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Institutional Co-Evolution and Hybrid Regulation in the Digital Economy: A Case Study of BRICS Nations

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Abstract

This study investigates the institutional co-evolution associated with digitalization processes in BRICS countries, emphasizing the development of hybrid regulatory frameworks that integrate state intervention, platform-based self-regulation, and entrepreneurial institutional agency. The primary objective is to analyze how these frameworks operate within heterogeneous governance environments and address the sustainability challenges arising in emerging digital economies. Grounded in the theory of institutional co-evolution, the research applies a mixed-methods design, combining bibliometric mapping, comparative policy analysis, and multiple linear regression on cross-national panel data from Brazil, Russia, India, China, and South Africa (2018 - 2022). The findings demonstrate that increasing levels of digitalization and innovation are significantly correlated with reductions in environmental risks, while GDP growth remains positively associated with CO_2 emissions; underscoring a structural tension between economic expansion and ecological resilience. To address this contradiction, the study proposes and empirically validates an Optimized Hybrid Model of institutional regulation, which improves sustainability indicators by 18.5%. The novelty of this research lies in the operationalization of institutional co-evolution within digital governance, offering a transferable policy model for flexible, adaptive regulation in complex, data-intensive economies. These results contribute to the advancement of institutional theory and provide actionable insights for the governance of transitional digital systems.

Keywords:

Digital Economy; Institutional Co-Evolution; Hybrid Regulation; BRICS Countries; Sustainable Development; Economic Growth and Environmental Risk; Regulatory Adaptation; Institutional Entrepreneurship; Self-Regulation of Platforms; Governance Models.

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1- Introduction

The digital economy is undergoing profound institutional transformation driven by the dynamic interplay between technological innovation, regulatory realignment, and market restructuring [1–3]. In contrast to traditional industrial paradigms, digital platforms, artificial intelligence (AI), and algorithmic systems have become central in shaping both economic governance and institutional logic [4, 5]. This ongoing evolution challenges the foundations of classical institutional theory, which has typically been framed around the dichotomy between market-based evolution [6, 7] and state-led intervention [8]. While these frameworks have informed early debates on institutional change, they fall short of capturing the recursive, real-time dynamics that characterize digital ecosystems, in which algorithmic actors, platform governance, and public regulation co-evolve continuously [4, 9].

Contemporary research has sought to address this gap. For instance, Davidson [4] and Eckardt [5] critique the inability of existing models to account for feedback loops between digital infrastructure and regulatory institutions. However, such analyses remain largely conceptual and disproportionately focused on OECD countries, particularly the European

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Union and the United States (e.g., Digital Markets Act) [2, 3], leaving BRICS economies comparatively underexplored. As Frolov [9] emphasizes, these countries face a dual challenge: rapid digitalization amid underdeveloped institutional architecture. Similarly, Kochetkov & Mamyshev [10] drew attention to the emergence of polycentric governance configurations in which digital platforms increasingly operate as autonomous norm-setting entities, a phenomenon insufficiently captured in prevailing theoretical models.

From a methodological standpoint, the extant literature tends to favor qualitative approaches, such as case studies and expert interviews, with limited use of scalable or comparative instruments. For example, Lyu et al. [11] underscored the absence of robust metrics for evaluating the pace of institutional adaptation in response to technological disruption. Cross-country quantitative models remain scarce, particularly those that link innovation dynamics to regulatory maturity and sustainability outcomes [12]. Moreover, algorithmic governance - through which platforms create quasi-legal regimes and influence market coordination via autonomous codes - remains a marginal topic in institutional analysis, despite critical contributions by Törnberg [13] and Radic et al. [3].

These analytical limitations are further compounded by the pronounced temporal lag. A significant portion of empirical studies reflect pre-pandemic or early-stage platformization dynamics without incorporating recent developments such as Web3 innovations, regulatory sandboxes, decentralized autonomous organizations (DAOs), or AI-assisted oversight mechanisms [14, 15]. As a result, existing models struggle to explain the hybrid and rapidly evolving institutional environments emerging across BRICS countries.

This study addresses these gaps by developing a novel analytical framework grounded in the concept of institutional co-evolution. Regulation in the digital economy is conceptualized as a layered and adaptive process shaped by the interdependence of state policy, platform-based self-regulation, and entrepreneurial institutional agencies. The analysis also responds to geographic and methodological imbalances in the literature by focusing on Brazil, Russia, India, China, and South Africa during 2018 - 2022. It employs a mixed-methods approach that integrates bibliometric mapping with cross-national econometric modeling. This model captures regulatory heterogeneity, algorithmic influence, and institutional feedback, and introduces an original index of institutional adaptability based on AI governance implementation timelines [11, 16].

Empirical results from our bibliometric and econometric analysis indicate that a substantial portion of institutional transformation in BRICS digital economies is driven not by state regulators but by digital platforms themselves [9, 10]. These findings highlight the growing capacity of platforms to shape norms, influence regulatory discourse, and conduct experiments with institutional forms, independent of formal policymaking channels. In doing so, they point to the emergence of a co-regulated, multi-actor governance landscape in which authority and regulatory innovation are increasingly dispersed across the public and private spheres.

The novelty of this study lies in its systematic investigation of the institutional co-evolution of digital organizations. It identifies the key drivers of transformation and demonstrates the significant role that digital platforms play in reshaping the institutional environment. Unlike conventional models that emphasize either market or state control, this study shows that digital economies evolve through hybrid mechanisms that integrate governance, market logic, and technological mediation. Particular emphasis is placed on platforms as independent institutional actors that define new norms of economic behavior and regulatory practice. Furthermore, the analysis explores the long-term implications of a hybrid regulatory architecture for the sustainability of digital economies. In doing so, this study extends institutional theory by offering new insights into the governance of digital markets and platform-based ecosystems [17]. Building on recent theoretical advancements, this study proposes a hybrid regulatory model that is tailored to the complex realities of emerging digital economies.

The theoretical framework of this study synthesizes the classical institutional theory, co-evolutionary models, and recent advances in hybrid governance research. This approach allows the analysis of institutional transformation in the digital economy as a dynamic, multi-actor process shaped by the continuous interaction between technological platforms, state regulations, and entrepreneurial agencies. By adopting this hybrid theoretical perspective, this study offers a more nuanced understanding of regulatory adaptation in transitional digital systems, and sets the foundation for the analytical model elaborated in Section 2.

The remainder of this paper is organized as follows. Section 2 reviews the theoretical background of institutional co-evolution, emphasizing digital regulatory frameworks, and the interaction between state authority and market institutions in the context of digital transformation. Section 3 details the methodological design, integrating bibliometric analysis, econometric techniques, and comparative evaluation of international regulatory practices. Section 4 presents the empirical results, highlighting the patterns of institutional change and the evolving role of digital platforms in governance and sustainability. Section 5 discusses hypothesis testing and situates empirical insights into the broader institutional theory. Section 6 concludes the paper by outlining key policy and theoretical contributions, acknowledging limitations, and suggesting directions for future research. Section 7 provides a complete list of references for ensuring transparency and replicability.

2- Theoretical Framework

Today, the digital economy is undergoing deep institutional transformations shaped by the continuous interaction of technological innovation, market forces, and regulatory responses [6, 8, 18-20]. Traditional theories often interpret institutional changes through two distinct lenses. The first, evolutionary, views institutions as products of decentralized adaptation, in which market mechanisms and technological progress naturally select the most efficient arrangements [19, 20]. From this perspective, institutions evolve organically, guided by the behavior of economic agents and organizational actors in response to shifting incentives. North [6] adds that institutions not only constrain but also facilitate innovation, serving as frameworks within which economic development occurs.

The second approach emphasizes directive change, in which institutions are shaped through deliberate actions by states or dominant actors, often driven by political objectives and strategic resource allocation. Contemporary examples include regulatory initiatives, such as the European Union's Digital Markets Act, designed to address the challenges of platform monopolization and ensure fair competition [2, 3].

However, as digital ecosystems become more complex, scholars increasingly recognize the limitations of viewing institutional change solely through either evolutionary or directive models. Recent research points to the rise of hybrid frameworks, where state regulation, market dynamics, algorithmic governance, and entrepreneurial agencies intersect to shape institutional environments [21, 22]. Hybrid governance models have also demonstrated effectiveness beyond the digital economy, particularly in sectors such as fintech regulations, healthcare innovation, and environmental management. For instance, regulatory sandboxes in the financial sector [23] and adaptive frameworks in climate governance illustrate how flexible institutional arrangements can balance innovation incentives and risk management across diverse policy domains. Mazzucato [8] pointed out the proactive role of the state as a driver of innovation, challenging the notion of the state as merely a regulatory authority. Potts [22], in turn, introduces the concept of "innovation commons," underlining the importance of flexible institutions capable of responding to rapidly evolving technological contexts [24, 25].

A notable contribution to this discourse is the concept of techno-economic institutions formulated by Shkalenko & Kozlova [12]. This concept underscores the critical role of institutional adaptability in managing the dual pressure of technological change and market volatility. Evidence from China and the European Union supports the argument that institutional flexibility is key to mitigating risks and fostering sustainable digital development [5, 11].

Adding further complexity is the emergence of algorithmic governance, where digital platforms increasingly assume quasi-regulatory functions, setting and enforcing norms independently of traditional authorities [26]. This phenomenon, described by Törnberg [13] as technopolitical, reflects the entanglement of corporate strategies and public governance. Legislative responses, such as the EU's Digital Services Act, attempt to navigate this evolving landscape by balancing platform autonomy with accountability. Recent studies [27] emphasize the growing role of co-regulation mechanisms and platform accountability frameworks introduced after 2023, reflecting a shift towards more participatory and adaptive regulatory practices. However, scholars argue that existing regulatory theories often fail to capture the layered and dynamic nature of digital ecosystems [28].

At the same time, antitrust challenges, the pursuit of digital sovereignty, and the development of metaregulation frameworks signal a broader shift towards anticipatory governance capable of addressing data-driven market power [14, 27]. These initiatives reflect the evolving understanding of how regulatory systems must adapt to platform-centric economies. Thus, it is important to distinguish between institutional entrepreneurship and platform self-regulation. Institutional entrepreneurship refers to proactive efforts by organizations or individuals to initiate and implement institutional change, often by leveraging opportunities within regulatory gaps [15, 29]. By contrast, platform self-regulation involves the establishment of internal governance rules by digital platforms to manage user behavior, content, and transactions, typically aimed at preempting external regulation. While both mechanisms contribute to institutional dynamics, they operate at different agency and intent levels.

Research on decentralized governance structures, including platform self-regulation, DAOs, and co-regulation models, illustrates practical examples of hybrid institutional arrangements in action [24, 30, 31]. Multi-stakeholder approaches emphasize balancing innovation incentives with public-interest protection. Radic et al. [3] explored how legal norms and platform governance evolve in tandem, reflecting co-evolutionary dynamics. Despite these advances, unresolved issues persist - from antitrust enforcement [2, 16] and data privacy [32] to public safety concerns [33] and the influence of digital elites in institutional norm settings [9, 32]. Scholars continue to call for transformative legal innovation to address these systemic challenges [6, 27, 34].

While much of the academic debate focuses on developed economies, a significant gap remains in understanding how hybrid governance models function within emerging markets, particularly across BRICS countries. These economies have distinct regulatory environments shaped by varying degrees of state involvement, institutional maturity, and technological infrastructure. To address this gap, the present study applies the institutional co-evolution framework to explore how state authority, platform governance, and institutional entrepreneurship interact to shape adaptive governance in the digital economies of BRICS nations.

By synthesizing insights from institutional theory, co-evolutionary models, and hybrid governance research, this study offers a composite analytical lens through which to examine institutional transformation in the digital economy. This theoretical integration underpins the study's empirical strategy, informing the design of bibliometric mapping, regression-based analysis, and development of an Optimized Hybrid Model of regulation. It enables a more comprehensive understanding of how technological capabilities, governance mechanisms, and regulatory norms co-evolve in emerging economies such as those of the BRICS.

2-1- Hypothesis Development

Recent research emphasizes the growing complexity of institutional change within the digital economy, particularly in contexts characterized by rapid technological advancement and uneven regulatory responses [12, 24]. The conventional dichotomy between market-driven (evolutionary) and state-imposed (directive) institutional models appears to be insufficient to explain the hybrid and adaptive structures emerging in digital ecosystems. Studies increasingly recognize that digital platforms act not only as economic intermediaries but also as autonomous institutional actors, establishing rules, and enforcing compliance outside traditional regulatory frameworks [4, 5]. Furthermore, the consolidation of digital elites and platform-based normative orders underscores the need to reconsider existing governance approaches [10].

Building on these insights, this study proposes the following hypotheses:

H1: *Institutional co-evolution of the digital economy follows a hybrid model combining both evolutionary ("bottom-up") and directive ("top-down") approaches.*

Building on Shkalenko & Kozlova's [12] concept of techno-economic institutions, this hypothesis emphasizes the dynamic balance between state intervention, market forces, and platform self-regulation in shaping digital institutional frameworks. Rather than viewing institutional evolution as purely spontaneous or centrally designed, evidence points to stable hybrid configurations in which formal regulation interacts with decentralized norms.

