

Control of Corruption, Digital Transformation, and Carbon Emissions: A Global Panel Analysis of Mediating and Threshold Effects

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Abstract: This study examines how anti-corruption affects carbon emissions and investigates the mediating and threshold effects of digital economy development. Using panel data from 121 countries for 2012–2022, the study employs stepwise regression, mediation analysis, threshold regression, heterogeneity analysis, and a series of robustness tests. The findings indicate that anti-corruption significantly reduces carbon emissions. Digital economy development partially mediates this relationship, mainly through e-participation and internet use. Moreover, as digital economy development progresses, the emissions-reducing effect of anti-corruption becomes stronger, revealing significant threshold effects. The relationship also varies across geographical regions and between countries with and without a colonial legacy. These findings provide global panel evidence on the interconnected roles of anti-corruption and digital economy development in reducing carbon emissions. By integrating mediation and threshold analyses within a unified empirical framework, the study demonstrates that digital economy development functions not only as a transmission mechanism but also as a factor shaping the effectiveness of anti-corruption policies in reducing carbon emissions. The findings offer practical implications for policymakers by highlighting the importance of strengthening institutional governance and digital development strategies to achieve more effective and sustainable carbon reduction. These implications are particularly relevant for countries seeking to align governance reforms with digital transformation and environmental sustainability.

Keywords: Anti-corruption, carbon emissions, digital economy, environmental governance, mediation analysis, threshold analysis.

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INTRODUCTION

Climate change now ranks among the most urgent challenges worldwide. Carbon emissions remain the main force behind rising global temperatures and continuing environmental damage. Published in 2023, the Sixth Synthesis Report of the Intergovernmental Panel on Climate Change (IPCC, 2023) estimates that human activities, especially greenhouse gas emissions, have increased the global average surface temperature by approximately 1.1 °C above pre-industrial levels. The United Nations Environment Programme (UNEP) reaches a similarly troubling conclusion in its Emissions Gap Report 2024: under current climate policy trajectories,



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global temperatures could rise by as much as 3.1 °C by 2100, with a probability exceeding 66%. That would place warming well above the 1.5 °C target set by the Paris Agreement. UNEP also identifies a considerable gap between countries' climate commitments and what they actually put into practice. To keep the 1.5 °C pathway within reach, global annual emissions must fall by approximately 7.5% by 2035 (United Nations Environment Programme, 2024). Together, these developments suggest that substantially reducing carbon emissions will require more than technological advances. It will also require stronger institutions, effective environmental governance, and policies that are implemented more successfully.

Consistent with these concerns, the International Energy Agency (IEA) reports in its World Energy Outlook 2024 that, despite the rapid expansion of clean energy technologies and substantial investment in low-carbon transitions, the global economy still depends heavily on fossil fuels, keeping upward pressure on carbon emissions (IEA, 2024).

Technological progress alone, therefore, cannot deliver long-term emission reductions. Sustained progress also depends on governance frameworks that support policy implementation, hold institutions accountable, and guide sustainable economic transformation. This makes identifying institutional mechanisms that strengthen carbon mitigation policies an increasingly important research priority.

Although substantial research has examined what drives carbon emissions, most studies have concentrated on economic growth, energy consumption, and environmental conditions. Institutional and governance-related factors, by comparison, have received less attention (Sarkodie & Strezov, 2019). This gap matters because environmental policies succeed through more than technological and economic conditions; they also depend on the quality of governance and institutional performance. Corruption is one institutional factor of particular concern. It can undermine environmental sustainability and weaken efforts to reduce carbon emissions (Benlemlih, Assaf, & El Ouadghiri, 2022).

Evidence from various regions shows that corruption can impose substantial environmental costs by weakening regulatory enforcement and encouraging the inefficient exploitation of natural resources. A notable example is Indonesia, where corruption in the mining and deforestation sectors has been associated with weak regulatory enforcement, facilitating illegal resource extraction, accelerating forest degradation, and contributing to rising carbon emissions (Tacconi, Rodrigues, & Maryudi, 2019; Williams & Dupuy, 2017). These governance challenges demonstrate how institutional weaknesses can compromise environmental protection efforts, underscoring the importance of anti-corruption measures for strengthening environmental governance and supporting carbon emissions reduction.

Corruption undermines the implementation of environmental regulations and reduces compliance with environmental policies, ultimately leading to higher energy consumption and increased carbon emissions (Rahman, Alam, & Velayutham, 2022; Sundström, Haring, Jagers, & Povitkina, 2024). It further allows firms to circumvent environmental regulations and related taxes through bribery and other illicit practices, indirectly contributing to greater carbon emissions and broader environmental degradation (Sundström et al., 2024; Williams & Dupuy, 2017).

Beyond its direct environmental impacts, corruption can undermine the effectiveness of the economic and institutional systems responsible for implementing environmental policies. By weakening regulatory efficiency and institutional quality, it may delay progress toward the turning point of the Environmental Kuznets Curve (EKC), slowing countries' transition to lower levels of carbon emissions (Rahman et al., 2022; Welsch, 2004). Strengthening anti-corruption efforts is therefore expected to improve environmental governance, enhance policy implementation, and support long-term reductions in carbon emissions (Sundström et al., 2024).

To ground the theoretical arguments, the study first presents descriptive evidence on the link between anti-corruption efforts and carbon emissions. It uses carbon-intensity data from the World Bank alongside the Corruption Perceptions Index published by Transparency International (Transparency International, 2024; World Bank, 2025). Figure 1 shows this association across 121 countries over the 2012–2022 period.

As Figure 1 shows that countries scoring higher on the Corruption Perceptions Index generally have lower and more stable carbon emissions. By contrast, countries with weaker anti-corruption performance tend to report relatively higher emissions.

This descriptive pattern does not establish causality, but it provides preliminary empirical support for the idea that stronger anti-corruption efforts may improve environmental governance and help reduce carbon emissions. It also motivates the empirical analysis that follows (Benlemlih et al., 2022; Sundström et al., 2024).

Although a growing body of evidence connects anti-corruption efforts with carbon emissions, earlier research has generally explained this link through familiar channels, especially environmental regulation and more efficient resource allocation (Pan, Zhang, Wang, & Shang, 2024; Sundström et al., 2024). Much less attention has been paid to whether the development of the digital economy can increase the environmental gains associated with anti-corruption policies. Consequently, the ways in which digital transformation may strengthen the connection between anti-corruption efforts and reductions in carbon emissions remain not fully understood (Adam & Fazekas, 2021; Ren, Ma, Apergis, & Sharp, 2021; Zhang, Chen, Li, & Ding, 2024).

The issue has gained importance as the digital economy has expanded rapidly across the world. According to the Digital Economy Report 2024 from the United Nations Conference on Trade and Development (UNCTAD), e-commerce sales rose by approximately 60% over the past decade (United Nations Conference on Trade and Development, 2024).

This increase reflects the broader influence of information and communication technologies (ICT) on economic activity, public administration, and industrial operations. It also presents the digital economy as a promising institutional mechanism for improving governance quality and advancing environmental sustainability (United Nations Conference on Trade and Development, 2024).

The digital economy is widely seen as an important force behind sustainable development. By making production more efficient, speeding up technological innovation, and improving energy use, it can reduce carbon emissions while also improving environmental performance (Ahmed & Le, 2021; Hao, Duan, Guo, Wu, & Ren, 2023). Its contribution extends beyond technology itself: Previous research indicates that the digital economy supports a shift toward more sustainable forms of economic development, helping countries move more quickly toward carbon peaking and their long-term decarbonization goals (Lyu, Yang, Zheng, & Zhang, 2023).

Anti-corruption and the digital economy reinforce one another. As anti-corruption policies strengthen, institutions tend to operate more transparently, administrative obstacles decline, and information moves more easily among public bodies. Together, these changes create a more supportive setting for digital innovation and the broader adoption of digital technologies (Park & Xiao, 2021). Digital governance applications, especially those used in public administration and government services, also contribute in the other direction by promoting transparency, reinforcing accountability, and improving the overall effectiveness of environmental governance.

The discussion above suggests that anti-corruption efforts and digital economy development belong within the same policy conversation. Stronger institutional integrity can support digital transformation, while a growing digital economy, in turn, may improve transparency, accountability, and governance quality. Together, these areas are expected to strengthen environmental governance and help reduce carbon emissions more effectively (Hao et al., 2023; Park & Xiao, 2021; Zhang et al., 2024).

Although research on corruption, digitalization, and environmental sustainability has grown substantially, several important questions remain open. Most earlier studies have treated these subjects separately, leaving limited evidence about how anti-corruption efforts reduce carbon emissions through the development of the digital economy.

Less is known about whether this connection operates through mediating mechanisms, varies across stages of digital economy development, or differs across countries with different institutional and economic conditions. These gaps make it difficult to fully understand how digital economy development can improve the environmental impact of anti-corruption policies (He, Chen, & Zhang, 2024; Lyu et al., 2023; Sundström et al., 2024). Based on the research gaps outlined above, this study asks three questions:

RQ1. How does anti-corruption affect carbon emissions across countries?

