

Institutional Governance, Emergent Adaptations, and Corporate CO₂ Emissions: A Complex Adaptive Systems Perspective

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ABSTRACT:

This study attempts to fill the gap in understanding how institutional governance influences CO₂ emissions through environmental pressures. By integrating institutional theory with complex adaptive systems perspectives, this study examines interactions among governance quality, flexible organizational structure and Co₂ emission outcomes. Panel vector autoregressive (VAR) framework is applied to data that is specifically taken from 500 multinational corporations over the period 2014-2024. From this sample countries dataset, the focus is on governance indicators (voice and accountability, control of corruption), adaptation proxies (vulnerability indices, renewable energy adoption rates), and CO₂ emission scopes. The modeling of this paper uses High-dimensional fixed effects (HDFE) where moderated-mediation analysis is performed that is drawn on Thomson Reuters ESG datasets. The results reveal that governance framework minimizes climate vulnerability, thereby CO₂ emissions is control to a certain extent. Further, the model is tested through interactions with corporate social responsibility (CSR) committees that shows minimal moderation that is suggesting governance influences primarily through adaptive capacity. Understanding of these patterns show heterogeneous responses across emission categories aligning with institutional pressures. These patterns underscore heterogeneous responses across emission categories, aligning with institutional pressures and system emergence. The emergent adaptations work as mediator to see the association between governance and emissions. This offers a novel insight of firm level shadow dynamics that is explained through complex adaptive system (CAS) offering novel insights into shadow dynamics and vulnerability in complex systems.

Keywords CO₂ emissions, Institutional governance, Complex adaptive systems, Emergent adaptations, Panel VAR

INTRODUCTION

Scholars and policymakers alike are concerned with effective governance practices to address environmental challenges (Odeyemi et al, 2024). Using green practices, firms enable operational efficiency to address environmental challenges. These initiatives help in promoting innovative operational practices that lead to competitive advantage, which is important for Sustainability in the global business landscape. In this context, the role of regulatory bodies is significant for sustainable corporate practices. This is imperative to elucidate the fundamental mechanisms governing firm-level carbon emission abatement (Hasanov et al., 2021; Wang et al., 2024). To achieve sustainable economic growth, industrial growth works as an important performance parameter. However, along with industrial growth, climate change has become a central concern for policymakers and scholars. The effectiveness of environmental Sustainability largely depends on institutional governance mechanisms that are required to be perfectly aligned with economic policies. Considering governance quality, the growth models should be aligned with policy implications where firms' governance structures focus on the quality of operational practices, which is necessary for sustainable growth. Conventional growth models have limitations in explaining technological disruptions, uncertain climate events and resource depletion that are particularly observed in African regions (Alam et al., 2012; Asongu et al., 2020).

Although Corporate CO₂ emissions stand at the forefront, the research has given little attention to how fixing this issue can reshape the governance framework, economic structure, and organizational development (Huang & Watson, 2015; Luo et al., 2019). Within the current debate of environmental

protection, the role of institutional governance is significant for global Sustainability to control global emissions. The CO₂ emission manifests economic policies, institutional practices and governance mechanisms through the level of their environmental compliance necessary for sustainable business operations.

Primarily, CO₂ emissions have a high financial cost as they assign more negative weight to firms that have potentially higher vulnerability towards climate risk (Bolton & Kacperczyk, 2021). Firms with higher financial risk have to respond to carbon emissions by complying with environmental protection agencies. The carbon profile is required to be linked with the long-term viability of the businesses. Due to a strict regulatory landscape, firms face threats that use stranded assets by contributing to carbon emissions. Organizations can recalibrate production strategies through the proliferation of carbon pricing instruments, such as emission trading schemes and taxes that internalize environmental externalities, compelling them to enhance competitiveness (Calel, 2020; Martin et al., 2016). As applied to corporate organizational settings in a region, the regulatory framework is loosely defined, under-theorized and not adequately measured. The regulatory frameworks provide broad carbon control guidelines without focusing on governance contextual dynamics of corporate organizations.

The current global context demands integrating regulatory and governance dimensions through policy initiatives to meet local dynamics and considering the strict regulatory compulsions, such as industrial pollution, that create pressure on a firm's reputation. In fact, the company's legitimacy is judged by the level of response towards climate protection (Freeman et al., 2022). A firm's supply

chain management determines the level of control towards environmental protection (Delmas & Burbano, 2011; Lyon & Maxwell, 2011). Yet, scholars are still struggling to understand the mechanism of effective governance that controls emission levels. Firms are no longer working in isolation, but they are interacting in a complex global environment where dynamic forces such as regulations and stakeholders' expectations affect them in a complex dynamic way, hindering their Sustainability.