As Ghobakhloo et al. [24] noted, the sustainability of such models hinges on their capacity to balance regulatory control with flexibility in the face of rapid technological change. Moreover, mechanisms such as path dependency and institutional layering embed new digital norms within existing frameworks, suggesting that hybrid governance is not a temporary response, but a lasting characteristic of institutional co-evolution in digital ecosystems.

H2: *The resilience and effectiveness of institutional co-evolution depend on the adaptability of institutions to rapid technological and market changes.*

Institutions confronted with rapid technological shifts must navigate a delicate balance between preserving regulatory stability and fostering adaptability. Lyu et al. [11] pointed out that when institutional frameworks become overly rigid, they impede timely responses, increase systemic vulnerabilities, and undermine both environmental outcomes and public confidence in governance. Resilience, therefore, should not be perceived as a fixed characteristic, but rather as an institution's capacity to maintain structural coherence while embracing innovation. Achieving this balance is essential to ensure that governance frameworks remain responsive and effective in the face of ongoing technological and market disruptions.

H3: *The expanding institutional agency of digital platforms and elites is reshaping governance logics within the digital economy, indicating a paradigm shift that challenges conventional regulatory frameworks - though its full extent requires deeper empirical exploration.*

Recent research [4, 9] highlights how digital platforms increasingly embed regulatory functions within their technological frameworks, extending their roles beyond traditional market operations [35]. Practices such as algorithmic rule setting and the enforcement of platform-specific norms illustrate this growing institutional agency, effectively blurring the lines between private infrastructure and public governance.

This evolution challenges conventional hierarchical models by introducing decentralized technology-driven mechanisms with minimal state oversight. The resulting hybrid governance structures expose tensions between maintaining institutional coherence and accommodating platforms' autonomous regulatory influence. The durability of these arrangements depends on how well institutional systems can adjust to the shifting power dynamics and rapid technological change. Rather than a binary opposition between state control and platform freedom, this reflects a nuanced co-evolution shaped by interactions among diverse stakeholders, a dynamic crucial for understanding the future trajectory of digital regulation.

3- Research Methodology

3-1- Data Description and Collection

To explore the dynamics of hybrid governance within the digital economy, this study employs a mixed-methods approach that integrates bibliometric analysis with econometric modeling. This combination enables a comprehensive examination of both the conceptual developments and empirical patterns associated with institutional adaptation. The overall research design, illustrated in Figure 1, demonstrates how these methodologies complement one another, analyzing the interplay between theoretical discourse and measurable governance outcomes in digital contexts.

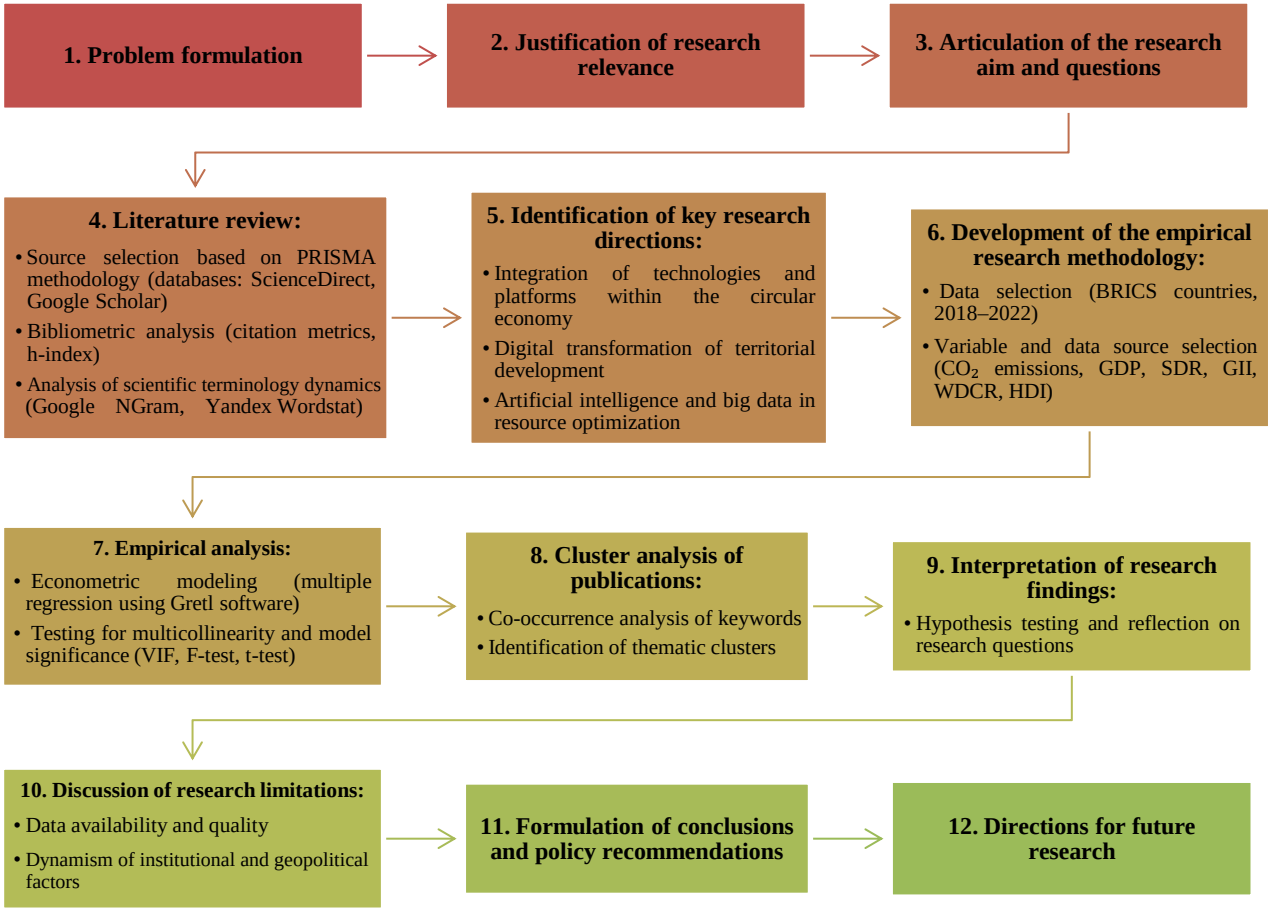

Figure 1. Methodological framework linking bibliometric and econometric approaches to analyze hybrid governance dynamics

Bibliometric analysis traces the evolution of scholarly perspectives on digital governance and institutional flexibility. Adhering to the PRISMA guidelines [36], a systematic review was conducted, resulting in the selection of 63 peer-reviewed articles published between 2021 and 2023. The selection criteria prioritized works with significant citation impact and direct relevance to the themes of digital regulation and institutional co-evolution. To enhance this analysis, additional tools, such as Google NGram Viewer and Yandex Wordstat, were utilized, providing insights into the dissemination and shifting prominence of key governance concepts across academic, policy, and professional arenas.

In parallel, the econometric component focuses on examining the relationship between digitalization metrics and sustainability indicators within BRICS countries. This empirical analysis translates theoretical assumptions into quantifiable patterns, offering a lens through which institutional responsiveness and structural rigidity can be assessed using various governance models.

Emerging themes from the literature, such as the contribution of digital platforms to circular economy practices, the rise of smart governance frameworks, and the integration of AI and big data in resource management, have directly shaped the study's empirical orientation. By aligning theoretical insights with quantitative evidence, this study provides a nuanced understanding of how institutional co-evolution unfolds amid the challenges and opportunities presented by digital transformation. While bibliometric analysis effectively captures conceptual trends within academic discourse, it remains limited to reflecting informal dynamics and unwritten governance practices. To address this, bibliometric insights were systematically integrated with econometric findings, allowing for a more grounded interpretation of how theoretical narratives align with the observable institutional transformations.

3-2- Variable Definitions and Data Sources

The 2018–2022 period was selected, as it marks a critical phase of accelerated digitalization and regulatory reforms across BRICS countries, particularly in areas such as platform governance, data sovereignty, and innovation policy. The BRICS nations were chosen because of their dual status as leading emerging economies and active arenas for hybrid regulatory experimentation, offering diverse governance architectures and varying capacities for digital integration. This study explores how digitalization influences sustainability outcomes within the distinct institutional landscapes of Brazil, Russia, India, China, and South Africa. BRICS countries offer a particularly diverse context, where divergent regulatory frameworks, varying levels of technological development, and evolving policy agendas intersect, shaping the emergence and configuration of hybrid governance models. Rather than adhering to a uniform trajectory, digital transformation in these economies is mediated by national institutional characteristics that dictate both the speed and direction of the adaptive processes. Appreciating this heterogeneity is crucial for understanding how institutional resilience and regulatory flexibility contribute to advancing Sustainable Development Goals (SDGs) within digital governance frameworks. Building on this contextual foundation, the empirical analysis utilizes macroeconomic and institutional indicators to explore how these dynamics manifest in measurable outcomes.

The empirical analysis is based on annual data covering the period from 2018 to 2022, a phase characterized by intensified digitalization efforts and notable regulatory shifts in areas such as platform governance, data protection, and innovation policy. This timeframe captures the early stages of the institutional response to technological disruption, providing a foundation for assessing co-evolutionary dynamics under conditions of accelerated change.

To examine these relationships, a multiple linear regression model was applied using the Ordinary Least Squares (OLS) method. While traditionally employed in macroeconomic studies to identify linear correlations, OLS facilitates the quantification of structural linkages between digitalization, institutional adaptability, and environmental sustainability. Acknowledging the challenges posed by potential endogeneity, particularly within the feedback-driven environment of the digital economy, this study emphasizes careful selection of variables and temporal structuring to minimize bias. Future research could benefit from more advanced econometric techniques, such as dynamic panel models or instrumental variable approaches, to enhance causal inference.

The choice of variables reflects the focus on capturing both external economic pressures and internal institutional capacities relevant to digital governance. Carbon dioxide (CO_2) emissions are utilized as a proxy for environmental impact and as an indicator of sustainability performance. The explanatory variables include key dimensions such as economic scale (GDP), alignment with international sustainability standards (SDR Index), innovation capacity (GII), digital infrastructure readiness (WDCR), and socioeconomic development (HDI), each representing critical aspects of institutional responsiveness within rapidly digitalizing economies.

Complementing the econometric analysis, a bibliometric review was integrated to contextualize the empirical findings within the prevailing theoretical discourses. This dual-method approach facilitates a comprehensive examination of how scholarly narratives on digital governance align – or diverge – from observable institutional practices. Although bibliometric techniques effectively map conceptual trends, their limitations in capturing informal institutional dynamics and tacit regulatory practices are acknowledged, suggesting avenues for future qualitative enrichment through case-based research.

All variable definitions and the corresponding data sources are detailed in Table 1, ensuring methodological transparency and enabling replication. Econometric modeling was conducted using the Gretl software package to ensure consistency and robustness in statistical estimation.

Table 1. Variable Definitions and Data Sources

Variable	Definition	Unit of Measurement	Data Source
CO_2	Carbon dioxide emissions	Million metric tons	Global Carbon Project (2025) [37]
GDP	Gross Domestic Product	USD (constant prices)	Our World in Data (2025) [38]
SDR Index	Sustainable Development Report Index	Score	SDSN (2025) [39]
GII	Global Innovation Index	Score	WIPO (2025) [40]
WDCR	World Digital Competitiveness Ranking	Score	IMD (2025) [41]
HPI	Human Development Index	Score	World Population Review (2025) [42]

The selected variables capture key aspects of economic scale, technological capacity, institutional alignment with sustainability goals, and socio-economic development, which critically shape how BRICS countries respond to digitalization challenges. This configuration allows us to examine how differences in institutional adaptability influence environmental outcomes in hybrid governance contexts. Notably, the inclusion of both innovation- and governance-related indicators provides insight into where flexibility supports sustainable transitions and institutional rigidity may

hinder progress. While this framework addresses the core dimensions of digital transformation, future analyses could benefit from incorporating measures of governance quality or platform-specific regulations to deepen our understanding of institutional performance in managing digital ecosystems.

3-3- Data Analysis Techniques

The analytical framework adopted in this study is designed to examine how digitalization processes interact with institutional structures to shape sustainability trajectories within the BRICS economies. These countries, characterized by heterogeneous governance models and varying capacities for technological integration, provide an empirical setting to explore the adaptive mechanisms underlying hybrid regulatory systems. This study integrates bibliometric analysis with econometric modeling to address both theoretical and empirical dimensions. This approach enables the tracing of conceptual developments in digital governance while empirically evaluating the relationships between digitalization, institutional adaptability, and environmental performance.

The econometric analysis applies a multiple linear regression model estimated via Ordinary Least Squares (OLS) to identify structural linkages within short time-series data reflective of transitional digital economies. The choice of Ordinary Least Squares (OLS) regression was driven by its interpretative clarity and suitability for identifying structural relationships within macroeconomic datasets characterized by short timespans. While acknowledging that OLS is sensitive to potential endogeneity, particularly in feedback-intensive contexts such as digital economies, this study employed careful variable selection and temporal structuring to mitigate bias. Future research could benefit from advanced techniques, such as dynamic panel models or instrumental variable approaches, to strengthen causal inferences.