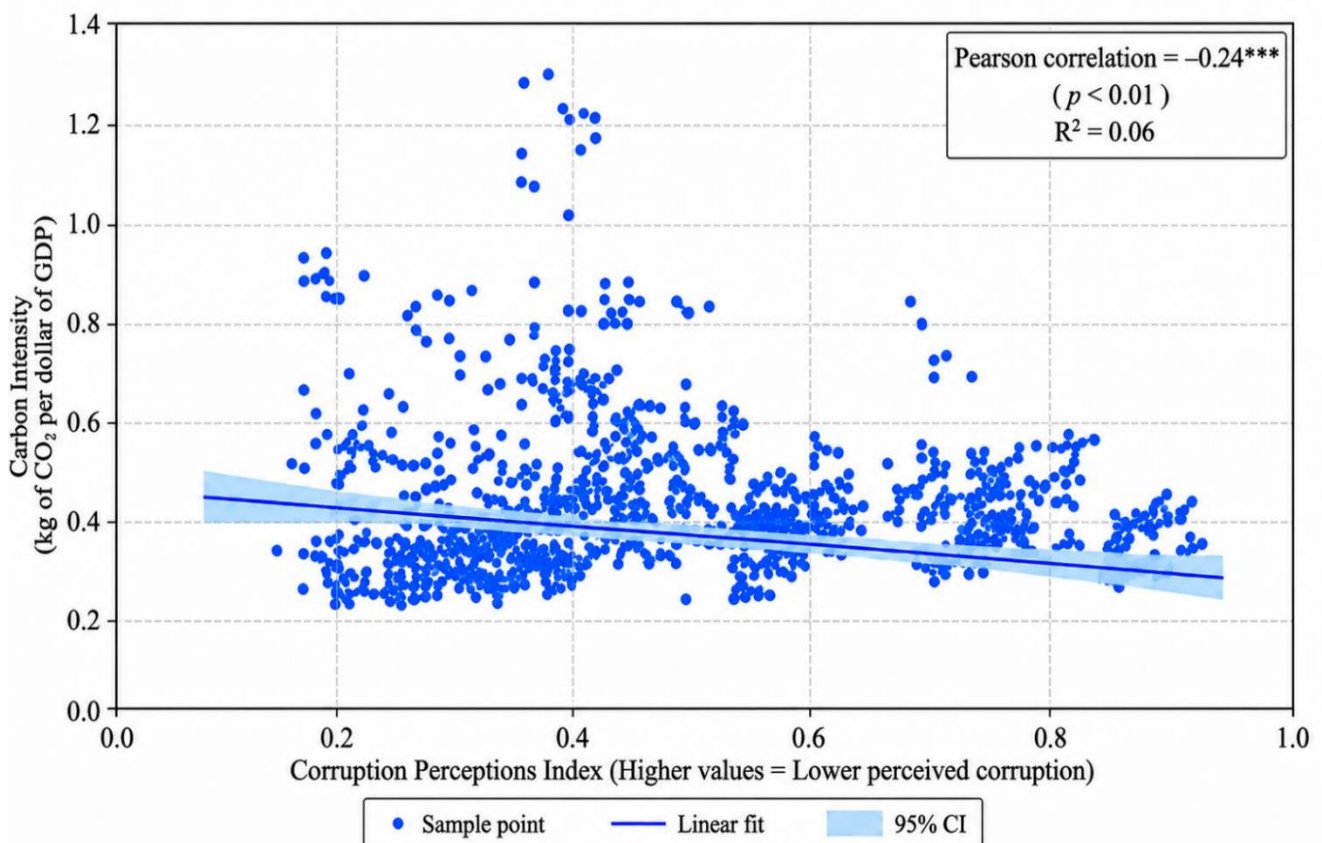
RQ2. Does digital economy development mediate the relationship between anti-corruption efforts and carbon emissions?

RQ3. Does digital economy development enhance the impact of anti-corruption on carbon emissions through threshold effects?

To answer these research questions, this study examines how recent changes in the digital economy affect the relationship between anti-corruption efforts and carbon emissions. It pays particular attention to whether the development of the digital economy improves the environmental effectiveness of anti-corruption efforts amid the rapid global spread of digital technologies over the past decade. The analysis covers 2012–2022, a period that reflects eleven years of accelerated digital transformation and institutional development across countries. The period also provides internationally comparable data for every variable in the analysis, supporting an empirical assessment of the links among anti-corruption efforts, digital economy development, and carbon emissions.

Because countries differ substantially in digital economy development, corruption patterns, and carbon emission performance (He et al., 2024; United Nations Conference on Trade and Development, 2024), the analysis draws on an international panel of 121 countries. These countries span a range of economic, institutional, and developmental contexts, making the sample suitable for examining whether the relationship between anti-corruption and carbon emissions changes with countries' levels of digital economy development.

To meet these objectives, the study uses an empirical framework built on a global panel dataset spanning 2012 to 2022. The analysis combines stepwise and threshold regressions with mediation and heterogeneity analyses, along with robustness tests. It examines the direct effect of anti-corruption measures on carbon emissions and assesses whether, and to what extent, digital economy development strengthens this relationship at different levels of digital development.



Note: The figure shows the relationship between carbon intensity and the Corruption Perceptions Index for 121 countries, 2012–2022. *** indicates significance at the 1% level.

Figure 1: Relationship between Anti-corruption and Carbon Intensity (2012–2022)

LITERATURE REVIEW

Corruption and Carbon Emissions

The connection between corruption and carbon emissions has attracted increasing interest in environmental economics and sustainable development. Corruption may undermine environmental governance, make policies less effective, and skew economic development (Mohammad Mafizur Rahman & Alam, 2022; Tacconi & Williams, 2020). Research to date suggests that its effects on emissions operate through several institutional and economic channels, including environmental protection, industrial production, economic development, resource allocation, policy implementation, and the enforcement of environmental regulations (Xie, Cui, Ren, & Li, 2023).

A growing body of empirical evidence shows that corruption undermines environmental sustainability by weakening environmental protection and accelerating environmental degradation. For instance, Asif, Sabir, and Qayyum (2024) reported that higher levels of corruption and political instability are associated with greater environmental degradation and increased carbon emissions across different regions. Comparable findings have also been documented in the industrial sector, where corruption weakens environmental oversight, reduces energy efficiency, and ultimately contributes to higher industrial greenhouse gas emissions (Pei, Zhu, & Wang, 2021).

Beyond its direct environmental impacts, corruption also influences carbon emissions indirectly through its adverse effects on economic development and resource allocation. Zhang, Jin, Chevallier, and Shen (2016) found that corruption lowers GDP per capita and delays the turning point of the Environmental Kuznets Curve (EKC), thereby indirectly contributing to higher carbon emissions. Xie et al. (2023) further reported that corruption distorts resource allocation, reduces production efficiency, and ultimately leads to increased carbon emissions.

Additional evidence indicates that corruption contributes to higher carbon emissions by weakening both the implementation and enforcement of environmental regulations. Chen, Hao, Li, and Song (2018) found that corruption undermines the effectiveness of environmental policies, resulting in higher levels of pollutant emissions. Consistent with these findings, Tacconi and Williams (2020) showed that greater involvement of public officials in corrupt practices weakens regulatory enforcement, which in turn contributes to higher carbon emissions and broader environmental pollution.

In addition to strengthening regulatory enforcement, anti-corruption policies represent an important institutional mechanism for improving environmental performance. Tacconi and Williams (2020) and Xie et al. (2023) argued that stronger anti-corruption efforts enhance environmental governance and reduce carbon emissions by limiting opportunities for corrupt practices. Consistent with this perspective, He et al. (2024) found that anti-corruption reinforces the alignment between government environmental objectives and firms' green innovation, thereby increasing firms' capacity to adopt environmentally friendly technologies and ultimately contributing to lower carbon emissions.

Recent institutional evidence further supports the theoretical argument that anti-corruption measures strengthen environmental governance by improving regulatory enforcement, reducing opportunities for bribery and rent-seeking, and enhancing the effectiveness of market-based environmental policies. France's Sapin II Law illustrates how regulatory reforms can strengthen corporate transparency and accountability, while China's anti-corruption campaign demonstrates that limiting opportunities for firms to obtain environmental exemptions through corrupt practices can encourage greater investment in green innovation. These institutional experiences provide additional theoretical support for the role of anti-corruption in improving environmental governance and reducing carbon emissions (Chen, Chen, Lin, Tang, & Ye, 2022; He et al., 2024; Tacconi & Williams, 2020).

Taken together, the existing literature consistently indicates that corruption is positively associated with carbon emissions through a range of institutional, regulatory, and economic channels. These findings collectively suggest that stronger anti-corruption efforts can improve the implementation of environmental

policies and support long-term carbon emissions reduction (Akhbari & Nejati, 2019; Asif et al., 2024; Mohammad Mafizur Rahman & Alam, 2022).

The Digital Economy and Carbon Emissions

The link between the digital economy and carbon emissions has drawn growing attention in recent years, as digital transformation reshapes production systems, energy consumption, and environmental sustainability. Evidence to date suggests that the digital economy does not have a consistent environmental effect. Under different technological, industrial, and institutional conditions, it may raise carbon emissions or help reduce them (Liu & Wang, 2025).

The expansion of the digital economy can raise carbon emissions as information and communication technologies (ICT) and digital infrastructure grow, increasing electricity demand and overall energy consumption (Salahuddin & Alam, 2015). At the same time, substantial research indicates that digital economy development may lower emissions by making production more efficient, encouraging technological innovation, and supporting sustainable economic development (Hao et al., 2023; Zhou et al., 2024). Lyu et al. (2023), for example, found that it reduces carbon emission intensity and brings forward the turning point of the Environmental Kuznets Curve (EKC), helping shift economic growth toward higher quality.

Firm-level research provides additional support for this relationship. Wang, Gong, and Yang (2024) found that the digital economy encourages low-carbon innovation and makes carbon emissions trading policies more effective, confirming its role as a key driver of environmentally sustainable production.

Comparable evidence appears at the city level. In their 2024 study, Hou, Li, and Zhang (2024) found that digital economy development improves carbon emission efficiency by encouraging green technological innovation, reshaping the energy structure, and generating positive spatial spillovers among cities.

The literature also points to digital finance and environmental regulation working together to support green innovation. Hu, Dai, and Zhao (2022) found that environmental regulations significantly strengthen the effect of digital finance on green technological innovation, which in turn helps reduce carbon emissions. Xiao, Wu, Liu, and Lin (2023) similarly reported that the digital economy's environmental benefits vary by region. Its carbon-reduction effects were stronger in both resource-based and non-resource-based cities, pointing to substantial regional differences.