Addressing these sustainable challenges, the institutional theory provides a useful way to see how governance actually gives opportunity to explore novel opportunities (DiMaggio & Powell, 1983; Scott, 2013). Emission reduction can be achieved through enforcing legitimate governance structures and regulations by controlling corruption and transparency, and along with promoting a recessive system where adaptability of external pressures enables firms to respond effectively (Meyer & Rowan, 1977; Suchman, 1995). The proactive, effective governance strategy encourages firms to switch to renewable practices (Reid & Toffel, 2009). However, corruption impedes organizations' efforts to control emissions as they lose control of operational activities (Fredriksson & Svensson, 2003; Cole, 2007; Ghani et al., 2023). The argument of effective governance is a key predictor of environmental resilience during climate anomalies, which is already established by scholars.

For renewal shifts in Sub-Saharan Africa, they are required to control emissions through flexible operational practices (Karekezi, 2002). This process works when institutions interact with governance indicators that facilitate green technology. Scholars are still looking forward to addressing corporate adaptations of governance

pressure (Teng et al., 2021). The effect of governance on emissions is non-linear because initially economic progression contributes to emissions in the short run (Barbier, 2016; Sachs & Warner, 2001). Therefore, CAS explains non-linear modeling where adaptations yield unintended consequences across regions (Allen & Sanglier, 1979; Stacey, 1995).

2. LITERATURE REVIEW AND THEORETICAL FOUNDATIONS

A considerable scholarly work has been carried out on institutional governance and CO₂ emissions, indicating how external pressures induce change in environmental behaviors in organizations. One such explanation is made by the institutional theory, entailing that firms tend to reflect legitimate behaviors, aligning with regulations and societal norms, with the expectations from their direct and indirect stakeholders (DiMaggio & Powell, 1983; Scott, 2013). In this pursuit, governance quality is intensified through elements like accountability and eradication of corruption that ultimately shun down the coercive regulatory frameworks, thereby maintaining professional standards (Meyer & Rowan, 1977; Suchman, 1995).

In corroboration with some empirical work, it is established that corporate environmental performance can be enhanced through the implementation of an established, reliable organizational framework. This not only improves efficiency but also fosters a fair and transparent stakeholder's engagement (Reid & Toffel, 2009; King & Soule, 2007). One such good practice is the implementation of anti-corruption measures that reduce evasion tendencies and improve the likelihood of an organization being more predictable. Some previous studies also suggest that encouraging a more predictable organizational environment earns investors' trust, resulting in an

increased investment portfolio due to low carbon emission practices (Fredriksson & Svensson, 2003; Cole, 2007).

Such patterns are also noted by work done in some top-tier journals extending the above insights to emerging markets, detailing that institutional voids increase the risk of carbon emissions and their associated challenges. It was observed that among African nations, tech innovation coupled with green initiatives significantly reduced CO₂ emissions. Some core factors studied by Obobisa et al. (2022) include green tech innovation, where institutional quality moderates to tone down emissions, which are essential for the sustainable transitions of developing societies. Similarly, Teng et al. (2021) found a direct relationship of foreign direct investment (FDI) with organizational quality standards, highlighting the role of institutional governance to channelize external influences toward environmental gains. Some other studies employed Panel VAR models to understand how institutional governance, coupled with green initiatives and technology (mobile penetration), diffuses carbon emissions and improves institutional strength (Traoré and Asongu, 2023), without yet adapting to complex adaptive systems (CAS).

However, the complex adaptive systems (CAS) perspective provides a more subtle and dynamic framework to better comprehend organizational response mechanisms to environmental imperatives like carbon emissions (Holland, 1992; Anderson, 1999). It suggests that institutions are adaptive agents which are intertwined through various networks, where behaviors result through an evolutionary process. These evolutionary processes include an on-ground feedback mechanism connected with linear and non-linear

interactions to learn environmental outcomes (Stacey, 1995; McKelvey, 1999). This CAS framework underscores the importance of institutional resilience while applying to sustainable practices entailing climate disruptions, which can further be studied through learning and experimentation (Folke et al., 2010; Walker et al., 2004). The CAS mechanisms identify cogent properties of global sustainability crises in natural ecosystems and offer better tools to project emission trajectories.