The model was estimated using the Gretl software package with standard diagnostic procedures, such as Variance Inflation Factor (VIF), F-statistics, and t-tests, to verify the consistency and reliability of the results. Nonetheless, it is acknowledged that quantitative approaches by their nature are insufficient to fully capture context-specific elements such as governance adaptability or institutional inertia, which frequently emerge through informal practices and unwritten norms. In light of these considerations, econometric outcomes should be viewed not as conclusive evidence but as an analytical foundation for pinpointing areas where institutional co-evolution is most evident. These results underscore the importance of integrating qualitative insights to deepen our understanding of the nuanced processes underpinning hybrid governance transformations in digitalizing economies.

3-4- Model Specification

To examine the impact of digital development on environmental outcomes across diverse institutional settings, this study employs a multiple linear regression model designed to reveal the structural patterns typical of emerging digital economies. Carbon dioxide (CO_2) emissions, measured in million metric tons, serve as a proxy for environmental performance, allowing the assessment of how economic growth and technological advancement intersect with sustainability challenges within BRICS countries over the 2018-2022 period.

The choice of explanatory variables is grounded in theoretical considerations, which aim to reflect the core aspects of institutional adaptability and technological capacity. GDP represents economic scale and growth dynamics; the SDR Index captures alignment with global sustainability targets; the GII reflects national innovation potential, influencing both modernization and regulatory complexity; WDCR indicates the maturity of digital infrastructure; and HDI accounts for socio-economic conditions relevant to governance resilience and human capital. Collectively, these indicators frame the various pressures and capacities that shape hybrid governance responses to digitalization.

Regression analysis was conducted using the Gretl software package with standard diagnostic checks integrated to ensure statistical validity. Special attention was paid to detecting multicollinearity through VIF analysis, acknowledging that overlaps between institutional and technological factors might distort individual effects. The overall adequacy of the model was assessed via the F-statistic, and t-tests were applied to evaluate the significance of individual coefficients, providing insights into the co-evolution of digital and institutional variables influencing environmental performance.

Beyond identifying statistical correlations, this model shows the structural constraints and opportunities arising from digital transformation within heterogeneous governance environments. By pinpointing instances where institutional rigidity exacerbates environmental risks or, conversely, where technological advancement fosters adaptive capacity, the analysis offers a deeper understanding of how hybrid regulatory frameworks can support or impede sustainable development amid rapid technological change.

3-5- Methodological Contribution

This study proposes a methodological framework to capture the intricate dynamics of institutional co-evolution during digital economic transformation. By combining bibliometric mapping with econometric analysis, the approach moves beyond traditional single-method designs, offering a comprehensive perspective on the emergence, stabilization, and adaptation of hybrid governance structures in response to technological disruption.

The selection of a multiple linear regression model (OLS estimation) is justified by its clarity and suitability for detecting structural relationships within macro-level datasets, which is particularly relevant when working with constrained time series data, as is often the case in emerging economies. At the same time, the study acknowledges that within the digital economy, where technological adoption, institutional shifts, and sustainability outcomes are closely interlinked, OLS estimations are inherently exposed to potential endogeneity concerns. Due to data limitations across the BRICS countries, the application of more sophisticated econometric techniques, such as instrumental variable methods, was not feasible. Consequently, the findings are positioned as indicative correlations, providing valuable insights into structural tendencies rather than definitive causal claims.

The focus on the 2018-2022 period reflects a critical phase wherein BRICS nations implemented strategic digitalization policies and regulatory reforms targeting platform governance, data sovereignty, and innovation ecosystems. This timeframe captures the initial institutional responses to accelerated technological change, providing a unique empirical window for early-stage co-evolutionary processes. The selection of BRICS countries is justified by their dual status as leading emerging economies and active arenas for hybrid regulatory experimentation, marked by diverse governance architectures and varying capacities for digital integration.

The bibliometric component systematically traces the evolution of academic discourse on digital governance and institutional adaptability, focusing on publications from 2021 to 2023 when scholarly engagement with platformization, algorithmic regulation, and sustainability intensified. This integration not only grounds conceptual trends in empirical evidence but also reveals areas where quantitative insights must be complemented by a qualitative understanding of governance practices.

This methodological synthesis reveals not only observable patterns but also structural tensions between innovation-driven transformation and institutional inertia. By situating quantitative analysis within a broader conceptual framework, this study offers tools to interrogate how hybrid regulatory models respond to technological pressures, where they exhibit resilience and vulnerabilities persist. While recognizing the constraints of secondary data and methodological scope, this framework contributes to advancing both institutional theory and policy-relevant understandings of governance dynamics in digitalizing economies.

4- Results

This section presents the results of bibliometric analysis, econometric modeling, and comparative case evaluations. Together, these findings offer empirical support for the proposed theoretical model of hybrid institutional co-evolution in digital economies and provide critical insights into the heterogeneous evolution of governance regimes across BRICS countries.

4-1- Bibliometric Overview and Trend Dynamics

The bibliometric review of publications from 2021 to 2023 highlights a significant increase in scholarly focus on the intersection of digitalization and sustainability, with 1,008 studies demonstrating an average annual growth rate of approximately 18%. This growing volume of literature reflects not only an expansion in research output, but also a deeper analytical engagement with the institutional challenges posed by emerging technologies. The thematic mapping of the dataset highlights three dominant clusters: (1) digital governance and platform regulation, (2) sustainability indicators and environmental resilience, and (3) institutional change in emerging economies. These clusters indicate growing convergence between digital transformation processes and sustainability-oriented governance frameworks.

positioned in the literature not merely as technical tools, but as institutional catalysts. These technologies reshape how decisions are made, how regulatory systems adapt, and how sustainability goals are operationalized. Their rising prominence corresponds to a broader shift towards data-driven, algorithmic approaches to governance, particularly in areas such as urban resilience, climate adaptation, and regional development.

The prevalence of terms such as “co-regulation,” “platform economy,” “institutional adaptation,” and “hybrid governance” further supports the relevance of institutional co-evolution theory in contemporary scholarship. These findings underscore a systemic departure from hierarchical top-down regulatory models towards more decentralized and adaptive institutional arrangements. Digital platforms and intelligent systems increasingly act not only as subjects of regulation, but also as co-creators of regulatory norms and practices. In this context, bibliometric evidence provides a robust empirical foundation for the study’s conceptual focus on hybrid regulatory models, affirming that institutional evolution in the digital age is inseparable from the governance of transformative technologies.

4-2- Keyword Co-Occurrence and Thematic Landscape

The analysis of keyword co-occurrence in publications from 2021 to 2023 revealed a well-defined thematic structure focused on the intersection of technological innovation and sustainability governance. As shown in Figure 2, terms such as Artificial Intelligence, Sustainable Development, and Industry 4.0 consistently dominate academic discourse, reflecting a clear consolidation of research interests around the role of emerging technologies in addressing both environmental and socio-economic challenges.

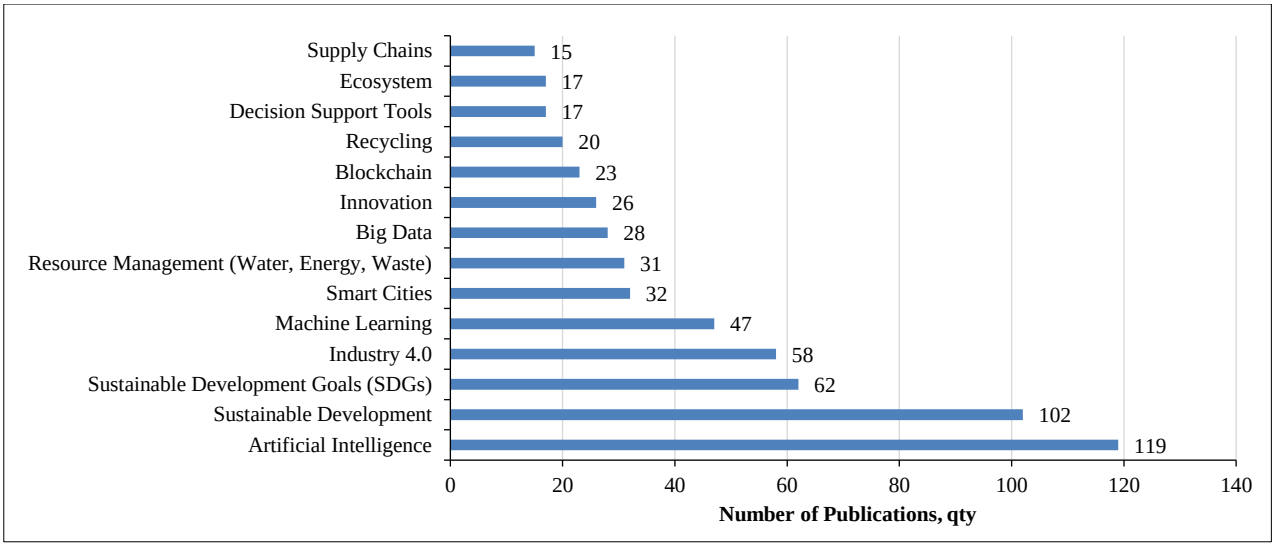

Figure 2. Frequency of key terms in scholarly literature (2021–2023), highlighting thematic convergence around digital technologies, sustainability goals, and emerging governance frameworks

A closer examination of these thematic clusters has identified two principal directions in the literature. The first frames the concept of the circular economy not merely as a technical or operational approach but as an evolving institutional paradigm. Emphasis is placed on redefining resource management through the core principles of transparency, accountability, and systemic resilience. Scholarly discussions extend beyond practical concerns such as waste reduction, showing the importance of regulatory and normative frameworks required to embed sustainability into production and distribution systems. This reflects the growing awareness that technological innovation alone cannot achieve sustainability goals without parallel institutional reforms.

The second direction emphasizes the transformative impact of digital technologies, particularly AI, machine learning, and blockchain, on governance practices. While AI and ML are widely recognized for enabling data-driven decision-making and enhancing predictive capabilities in environmental management, their integration also raises critical questions regarding institutional oversight and safeguarding the public interest. The discourse surrounding blockchain further illustrates this complexity; despite its potential to promote transparency and decentralization, ongoing debates about its scalability and regulatory compatibility expose persistent gaps within existing institutional structures.

These keyword dynamics further validate the bibliometric observations discussed in Section 4.1, confirming that institutional governance and technological convergence are not separate trajectories, but are increasingly interwoven. The prominence of governance-related terms alongside digital technologies highlights a growing scholarly recognition that sustainability cannot be operationalized without parallel regulatory innovation.

Keyword mapping (see Figure 2) also underscores the dual focus in contemporary research. On the one hand, it explores how advanced technologies can drive sustainability transitions; on the other hand, it addresses the institutional adaptation needed to ensure regulatory coherence in digitally evolving environments. This duality reflects a deeper concern within the academic literature that rapid digitalization, while offering new tools for sustainable development, can also exacerbate governance asymmetries if not accompanied by corresponding institutional evolution.

Taken together, these patterns suggest an emerging consensus that sustainable development in the digital age depends on the co-evolution of technological capabilities and institutional governance. The recurring emphasis on hybrid regulatory models in recent studies underscores the need to balance innovation dynamics with institutional stability. This thematic landscape not only shapes the conceptual foundation of the present research, but also sets the stage for the deeper thematic clustering in Section 4.3 and the quantitative analysis in Section 4.4, where specific mechanisms of institutional adaptation are assessed in comparative and empirical terms.

4-3- Thematic Clustering of Research Domains

The examination of research domains at the nexus of digital technologies and sustainable development reveals how innovation persistently tests and reshapes the existing regulatory frameworks. Rather than addressing isolated issues, the literature underlines a network of interrelated areas in which digital tools actively transform institutional practices and governance paradigms.

A substantial number of studies have concentrated on embedding circular economy principles through technologies such as blockchain and the Internet of Things (IoT), where transparency and traceability are not merely features but are institutionalized within digital infrastructures. This trend reflects a shift towards integrating sustainability objectives

directly into the design and operation of technological systems. Further, research focusing on AI, machine learning, and Industry 4.0 platforms underscores their growing influence in redefining governance through algorithmic decision-making. These advancements introduce complex challenges related to data governance, ethical standards, and the institutional capacity to oversee autonomous digital processes, thereby calling for more adaptive and responsive regulatory approaches. Transformations in urban governance are frequently exemplified by initiatives such as India's Smart Cities Mission or China's deployment of blockchain for environmental monitoring – cases in which smart infrastructure acts as a catalyst for institutional change.