The literature further suggests that transparent governance, effective public administration, and a predictable regulatory environment are important institutional conditions for digital economy development. Anti-corruption measures contribute to strengthening these institutional conditions by improving market transparency, reducing opportunities for bribery and preferential treatment, and enhancing trust between governments and firms. Consequently, stronger institutional quality encourages digital investment, technological innovation, and the expansion of digital economy activities, providing a theoretical explanation for the role of digital economy development in reducing carbon emissions (Munshi & Manni, 2025; Dou, Lu, & Hongqing, 2025; Iorio & Segnana, 2025; Xu & Yang, 2024).

Taken together, the existing literature consistently demonstrates that digital economy development supports the transition toward sustainable development by improving energy efficiency, fostering green innovation, and enhancing the effectiveness of environmental policies, ultimately contributing to lower pollution levels and reduced carbon emissions.

Research Gaps and Limitations

Although the link between anti-corruption policies (ACP) and carbon emissions has attracted growing attention, earlier research has largely interpreted it through familiar channels, including environmental regulation, resource allocation, and economic development. Much less research, however, has examined whether digital economy development affects how effectively anti-corruption efforts reduce carbon emissions.

Another limitation lies in how empirical research addresses the digital economy. Most existing studies still rely mainly on conventional controls, such as GDP, urbanization, and economic openness. By contrast, the digital economy is usually added as an additional control rather than examined as a mechanism through which

effects are transmitted. Consequently, evidence remains limited regarding the direct and indirect pathways through which digital economy development shapes the relationship between anti-corruption and carbon emissions.

Recent studies have used mediation and threshold models to examine carbon emissions, but they have largely relied on broad measures of development, such as the Human Development Index (HDI), to characterize countries' development levels. These indicators provide a general picture of socioeconomic conditions. They do not, however, adequately show how digital economy development shapes institutional and environmental outcomes or whether its effects vary across different stages of digital development (Sun et al., 2024; Zhang et al., 2024).

Another limitation concerns the breadth of the available evidence. Research on anti-corruption and carbon emissions has grown considerably, yet relatively few studies examine this relationship using comprehensive international datasets that reflect substantial cross-country differences in institutional quality and digital economy development. Instead, most empirical analyses draw on local or regional samples, concentrating on individual cities, particular regions, or a limited set of countries. This narrow coverage limits the external validity of the findings and makes it harder to generalize them to countries with different institutional, economic, and developmental characteristics.

Research Contributions

This study contributes to the literature on anti-corruption and carbon emissions by explicitly incorporating the digital economy into its analytical framework. Unlike earlier studies, which have primarily focused on conventional channels linking anti-corruption to environmental outcomes, the present analysis investigates whether digital economy development functions as a mediating mechanism through which anti-corruption efforts contribute to reducing carbon emissions.

The analysis further incorporates four complementary dimensions of the digital economy, telecommunications infrastructure, e-participation, internet development, and digital economy integration, to provide a more comprehensive assessment of the mechanisms linking anti-corruption and carbon emissions. By integrating these complementary dimensions within a unified empirical framework that captures both mediation and threshold effects, the study offers a comprehensive understanding of the linear and nonlinear mechanisms through which digital economy development shapes the relationship between anti-corruption and carbon emissions across countries.

Given the considerable cross-country variation in telecommunications infrastructure, e-government, and digital development, the study further explores whether the environmental effectiveness of anti-corruption efforts differs across various stages of digital economy development. To capture this potential nonlinear relationship, a panel threshold model is employed to determine whether the impact of anti-corruption on carbon emissions changes once digital economy development reaches specific threshold levels.

THEORETICAL MECHANISMS AND RESEARCH HYPOTHESES

The Impact of Anti-Corruption Measures on Carbon Emissions

Building on the theoretical and empirical evidence discussed in the literature, anti-corruption measures are expected to reduce carbon emissions by strengthening environmental governance and improving the effectiveness of environmental policies. By limiting corruption-related distortions in policy implementation and resource allocation, anti-corruption efforts create institutional conditions that support more effective environmental regulation and sustainable economic activities.

Moreover, anti-corruption measures enhance the effectiveness of environmental policies by improving the joint governance of carbon emissions and smog, as evidenced by low-carbon city initiatives (Li, Bai, & Tang, 2022). They also strengthen cooperation between governments and markets, promoting a more efficient allocation of public resources and creating conditions that support green technological innovation (He et al.,

2024; Tacconi & Williams, 2020). Collectively, these mechanisms suggest that stronger anti-corruption efforts contribute directly to reducing carbon emissions. Based on this theoretical reasoning, the following hypothesis is proposed.

H₁: Anti-corruption efforts contribute directly to reducing carbon emissions.

The Mediating Role of the Digital Economy in the Relationship Between Anti-Corruption and Carbon Emissions

Building on the theoretical and empirical evidence presented in Section 2.2, anti-corruption efforts are expected to promote digital economy development by strengthening institutional conditions that support technological innovation, digital investment, and market efficiency. Through these institutional improvements, anti-corruption efforts may indirectly contribute to reducing carbon emissions by facilitating the expansion and effectiveness of the digital economy (Munshi & Manni, 2025; Dou et al., 2025).

One important mechanism through which anti-corruption influences digital economy development is the institutional relationship between governments and firms engaged in digital activities (Dou et al., 2025). In highly corrupt environments, preferential treatment, bribery, and unequal access to public resources distort market competition and weaken incentives for technological innovation. Consequently, firms developing advanced digital technologies may face greater regulatory uncertainty and administrative barriers, increasing transaction costs and discouraging digital investment and innovation (Iorio & Segnana, 2025).

A corrupt institutional environment also distorts firms' investment decisions by encouraging the pursuit of political support and administrative privileges rather than productive and innovative activities. As a result, resources are diverted away from research, development, and technological innovation, reducing resource allocation efficiency and weakening trust between firms and public institutions. These institutional distortions ultimately constrain digital economy development (Ngoc & Dang, 2026; Xu & Yang, 2024).

Institutional distortions also affect the regulatory environment. Corruption can increase administrative barriers and regulatory uncertainty for multinational telecommunications companies and digital infrastructure projects, discouraging investment and slowing the expansion of digital economy activities (OECD, 2026b). Conversely, anti-corruption policies enhance transparency and promote information exchange both within and across institutions, fostering a more supportive environment for digital transformation and technological development (Business at OECD, 2022; Le Thanh, 2022).

Beyond its institutional contributions, digital economy development can also reduce carbon emissions through multiple technological mechanisms (Liu & Wang, 2025; Zhou et al., 2024). Digital technologies improve production efficiency, optimize resource utilization, and enhance forecasting accuracy, helping to reduce unnecessary energy consumption and carbon emissions (Ma, Li, Zhang, & Wang, 2024). One prominent example is the Internet of Things (IoT), which enables real-time monitoring of production processes, allowing firms to improve operational efficiency and energy management (Ma et al., 2024; Pittri et al., 2025). In addition, integrating IoT with deep learning techniques enhances environmental forecasting and supports the development of more effective environmental regulations and carbon reduction strategies (Mohandas, Subramanian, & Surendran, 2025).

Digital economy development also contributes to lower carbon emissions by facilitating structural transformation and technological innovation. Digital technologies improve energy production efficiency, support the transition toward cleaner energy systems, and promote more sustainable industrial development (Lyu et al., 2023; Shahbaz, Wang, Dong, & Zhao, 2022). In addition, the rapid expansion of artificial intelligence (AI) further strengthens these environmental benefits by improving renewable energy management, optimizing production processes, and supporting investment decisions that accelerate the transition toward cleaner energy systems (Liu & Wang, 2025; Zinoviev, Koeva, Tsankov, & Kutkarska, 2026).

Taken together, these institutional and technological mechanisms provide a theoretical basis for expecting digital economy development to mediate the relationship between anti-corruption efforts and carbon emissions. Based on this reasoning, the following hypothesis is proposed.

H₂: Anti-corruption efforts contribute to reducing carbon emissions through digital economy development, particularly by strengthening telecommunications infrastructure, e-participation, and internet development.

Analysis of the Impact of the Digital Economy on the Relationship Between Anti-Corruption and Carbon Emissions

The effectiveness of anti-corruption policies in reducing carbon emissions is unlikely to be uniform across countries because it depends on the level of digital economy development. As digital technologies become more deeply integrated into public administration, market activities, and regulatory systems, they strengthen the institutional capacity required for anti-corruption policies to achieve their environmental objectives (Tacconi & Williams, 2020).

Digital economy development enhances the implementation of anti-corruption policies by improving transparency, facilitating information exchange, and increasing the efficiency of administrative and regulatory processes (Munshi & Manni, 2025; Business at OECD, 2022). Consequently, the environmental benefits of anti-corruption are expected to become stronger as digital economy development advances.

Digital economy development enhances public oversight by expanding access to government information and increasing the transparency of administrative processes (United Nations Development Programme, 2024; Zhao & Du, 2025). E-government systems facilitate the digital integration and public disclosure of government information, exposing administrative procedures to greater public scrutiny and reducing opportunities for corrupt practices (Castro & Lopes, 2023; Santiso, 2022). In addition, wider internet access accelerates the dissemination of information, making corrupt practices more visible and strengthening the effectiveness of public oversight and electronic disclosure (Santiso, 2022; Zhao & Du, 2025).

The continued expansion of digital economy applications further strengthens anti-corruption efforts by improving access to knowledge and supporting human capital development through digital learning platforms (United Nations Conference on Trade and Development, 2024). Digital technologies enable educational institutions to broaden learning opportunities, reduce barriers to knowledge acquisition, and improve both educational participation and quality (Bond, Bedenlier, Marín, & Händel, 2024; OECD, 2025). Together, these developments create a more supportive institutional environment that promotes transparency, accountability, and anti-corruption practices.

As digital economy development progresses, these institutional and technological improvements are expected to enhance the effectiveness of anti-corruption policies. Consequently, the environmental impact of anti-corruption is unlikely to remain constant across countries; instead, it is expected to become stronger as digital economy development reaches higher levels. This pattern suggests the existence of a threshold effect in the relationship between anti-corruption and carbon emissions (Dou et al., 2025; Sun et al., 2024). Based on this theoretical rationale, the following hypothesis is proposed.