The CAS framework is also studied to integrate corporate Sustainability and non-linear emission reduction through the Adaptive Systemic Approach (ASA) that brings transformative change. The transformative behavior in the river basins and found that systemic interventions, in response to firms'/organizational pressures, enhance institutional adaptive capacity. However, such interventions are contextual and may yield a different outcome once studied in an altogether different context. For example, from a health and climate context, the CAS framework reflects more adaptive and emergent behavior when ecological services are combined with disaster management practices, demonstrating how such practices mitigate emission-related risks (Li et al., 2024). Van der Vegt et al. (2015) studied the interplay of organizational connectedness and diversity in a corporate culture and found organizational resilience to be the primary driver of a firm's sensemaking process. Firms with a clear vision are found to have more resilient employees, where adaptations evolve through the Adaptive Systemic Approach (Weick, 1995; Levinthal & March, 1993).

Furthermore, in establishing better organizational processes, emergent adaptations play a pivotal role. Past studies are evident that in the presence

of emergent adaptations, institutional theory and CAS form a better fit, serving as a critical bridge between organizational processes and emergent practices (Oliver, 1991; Pache & Santos, 2010). Emergent adaptations encompass Organizational capabilities like resilience and green innovation, which are some good examples of emergent adaptations which arise from the direct interplay of legitimate organizational structures and shadow informal networks (Stacey et al., 2000). Recently, this is indicative through some top research journals too, as Nyberg and Wright (2024) viewed that employees' perceptions are linked with climate adaptation initiatives while applying the CAS framework to learn organizational constraints. This was further reinforced by Benischke et al. (2025), who explored firms' adaptive responses that lead to formal compliance by their members (employees) through an agency relationship; that is to say, employees represent the organization in the same spirit if an organization opts for such an adaptive mechanism.

Since climate protection is a very compelling phenomenon in the Sub-Saharan region, studies underscore the interplay of green tech initiatives with institutional governance. Such interconnection is primitive for emission control, which defines the very need for green initiatives both in technology and governance. From non-African contexts, different studies demonstrate the link of tech (ICT) adoption to environmental degradation, thereby advocating for institutional quality through enhanced and renewable options to emit less carbon in the external environment of the organization (Azam et al., 2021). Lack of such initiatives exacerbates economic growth since carbonization is considered to be a worldwide threat. Firms at all levels are required to establish decarbonization protocols to protect the climate and the external environment of the organization

(which includes all stakeholders). Studies have shown governance effectiveness, strong institutional practices, and accountability pressures.

In literature, many studies have highlighted the role of institutional regulatory reforms and accountability for environmental Sustainability. For instance, recent evidence shows that government effectiveness can improve environmental quality in Sub-Saharan Africa (SSA). However, the governance and its relationship with emissions are complex and dynamic. The Institutional structure and governance mechanisms may increase short-term emissions. These forces foster industrial growth and resource extraction at the cost of CO₂ emissions.

Using the Complex Adaptive System perspective (CAS), the corporate governance outcomes may be unpredictable. The interaction among firms and institutions is a complex and dynamic process, increasing the complexity of measuring consequences. At the macro level, globalization adds further to complexity as firms for growth maximization pollute the environment due to a weak regulatory environment (Aichele & Felbermayr, 2012; Peters & Hertwich, 2008). In SSA, corruption also has a mixed role, as it is challenging to implement environmental protection regulations. Both governance and institutional coordination are important for CO₂ emission control. Several gaps in the literature open a debate on integrating the institutional and CAS framework as a more effective way of addressing corporate-level analysis.

Few studies on the firm level dynamics are missing; most studies focus on the relationship between governance energy and emission (Inglesi-Lotz & Dogan, 2018; Levinthal & Workiewicz, 2018).

Studies conducted in Sub-Saharan Africa have focused on energy poverty and biomass dependence, but they have not focused on governance and adaptive strategies. Despite scholars having focused on investigating the adaptive ESG mechanisms to control environmental challenges, there are still few studies addressing adaptability challenges and less focus on panel-based evidence.

At the firm level, there is a governance pressure referred to as isomorphism, where firms try to align social and regulatory expectations. While firms engage with social and regulatory practices, their interaction with other stakeholders leads them to adapt according to contextual changes.