Across these thematic clusters, scholars increasingly emphasize mechanisms such as regulatory sandboxes, public-private partnerships, and emerging forms of platform self-regulation, including Decentralized Autonomous Organizations (DAOs), as innovative responses to the constraints of traditional legal frameworks. For instance, analyses of Brazil's fintech sector illustrate how flexible regulatory environments can stimulate technological innovation, while simultaneously raising critical questions about accountability and systemic stability. These findings support the theoretical proposition that institutional adaptation is increasingly shaped not only by policy and legal reforms but also by the architecture of digital systems themselves. The emergence of algorithmic decision-making in governance reflects a deeper shift in institutional logic from rule-based enforcement to systems-based regulation. This transition, while promoting operational efficiency, also generates governance gaps, especially in developing economies, where institutional capacity is still forming. For example, in India's Smart Cities initiative, algorithmic coordination outpaced legal codification, leading to fragmented accountability frameworks. Similarly, Brazil's fintech sandboxes demonstrate how agile regulation can stimulate innovation, yet requires enhanced institutional reflexivity to mitigate systemic risks. These cases illustrate how co-evolutionary mechanisms operate unevenly across contexts and demand differentiated regulatory responses.

Collectively, these patterns suggest that institutional co-evolution in the digital age is shaped by ongoing negotiations between technological disruptions and governance adaptation. Hybrid regulatory models, blending formal oversight with flexible, technology-enabled governance instruments, are becoming essential for navigating this evolving landscape.

Understanding the development and interaction of such mechanisms is vital for advancing institutional theory, particularly in the context of the governance challenges emerging from rapid digitalization. This perspective forms the basis for constructing a comprehensive framework of institutional co-evolution, which is further discussed in the subsequent section.

4-4- Synthesis of Core Research Streams

An analysis of contemporary research states that work at the intersection of the digital economy and sustainable development concentrates on three core thematic areas.

Integration of communities and technologies in the circular economy explores the ways in which digital technologies, particularly blockchain, big data, and the Internet of Things (IoT), are utilized to advance closed-loop supply chains, improve operational transparency, and address pressing environmental challenges. Recent contributions describe how these tools enhance resource efficiency and promote collaborative models that integrate community participation within circular economic frameworks. Son et al. [43] and Bibri et al. [44] underscore the critical role of digital solutions in enabling effective systems for resource monitoring and management, positioning them as key enablers in the institutionalization of circular economy practices.

Sustainable models of territorial development and technological synergy focus on the integration of artificial intelligence (AI) and smart city initiatives as mechanisms for promoting environmental sustainability and enhancing resource efficiency in urban contexts [43, 45]. Scholars have discussed how AI and big data analytics offer substantial opportunities to improve urban planning, optimize transportation networks, and enhance infrastructure management. Such advancements are instrumental in supporting the attainment of sustainable development goals while simultaneously mitigating environmental impacts [43].

Waste management and sustainable development examine how digital technologies are applied to improve waste collection, recycling, and reuse processes, with the objective of reducing environmental impact and promoting resource efficiency [46-48]. Scholars emphasize the contribution of digital platforms and innovative solutions in establishing transparent and efficient waste management systems, highlighting their importance in achieving environmental compliance and supporting progress towards sustainable development goals [49].

To synthesize the conceptual landscape derived from the literature, the three streams were consolidated into a visual framework that captures their interrelations and thematic overlaps. The research directions are illustrated in Figure 3.

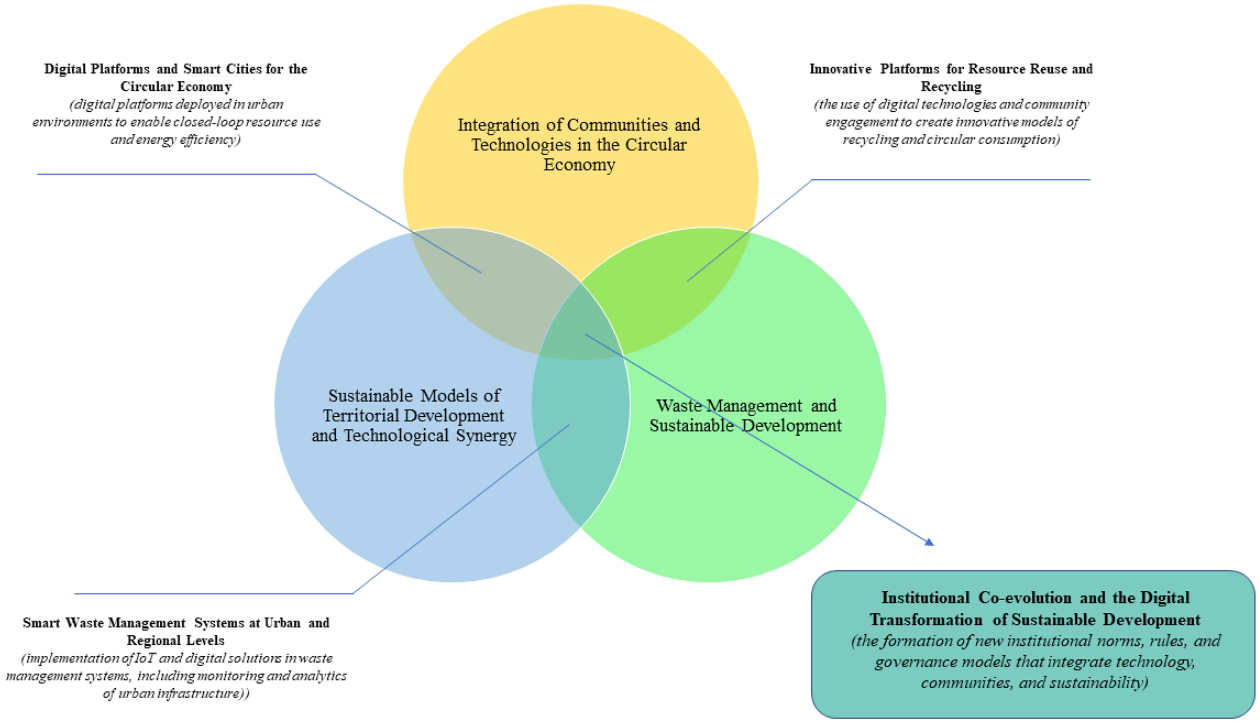

Figure 3. Key Research Directions in the Field of Digital Economy and Sustainable Development

Figure 3 offers a structured representation of how these thematic clusters contribute to the evolving discourse on sustainability and digitalization. The literature consistently emphasizes that digital technologies are not deployed in isolation but are increasingly integrated within institutional frameworks designed to support sustainable development objectives. The incorporation of digital tools into circular economy practices has facilitated more effective resource monitoring and process management in urban and regional settings. Importantly, the synthesis of these research streams reveals that digital transformation is not simply a driver of technical modernization, but also a catalyst for institutional reconfiguration. For instance, the integration of AI into smart urban infrastructure cannot be decoupled from questions of institutional design, such as oversight mechanisms, ethical standards, and the allocation of decision-making authority. Similarly, blockchain's potential in a circular economy extends beyond traceability – it alters the foundational assumptions of regulatory control by embedding governance functions directly into technological protocols. These developments underscore the necessity for hybrid governance models that not only accommodate technological advancements, but also ensure coherence, accountability, and legitimacy across multiple regulatory levels. This synthesis directly informs the development of the Optimized Hybrid Model proposed in Section 5, offering a structured response to the institutional challenges identified in the empirical trends.

Simultaneously, the expansion of smart city initiatives illustrates how the convergence of artificial intelligence and digital platforms can drive improvements in environmental performance. However, these developments also expose limitations in existing regulatory capacities and governance structures as technological innovations often advance faster than legal frameworks can adapt, thereby underscoring the need for more flexible oversight mechanisms. Similarly, advances in digital waste management demonstrate the critical role of institutional design in ensuring that technological progress translates into sustainable outcomes, rather than focusing solely on efficiency gains. The effectiveness of such initiatives frequently depends on governance practices that prioritize transparency, accountability, and adaptability to shifting technological landscapes.

Taken together, these research trajectories suggest a transition towards governance models that balance flexibility with institutional stability. Emerging patterns point to hybrid regulatory approaches, where instruments such as soft law, platform self-regulation, and multi-stakeholder collaboration become essential for aligning rapid digital transformation with long-term sustainability goals.

4-5- Descriptive Statistics and Regression Framework

Before proceeding with the regression analysis, the descriptive statistics were examined to understand the key patterns within the dataset (Table 2). This review revealed notable deviations from the normal distribution for several variables. Specifically, CO_2 emissions, GDP, and the Global Innovation Index (GII) showed positive kurtosis, indicating the presence of extreme values – a reflection of the economic and technological disparities typical across BRICS countries. By contrast, indicators such as the SDR Index, WDCR, and HDI displayed flatter distributions, which may obscure the underlying institutional differences.

Table 2. Descriptive Statistics*

Variable	Mean	Median	Minimum	Maximum
CO_2	3232.4	1705.0	404.05	11397
SDRindex	68.787	71.620	60.940	74.050
GDP	4.3581e+012	1.8299e+012	3.3672e+011	1.7866e+013
WIPO	39.535	36.386	11.000	61.000
WDCR	62.313	58.648	43.641	86.420
HPI	0.74156	0.75800	0.63300	0.83000
Variable	**Std. dev.**	**Coefficient of Variation**	**Skewness**	**Kurtosis**
CO_2	4027.3	1.2459	1.3518	0.065693
SDRindex	4.9697	0.072247	-0.38057	-1.6997
GDP	5.6424e+012	1.2947	1.4813	0.42859
WIPO	10.726	0.27131	0.0033883	0.65097
WDCR	12.349	0.19818	0.77151	-0.49115
HPI	0.062332	0.084055	-0.36441	-0.87760
Variable	**5th Percentile**	**95th Percentile**	**Interquartile Range (IQR)**	**Missing Observations**
CO_2	410.53	11379.0	2282.5	0
SDRindex	61.315	74.035	9.7350	0
GDP	3.4168e+011	1.7247e+013	1.6317e+012	0
WIPO	17.282	59.146	16.100	0
WDCR	44.819	85.923	16.326	1
HPI	0.63570	0.82820	0.071000	0

* Observations from 1:1 to 5:5 were used (missing data are omitted).

These characteristics suggest that the variability and asymmetry in the data could affect the interpretation of the regression results, particularly in terms of coefficient stability. Recognizing these distributional features is essential to accurately assess the relationship between digitalization, governance factors, and sustainability outcomes in diverse institutional contexts.

Understanding these distributional characteristics is critical because they offer early insights into potential data asymmetries and outlier behavior, which may influence the robustness of subsequent regression analyses. By pointing out the variability and concentration tendencies within the dataset, descriptive statistics serve not merely as a preliminary overview but also as a diagnostic tool to inform model specification and the interpretation of econometric results.

Table 2 indicates considerable variation across key economic, technological, and sustainability indicators within BRICS countries. The high dispersion and positive skewness in GDP and CO_2 emissions reflect uneven development patterns and ongoing environmental challenges typical of emerging economies. By contrast, the more uniform distributions observed in the SDR Index and HDI may conceal important institutional differences.

Multicollinearity checks using the Variance Inflation Factor (VIF) showed no critical correlations between the variables, supporting the reliability of the regression estimates. Although some deviations from normality were present, OLS was deemed appropriate for this exploratory cross-country analysis.

The regression results, summarized in Table 3, are based on 24 observations from five BRICS countries from 2018 to 2022, following the exclusion of one case due to missing data in the WDCR variable. The analysis identified GDP, innovation capacity (WIPO/GII), and the SDR Index as significant factors influencing CO_2 emissions. The positive link between GDP and emissions reflects continued reliance on carbon-intensive growth, while the negative association with the SDR Index suggests that stronger sustainability commitments can help reduce the environmental impact. The moderate positive effect of innovation points to a critical balance; without effective governance, technological progress may contribute to increased ecological risks alongside economic gains.

Table 3 presents the core regression results, identifying the key determinants of CO_2 emissions and highlighting the structural relationships between economic, innovation, and sustainability variables.

Table 3. Results of the Regression Analysis on the Target Variable (Model 1)

Variable	Coefficient	Std. error	t-statistic	p-value	Significance
Const	3287.48	1672.83	1.965	0.0634	*
GDP	7.16764e-010	2.18535e-011	32.80	<0.0001	***
WIPO	23.4337	10.9084	2.148	0.0441	**
HPI	6734.43	4159.43	1.619	0.1211	
SDRindex	-132.281	53.7477	-2.461	0.0231	**

Note: Significance levels: *** p < 0.001; ** p < 0.05; * p < 0.1

The pooled OLS regression covering five BRICS countries over 2018-2022 identified GDP, innovation capacity (WIPO/GII), and the SDR Index as key factors influencing CO_2 emissions. The strong positive correlation between GDP and emissions reflects ongoing dependence on resource-intensive growth strategies. In contrast, a higher alignment with sustainability objectives, as indicated by the SDR Index, is associated with lower emissions, demonstrating the role of institutional frameworks in mitigating environmental impact. The positive relationship between innovation and emissions suggests that technological progress without supportive regulatory measures can inadvertently contribute to ecological pressure.

These results illustrate the tension among economic growth, innovation, and sustainability in emerging digital economies. Effective policy responses require frameworks that integrate environmental priorities into economic and technological development.

Table 4 presents diagnostic statistics, confirming the model's high explanatory capacity ($R^2 = 0.98$), while also indicating potential autocorrelation due to low Durbin-Watson values. This reflects structural delays in institutional adaptation relative to rapid technological change – a common feature in economies experiencing accelerated digital transformation. Addressing such temporal dynamics may require advanced modeling approaches in future analyses to better capture the evolving nature of digital-era governance challenges. The diagnostic statistics in Table 4 confirm the robustness of the model, while revealing the temporal challenges inherent in institutional adaptation processes.