H₃: The effect of anti-corruption on carbon emissions varies across different levels of digital economy development, indicating the existence of a threshold effect.

RESEARCH DESIGN

Model Setup

Reference Regression Model

Following Lu and Wu (2025), this study employs a stepwise regression approach to estimate the baseline regression models. This approach allows control variables to be introduced sequentially across the estimated models to examine the robustness and stability of the relationship between anti-corruption and carbon emissions. All baseline regressions were estimated using Stata/MP 17.0 with robust standard errors to account for potential heteroskedasticity. Accordingly, the baseline regression model is specified as follows:

$$CO_{2it} = \beta_0 + \beta_1 ACP_{it} + \beta_2 Control_{it} + \pi_i + \gamma_t + \varepsilon_{it} \quad (1)$$

Where CO_{2it} represents the carbon emissions intensity of country i in year t ; ACP_{it} denotes the level of anti-corruption in country i during year t ; $Control_{it}$ represents the vector of control variables, including energy use per capita (EU), GDP per capita (GDP), trade openness (OP), and the degree of urbanization (UR); β_0 is a

constant term; β_1 denotes the coefficient associated with the core explanatory variable; π_i is a country-fixed effect; γ_t is a year-fixed effect; and ε_{it} is a random error term.

Modeling of Channel Mechanisms (Intermediate Effects)

To test the second hypothesis (H2), this study adopts the stepwise mediation approach proposed by Baron and Kenny (1986) in conjunction with the procedure developed by Wen and Ye (2014) to examine the mediating role of the digital economy.

The first step estimates each mediating variable as a dependent variable to examine whether anti-corruption influences the different dimensions of the digital economy, namely telecommunications infrastructure, e-participation, and internet penetration.

The second step employs carbon emissions (CE) as the dependent variable and incorporates each mediating variable into the regression model to examine whether the digital economy influences carbon emissions. The stepwise mediation approach enables an independent examination of each digital economy dimension, thereby providing a clearer understanding of the mediating mechanisms through which anti-corruption affects carbon emissions. Accordingly, the following models are specified:

$$M_{it} = \phi_0 + \phi_1 ACP_{it} + \phi_2 Control_{it} + \pi_i + \gamma_t + \delta_{it} \quad (2)$$

$$CO_{2it} = \tau_0 + \tau_1 ACP_{it} + \tau_2 Control_{it} + \tau_3 M_{it} + \pi_i + \gamma_t + \mu_{it} \quad (3)$$

Where M_{it} represents the mediating variables of the digital economy, including telecommunications infrastructure (TII), e-participation (EPI), and internet penetration (IU). ϕ_1 measures the effect of anti-corruption (ACP) on each digital economy dimension; ϕ_0 is a constant term; δ_{it} is a random error term; τ_1 measures the direct effect of ACP on carbon emissions, while τ_3 captures the mediating effect of each digital economy dimension on the relationship between ACP and carbon emissions; τ_0 is a constant term; μ_{it} is a random error term.

Threshold Effect Model

To examine whether digital economy development has a threshold effect on the relationship between anti-corruption measures and carbon emissions, this study employs a panel threshold regression model. The analysis considers four dimensions of digital economy development as threshold variables: telecommunications infrastructure (TII), e-participation (EPI), internet penetration (IU), and the Digital Economy Synthesis Index (DES).

The theoretical foundation of this approach draws on the Diffusion of Innovation Theory, which proposes that the benefits of new technologies become more pronounced only after they achieve sufficient levels of diffusion and adoption within society. Consistent with this perspective, the threshold regression model makes it possible to identify the critical levels of digital economy development at which the effect of anti-corruption on carbon emissions changes significantly. Moreover, this approach avoids relying on arbitrary classifications of countries according to their levels of digital development by allowing the threshold values to be determined endogenously from the data. The threshold models are estimated using the xthreg command, with statistical inference based on 500 bootstrap replications to obtain robust threshold estimates. Accordingly, the following threshold regression model is specified.

$$CO_{2it} = \partial_0 + \partial_1 ACP_{it} \times I(Digit_{it} \leq \theta) + \partial_2 ACP_{it} \times I(Digit_{it} > \theta) + \partial_3 Control_{it} + \pi_i + \gamma_t + \sigma_{it} \quad (4)$$

Where $I(\cdot)$ denotes the threshold indicator function, $Digit_{it}$ represents the threshold variable measuring the level of digital economy development, including telecommunications infrastructure (TII), e-participation (EPI), internet penetration (IU), and the Digital Economy Synthesis Index (DES). θ denotes the estimated threshold value. ∂_1 and ∂_2 represent the effects of anti-corruption on carbon emissions below and above the estimated threshold, respectively. ∂_3 denotes the coefficients of the control variables, while ∂_0 represents the constant term. π_i denotes the country fixed effects, γ_t represents the year fixed effects, and σ_{it} is the error term.

Data Description and Sources

Owing to differences in data availability and collection periods across countries, this study employs a balanced panel dataset covering 121 countries over the period 2012–2022. The sample spans all continents, providing broad global coverage. To enhance the representativeness of the sample, the selected countries account for an average of approximately 82.3% of global carbon dioxide (CO₂) emissions and 84.7% of global gross domestic product (GDP) over the study period. The geographical distribution of the sampled countries is presented in Appendix A.

The data were compiled primarily from the World Bank, the United Nations, and databases maintained by relevant international organizations (United Nations, 2024; World Bank, 2025). Information on the Corruption Perceptions Index (CPI) was obtained from the annual reports published by Transparency International (Transparency International, 2024), while data on energy use per capita (EU) were sourced from the U.S. Energy Information Administration (EIA) (U.S. Energy Information Administration, 2025).

To enhance data comparability across countries, the Corruption Perceptions Index (CPI) was adopted as the measure of anticorruption, while foreign direct investment (FDI) net inflows as a percentage of GDP served as the proxy for economic openness. The urbanization rate was measured as the proportion of the population living in urban areas, divided by 100; energy use per capita was rescaled by dividing the original values by 10,000; and GDP per capita was transformed using the natural logarithm. The logarithmic transformation of GDP per capita was applied to reduce the skewness of income data and improve cross-country comparability, whereas the rescaling of energy use per capita was intended to improve numerical stability and facilitate coefficient interpretation without altering the underlying relationships among the variables.

Missing observations were addressed through linear interpolation, whereas variables reported in alternate years were completed using mean imputation. The main variables included in this study are presented below.

This approach was adopted because the cross-country dataset was compiled from multiple international sources with different reporting frequencies and data availability. Linear interpolation was applied only to limited missing observations in time-series variables that exhibited relatively stable year-to-year changes, thereby preserving the balanced panel structure of the dataset. Mean interpolation was applied exclusively to indicators reported in alternate years to maintain consistency across the observation period. Although these approaches may smooth short-term fluctuations and may not fully capture abrupt changes, they were considered appropriate for the present study because the primary objective was to preserve the balanced panel structure and ensure cross-country comparability. More advanced imputation methods, such as multiple imputation, were not adopted because they generally require stronger distributional assumptions and were not considered necessary for the present study.

The Dependent Variable

Carbon intensity, measured as carbon dioxide (CO₂) emissions per unit of GDP, is used as the dependent variable representing carbon emissions, following Dou et al. (2025). Carbon intensity is particularly suitable because it accounts for differences in economic size while reflecting environmental performance relative to economic output.

Explanatory and control variables

The Corruption Perceptions Index (CPI) serves as the principal explanatory variable, following Dou et al. (2025). As one of the most widely used indicators in the anti-corruption literature, the CPI provides a comparable and consistently measured proxy for the level of anti-corruption across countries (Table 1).

Table 1: Descriptive statistics of variables

Type	Variables	Hidden meaning	Average value	Standard error	Minimum	Maximum
ACP	ACP	Anti-corruption measured using the CPI	0.44	0.01	0.14	0.93
CE	CO ₂	Kilograms of CO ₂ emitted per dollar of GDP	0.23	0.00	0.03	1.31
Control	GDP	GDP per capita	8.71	0.04	5.49	11.78
Control	OP	Foreign direct investment, net inflows as share of GDP	0.06	0.00	-0.45	2.34
Control	EU	Energy use per person (kWh per person)	2.95	0.13	0.02	25.11
Control	UR	Share of the population living in urban areas	0.63	0.01	0.10	1.00
DE	EPI	E-Participation Index	0.49	0.01	0.01	1.00
DE	TII	Telecommunications infrastructure index	0.40	0.01	0.01	1.00
DE	IU	Share of the population using the Internet	58.42	0.95	1.08	100.00
DES	FB	Fixed broadband subscription (per 100 people)	15.62	0.45	0.00	52.43
DES	IT	Fixed telephone subscription (per 100 people)	4.88	2.97	-2.05	12.74
DES	GSM	Mobile cellular subscriptions (per 100 people)	114.83	1.08	14.02	228.46
DES	ICTP	ICT goods exports (% of total goods exports)	3.51	0.22	0.00	53.72
DES	ICTS	ICT service exports (% of total service exports)	10.44	0.37	0.00	64.93
DES	SI	Secure internet servers (per 1 million people)	4.89	2.35	-4.11	10.84
DES	DD	Exports of digitally deliverable services as a percentage of total services exports (%)	29.76	0.69	1.26	91.37
DES	EGDI	E-Government Development Index	0.31	0.01	0.01	0.89

GDP per capita (GDP) is incorporated as a control variable because the level of economic development is closely associated with carbon emissions. As economies develop, structural transformation and technological progress may gradually reduce carbon emission intensity after certain stages of development, consistent with the Environmental Kuznets Curve (Dou et al., 2025).

Energy use per capita (EU) is included to capture the direct effects of energy demand and economic activity, both of which are closely linked to carbon emissions and environmental performance (Dou et al., 2025).