Considering the underlying mechanism is essential for firms to counter vulnerability issues. To address the vulnerability challenge, strong governance practices critically handle related technologies emitting carbon. During the implications of effective governance practices, corruption may reduce the efforts to control emissions. Previous studies have also highlighted that the governance system aligned with strategic adaptive practices can improve environmental performance. While effective governance initially supports industrial expansion without focusing on emission challenges, institutional pressure exerts a long-run impact on environmental performance.

This review synthesizes these strands, drawing from literature outlets like *Journal of Cleaner Production*, where asymmetric patent impacts on ecological footprints, and *Sustainability*, which advocates system-based corporate sustainability theories (Kantabutra, 2022). By addressing these gaps, the present study employs panel VAR to probe governance-adaptation-emission nexuses,

contributing to theoretical refinement and policy relevance in global and SSA contexts.

Theoretical foundations address how to enhance formal organizational efforts. For instance, Institutional theory suggests that isomorphism drives carbon emission alignment with firm norms (Meyer & Rowan, 1977). CAS explains how agents interact that enable shadow structures fostering formal efforts of the firms (Stacey et al., 2000). However, corporate vulnerability reduces carbon; the role remains limited in corrupt settings (Damanian et al., 2003).

3. METHODOLOGY

The epistemological assumption of this study is based on empirical investigation of objective reality, where the scope is widened to understand institutional governance, emergent adaptations, and corporate CO₂ emissions by using a panel VAR approach. For this purpose, a global sample of 500 firms from 2014 to 2024 is taken. Further, it is synthesized how complex adaptive systems describe the mediation process to capture the dynamic vulnerability of firms across regions (Abrigo & Love, 2016). The policy implications offer deep insights into adaptive resilience that is possible through enhancing governance (Azam et al., 2021; Teng et al., 2021).

The panel vector autoregressive framework (VAF) is employed. In the literature, the causal direction between governance quality and corporate adaptation has been discussed by scholars. Traoré and Asongu (2023) use the application of panel VAR to study green technology diffusion and governance effects.

This study conceptualizes how firms under different governance environments develop or fail to

develop adaptive systems to low-carbon emissions. Vulnerability, mediated by governance quality, appears to structure which firms can realistically invest in clean technology and which remain locked into high-emission pathways. The organizational climate shapes how governance signals are actually interpreted and acted upon by organizational members. For instance, Levinthal and Workiewicz (2018) explain the mediating role of adaptive behavior, though neither fully integrates Human Resource Management Practices as a distinct explanatory layer.

Key Hypotheses:

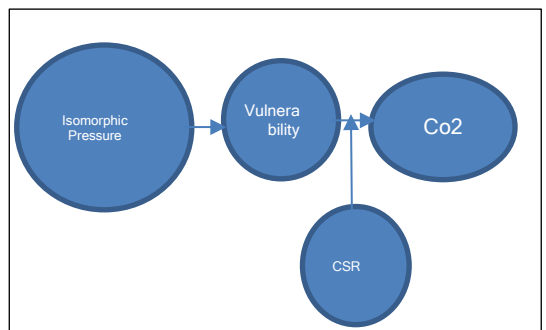
- H1: Stronger institutional controls (e.g., Control of Corruption) promote mimetic isomorphism, increasing renewable use.
- H2: CAS interactions (e.g., vulnerability * adaptation measures) mediate institutional effects on emissions reductions.
- H3: Governance committees moderate for normative isomorphism in implementation.

		KMO > .08 and Bartlett's test is significant, p < 0.05
Mediator	Corporate vulnerability	Emergent adaptations.
Dependent Variables	CO2 Equivalent Emissions (co2s1, co2s2, co2s3), SDG 13 Climate Action.	Sustainability outcomes.
Moderators	CSR Sustainability Committee	Internal alignment for strategy implementation.
Controls	Year, Country of Headquarters, Total Liabilities.	Temporal and contextual controls.