Table 4. Model 1 Summary Statistics

Statistic	Value	Statistic	Value
Mean of dependent variable	3232.393	Standard deviation of dependent variable	4027.298
Residual sum of squares (RSS)	6274493	Standard error of the model	560.1113
R-squared	0.983881	Adjusted R-squared	0.980657
F-statistic (F(4. 20))	305.1916	p-value (F)	1.28e-17
Log-likelihood	-190.8876	Akaike Information Criterion (AIC)	391.7751
Schwarz Criterion (BIC)	397.8695	Hannan-Quinn Criterion (HQC)	393.4654
Rho (intra-class correlation)	0.809157	Durbin–Watson statistic	0.288110

The results reveal how the BRICS countries navigate the complex balance between pursuing economic growth, advancing technological innovation, and addressing environmental sustainability. These dynamics reflect the core principles of institutional co-evolution, in which market forces, technological change, and governance structures continuously interact and adapt. The extent to which these empirical patterns support the study's hypotheses is examined in detail in section 4.9, and the implications for hybrid governance models are further explored.

To enhance conceptual clarity and ensure replicability, we have added Table 5, which details how key institutional constructs were operationalized in the empirical analysis. This table clarifies how theoretical variables such as institutional co-evolution, entrepreneurial agency, and platform governance were measured using specific empirical indicators, including interaction terms and governance indexes.

Table 5. Construct Operationalization of Key Institutional Variables

Construct	Indicator(s) Used	Source / Description
Institutional Co-evolution	Interaction term: Digitalization Index × Rule of Law	Measures synergy between digital transformation and institutional quality (WDCR + WGI)
Entrepreneurial Agency	High-tech Startup Density; FinTech Adoption Index	Reflects proactive institutional innovation via entrepreneurship
Platform Governance	Digital Platform Regulation Index; Data Localization Laws	Captures regulatory interventions targeting digital platforms
Innovation Output (Control)	Number of Patent Applications per 1M population	World Bank, WIPO
Institutional Quality (Control)	Rule of Law, Government Effectiveness (WGI)	Standard governance metrics

This framework ensures the empirical grounding of abstract institutional concepts and facilitates a comparative analysis across contexts.

4-6- Interpretation of Findings and Policy Implications

The regression results show a critical inverse relationship between CO_2 emissions and the Sustainable Development Report Index (SDR Index), emphasizing that stronger institutional alignment with sustainability goals effectively reduces environmental pressures. The overall statistical significance of the model ($p < 0.01$) reinforces the robustness of these findings and provides a solid foundation for policy-relevant interpretations. Additionally, the calculated F-statistic was compared with the critical value of the Fisher distribution at a significance level of $\alpha = 0.05$

$$F_{\text{calculated}} = 16.2996 > F_{\text{critical}} = 3.3258 \quad (1)$$

This confirms that the null hypothesis of no joint significance of the regression coefficients is rejected at $\alpha = 0.05$, suggesting that the explanatory variables jointly exert a statistically significant effect on the dependent variable. As shown in Table 6, the coefficients for the WIPO and SDR indices are statistically significant at the 5% level (indicated by two asterisks), whereas GDP is significant at the 1% level (three asterisks). After excluding the HDI variable, which demonstrated no statistical significance in the initial estimation, a revised regression model was constructed to improve analytical rigor. As reflected in Table 6, GDP and the SDR Index remain the primary determinants influencing CO_2 emissions, whereas the WIPO/GII indicator exhibits a moderate yet statistically significant effect within the updated specification.

Table 6. Regression Results for the Target Variable (Model 2)

Variable	Coefficient	Std. error	t-statistic	p-value	Significance
Const	3003.15	1726.62	1.739	0.0966	*
GDP	7.10303e-010	2.23001e-011	31.85	<0.0001	***
WIPO (GII)	22.2863	11.2978	1.973	0.0618	**
SDRindex	-54.4784	24.9880	-2.180	0.0408	**

Note: Significance levels – *** p < 0.001; ** p < 0.05; * p < 0.1

The revised estimation underscores a persistent and robust positive linkage between GDP growth and environmental degradation, reflecting the BRICS economies' structural dependence on carbon-intensive development pathways. Conversely, the negative coefficient associated with the SDR Index highlights the potential of sustainability-oriented policies to counterbalance these adverse effects. This persistent correlation suggests that BRICS economies exhibit entrenched reliance on carbon-heavy industries as a core driver of their economic expansion. Rather than representing a temporary by-product of early-stage industrialization, this pattern reflects entrenched institutional and infrastructural factors that delay the transition towards low-carbon development pathways. Without significant policy intervention and investment in green technologies, these structural constraints are likely to perpetuate environmental risk. While the Environmental Kuznets Curve (EKC) posits that economic growth eventually leads to environmental improvements, the BRICS context illustrates a delayed or absent turning point due to institutional inertia and limited incentives for sustainable innovation. The role of innovation emerges as particularly nuanced: while technological advancement contributes to economic dynamism, its environmental implications appear ambivalent, suggesting that without targeted institutional frameworks, innovation alone may exacerbate ecological pressure. This duality reinforces the imperative for adaptive governance mechanisms capable of aligning technological progress with sustainability objectives, thereby operationalizing the principles of institutional co-evolution within digitalizing economies. To effectively resolve this paradox, policymakers in BRICS should prioritize the development of targeted green innovation policies that align technological advancements with environmental objectives. This approach should encompass implementing fiscal incentives for clean technologies, establishing adaptive regulatory frameworks to encourage eco-innovation, and fostering public-private partnerships aimed at accelerating the adoption of sustainable technologies.

The diagnostic results presented in Table 7 confirm that the refined regression model maintains a high explanatory capacity (Adjusted $R^2 = 0.979$), indicating that the key economic, innovation, and sustainability variables effectively capture the drivers of CO_2 emissions across BRICS countries. However, beyond statistical robustness, the findings reveal persistent structural dependencies that characterize the development trajectories of these emerging economies.

Table 7. Summary Statistics for Model 2

Statistic	Value	Statistic	Value
Mean of dependent variable	3232.393	Standard deviation of dependent variable	4027.298
Residual sum of squares (RSS)	7096893	Standard error of the model	581.3323
R-squared	0.981768	Adjusted R-squared	0.979164
F-statistic (F(3. 21))	376.9445	p-value (F)	2.06e-18
Log-likelihood	-192.4271	Akaike Information Criterion (AIC)	392.8542
Schwarz Criterion (BIC)	397.7297	Hannan–Quinn Criterion (HQC)	394.2065
Rho (intra-class correlation)	0.861770	Durbin–Watson statistic	0.216763

The strong positive linkage between GDP growth and environmental degradation reflects an enduring reliance on carbon-intensive industrialization. This dependency is reinforced by institutional limitations, ranging from fragmented regulatory frameworks to insufficient incentives for green innovation, which impedes the transition towards sustainable development pathways. The observed patterns challenge the applicability of the Environmental Kuznets Curve (EKC) within the BRICS context, where governance inefficiencies prevent the anticipated decoupling of economic growth from the environmental impact.

The dual role of innovation, marked by the positive correlation between WIPO/GII and emissions, further underscores the need for adaptive institutional frameworks. Without targeted regulatory guidance, technological advancement risks exacerbate rather than alleviate ecological pressures.

These challenges manifest differently across the BRICS nations, reflecting diverse institutional architectures and policy approaches. While the empirical analysis treats BRICS as a collective framework for examining hybrid governance dynamics, we explicitly account for institutional asymmetries through methodological and interpretive means. First, interaction terms such as the digitization index × Rule of Law are used to capture the extent to which digital transformation is shaped by varying institutional contexts. This allows us to approximate the co-evolutionary effects that emerge from divergent governance capacities across BRICS states. Second, to compensate for the limitations of the sample size that preclude full fixed-effects modeling, we adopt a qualitative disaggregation strategy. In the interpretive discussion, we compare countries such as China, with its highly centralized regulatory architecture, to Brazil, whose federalist structure yields more decentralized and often fragmented environmental and platform governance regimes. Such contrasts underscore how the institutional logic of hybrid co-evolution varies not only in degree, but also in form. These asymmetries are essential to understanding how similar digital pressures generate divergent regulatory trajectories across contexts. In China, the establishment of a National Carbon Market represents a significant step towards centralized environmental regulation, yet integration with decentralized innovation ecosystems remains limited. India's Perform, Achieve, and Trade (PAT) scheme exemplifies efforts to merge regulatory mandates with market-based incentives for energy efficiency, although enforcement disparities persist. Brazil faces institutional contradictions where progressive environmental policies coexist with governance gaps, particularly in managing deforestation linked to infrastructure expansion. Russia has introduced digital platforms such as GIS Ekologiya (*ГИС Экология*) to enhance environmental monitoring, but lacks comprehensive mechanisms to align innovation with sustainability objectives. In South Africa, reliance on public-private partnerships within renewable energy initiatives claims both the potential and constraints of hybrid governance in contexts marked by institutional capacity challenges.

These examples demonstrate that the effectiveness of hybrid governance models in BRICS countries is highly contingent upon context-specific institutional capacities, political will, and the ability to synchronize technological advancement with coherent sustainability strategies.We further contextualize the policy recommendations for individual BRICS countries to enhance the practical utility of our findings. In South Africa, strengthening institutional capacity remains essential, particularly in expanding the reach and coordination of public-private partnerships for renewable energy, as well as in addressing regulatory gaps that hinder implementation at the municipal level. Priority should be given to digital infrastructure investments to support environmental data collection and transparency. In Russia, efforts should focus on aligning its digital governance innovations, such as GIS Ekologiya (*ГИС Экология*), with broader environmental and industrial strategies. Policymakers should prioritize cross-sectoral coordination between innovation agencies and environmental regulators to ensure that technological modernization is embedded within a coherent green development framework. In Brazil, the challenge lies in resolving institutional contradictions through improved interagency collaboration and enforcement mechanisms, particularly in relation to deforestation and land use. In India, scaling up successful programs such as PAT requires institutional streamlining and mechanisms for adaptive feedback. Meanwhile, China could benefit from enhancing the interoperability between centralized regulatory mandates and local innovation ecosystems to support green experimentation. Tailoring these recommendations to national institutional realities ensures greater relevance, and facilitates the co-evolutionary alignment of digital transformation and sustainability governance across the BRICS.

These country-specific experiences illustrate that while elements of hybrid regulatory models are emerging across BRICS countries, their effectiveness is constrained by inconsistent policy implementation, regulatory fragmentation, and limited institutional adaptability. The findings emphasize that the successful decoupling of growth from environmental degradation requires coherent, context-sensitive institutional ecosystems that foster synergy between state intervention, market dynamics, and technological innovation.

In this light, the concept of institutional co-evolution is central to addressing these systemic challenges. Effective advancement of sustainability in BRICS economies requires moving beyond reliance on technological progress or fragmented policy measures towards the development of governance frameworks in which sustainability is intrinsically linked to digital and economic transformation processes. Strengthening regulatory coherence, promoting green innovation ecosystems, and leveraging digital governance tools are essential steps towards aligning development trajectories with long-term environmental resilience. These findings not only contribute to the empirical understanding of institutional dynamics within the BRICS context but also extend and contextualize previous studies in the field. While

our primary model focuses on structural associations between institutional quality, innovation, and sustainability outcomes, we acknowledge that several moderating factors, such as governance capacity, civil society strength, and international digital partnerships, may influence the strength and direction of these relationships. Although these dimensions are not explicitly included as interaction terms in our empirical framework, their relevance is reflected in our contextual interpretation of country-specific dynamics. For example, the role of centralized state capacity in China or Brazil's civil society mobilization around environmental issues exemplifies how institutional moderators can shape regulatory effectiveness. Future studies could integrate these variables more systematically, using interaction models or multilevel analysis to assess their mediating influence on the co-evolutionary governance–sustainability nexus.

For instance, while the Environmental Kuznets hypothesis has been widely discussed in the literature [27], our results challenge its universal applicability, revealing that the expected turning point is often delayed or absent in emerging economies with institutional inertia. Furthermore, studies such as Gleiss et al. (2023) [21] and Kokshagina et al. (2023) [26] emphasized the importance of digital systems as institutional infrastructure, and substantiated and nuanced these claims by demonstrating how algorithmic governance, in the absence of adaptive regulatory capacity, may produce governance asymmetries rather than coherence. In contrast to research focused on high-income contexts, which often highlights the enabling role of digital technologies in achieving sustainability transitions [33], our findings reveal a more complex reality for developing economies, in which digital acceleration can outpace institutional maturity, leading to fragmented regulatory landscapes. By situating the BRICS-specific results within the broader scholarly debate, this study reinforces the need for differentiated, context-sensitive models of institutional co-evolution, and provides empirical justification for the hybrid regulatory framework proposed in Section 5.