Trade openness (OP), proxied by foreign direct investment (FDI) as a percentage of GDP, is incorporated to account for the potential environmental effects of international investment. While FDI may increase carbon emissions through industrial expansion, it can also facilitate cleaner production by promoting technology transfer (Zhang et al., 2024).

Urbanization (UR), measured as the ratio of the urban population to the total population, is controlled for because urban expansion and industrial concentration can substantially influence carbon emissions (Wang, Liu, Liao, & Wei, 2021).

Mediating Variables

The Telecommunications Infrastructure Index (TII), the E-Participation Index (EPI), and Internet users per 100 people (IU) are employed as mediating variables representing digital economy development (DE), following the empirical framework of Dou et al. (2025) and the official indicators reported in the United Nations E-Government Survey (United Nations, 2024) and the World Development Indicators database (World Bank, 2025).

The Telecommunications Infrastructure Index (TII) captures a country's digital infrastructure, including telecommunications services, broadband networks, and digital connectivity (United Nations, 2024).

The E-Participation Index (EPI) assesses the extent to which governments use digital technologies to encourage public participation in decision-making and strengthen digital governance (OECD, 2025; United Nations, 2024).

Internet users per 100 people (IU) are used to represent internet development levels.

Threshold Variables

Consistent with Zhou et al. (2024) and Ran, Wang, Wang, and Hua (2023), the Telecommunications Infrastructure Index (TII), the E-Participation Index (EPI), internet users per 100 people (IU), and the Digital Economy Synthesis Index (DES) are employed as threshold variables to capture different dimensions of digital economy development.

To construct the Digital Economy Synthesis Index (DES), the study combines indicators related to digital infrastructure and information and communication technology (ICT) development, including fixed broadband subscriptions, fixed-line telephone subscriptions, mobile telephone subscriptions, ICT product exports, ICT service exports, secure internet servers, and interactive digital services. These data were obtained from the World Bank and the United Nations E-Government Development Index (EGDI).

All indicators were standardized before being aggregated to construct the composite DES index. The resulting index provides a comprehensive measure of digital economy development by capturing multiple dimensions of digital infrastructure and ICT development (Dou et al., 2025).

Compared with individual digital indicators, DES captures the overall level of digital integration across infrastructure, digital services, and ICT development. Therefore, including DES as an additional threshold variable provides a more comprehensive assessment of how different stages of digital economy development condition the relationship between anti-corruption and carbon emissions.

BENCHMARK REGRESSION RESULTS

Table 2 reports the benchmark regression results obtained from stepwise regression models examining the relationship between anti-corruption (ACP) and carbon emissions (CE).

Regarding the core explanatory variable, the results presented in Table 2 indicate that the absolute value of the anti-corruption coefficient increased slightly with the inclusion of additional control variables. As additional control variables were introduced, the anti-corruption coefficient became statistically significant at the 5% level in Models (2) and (5) and remained significant at the 10% level in Models (3) and (4). Overall, the anti-corruption coefficient was negative and statistically significant across all estimated models at the 10% significance level or better.

These findings indicate an inverse relationship between anti-corruption efforts and carbon emissions, suggesting that stronger anti-corruption measures contribute to lower carbon emissions. From an economic perspective, the estimated coefficient in the fully specified model (Model 5) indicates that improvements in the anti-corruption index are associated with lower carbon intensity. Specifically, the estimated coefficient suggests that, all else being equal, a one-unit increase in the anti-corruption index is associated with an average reduction of approximately 0.104 kilograms of CO₂ emissions per dollar of GDP. Although this magnitude should be interpreted within the observed scale of the anti-corruption index, the result demonstrates that stronger anti-corruption efforts can generate measurable improvements in carbon efficiency by reducing the amount of CO₂ emitted for each dollar of economic output. Therefore, the estimated effect is not only statistically significant but also economically meaningful, highlighting the practical environmental benefits associated with stronger anti-corruption efforts.

This negative relationship suggests that enhanced anti-corruption efforts improve environmental governance by limiting practices that weaken regulatory enforcement and distort resource allocation. This

interpretation is supported by He et al. (2024), who argued that anti-corruption initiatives strengthen environmental governance by curbing unlawful practices and improving market transparency. Stronger anti-corruption policies also reduce firms' reliance on informal political connections while facilitating the reallocation of resources toward green technological innovation, ultimately contributing to lower carbon emissions (Chen et al., 2022; Tang, Xu, Zhang, & Peng, 2026). Overall, the empirical evidence supports Hypothesis H1, which proposes that anti-corruption efforts directly contribute to carbon emissions reduction.

Although the estimated coefficient of anti-corruption does not reach the 1% significance level, it remains consistently negative and statistically significant across all model specifications, indicating a stable relationship between anti-corruption and carbon emissions. The relatively lower level of statistical significance suggests that the influence of anti-corruption on carbon emissions may not be fully captured through the direct relationship estimated in the benchmark model alone. This possibility is investigated further in the subsequent mediation analysis.

With respect to the control variables, the coefficient of energy use (EU) reported in Column (2) was positive and statistically significant at the 1% level, indicating that higher energy consumption is associated with increased carbon emissions. This finding is consistent with continued global reliance on fossil fuels, which remain the dominant source of energy worldwide and continue to place upward pressure on carbon emissions despite the rapid expansion of clean energy technologies (IEA, 2025).

The coefficient of gross domestic product per capita (GDP) reported in Column (3) was negative and statistically significant at the 1% level, indicating that higher levels of economic development are associated with lower carbon-emission intensity. This finding supports the view that economic development contributes to lower carbon intensity through improvements in environmental governance, technological progress, and energy efficiency, particularly in economies that have progressively decoupled economic growth from carbon emissions (Gbadeyan, Muthivhi, Linganis, & Deenadayalu, 2024).

The estimated coefficient for trade openness (OP) was positive but statistically insignificant, suggesting that the impact of foreign direct investment (FDI) on carbon emissions may differ across countries because of variations in environmental regulations, industrial structures, and the composition of foreign investment. Although FDI can facilitate the transfer of cleaner technologies, it may also encourage the relocation of pollution-intensive activities to countries with less stringent environmental regulations (Holtbrügge & Raghavan, 2025). The potential bidirectional relationship between FDI and carbon emissions may also contribute to the absence of statistical significance (Mosikari & Xaba, 2025).

The coefficient of the urbanization rate (UR) reported in Column (5) was positive and statistically significant at the 1% level, indicating that urbanization contributes to higher carbon emissions. This outcome reflects the growing demand for energy, infrastructure, and public services accompanying urban expansion, together with structural economic changes that increase resource and energy consumption (Dou et al., 2025).

Table 2: Benchmark regression table

Variables	Model 1 CO ₂	Model 2 CO ₂	Model 3 CO ₂	Model 4 CO ₂	Model 5 CO ₂
ACP	-0.0912* (-1.94)	-0.1098** (-2.37)	-0.0907* (-1.97)	-0.0941* (-2.01)	-0.1036** (-2.28)
EU		0.0135*** (4.02)	0.0181*** (5.19)	0.0180*** (5.16)	0.0158*** (4.48)
GDP			-0.0789*** (-4.21)	-0.0784*** (-4.18)	-0.0758*** (-4.03)
OP				0.0121 (1.19)	0.0114 (1.13)
UR					0.537*** (3.57)
Constant term	0.274*** (13.21)	0.246*** (11.42)	0.901*** (5.78)	0.897*** (5.73)	0.571*** (3.19)
Country fixed	Y	Y	Y	Y	Y

Variables	Model 1 CO ₂	Model 2 CO ₂	Model 3 CO ₂	Model 4 CO ₂	Model 5 CO ₂
Year fixed	Y	Y	Y	Y	Y
N	1331	1331	1331	1331	1331
R ²	0.961	0.962	0.963	0.963	0.964
Adj. R ²	0.956	0.957	0.958	0.958	0.959

Note: t/z statistics are reported in parentheses; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; Y indicates that country and year fixed effects are included.

ROBUSTNESS ANALYSIS

To verify the robustness of the benchmark regression results, three additional robustness tests were conducted. The first test replaced the benchmark dependent variable, carbon intensity, with per capita carbon emissions (CC). The second addressed potential endogeneity using the instrumental variable approach proposed by Song, Pan, Vardanyan, and Shen (2023), in which the one-period lagged anti-corruption index (L.ACP) served as the instrumental variable in a two-stage least squares (2SLS) estimation. As a further robustness check, the 2SLS estimator was re-estimated using each country's official language (LAU) as an alternative instrumental variable. The results reported in Column (1) of Table 3 show that the coefficient of anti-corruption (ACP) remained negative and statistically significant at the 10% level after replacing carbon intensity with per capita carbon emissions (CC). This result indicates that the main findings are robust to alternative measures of carbon emissions. Columns (2) and (3) of Table 3 report the results of the second robustness test based on the two-stage least squares (2SLS) estimator. The one-period lagged anti-corruption index (L.ACP), following Ma, Duan, and Tang (2023) and Zheng et al. (2023), was employed as an instrumental variable to address potential endogeneity arising from omitted variables. The first-stage results reported in Column (2) show that the coefficient of L.ACP was positive and statistically significant at the 1% level, confirming the relevance of the selected instrumental variable. Moreover, the first-stage F-statistic of 571.89 exceeds the conventional threshold of 10, supporting the strength of the selected instrument and suggesting that it is unlikely to suffer from the weak-instrument problem. The second-stage results reported in Column (3) indicate that the coefficient of anti-corruption remained negative and statistically significant at the 1% level. This result is consistent with the benchmark regression findings and provides additional evidence that the estimated relationship between anti-corruption and carbon emissions is robust to potential endogeneity.

Columns (4) and (5) report the results of the third robustness test based on the two-stage least squares (2SLS) estimator. To further address potential endogeneity, the official language of each country (LAU) was employed as an alternative instrumental variable, with English-speaking countries coded as 1 and non-English-speaking countries coded as 0. Following Dou et al. (2025), the official language satisfies the relevance condition because it is associated with institutional and behavioral characteristics that may influence anti-corruption, while it is not expected to exert a direct effect on carbon emissions, thereby satisfying the exogeneity condition.