Table 1: Variables Operationalization

Component	Variables from the Dataset	Role
Independent Variables (Governance)	Control of Corruption: Estimate [CC.EST], Voice and Accountability [VA.EST].	Isomorphic pressures. Governance index using A Principal Component Analysis (PCA) where

Figure 1: Theoretical Framework



Using the Thomson Reuters ESG database, the sample comprises 500 multinational corporations spanning the period 2014-2024. The scope of this study demands MNCs for their vulnerable and adaptive efforts towards climate change issues. Keeping in view the research objectives, the

selection criteria are strictly based on reporting of the firms on CO₂ emissions, governance standards, and balanced representation of service, manufacturing, and energy sectors. The scope of this study is to capture post-Paris Agreement dynamics towards decarbonization, which is the outcome of governance pressure (United Nations, 2015). Data of the relevant variables include CO₂ emission scopes 1, 2, and 4, which cover direct, indirect and value chain from Carbon Disclosure Project (CDP) reports. For modeling the data, the dataset is standardized to metric tons CO₂e (Cao et al., 2012). Further, the governance quality Indicators are focusing on voice and accountability (VA) and control of corruption (CC). And these are aggregated at the firm headquarters country level (Kaufmann et al., 2010). Controls encompass firm size (log total assets), industry dummies (SIC codes), and macroeconomic factors like GDP growth from World Bank databases.

To test mediation pathways, high-dimensional fixed effects (HDFE) moderated-mediation models are integrated, following Hayes (2018). The framework examines governance impact on adaptations that further affect emissions. Where the CSR committee acts as a moderator on path b. For path analysis of Indirect effects (ACME) and direct effects (ADE) are bootstrapped (5000 replications) for inference, accommodating outcome-specific heterogeneities (Preacher & Hayes, 2008). Model assumptions are also tested, where Multicollinearity is assessed via variance inflation factors (VIF<5). Further Levin-Lin-Chu tests are needed.

Ethical considerations are followed to keep the anonymity of the data of firms. Finally, this methodology provides robust analysis to capture governance adaptation mechanisms to control emissions, which is the extension of previous

environmental management models (Obobisa et al., 2022; Teng et al., 2021).

4. FINDINGS

Panel VAR estimates reveal significant interdependencies of variables over time. The results of this study reveal how governance helps companies to manage climate vulnerability over time. The direct effect of governance on Scope 1 and Scope 2 emissions is very small and statistically insignificant (ADE \approx 0.001, $p > 0.05$). It indicates that only governance and policies cannot reduce carbon emissions. However, the indirect effect through adaptation measures is positive (ACME = 0.030). This suggests that efforts to reduce corporate vulnerability may be associated with slight increases in direct emissions. Such a result may occur because adaptation activities can expand operational processes or increase energy use, leading to minor rises in emissions despite improved resilience.

Table 2: Model results

Outcome Variable	a (Gov → VUL)	b1 (VUL → Outcome, CSR = 0)	b3 (VUL × CSR)	ACME
Scope 1 Emissions	-0.0070	0.0010	0.0001	0.0003
Scope 2 Emissions	-0.0070	0.0012	0.0002	0.0004
Scope 3 Emissions	-0.0070	0.0015	0.0003	0.0005
Climate Action SDG 13	-0.0070	-0.8354***	0.2453**	0.0042*

$p < .05$, * $p < .01$, ** $p < .001$.

Path a clearly shows that the effect of governance on vulnerability is consistently negative across all models (-0.0070). This association explains that

better governance is associated with lower corporate vulnerability. Further, the most important result of this study is that climate action has a strong negative effect. It can be witnessed that when there is no CSR committee (CSR=0), the model suggests that higher vulnerability (VUL) strongly and negatively impacts SDG 13. The score can be seen in Table 2 (coefficient $b1=-0.8354$). CSR helps companies to handle climate risk. The presence of a CSR committee positively mitigates this strong negative effect (moderation coefficient $b3=+0.2453$), reducing the magnitude of VUL's negative impact on climate performance. The indirect effect value is very small, which explains that governance has little indirect influence on emission outcomes through corporate vulnerability. For instance, a firm with strong governance and CSR practices may improve climate policies by first reducing vulnerability.

Finally, this study demonstrates that quality governance reduces corporate climate vulnerability. However, the role of corporate governance has a limited indirect effect on scope 1 and scope 3 emissions (Table). The results show that better governance consistently reduces corporate climate vulnerability across all models. However, governance has limited indirect effects on Scope 1-3 emissions, as indicated by the very small ACME values. The strongest findings are observed for SDG 13, where vulnerability significantly reduces climate action performance in firms without CSR committees. The positive moderation effect suggests that CSR committees help weaken this negative relationship. Overall, the findings indicate that governance and CSR structures play a more important role in strengthening climate action and resilience than in directly reducing operational emissions.