While the panel regression model provides robust insights into the associations between digitalization, institutional quality, and environmental performance, we acknowledge the important limitations in making strong causal claims. The observed relationships may be influenced by the time-lagged effects of digital infrastructure deployment, delayed policy implementation, or institutional inertia, which are not fully captured in the current specification. Moreover, omitted variables, such as global economic shocks, sector-specific policy reforms, or changes in international regulatory environments, may also shape environmental outcomes. Therefore, the findings should be interpreted as indicative of structural correlations rather than definitive causal pathways. Future research employing dynamic panel models, Granger causality tests, or instrumental variable approaches could further validate the temporal and causal dimensions of institutional coevolution.

4-7- Institutional Change and Entrepreneurial Agency

Institutional change within the digital economy increasingly emerges from the interaction between entrepreneurial agencies and regulatory adaptation, challenging traditional models of gradual, top-down evolution. Unlike classical frameworks, in which institutions adjust reactively to market shifts, contemporary institutional entrepreneurs actively shape governance landscapes by exploiting regulatory gaps and prompting institutional responses.

This dynamic is particularly evident in the proliferation of FinTech platforms, where startups have leveraged technological innovation to bypass the conventional financial infrastructure. Rather than merely introducing new services, companies such as Robinhood [50] and Klarna [51] have compelled regulators to reconsider established legal frameworks, illustrating a form of institutional co-evolution driven by market disruptions. These cases illustrate how entrepreneurial strategies are not only economic in nature but also inherently political, as they redefine the boundaries of acceptable market behavior and institutional authority.

In the BRICS context, Paytm's trajectory exemplifies this bottom-up transformation. Initially operating in a regulatory vacuum, Paytm's rapid expansion forced the Reserve Bank of India to formalize governance over digital payment systems. This interaction reflects a shift towards hybrid governance models, where institutional frameworks are reshaped in response to entrepreneurial innovation, balancing flexibility with the need for oversight.

These examples reveal that institutional entrepreneurship in the digital era functions as both a catalyst for innovation and driver of regulatory complexity. While such agencies accelerate market modernization, they also introduce governance challenges related to stability, accountability, and public interest protection. The capacity of institutions to adapt without undermining core regulatory objectives is a defining factor in sustaining balanced digital ecosystems. Thus, understanding institutional change in the digital economy requires moving beyond linear models of adaptation, focusing instead on the dynamic interplay between entrepreneurial initiatives and institutional resilience. This perspective underscores the importance of adaptive governance frameworks capable of integrating bottom-up innovations while safeguarding systemic integrity, a core principle underpinning institutional co-evolution in rapidly digitalizing markets.

Similarly, platforms such as Uber have demonstrated how business models are strategically designed to exploit institutional gaps, triggering legal debates and regulatory realignment. These cases collectively show that institutional entrepreneurs in the digital economy – often emerging from agile startups rather than from traditional corporations – serve as catalysts for redefining both market norms and governance practices.

In this context, institutional entrepreneurship has become integral to the development of hybrid regulatory frameworks, in which state authority, market forces, and platform governance intersect. The challenge for policymakers is to harness the transformative potential of entrepreneurial initiatives, while ensuring that institutional stability, transparency, and public interest protection are maintained. This reinforces the necessity for adaptive governance systems capable of accommodating bottom-up institutional dynamics and aligning them with broader socioeconomic and sustainability objectives – a core principle of institutional co-evolution in the digital era.

4-8- Typology of Institutional Dynamics and Concluding Insights

As "it is evident that no actor can single-handedly transform existing institutions," the concept of collective institutional entrepreneurship becomes increasingly relevant. At its core lies a community of diverse actors who share, to varying degrees, an interest in institutional change, often not driven solely by profit motives. This community of institutional transformation can be understood as "a network of internal and external actors linked to a given institution by their interests and/or values." In the case of emerging energy technologies, for example, the institutional change community may include entrepreneurs, policymakers and political parties, industry associations and lobbyists, environmental groups, activist influencers (e.g., bloggers), as well as experts and scholars. These coalitions operate across institutional boundaries and engage in both formal and informal efforts to reshape norms, rules, and expectations. As Frolov [9] emphasizes, both digital technologies and the institutions of digital capitalism possess an intrinsic feature of "editability." In digital environments, institutional frameworks tend to remain open to adjustments from a wide spectrum of actors, ranging from end users to platform owners and public authorities. Even everyday users contribute to incremental institutional change by altering behaviors, routines, and normative practices, forming new expectations, and reinforcing (or rejecting) dominant narratives. Over time, such a cumulative effect of minor individual changes can lead to qualitative institutional shifts, demonstrating how digital institutions are co-constructed and continuously renegotiated through distributed agencies.

Thus, a typology of institutional change within the digital economy is proposed and visualized in Figure 4. This typology categorizes the primary mechanisms through which institutional transformations unfold, distinguishing between top-down political interventions, bottom-up entrepreneurial initiatives, and spontaneous evolutionary processes. It serves as an analytical framework to interpret how hybrid regulatory models emerge in response to digital transformation pressure.

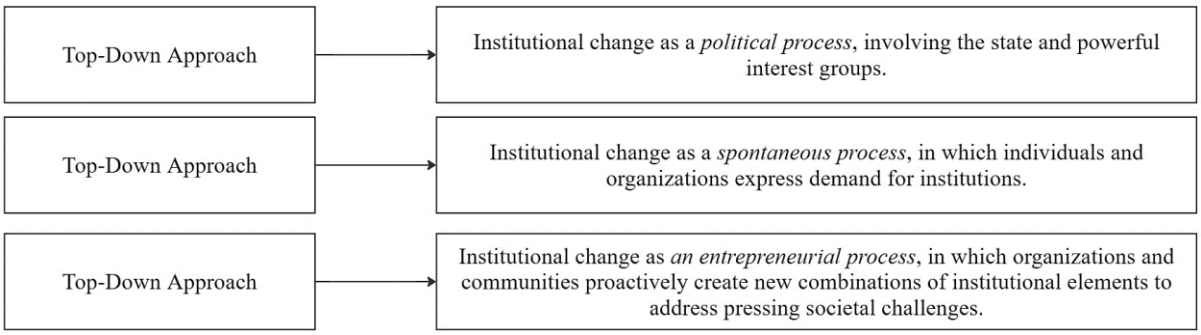

Figure 4. Types of Institutional Changes in the Digital Economy

As illustrated in Figure 4, institutional change in digital markets does not follow a singular path but results from the dynamic interaction of these three approaches. This explains the emergence of hybrid governance models in BRICS countries, where state-led initiatives, market forces, and entrepreneurial innovations collectively shape regulatory practices. This typology provides a foundation for understanding how flexible and adaptive institutional responses can address the challenges posed by rapid digitalization.

The results indicate that GDP growth has a negative impact on environmental sustainability by increasing CO_2 emissions, whereas a high level of digitalization and innovation development contributes to reducing environmental risks and improving resource management efficiency. Lyu et al. [11] reported a positive correlation between GDP growth and carbon emissions, in contrast to the mitigating effects of digitalization and innovation on environmental degradation, which is broadly consistent with the findings of the present study. To identify the relationships among different aspects of the digital transformation of territorial governance, an analysis of scientific publication clustering was conducted. The methodology of co-occurrence keyword analysis was applied, which allowed for the identification of three main groups as drivers of sustainable development: 1) technological innovations and sustainable development, including AI, blockchain, and Industry 4.0. 2) Urban technologies and resource management ecosystems – IoT, smart city solutions, and waste management are analyzed. 3) Data security and supply chain tracking focus on digital mechanisms for transparency and resource control. This analysis helps determine which scientific and practical directions are prioritized in the context of digital regulation and institutional changes.

4-9- Hypothesis Testing

In line with the objectives and tasks of this study, the formulated hypotheses were empirically verified based on the obtained results. Below is a discussion of the confirmation or rejection of each hypothesis, including the specific empirical data and calculations.

H1: *Institutional co-evolution of the digital economy follows a hybrid model combining both evolutionary ("bottom-up") and directive ("top-down") approaches.*

To empirically verify the first hypothesis, bibliometric and cluster analyses of scientific literature were conducted (Table 2, Figure 2). The keyword frequencies presented in Figure 2 were derived through manual coding and statistical aggregation using Excel based on a corpus of 63 peer-reviewed articles published between 2021 and 2023. This methodological approach ensured accurate identification of thematic clusters relevant to hybrid regulatory models in the digital economy.

The results confirm the prevalence of hybrid approaches to digital economy regulation, which combine elements of directive state intervention and self-regulation at the level of digital platforms. High-frequency terms such as "regulation," platform governance, "blockchain," and "digital policy" frequently co-occurred with keywords such as "self-regulation," decentralization," and "algorithmic control." This indicates an ongoing synthesis between centralized regulatory frameworks and decentralized governance mechanisms.

Figure 4 provides a conceptual framework for understanding institutional transformation. It categorizes institutional change into three primary approaches:

- Top-down approach, where institutional changes are driven by state policies and influential actors.
- Evolutionary approach, where institutional adaptation occurs spontaneously in response to market and technological developments.
- Bottom-up entrepreneurial approach, where organizations and communities actively construct new institutional arrangements to address emerging challenges.

The visualization in Figure 4 illustrates how these mechanisms interact within the digital economy, supporting the argument that institutional change is frequently the product of both centralized (top-down) and decentralized (bottom-up) initiatives.

Moreover, recent literature stresses practical examples of hybrid governance models such as the European Union's Digital Services Act, China's platform compliance frameworks, and the rise of decentralized autonomous organizations (DAOs), which blend regulatory oversight with self-enforcing digital protocols.

The empirical findings reinforce that hybrid institutional evolution extends beyond theoretical propositions but an observable trend in regulatory practices in digital economy governance. These conclusions align with recent studies emphasizing hybrid governance in digital economies beyond BRICS, including adaptive regulatory frameworks observed in Southeast Asia and Nordic countries [34]. This evidence reinforces the global relevance of hybrid institutional models in managing digital transformation. Furthermore, the persistence of hybrid governance models observed across various contexts suggests that these configurations are not merely adaptive responses to digital disruption, but are reinforced by existing institutional trajectories. The mechanisms of path dependency and institutional layering contribute to this stability, as new digital norms and decentralized practices are integrated within established regulatory frameworks rather than replacing them entirely. This institutional continuity coupled with incremental adaptation underscores the durability of hybrid models as a defining feature of institutional co-evolution in the digital economy. Thus, Hypothesis 1 is empirically confirmed.

H2: *The resilience and effectiveness of institutional co-evolution depend on the adaptability of institutions to rapid technological and market changes.*

Econometric analysis was used to test the second hypothesis, including general least squares (OLS) regression analysis. The results are shown in Tables 4-7. Empirical results suggest that improvements in the Digital Competitiveness Index (WDCR) and Global Innovation Index (GII) are associated with lower levels of environmental risk and stronger institutional capacity within the digital economy. In contrast, rising GDP appears to correlate with increased ecological pressure, indicating that institutional arrangements must remain responsive to rapidly changing technological and market environments. Therefore**,** Hypothesis 2 is fully supported by the results of the econometric analysis. Similar findings were reported by Nanni et al. [27], who highlighted that institutional resilience in digital economies depends on the capacity to integrate sustainability objectives into innovation policies. This underscores the necessity of dynamic governance mechanisms capable of aligning technological advancement with environmental and social priorities.

While the econometric analysis was conducted at the aggregate BRICS level, preliminary country-level observations indicated variations in institutional adaptability. For instance, China and India demonstrate stronger digital

competitiveness improvements, whereas Brazil and South Africa face greater challenges in aligning digitalization with environmental risk mitigation. This finding suggests that future research should disaggregate these dynamics to capture country-specific institutional responses.

The positive correlation between innovation indicators and CO_2 emissions indicates the need for targeted innovation policies that prioritize green technologies and sustainable practices. Policymakers should ensure that innovation-driven growth aligns with environmental objectives through fiscal incentives, regulatory frameworks, and support for eco-innovation ecosystems. These insights reinforce the critical importance of adaptive institutional frameworks that can effectively channel innovation towards sustainability goals rather than allowing unchecked technological growth to exacerbate environmental risks.

To strengthen the empirical grounding of Hypothesis 2, we refer to the construct operationalization presented in Table 5, which details how core institutional variables, such as institutional co-evolution, platform governance, and entrepreneurial agency, were measured using standardized indicators. The interaction term combining the World Digital Competitiveness Ranking (WDCR) and the Rule of Law effectively captures the institutional co-evolution process. The extended conceptual framework presented in Figure 5 illustrates how these institutional domains interact dynamically to shape sustainability outcomes. Together, Table 5 and Figure 5 provide methodological and theoretical support for interpreting the observed associations between governance quality, innovation dynamics, and environmental performance across BRICS countries.

H3: *The expanding institutional agency of digital platforms and elites is reshaping governance logics within the digital economy, indicating a paradigm shift that challenges conventional regulatory frameworks – though its full extent requires deeper empirical exploration.*

Hypothesis 3 was tested through literature review and cluster analysis of scientific publications (Figure 2), which revealed the growing prominence of terms related to *platform governance, blockchain, AI, and decentralization*. These findings suggest that digital platforms and institutional entrepreneurs play increasingly significant roles in defining governance norms and institutional frameworks within the digital economy.