The first-stage results reported in Column (4) show that the coefficient of the official language variable (LAU) was positive and statistically significant at the 1% level, confirming the relevance of the selected instrumental variable. Moreover, the first-stage F-statistic of 62.63 exceeds the conventional threshold of 10, supporting the strength of the selected instrument and suggesting that it is unlikely to suffer from the weak-instrument problem. The second-stage results reported in Column (5) indicate that the coefficient of anti-corruption remained negative and statistically significant at the 10% level. This result is consistent with the benchmark regression findings and provides further evidence that the estimated relationship between anti-corruption and carbon emissions is robust to potential endogeneity.

Table 3: Robustness test table

Variables	(1) CC	(2) ACP	(3) CO ₂	(4) ACP	(5) CO ₂
ACP	-1.412* (0.861)		-0.214*** (-2.988)		-0.305* (-1.746)
L.ACP		0.637*** (23.914)			
GDP	0.436 (0.354)	0.005 (0.319)	-0.075*** (-3.964)	0.044*** (3.221)	-0.040* (-1.981)
OP	-0.071 (0.191)	0.005 (0.941)	0.012 (1.314)	0.000 (1.471)	0.000 (1.276)
EU	0.966*** (0.068)	0.004* (1.793)	0.019*** (5.248)		
UR	7.603*** (2.887)	0.040 (0.404)	0.357** (2.208)	0.233* (1.954)	0.556*** (3.337)
LAU				0.639*** (7.914)	
Country fixed	Y	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y	Y
Constant term	-3.811 (4.021)				
R ²	0.993				0.030
First-stage F-statistic		571.89		62.63	

Note: t/z statistics are reported in parentheses; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; Y indicates that country and year fixed effects are included.

ADDITIONAL ANALYSIS

Mediation Effect Analysis

To examine whether anti-corruption (ACP) contributes to reducing carbon emissions through digital economy (DE) development, the mediating roles of telecommunications infrastructure (TII), e-participation (EPI), and internet development (IU) were evaluated. The corresponding results are presented in Table 4. Due to variations in data availability for certain mediating indicators across countries and years, the sample sizes (N) vary across the estimated models as a result of standard listwise deletion. Accordingly, each mediation model was estimated using the maximum number of complete observations available for the variables included in that model.

Regarding telecommunications infrastructure, Column (1) reports a positive but statistically insignificant coefficient for anti-corruption. This finding suggests that telecommunications infrastructure development is only marginally affected by anti-corruption efforts, as investment in this sector is primarily driven by large telecommunications companies with substantial financial resources and relatively limited dependence on corruption-related incentives (European Bank for Reconstruction and Development, 2025; OECD, 2026a).

Column (2) reports a positive and statistically significant coefficient for the telecommunications infrastructure index (TII) at the 5% level. This result indicates that expanding telecommunications infrastructure may increase carbon emissions because the construction, deployment, and operation of digital infrastructure require substantial energy inputs, consistent with the findings of Salahuddin and Alam (2015).

Turning to e-participation, Column (3) reports a positive and statistically significant coefficient for anti-corruption at the 1% level. This finding indicates that stronger anti-corruption efforts promote e-participation by strengthening digital interaction between governments and citizens and encouraging greater participation in digital governance. This interpretation is supported by Dou et al. (2025), who identified e-participation as an important dimension of digital economy development fostered by anti-corruption efforts.

Column (4) reports a negative and statistically significant coefficient for the E-Participation Index (EPI) at the 10% level. This result suggests that greater e-participation contributes to lower carbon emissions by improving transparency, strengthening public oversight, and enhancing environmental governance through

digital participation mechanisms. These findings support the view that e-participation constitutes an important channel through which anti-corruption contributes to carbon emission reduction, consistent with Dou et al. (2025).

Table 4: Table for analysis of intermediation effects

Variables	(1) TII	(2) CO ₂	(3) EPI	(4) CO ₂	(5) IU	(6) CO ₂
ACP	0.0361 (0.49)	-0.174*** (-3.48)	0.573*** (3.18)	-0.156** (-2.57)	16.42*** (5.94)	-0.0614 (-1.36)
GDP	-0.0314** (-2.14)	-0.0762*** (-4.09)	-0.0285* (-1.82)	-0.0746*** (-3.98)	0.0388* (1.92)	-0.0712*** (-3.86)
OP	-0.0204 (-1.31)	0.0141 (1.34)	-0.001*** (-3.41)	0.000 (0.72)	-0.311 (-0.50)	0.010 (0.91)
EU	-0.013* (-1.94)	0.017*** (3.93)	0.0241 (1.73)	0.0152*** (3.18)	-0.471** (-2.26)	0.0138*** (3.94)
UR	0.812*** (3.28)	0.451** (2.71)	0.624 (0.91)	0.689*** (2.97)	-1.244 (-0.17)	0.571*** (3.84)
TII	—	0.054** (2.24)	—	—	—	—
EPI	—	—	—	-0.029* (-1.91)	—	—
IU	—	—	—	—	—	-0.004*** (-7.48)
Constant term	-0.781** (-2.58)	0.742*** (3.67)	-0.126 (-0.31)	-0.149 (-1.02)	-57.36*** (-5.11)	0.356* (1.96)
Country fixed	Y	Y	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y	Y	Y
N	1,144	1,144	811	811	1,331	1,331
R ²	0.967	0.953	0.862	0.955	0.983	0.966
adj. R ²	0.962	0.946	0.836	0.947	0.980	0.961

Note: t/z statistics are reported in parentheses; ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; Y indicates that country and year fixed effects are included.

Turning to internet development, Column (5) reports a positive and statistically significant coefficient for anti-corruption at the 1% level. This finding indicates that stronger anti-corruption efforts promote internet development by creating institutional conditions that support digital transformation, consistent with the findings of Park and Xiao (2021).

Column (6) reports a negative and statistically significant coefficient for internet users (IU) at the 1% level. This result indicates that greater internet penetration contributes to lower carbon emissions by facilitating the adoption of digital technologies that improve resource utilization and environmental efficiency, consistent with Zhou et al. (2024).

Although telecommunications infrastructure (TII) exhibited a positive relationship with carbon emissions, both e-participation (EPI) and internet development (IU) remained negatively associated with

carbon emissions. Taken together, these findings suggest that anti-corruption contributes to reducing carbon emissions primarily by strengthening digital participation and internet development.

Overall, the results indicate that anti-corruption contributes to carbon emission reduction by reinforcing selected dimensions of digital economy development, particularly e-participation and internet development. They further suggest that improvements in digital governance and internet development constitute the principal mediating mechanisms through which anti-corruption enhances environmental performance. This interpretation is supported by Park and Xiao (2021), who argued that anti-corruption reforms create institutional conditions that facilitate digital transformation. Accordingly, the empirical evidence supports Hypothesis H2.

Threshold Effect Analysis

To further examine the role of the digital economy (DE) in strengthening the impact of anti-corruption (ACP) on carbon emissions (CE), this study investigated the threshold effects across four dimensions of digital economy development: telecommunications infrastructure (TII), e-participation (EPI), internet development (IU), and the comprehensive digital economy index (DES).

The results reported in Table 5 indicate significant double-threshold effects across the four dimensions of digital economy development. The 95% confidence intervals reported in Table 5 further demonstrate the precision of the estimated threshold values, providing additional support for the reliability of the threshold estimates. Table 6 reports the corresponding threshold regression estimates for each digital economy dimension. The coefficients of the control variables remained stable across all threshold specifications and were consistent with the benchmark regression results.

Below the telecommunications infrastructure (TII) threshold, the relationship between anti-corruption and carbon emissions varied with the level of telecommunications infrastructure development. When telecommunications infrastructure remained at a relatively low level ($TII \leq 0.22$), the carbon-reducing effect of anti-corruption was weak and statistically insignificant, suggesting that limited digital infrastructure constrained the environmental effectiveness of anti-corruption policies. This interpretation is supported by Dou et al. (2025), who likewise reported that the carbon-reducing effect of anti-corruption becomes stronger as digital economy development advances.

As the telecommunications infrastructure index increased, the carbon-reducing effect of anti-corruption became both stronger and more statistically significant. The estimated coefficient increased in absolute magnitude from -0.068 to -0.191 while remaining significant at the 1% level.

These findings suggest that improvements in digital infrastructure enhance the environmental effectiveness of anti-corruption policies. A plausible explanation is that the expansion of digital infrastructure improves transparency, supports e-government applications, and strengthens digital monitoring and public oversight, thereby reinforcing the effectiveness of anti-corruption efforts (Doran et al., 2022; Lee, Park, Ghauri, & Kumar, 2024).

Turning to the e-participation (EPI) threshold, the effect of anti-corruption remained relatively limited when e-participation was low ($EPI \leq 0.34$), with the estimated coefficient being only marginally significant at the 10% level.

As e-participation increased, the impact of anti-corruption became stronger and more statistically significant, with the estimated coefficient increasing in absolute magnitude from -0.063 to -0.186 while remaining significant at the 1% level. These results indicate that higher levels of digital participation enhance the environmental effectiveness of anti-corruption policies by strengthening transparency, public oversight, and government responsiveness.

This finding may be explained by the greater integration of digital technologies into public services, which enhances transparency, improves accountability, and strengthens institutional effectiveness (Darusalam, Janssen, Said, Sanusi, & Omar, 2023). As digital participation expands, public monitoring and government responsiveness become more effective, thereby reinforcing the capacity of anti-corruption policies to reduce carbon emissions.

