Governance, represented by Regulatory Quality and Rule of Law, which directly influence Economic Development (ED). Economic Development then serves as a foundation for Social Development (SD) and environmental resilience variables, such as the Environmental Performance Index (EPI) and Climate Change Adaptation Capacity (ND-GAIN). This sequence suggests that efficient and stable governance initiates development processes—both economic and social—creating a chain effect that extends beyond economic growth to encompass social and environmental improvements.

Public Governance, rooted in Regulatory Quality and Rule of Law, is the cornerstone of sustainable development. Regulatory Quality evaluates the government's ability to establish effective and stable policies that foster private sector growth, reduce uncertainty, and attract investment [63]. Rule of Law reflects trust in and adherence to laws, including the efficacy of the judicial and security systems. Together, these elements create a predictable and secure economic environment that reduces risks for private sector growth [89].

Public Governance directly impacts Regulatory Quality and Rule of Law, with loadings of 0.969 and 0.959, respectively, underscoring their strong connection. Croft et al. [3] emphasize that inclusive governance and equitable regulation are essential for stability. Similarly, Al-Husseini [26] notes that strengthening the Rule of Law ensures fair resource distribution and combats corruption.

Economic Development, represented by GDP per capita (0.907) and Infrastructure Quality (0.927), is a natural outcome of good governance. GDP per capita reflects the average standard of living, underscoring its importance for sustainability and competitiveness. Infrastructure highlights the critical role of structural foundations such as transportation and energy networks in ensuring economic efficiency and attracting investment [90]. Economic Development extends beyond wealth generation, supporting productivity, investment, and innovation [91].

Economic Development significantly influences Social Development (loading 0.879), improving social indicators such as health and education through investments in human capital [92]. Social progress enhances life expectancy (0.884) and HDI (1.000), driven by improved access to essential services [93].

ND-GAIN (0.969) reflects a nation's capacity for climate adaptation, demonstrating how strong economies allocate resources to climate readiness through adaptive technologies and resilience policies [35]. The EPI (0.772), while slightly lower, measures environmental responsibility and resource conservation, highlighting the managerial emphasis on climate adaptation.

The hypotheses analyzed confirm the interdependencies between Public Governance, Economic Development, Social Development, Climate Change Adaptation, and Environmental Performance. Efficient governance fosters economic growth by attracting investments and promoting stability [5]. Economic growth, in turn, drives social development by enabling greater investments in health and education, thereby reducing inequalities [92]. Furthermore, robust economies enhance climate adaptation capacity through investments in resilient infrastructure and technologies [35]. Finally, economic growth contributes to environmental performance when coupled with effective governance policies aimed at ensuring sustainability [12].

In conclusion, the findings presented in Table 7 validate the proposed hypotheses, emphasizing the critical interplay between Public Governance, Economic Development, Social Development, Climate Change Adaptation, and Environmental Performance. Effective governance lays the foundation for sustainable economic growth by promoting transparency, attracting investments, and ensuring stability. This growth, in turn, drives improvements in social well-being through enhanced access to health, education, and essential infrastructure. Moreover, robust economies are better equipped to allocate resources for climate resilience and environmental sustainability, provided that governance frameworks prioritize long-term ecological balance. These results underscore the importance of an integrated, multidimensional approach to development, where governance serves as the linchpin connecting economic, social, and environmental progress.

5. Final considerations

The findings of this research confirm that effective governance, alongside economic, social, and environmental development, are interconnected and essential pillars for sustainable development. Governance, rooted in regulatory quality and the rule of law, plays a crucial role in driving economic growth, which, in turn, fosters significant improvements in social indicators such as the Human Development Index (HDI) and life expectancy [25]. Robust economies enhance the capacity to adapt to climate change through investments in resilient technologies and infrastructure [25]. Furthermore, economic growth can contribute to environmental performance, provided it is aligned with public policies that prioritize sustainability [68].

Effective governance, characterized by robust regulation and the enforcement of the rule of law, is essential for advancing economic growth, social progress, and environmental resilience. While public governance does not directly impact environmental dimensions, it has a significant indirect effect that must be considered when designing governmental and intergovernmental public policies, especially in countries facing challenges in governance and economic development.

The study provides empirical evidence that effective governance—by fostering regulatory and institutional stability—serves as a catalyst for economic growth, which, in turn, enables advancements in social indicators such as the Human Development Index (HDI) and life expectancy, strengthens climate adaptation capacity (as measured by ND-GAIN), and positively influences environmental performance (as evaluated by the Environmental Performance Index, EPI). This systemic approach stands out in contrast to much of the traditional literature, which often analyzes these dimensions in isolation, overlooking their interrelations and existing mediation mechanisms. By demonstrating that the effects of governance on environmental and social outcomes occur primarily through economic development, the article offers a solid empirical foundation for the formulation of cross-sectoral public policies.

From a practical standpoint, the findings underscore that investments in governance not only promote economic growth but also enhance the effectiveness and coordination of environmental and social policies. This insight is particularly relevant for developing countries, where limited resources necessitate strategic prioritization of high-impact investments. The study further emphasizes that more robust economies, when underpinned by reliable institutions, are better positioned to implement green technologies, develop resilient infrastructure systems, and promote social equity—key pillars for a sustainable transition.

As for directions for future research, the study opens multiple avenues. First, it recommends deepening regionalized analyses of these relationships through spatial approaches that take into account subnational contexts, especially in countries marked by significant internal inequalities. Additionally, future investigations could incorporate new variables representing cultural, technological, and political dimensions, which may moderate the relationship between governance and sustainability. The use of mixed methods—combining SEM with machine learning techniques or spatial analysis—could further enrich findings and reveal nonlinear patterns or threshold effects not captured by conventional linear models.

Another promising path involves applying the proposed model longitudinally using time-series data, to explore the dynamics and feedback loops among variables over time—such as the impact of political instability on sustainable development across different economic cycles. Finally, future studies are encouraged to examine the role of international cooperation and multilateral agreements as modulators of the relationship between development and the environment, particularly in areas such as climate justice and green finance.

Therefore, it is recommended to formulate integrated public policies that combine investments in infrastructure, education, and health with sustainable practices, thereby promoting both human development and environmental preservation. Furthermore, prioritizing international cooperation and institutional strengthening is crucial to reduce regional inequalities and mitigate the impacts of climate change in a coordinated manner.

CRediT authorship contribution statement

Everton Anger Cavalheiro: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Ianuska Ramos Oliveira:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Diuliana Leandro:** Writing – review & editing. **Leonardo Betemps Kontz:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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