Empirical evidence from BRICS countries supports this trend. For instance:

- In China, platforms such as *Alibaba* and *Tencent* not only dominate e-commerce and financial services but also integrate state-led initiatives such as the *Social Credit System* and embedding data-driven governance practices.
- In India, the *Aadhaar* digital identity system has revolutionized public service delivery, while private platforms, such as *Flipkart* and *Paytm* are reshaping market structures and regulatory approaches.
- In Russia, *Yandex* influences data governance and content regulation, whereas the state-operated *Gosuslugi* platform institutionalizes digital interactions between citizens and government bodies.
- Brazil's *gov.br* platform consolidates thousands of public services into a unified digital interface, whereas *Mercado Livre* drives regulatory discussions in the e-commerce and fintech sectors.
- In South Africa, the *e-Government Gateway* and platforms such as *Takealot* illustrate how digital infrastructure is redefining both public administration and market governance.

Table 8 summarizes the interplay between public and private digital platforms across BRICS countries, highlighting the distinct governance approaches shaped by national institutional contexts.

Table 8. Comparative Overview of Public and Private Digital Platforms in BRICS and Their Governance Focus

Country	Public Platforms	Private Platforms	Governance Focus
China	Social Credit	Alibaba [56], Tencent [57]	Data-driven, State-led
India	Aadhaar [52]	Flipkart [58], Paytm [59]	Market-driven, Public-Private
Russia	Gosuslugi [53]	Yandex [60]	Mixed Model
Brazil	gov.br [54]	Mercado Livre [61]	Integration, E-commerce
South Africa	eGov Gateway [55]	Takealot [62]	Digital Access, Consumer Law

As shown in Table 8, governance models across BRICS countries reflect a spectrum ranging from state-centric digital control to market-driven platformization, with varying degrees of public-private interaction. This cross-country evidence underscores that digital platforms – both private and state-led – are no longer merely intermediaries, but active institutional agents shaping governance logic.

The convergence of public digital infrastructure with private platform ecosystems illustrates a paradigm shift towards platform-based governance models, where traditional regulatory boundaries are increasingly blurred. However, despite these developments, the scope and depth of this transformation require further empirical investigation. Existing data do

not provide a comprehensive assessment of how deeply platform logic has supplanted conventional regulatory paradigms across different institutional contexts. However, scholars have warned that the expanding influence of digital platforms may lead to regulatory capture and reduced transparency in governance processes [31]. These risks highlight the importance of developing robust co-regulation frameworks and ensuring multi-stakeholder participation to mitigate power asymmetries inherent in platform-based governance models. Therefore, Hypothesis 3 is partially supported. Future research should focus on detailed case studies of institutional restructuring driven by platformization, particularly examining the issues of accountability, transparency, and power asymmetries in digital governance environments.

Overall, empirical validation of these hypotheses provides a foundation for rethinking regulatory strategies in the digital age. However, given the complexity of institutional dynamics within digital ecosystems, future research should adopt a multimethod approach that combines quantitative analysis with qualitative insights to capture the full spectrum of governance transformations.

5- Discussion

The results of this study reveal that institutional change in the digital economy arises through the interplay of evolutionary mechanisms, state regulation, and institutional entrepreneurship. This finding significantly expands upon traditional liberal economic views that separate the roles of the market and the state. While classical economic theory, following the works of Adam Smith and later Ronald Coase, largely defined the role of the state as limited to property rights enforcement and provision of a legal framework [6], the present research shows that in the digital context, the state evolves into an active institutional architect.

These findings align with Mazzucato's [8] concept of the "entrepreneurial state," where public institutions regulate and actively co-create markets and innovation ecosystems. The hybrid regulatory model observed in digital economies illustrates this dynamic as states increasingly engage in shaping technological trajectories alongside private actors and platform entrepreneurs. Furthermore, Potts' [22] notion of "innovation commons" underscores the importance of collaborative institutional frameworks that facilitate adaptive governance in rapidly evolving digital contexts. Empirical evidence supports this transformation; policy innovations such as the EU's Digital Markets Act [2, 3] and regulatory programs in China [11] demonstrate how governments actively shape digital ecosystems. Similarly, U.S. initiatives supporting digital startups indicate that adaptive regulation can accelerate innovation diffusion while preserving market dynamics.

A key contribution of this study lies in emphasizing the role of institutional entrepreneurship and stakeholder communities. While prior research typically treats such communities as agents of technological commercialization [63], the present findings suggest that these actors are also central to the generation of institutional innovations. Fintech startups [50, 51, 64] exemplify how institutional entrepreneurs can challenge legacy regulatory frameworks by introducing alternative governance norms such as commission-free trading [50] or flexible credit models [51]. Disruptive models often prompt regulatory bodies to revise outdated rules, fostering a more dynamic interaction between innovation and regulation. Similarly, DAOs represent a frontier in decentralized governance, in which algorithmic protocols replace traditional hierarchical decision-making structures, raising new questions about accountability, transparency, and legal recognition within existing institutional systems.

These dynamics illustrate how digital ecosystems increasingly transcend the binary opposition between directive and evolutionary models of institutional change. The findings reveal the emergence of hybrid regulatory models that integrate top-down (state-led) and bottom-up (platform-driven) dynamics. This pattern is particularly evident in the regulation of digital platforms in the EU and the U.S., where adaptive governance frameworks coexist with decentralized innovations such as DAOs, combining blockchain-based transparency with flexible institutional arrangements [24].

Building on this observation, it is essential to consider how such hybrid frameworks can be tailored to the governance environments of emerging economies. The effectiveness of the proposed hybrid regulatory model depends on its alignment with the specific political, institutional, and economic context of each BRICS country. Given the diversity within a bloc, a uniform application is neither feasible nor desirable. In China, the model relies predominantly on directive state mechanisms, leveraging the government's centralized control to enforce digital governance standards while integrating platform-based compliance protocols. India, characterized by a more decentralized and market-oriented institutional environment, may benefit from empowering platform self-regulation supported by targeted policy frameworks and public-private partnerships. Russia and Brazil present cases in which a balanced approach is viable, combining strong state oversight with institutional entrepreneurship to foster adaptive regulatory ecosystems. South Africa, facing resource constraints and institutional fragmentation, could prioritize collaborative governance models involving multi-stakeholder engagement to enhance regulatory capacity and accountability. This adaptive flexibility underlines the robustness of the hybrid model, thus ensuring its relevance across heterogeneous governance architectures in emerging digital economies. Digital governance rarely adheres to a single trajectory. Decentralized governance structures, particularly those inspired by DAO (Decentralized Autonomous Organization) principles, often originate as bottom-up innovations that leverage blockchain-based protocols to enable autonomous decision-making and transparent

operations. However, as these platforms scale, they frequently encounter the necessity of top-down legal frameworks to address regulatory compliance, liability, and jurisdictional challenges. This dynamic underscores an iterative feedback loop where decentralized experimentation is progressively codified through formal institutional mechanisms, reflecting the inherent fluidity and hybridity of institutional evolution within digital ecosystems.

However, translating this flexibility into effective governance practices is a significant challenge. In BRICS countries, the implementation of hybrid regulatory models faces additional complexity owing to the fragmented coordination between state authorities and market actors. Institutional inertia, divergent policy priorities and limited stakeholder engagement often hinder the development of cohesive governance frameworks. Addressing these challenges necessitates the establishment of adaptive policy platforms that facilitate dialogue among regulators, digital platforms, and civil society, ensuring that governance remains both flexible and inclusive.

These three domains – State-Led Regulation, Platform Self-Governance, and Institutional Entrepreneurship – correspond to the institutional logic explored throughout this section. To further operationalize these dynamics, Figure 5 presents an expanded visualization of the hybrid co-evolutionary governance model. This illustrates how state-led regulation, platform self-governance, and institutional entrepreneurship interact through mechanisms such as co-regulation, feedback loops, and adaptive alignment to shape sustainability outcomes. This integrated model captures both the structural roles and processual interdependencies among key actors, emphasizing their collective contribution to institutional resilience in the digital economy. While state-led regulation captures top-down mechanisms of legal and policy control, platform self-governance reflects decentralized and algorithmic rule-making within digital ecosystems, and institutional entrepreneurship emphasizes the role of actors driving institutional innovation from within. Figure 5 synthesizes these components into a structural model of hybrid co-evolutionary governance, highlighting their dynamic interplays and contextual interdependence. This architecture emphasizes that institutional resilience in the digital age is achieved through dynamic combination and contextual alignment, not through the dominance of a single mechanism.

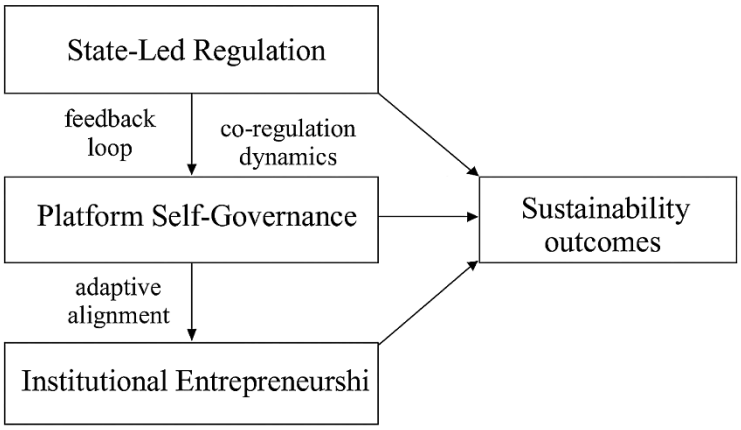

Figure 5. Interplay between Regulatory Actors, Institutional Co-evolution Mechanisms, and Sustainability Outcomes

Figure 4 (introduced earlier) further elaborates the typology of institutional change trajectories through which the hybrid model evolves in practice. These challenges indicate the necessity of understanding institutional change as a dynamic and context-sensitive process – an issue further elaborated through the typology presented below. The typology of institutional change presented in this article (Figure 4) distinguishes three principal trajectories through which institutions evolve in the digital economy: *top-down, bottom-up, and evolutionary*. Each pathway reflects a distinct mechanism of transformation. In a top-down approach, institutional change is conceptualized as a *political process* shaped by state intervention and the influence of powerful interest groups. The bottom-up perspective frames change as an *entrepreneurial process*, whereby communities and organizations actively assemble new institutional configurations in response to emerging societal needs. The evolutionary approach, by contrast, highlights *spontaneous processes*, where institutional shifts result from aggregated preferences and decentralized demand for new arrangements.

Although analytically distinct, these trajectories often intersect. For instance, experimental models developed by digital startups or user networks may later be codified through formal regulations, reflecting a transition from bottom-up to top-down. Conversely, state-led reforms can generate unexpected adaptation patterns at the platform level. This typology offers a framework for interpreting how institutional change unfolds in dynamic digital contexts where agency is distributed, feedback is continuous, and boundaries between actors are increasingly porous.

Despite its flexibility, the hybrid regulatory model faces several implementation challenges in the BRICS countries. These include political volatility, varying degrees of institutional maturity, and potential resistance from entrenched interests, both governmental and corporate. In highly centralized systems, such as China and Russia, there is a risk that state dominance may suppress the adaptive capacity of platform-driven governance. Conversely, in countries with

weaker regulatory frameworks, such as South Africa and India, over-reliance on self-regulation can exacerbate accountability gaps and power asymmetries. Furthermore, the influence of major digital corporations raises concerns about regulatory capture, whereby platforms shape rules in their favour. Addressing these barriers requires a balanced approach that reinforces institutional checks and ensures inclusive stakeholder participation in the governance processes. One practical mechanism to facilitate this balance is the use of regulatory sandboxes and adaptive policy frameworks, which allow BRICS countries to experiment with hybrid governance models in a controlled environment, fostering innovation while managing systemic risks [23].

6- Conclusions and Policy Recommendations

6-1- Findings of the Study

The findings of this study suggest that institutional change in the digital economy does not proceed in a straightforward or uniform fashion. Instead, it emerges from the interplay of distinct, yet overlapping mechanisms: incremental evolutionary adjustments, deliberate regulatory interventions, and the strategic activity of entrepreneurial actors. This combination produces institutional configurations that are adaptive in structure and heterogeneous in function.

The empirical results reinforce the growing institutional role of digital platforms and technological ecosystems. Their influence is not exerted independently, but rather through interactions with state regulators and private sector stakeholders. Within this evolving landscape, governance arrangements combining formal oversight with platform-led coordination appear to offer greater flexibility and operational robustness.

Hypothesis testing confirmed that institutional co-evolution in digital systems reflects both distributed and structured interventions. While some institutional shifts arise from decentralized trial-and-error processes shaped by technology adoption, others are the result of purposeful rule setting by state institutions. The interaction between these forces underscores the layered character of institutional change under the conditions of accelerated innovation and regulatory uncertainty.

One of the central observations of this study is that institutional responsiveness plays a critical role in sustaining regulatory capacity over time. As digital platforms increasingly participate in norm-setting – shaping behavioral standards and operational expectations – the rigidity of traditional governance models becomes more apparent. This highlights the need for frameworks capable of engaging with network-based authority and accommodating distributed innovation processes.