Table 5: Threshold effect test table

Variables	Number of thresholds	Threshold value	95% Confidence Interval	F-value	P-value	10%	5%	1%
TII	Single threshold	0.22	[0.20, 0.24]	50.84	*0.01	26.441	30.1284	43.9152
	Double threshold	0.55	[0.52, 0.58]	28.93	*0.05	24.9861	29.8745	38.1168
EPI	Single threshold	0.34	[0.31, 0.37]	52.16	0.01	24.1035	31.0847	49.6123
	Double threshold	0.66	[0.63, 0.69]	27.58	0.06	22.9148	27.9863	41.5036
IU	Single threshold	41.27	[39.50, 43.00]	48.02	0.02	27.6642	34.1185	53.4479
	Double threshold	68.41	[66.10, 70.20]	27.11	0.07	25.9934	31.8872	39.4186
DES	Single threshold	0.57	[0.54, 0.60]	50.26	*0.01	26.8741	32.5486	52.9144
	Double threshold	0.67	[0.64, 0.70]	27.35	0.07	25.8647	31.7765	45.2837

Note: * indicate significance at the 10% levels, respectively.

Below the internet development (IU) threshold, the relationship between anti-corruption (ACP) and carbon emissions (CO_2) followed a pattern similar to that observed under the other threshold dimensions. As internet penetration increased, the anti-corruption coefficient became progressively more negative, changing from -0.053 to -0.187 while remaining statistically significant at the 1% level.

These results suggest that higher levels of internet development enhance the environmental effectiveness of anti-corruption policies. Greater internet penetration improves the effectiveness of digital governance mechanisms, particularly e-government systems, by reducing human intervention in administrative processes, strengthening the monitoring of public officials, and increasing the transparency of government operations (Li, Wei, & Ma, 2021). In addition, secure internet environments reinforce these institutional improvements by protecting government information systems and enhancing accountability, thereby increasing the effectiveness of anti-corruption efforts (Ibrahimy, Norta, & Normak, 2024).

Overall, these findings suggest that higher levels of internet development provide a more supportive institutional environment in which anti-corruption policies can more effectively contribute to reducing carbon emissions.

Consistent with the results obtained for the previous threshold dimensions, the anti-corruption coefficient became more negative as the comprehensive digital economy index (DES) increased, changing from -0.073 to -0.176 while remaining statistically significant at the 1% level. This finding suggests that higher levels of overall digital economy development strengthen the environmental effectiveness of anti-corruption policies. The result is consistent with Dou et al. (2025).

The increase in the estimated effect was more pronounced during the transition from low to medium levels of digital economy development than during the transition from medium to high levels. This pattern suggests diminishing marginal governance benefits, whereby improvements in digital economy development generate relatively larger gains in anti-corruption effectiveness at earlier stages of digital development, consistent with Zhang et al. (2024).

Taken together, the threshold results demonstrate that the environmental effectiveness of anti-corruption policies increases as countries progress toward higher levels of digital economy development. While all four dimensions strengthen the relationship between anti-corruption policies and carbon emission reduction, the threshold effects associated with e-participation (EPI) and internet development (IU) emerge at relatively lower levels of digital development, indicating that these dimensions provide earlier institutional support for enhancing the effectiveness of anti-corruption policies. Accordingly, the empirical evidence supports Hypothesis H3.

Although the threshold models report relatively modest R^2 values (0.131–0.133), these values should be interpreted in light of the objective of the threshold analysis. The objective of the threshold analysis is to identify statistically significant regime changes and structural nonlinearities, rather than to maximize overall explanatory power. Carbon emissions are influenced by numerous economic, institutional, technological, and environmental factors that are beyond the scope of the present model. Therefore, the reported R^2 values reflect the partial explanatory power of the threshold specifications.

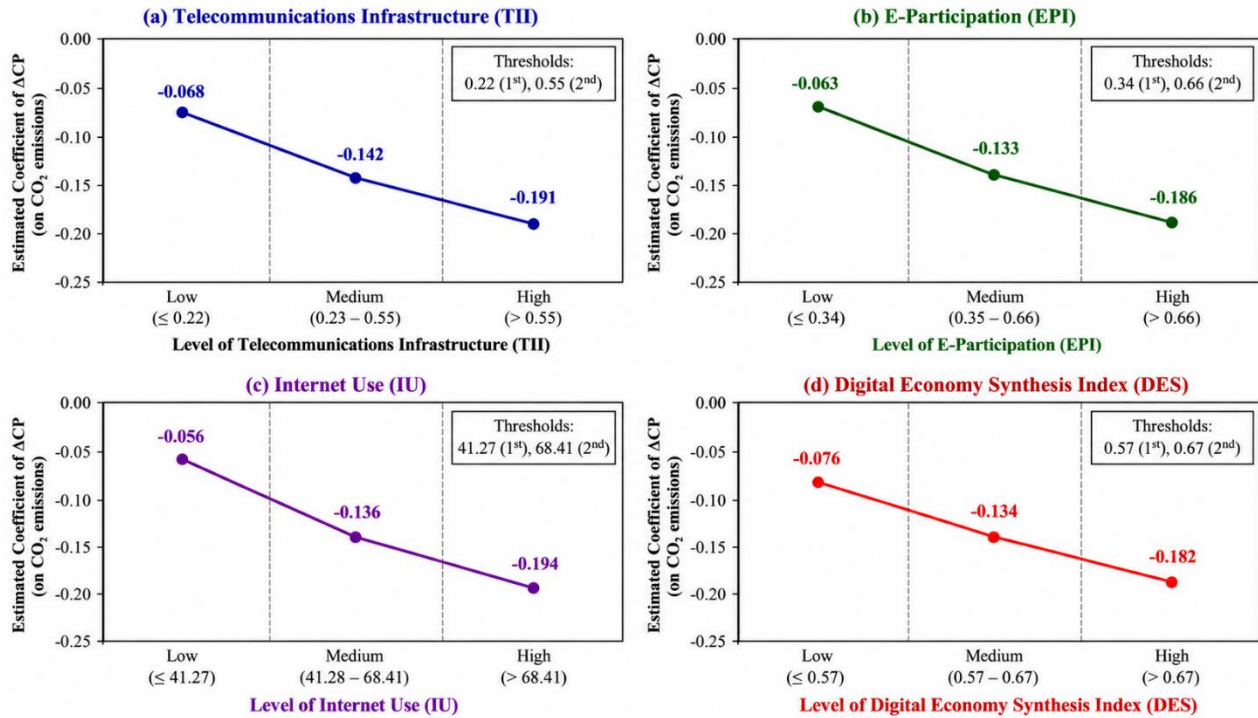


Figure 2: Strengthening Effect of Digital Economy Development on the Impact of Anti-Corruption on Carbon Emissions (Marginal effect of Anti-Corruption (ACP) on CO₂ emissions across threshold regimes)

Note: The figure illustrates the estimated coefficients of Anti-Corruption (ACP) on carbon emissions (CO₂) across three threshold regimes (low, medium, high) for each digital economy dimension. The threshold values are determined using the double-threshold model reported in Table 5. More negative coefficients indicate a stronger carbon-reduction effect of anti-corruption.

Figure 2 illustrates the estimated marginal effects of anti-corruption measures on carbon emissions across the three threshold regimes of digital economy development for each threshold variable. Across all four dimensions, the estimated coefficients become progressively more negative as countries move from low to medium and high levels of digital economy development, indicating that the environmental effectiveness of anti-corruption policies increases with digital development.

The largest marginal effects are observed for Internet Use (IU) and the Digital Economy Synthesis Index (DES), followed by E-Participation (EPI) and Telecommunications Infrastructure (TII). These results suggest that broader digital integration and greater internet development create more favorable institutional conditions for enhancing the carbon-reducing effects of anti-corruption policies. Overall, the figure provides visual support for the threshold regression results, illustrating that the effectiveness of anti-corruption policies increases as countries advance to higher levels of digital economy development.

Table 6: Threshold Effect Analysis Table

Variables	TII (CO ₂)	EPI (CO ₂)	IU (CO ₂)	DES (CO ₂)
GDP	-0.066*** (-2.94)	-0.066*** (-2.95)	-0.065*** (-2.95)	-0.066*** (-2.94)
OP	0.008 (0.75)	0.008 (0.76)	0.008 (0.75)	0.008 (0.76)
EU	0.017*** (4.82)	0.017*** (4.84)	0.016*** (4.81)	0.0162*** (4.83)
UR	0.194* (1.98)	0.193* (1.97)	0.195* (1.99)	0.191* (1.95)
ACP(TII≤0.22)	-0.068 (-1.63)			
ACP(EPI≤0.34)		-0.063* (-1.72)		
ACP(IU≤41.27)			-0.056* (-1.49)	
ACP(DES≤0.57)				-0.076 (-1.69)
ACP(0.23-0.55)	-0.142*** (-3.04)			
ACP(0.35-0.66)		-0.133*** (-3.08)		
ACP(41.28-68.41)			-0.136*** (-3.15)	
ACP(0.57-0.67)				-0.134*** (-2.98)
ACP(TII>0.55)	-0.191*** (-4.71)			
ACP(EPI>0.66)		-0.186*** (-4.88)		
ACP(IU>68.41)			-0.194*** (-4.79)	
ACP(DES>0.67)				-0.182*** (-4.03)
Constant term	0.583*** (-5.31)	0.728*** (-6.37)	0.674*** (-5.28)	0.714*** (-5.42)
Country fixed	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y
N	1331	1331	1331	1331
R ²	0.132	0.133	0.132	0.131
Adj. R ²	0.018	0.017	0.018	0.016

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; t-statistics are reported in parentheses; Y indicates that country and year fixed effects are included.

HETEROGENEITY ANALYSIS

This study investigates heterogeneity in the relationship between anti-corruption (ACP) and carbon emissions (CE) across two dimensions: continents and colonial history. These dimensions were selected because variations in institutional quality, economic development, and digital economy development may influence the effectiveness of anti-corruption policies in reducing carbon emissions. Drawing on a global panel of 121 countries, the heterogeneity analysis provides additional evidence of whether the estimated effects differ across regional and historical contexts.

Colonial history constitutes an important source of institutional heterogeneity because colonial legacies may continue to shape institutional quality, governance capacity, and digital economy development. Previous research indicates that these historical differences influence both the effectiveness of anti-corruption policies and the pace of digital transformation, thereby affecting environmental outcomes (Johnson, 2025; Kwet, 2019). To explore this issue, the analysis compares formerly colonized and non-colonized countries to determine whether historical institutional differences influence the relationship between anti-corruption and carbon emissions.

Countries were classified as former colonies if they had experienced formal colonial rule under a foreign sovereign during the modern colonial period, whereas countries without such historical experience were classified as non-colonized countries. This classification was adopted to capture broad institutional differences associated with colonial legacies rather than to distinguish between specific colonial experiences. Accordingly, the colonial history grouping provides a suitable basis for examining whether the environmental effects of anti-corruption differ across countries with distinct institutional backgrounds.

By contrast, the coefficient of anti-corruption was positive and statistically significant at the 10% level in countries of the Americas. This result indicates that the relationship between anti-corruption and carbon emissions differs across regional contexts and stages of economic development. From the perspective of the Environmental Kuznets Curve (EKC), stronger anti-corruption efforts may improve institutional quality and economic efficiency, thereby stimulating economic activity, industrial production, and energy demand during the early stages of development, before the environmental benefits of improved governance are fully realized. As a result, carbon emissions may increase temporarily despite improvements in governance (Li et al., 2022).

The estimated effect for the Pacific region should be interpreted with caution because this subgroup contains only 22 country-year observations.

Although the Pacific region was included to provide a comprehensive regional comparison, the relatively small sample size may reduce the statistical precision of the estimated coefficients and limit the generalizability of the regional findings. Nevertheless, these estimates remain informative for comparative purposes and provide supplementary evidence regarding regional heterogeneity in the relationship between anti-corruption and carbon emissions.

Regarding colonial history, the coefficient of anti-corruption was positive but statistically insignificant in formerly colonized countries, whereas it was negative and statistically significant at the 5% level in non-colonized countries. These results indicate that colonial legacies may continue to shape the institutional and developmental conditions under which anti-corruption policies operate. Formerly colonized countries may face persistent institutional constraints that weaken the effectiveness of anti-corruption efforts and limit the capacity of digital economy development to support carbon emission reduction. By contrast, non-colonized countries generally exhibit stronger institutional capacity and higher levels of economic and digital development, thereby enhancing the environmental effectiveness of anti-corruption policies (Johnson, 2025; Nothias, 2025).

Overall, the heterogeneity analysis indicates that the impact of anti-corruption measures on carbon emissions is not uniform across countries but varies according to regional and historical characteristics (see Table 7). Taken together, these findings suggest that differences in institutional quality and digital economy development influence both the magnitude and, in some cases, the direction of the environmental effects of anti-corruption policies.

Table 7: Heterogeneity Analysis Table

Variables	Africa	America	Asia	Europe	Pacific	Former colony	Non-former colonial
ACP	-0.188*** (0.061)	0.079* (0.048)	-0.149 (0.112)	-0.244*** (0.068)	-0.142 (0.131)	0.074 (0.060)	-0.121** (0.050)
GDP	0.024 (0.023)	-0.031 (0.027)	-0.029 (0.045)	-0.221*** (0.036)	0.472 (0.392)	-0.095*** (0.028)	-0.067*** (0.020)
OP	0.026 (0.030)	-0.042 (0.057)	0.583*** (0.079)	-0.009 (0.009)	0.241 (0.341)	0.003 (0.014)	0.018 (0.011)
EU	0.172*** (0.027)	0.014*** (0.003)	0.007 (0.006)	0.036*** (0.005)	-0.004 (0.010)	0.027*** (0.008)	0.015*** (0.004)
UR	1.084*** (0.198)	0.021 (0.159)	-0.347 (0.351)	0.986*** (0.309)	13.972 (7.204)	-0.731*** (0.176)	0.951*** (0.178)
Constant term	-0.401 (0.239)	0.301 (0.298)	0.548 (0.451)	3.147*** (0.537)	-18.624 (10.106)	1.502*** (0.319)	0.231 (0.238)
Country fixed	Y	Y	Y	Y	Y	Y	Y
Year fixed	Y	Y	Y	Y	Y	Y	Y
N	385	231	363	319	22	220	111
R ²	0.975	0.997	0.957	0.967	1.000	0.981	0.966

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively; t-statistics are reported in parentheses; Y indicates that country and year fixed effects are included.

MAIN CONCLUSIONS AND PROSPECTS

Conclusions

Despite its contributions, this study has several limitations. Because data are available only for 2012–2022, the analysis cannot fully capture the long-term dynamics connecting anti-corruption, digital economy development, and carbon emissions. The measure of anti-corruption also warrants caution: The Corruption Perceptions Index (CPI) relies primarily on assessments from experts and businesses, so it reflects perceived corruption rather than corruption levels observed directly. Instrumental variables and robustness analyses were used to address endogeneity concerns, but reverse causality cannot be ruled out entirely. Environmental performance may itself shape governance reforms and anti-corruption efforts. While the empirical models contain a range of relevant controls, omitted variable bias remains possible, since unobserved institutional, political, and environmental factors may also influence carbon emissions. Although the study draws on a broad international sample, its findings may not fully reflect the institutional and economic conditions of individual countries. Aggregating the data at the country level can conceal substantial differences within countries in institutional quality, digital economy development, and environmental performance, creating a risk of aggregation bias.

Future studies could cover a longer period and use different measures of anti-corruption and digital economy development, which would help assess how broadly the empirical findings hold. They could also examine how the digital economy improves the environmental effectiveness of anti-corruption policies through other channels, especially institutional governance and technological spillovers. Alternative empirical methods could provide another way to validate the results.

Policy Recommendations

Based on the findings of this study, the following policy recommendations are proposed.

Governments should begin by tightening anti-corruption policies: improving the quality of governance, upholding the rule of law, and strengthening transparency, monitoring, and accountability mechanisms. International cooperation on anti-corruption efforts can also improve environmental governance and contribute to long-term reductions in carbon emissions.

Second, policymakers should bring anti-corruption efforts into closer alignment with digital economy development. Empirical evidence suggests that digital development makes anti-corruption policies more environmentally effective. Expanding e-government services and adopting technologies such as blockchain and artificial intelligence can make public transactions more transparent and traceable while also limiting opportunities for corruption, especially in environmental governance and public administration.

Finally, because the development of the digital economy significantly affects the environmental effectiveness of anti-corruption policies, governments should continue investing in digital infrastructure, expanding internet access, and promoting the use of digital technologies. Where digital development remains relatively low, efforts should focus first on e-government systems, telecommunications infrastructure, and internet accessibility.

Countries with more advanced digital economies should take a different approach by linking digital economy initiatives more closely to anti-corruption strategies and adopting new digital technologies to improve transparency, environmental monitoring, and regulatory effectiveness.

In addition, governments should continue strengthening their strategies to reduce carbon emissions. This means tightening pollution controls, participating more fully in international climate initiatives, and pursuing carbon neutrality without sacrificing sustainable economic growth. Institutional quality and governance capacity matter equally: they can enhance the environmental benefits of digital transformation and help anti-corruption and environmental policies function effectively.

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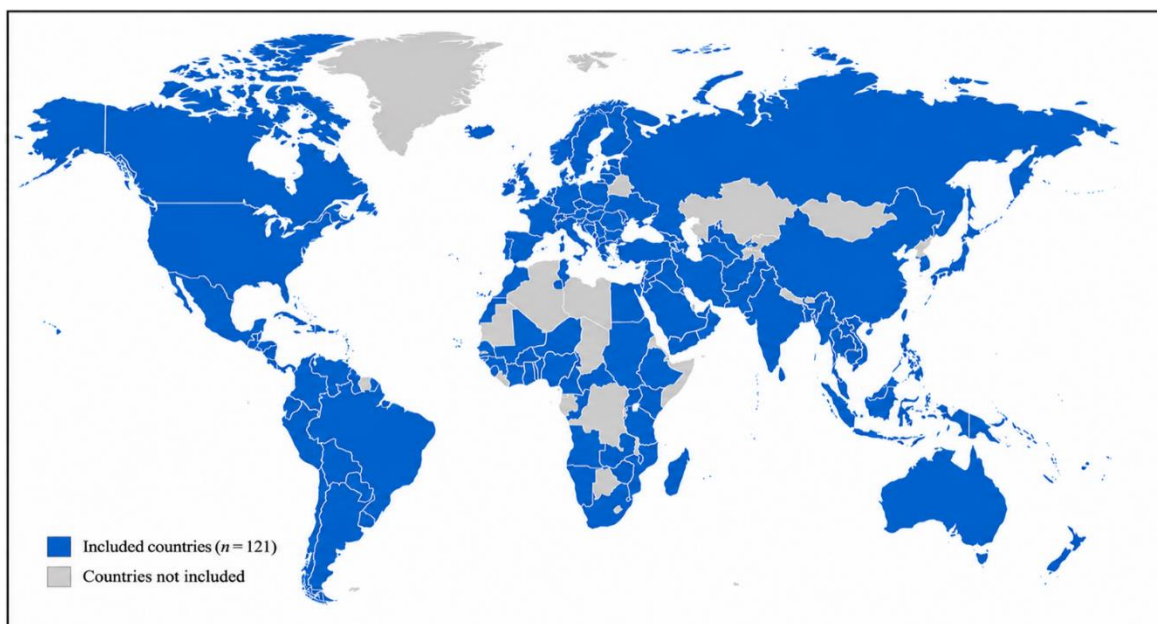
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APPENDICES

Appendix A. Geographical Coverage of the Study Sample.



Note: Countries highlighted in blue were included in the balanced panel dataset, whereas countries shown in light gray were excluded due to incomplete data availability during the study period (2012–2022).

Figure A1: Geographical distribution of the study sample (121 countries), 2012–2022