Quantitative analysis further supports the general proposition that digitalization can yield environmental benefits. A statistically significant association was found between higher levels of technological sophistication and reduction in ecological risk. However, this trend does not hold across all dimensions; increases in GDP continue to correlate with higher carbon emissions, exposing a structural contradiction between economic expansion and environmental goals. These findings reinforce the urgency of designing institutional systems that can reconcile innovation-driven growth with long-term sustainability.

6-2- Policy Implications

The analysis conducted in this study highlights the need for regulatory approaches that reflect the layered and evolving nature of digital institutions. In particular, the evidence supports hybrid governance models, in which public oversight is complemented by the self-organizing capacities of digital platforms. These arrangements enable a more effective alignment between formal regulatory aims and decentralized logic that underpins digital infrastructure and innovation networks. In contexts in which technological conditions shift rapidly, institutional flexibility becomes essential for maintaining regulatory coherence and adaptive capacity. To operationalize the proposed hybrid governance framework within BRICS countries, policymakers should adopt a set of adaptive governance instruments that align with the dynamic nature of digital transformation. One effective approach involves the establishment of regulatory sandboxes, enabling digital platforms and innovative enterprises to experiment with new technologies within controlled environments under temporary regulatory relaxation. This facilitates not only risk assessment, but also policy learning while promoting innovation.

In addition, fostering structured public-private partnerships can enhance collaborative rule-making, allowing state authorities, platform operators, and institutional entrepreneurs to co-develop regulatory standards that balance market dynamism with societal safeguards. The introduction of platform governance codes, focused on transparency, data protection, algorithmic accountability, and fair competition, represents another critical mechanism for embedding self-regulatory practices within broader legal frameworks.

Policymakers should also prioritize the design of flexible legal architectures that incorporate iterative review processes, ensuring that regulatory provisions remain responsive to technological advancements. The creation of multi-stakeholder governance councils, involving representatives from the government, industry, civil society, and academia, can further support inclusive decision-making and enhance the legitimacy of governance outcomes.

Capacity-building initiatives aimed at strengthening institutional competencies in areas such as AI governance, blockchain oversight, and digital market regulation are essential to ensure effective implementation and enforcement of hybrid regulatory models. Collectively, these measures provide a practical pathway for BRICS countries to embed flexibility, resilience, and accountability into their digital governance systems, aligning regulatory practices with both innovation imperatives and public-interest objectives.

Comparative examples from jurisdictions such as the European Union, the United States, Hong Kong, and Thailand provide further insight into how mixed regulatory systems operate in practice. These cases illustrate that combining statutory frameworks with more flexible bottom-up mechanisms can help mitigate institutional uncertainty while fostering space for experimentation and innovation. Where regulatory hierarchies coexist with adaptive rule-making, institutional responses tend to be more resilient to disruption and more capable of supporting long-term system development.

From a policy design perspective, the findings revealed the importance of incorporating algorithmic tools, participatory governance elements, and entrepreneurial actors into regulatory frameworks. Policymakers are increasingly faced with the challenge of governing institutions evolving in tandem with technology. Static approaches are unlikely to suffice in such an environment. Instead, regulatory architectures must allow for iterations, feedback, and learning. The ability to respond to emerging technological trajectories and shifts in market coordination is essential if institutional systems support innovation, while addressing wider social and environmental goals.

For regulators in developed economies, the proposed hybrid framework offers a pathway to balance innovation incentives with societal oversight, particularly in sectors in which rapid technological change outpaces traditional regulatory cycles. Lessons from adaptive governance in BRICS can inform flexible policy architectures suited to dynamic digital markets in the EU, North America, and East Asia.

6-3- Theoretical Implications

The novelty of this study lies in the development of a hybrid model of institutional regulation for the digital economy that integrates state regulation, institutional entrepreneurship, and self-regulation of digital platforms. Rather than reproducing the conventional divide between bottom-up and top-down institutional designs, this model reflects how formal regulatory authority, market-driven logic, and technological agencies coexist and interact. Digital environments rarely conform to binary classification. Instead, institutional dynamics are often shaped by overlapping layers of influence, such as legal frameworks, algorithmic infrastructure, and innovation networks.

Governance in digital systems is often framed as the tension between state control and market-driven autonomy. The proposed framework shifts focus to their interaction, showing how regulatory authorities and technological agencies continuously reshape each other in dynamic digital contexts. Thus, the hybrid model contributes to the institutional theory by capturing these interdependencies and translating them into an analytical structure relevant to rapidly evolving economies.

The central theoretical contribution of this study lies in articulating the role of institutional entrepreneurship as a key mechanism in the emergence and reconfiguration of digital institutions. Interaction among technology developers, innovation-driven communities, and formal governance bodies forms the basis for new institutional trajectories. This triangulated process offers insight into how regulatory and normative structures consolidate under the conditions of ongoing innovation and technological disruption.

In addition, the study engages with current debates on algorithmic governance, positioning it not as a technical subsystem, but as a central feature of institutional flexibility in the digital age. Adaptive governance frameworks increasingly rely on algorithmic mechanisms to respond to the nonlinear and rapidly changing dynamics of digital transformations. The integration of digital technologies, such as artificial intelligence and blockchain, into regulatory architectures is shown not merely as a technical enhancement but also as a paradigm shift in institutional oversight. These insights underline the necessity of moving beyond rigid regulatory templates towards more flexible, reflexive frameworks capable of responding to high-velocity technological change and institutional experimentation inherent to the digital domain. These findings open new avenues for institutional theory by providing a framework for analyzing hybrid governance beyond digital contexts, including areas such as fintech regulation, AI ethics, and platform labor markets. Future research can expand this model to explore how hybrid institutional arrangements evolve in response to emerging technologies and sociopolitical pressures.

6-4- Strengths and Limitations

This study offers several substantive conceptual and empirical contributions. One of its main strengths is the use of a mixed-methods approach that integrates bibliometric analysis, econometric modeling, and theory-informed interpretation. This combination allows for a multidimensional view of institutional co-evolution in the digital economy, bringing together the structural, technological, and policy-driven aspects of transformation.

The hybrid regulatory framework developed in this study captures how state authority, algorithmic coordination, and platform-level norm formation intersect. Rather than relying on the binary models of top-down versus bottom-up governance, this approach reflects the layered and often overlapping nature of institutional development in digital systems.

The empirical analysis was based on verified open-access data covering five BRICS countries from 2018 to 2022. This design introduces both geographical and temporal variations, improving the relevance of the model for cross-country comparisons. Statistically significant links between digitalization indicators and environmental outcomes add empirical weight to the broader theoretical argument on the impact of institutional adaptation in technologically dynamic settings. However, this study had limitations. Reliance on publicly available data restricts insights into the internal governance routines of digital platforms, especially informal norms, tacit coordination, and algorithmic processes that are central to self-regulation. These aspects were largely invisible in the current dataset.

The focus on BRICS countries brings consistency, but narrows external validity. Digital economies with different legal systems, regulatory cultures, and innovation ecosystems may exhibit distinct institutional dynamics that are not captured here.

Finally, while the roles of institutional entrepreneurship and bottom-up change are acknowledged in the theoretical discussion, these elements are not directly observed in the empirical part of the study. Future research could address this issue by using network analysis, actor-centered case studies, or process tracing to explore how these forces operate within specific institutional settings. Moreover, the empirical validation of hybrid governance remains constrained by the lack of longitudinal data on the dynamic interactions between state actors, platforms, and institutional entrepreneurs over time. This limitation restricts our ability to assess how hybrid regulatory models evolve in response to shifting technological and institutional environments. Additionally, reliance on bibliometric and econometric analyses may not fully capture informal governance dynamics and tacit institutional practices within digital ecosystems. Future research should incorporate qualitative case studies and longitudinal data to deepen our understanding of institutional adaptation processes.

6-5- Recommendations for Future Research

Despite its structured contributions, this study faces several methodological constraints that shape the interpretation of its findings. Perhaps the most notable is the use of publicly available data. While such datasets offer broad accessibility, they rarely provide insights into the internal processes of platform governance, particularly those that involve informal decision-making or algorithmic discretion. Consequently, some institutional dynamics, especially those occurring behind formal interfaces, likely remain beyond the scope of this analysis.

Another limitation was related to the temporal and geographical scope of the dataset. Focusing on BRICS countries over a five-year period is necessary to maintain analytical clarity. However, this choice also narrows the range of institutional variation and may obscure the patterns that emerge in other digital economies with different legal traditions or policy frameworks.

Future research could build on the analytical foundation developed in this study by exploring how geopolitical dynamics and shifts in international alignment influence the configuration of digital institutions. Countries experiencing accelerated digitalization, where governance structures remain fluid and unsettled, provide especially relevant contexts for examining how institutional forms take shape. In such settings, refining tools for assessing the performance of hybrid governance regimes could enhance both practical policy diagnostics and the theoretical frameworks for institutional adaptability.

Comparative studies involving developed economies can further clarify how different levels of institutional maturity and technological infrastructure shape the effectiveness of hybrid governance frameworks. Such analyses would highlight whether the flexibility observed in emerging markets is equally applicable in contexts with more rigid legal traditions or advanced regulatory systems.

Another area that warrants further investigation is the role of user communities as institutional actors. These communities are not only instrumental in disseminating technological innovations but also contribute to the formation, negotiation, and consolidation of governance norms. Their agency, though often informal or decentralized, represents an important force in shaping institutional trajectories in digital spaces. Their contribution to institutional change, although often informal and distributed, is an essential dimension of co-evolutionary dynamics and remains insufficiently explored in empirical research. Simultaneously, the domain of algorithmic governance warrants further investigation. Future studies could compare different algorithmic coordination models by examining their implications for institutional robustness, regulatory legitimacy, and adaptability. Particular emphasis should be placed on the capacity of public regulators to develop strategies that respond effectively to the speed and complexity of technological change, balancing the imperatives of innovation with the requirements of long-term institutional sustainability.

7- Declarations

7-1- Author Contributions

Conceptualization, A.V.S.; methodology, A.V.S.; software, S.A.K.; validation, A.V.S., S.A.K, and A.V.N.; formal analysis, A.V.S. and A.V.N.; investigation, A.V.S.; resources, A.V.S. and S.A.K.; data curation A.V.S.; writing—original draft preparation, A.V.S.; writing—review and editing, A.V.S. and S.A.K; visualization, A.V.S. and S.A.K.; supervision, A.V.S.; project administration, A.V.S.; funding acquisition, A.V.S. All authors have read and agreed to the published version of the manuscript.

7-2- Data Availability Statement

All the data used in this study are publicly available and obtained from reputable international sources that ensure transparency, comparability, and reproducibility. The variables included in the econometric model (see Table 1) were collected for BRICS countries for the period 2018–2022 and structured in machine-readable formats (.csv and .xlsx). Below is a detailed overview of each variable and its data sources.

1) CO_2 Emissions (million tons)

Source: *Global Carbon Atlas*

Access: https://globalcarbonatlas.org/emissions/carbon-emissions/

Format: Downloadable .csv tables

Description: Provides annual data on national CO_2 emissions maintained by the Global Carbon Project and partners.

2) Gross Domestic Product (GDP, constant USD)

Source: *Our World in Data*

Access: https://ourworldindata.org/grapher/national-gdp-constant-usd-wb

Format: Interactive tables and downloadable .xlsx/.csv files

Description: Annual GDP data based on the World Bank methodology enable cross-country comparability.

3) Sustainable Development Index (SDR Index)

Source: *Sustainable Development Report / SDG Index Explorer*

Access: https://dashboards.sdgindex.org/explorer

Format: .xlsx downloadable datasets

Description: Includes aggregate scores across all 17 Sustainable Development Goals; published by SDSN and Bertelsmann Stiftung.

4) Global Innovation Index (GII)

Source: *WIPO Global Innovation Index Reports*

Access: https://www.wipo.int/global_innovation_index/en/

Format: Annual PDF and Excel data files

Description: Covers over 80 innovation indicators; reports for 2018–2022 are used to capture national innovation performance.

5) World Digital Competitiveness Ranking (WDCR)

Source: *IMD World Competitiveness Center*

Access:https://www.imd.org/centers/world-competitiveness-center/rankings/world-digital-competitiveness/

Format: Annual rankings in .pdf/.xlsx format

Description: Measures digital infrastructure, regulatory conditions, and digital skills across countries.

6) Human Development Index (HDI)

Source: *United Nations Development Programme (UNDP) – Human Development Reports*

Access: https://hdr.undp.org/

Format: Interactive explorer and downloadable .csv/.xlsx files

Description: The composite index of life expectancy, education, and income per capita is used as a proxy for socio-institutional capacity.

All data were accessed between January and March 2025 and were structured for empirical analysis. Econometric modeling was conducted using Gretl, an open-source software for statistical analysis, which ensured the reproducibility of all results. Variable definitions, transformations, and model specifications are fully documented and are available upon request.

7-3- Funding

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7-4- Institutional Review Board Statement

Not applicable.

7-5- Informed Consent Statement

Not applicable.

7-6- Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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