These patterns affirm institutional pressures

homogenizing emission practices via adaptations, with heterogeneous scope impacts reflecting CAS non-linearity (Stacey, 1995). In SSA firms, governance shocks yield stronger vulnerability attenuation, linking to green tech diffusion (Asongu et al., 2020).

Geographical Analysis of Corporate Vulnerability (VUL)

This global map visualizes the concentration and average VUL score of companies.

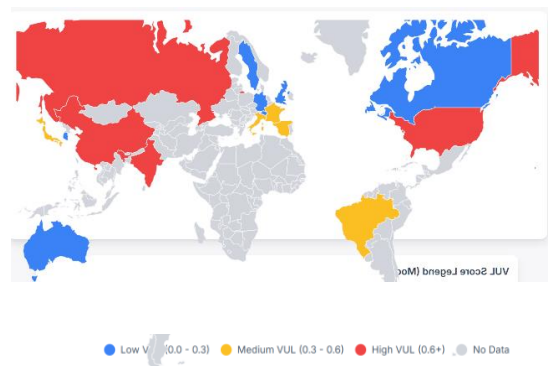


Figure 1: Geographical Analysis

The global map clearly shows that the most vulnerable countries include China, India, and Russia. It demonstrates a clear concentration of high corporate vulnerability (VUL). A score above 0.6 demonstrates vulnerability of countries. This is aligned with our findings, where results have shown that higher corporate vulnerability has a strong negative effect on corporate climate action performance (coefficient ≈ -0.83). The corporate instability and structural challenges create critical challenges in addressing environmental issues. Addressing environmental regulations becomes difficult for firms, as they face high vulnerability conditions.

There are two important outcomes of this study; firstly, improving corporate governance can help in

reducing vulnerability. The results reveal that the stronger governance structures are associated with lower vulnerability scores. Second, the strengthening of CSR committees appears particularly important in vulnerable firms. The empirical results indicate that CSR committees significantly weaken the negative relationship between vulnerability and climate action performance. This suggests that CSR committees function as an important institutional mechanism that enhances organizational resilience and supports more effective climate governance in high-risk economies.

5. DISCUSSION

Findings illuminate governance's pivotal mediation through emergent adaptations in curbing corporate emissions, extending institutional theory by embedding CAS dynamics. The results of the study highlight that the role of governance through emergent adaptations is critical to control CO₂ emission (DiMaggio & Powell, 1983; Holland, 1992). CAS dynamics and institutional perspectives are extended to support the theoretical model. The mechanism of the indirect pathway, corporate vulnerability, fosters resilience to decarbonization practices (Folke et al., 2010; Walker et al., 2004). This finding aligns with Obobisa et al. (2022), where they only focus on institutional quality that amplifies green innovation emission in Africa, but in this study, the firm-level focus reveals corporate adaptability across regions.

Counterarguments are partially addressed: while governance may spur short-term growth-linked emissions (Barbier, 2016), our negligible direct effects suggest adaptive buffering mitigates this. Greenwashing risks under accountability appear

limited, as mediation implies substantive changes (Lyon & Maxwell, 2011). CAS unpredictability manifests in scope heterogeneities, where direct operations show paradoxical rises, possibly from rebound effects or measurement (Stacey, 1995). Globalization critiques hold, with potential leakage in multinational samples, warranting border-adjusted policies (Aichele & Felbermayr, 2012).

While linking CAS and institutional theory, the complex behavior of environment management highlights the shadow structure enabling firm-level adaptations (Stacey et al., 2000). Policy-wise, enhancing voice and accountability and control of corruption could enhance corporate Sustainability, especially in African regions (World Bank, 2022). The adaptive capabilities require working at two levels. Initially, the legitimate governance structure and secondly, the role of organizations to adapt through a shadow structure. Therefore, firms should invest in adaptive capabilities for sustainable results, like renewables, to leverage governance for legitimacy (Suchman, 1995). Extending the current work, future studies may focus on micro-level governance parameters (Teng et al., 2021).

6. CONCLUSION

Using 500 firms' data, this study finds the role of institutional governance in managing CO₂ emissions. The emergent adaptations play an important role in addressing CO₂ emissions. The CAS framework is used to see the legitimate role of governance through rigid policies to control environmental issues. The theoretical underpinning further explains the mediation role of vulnerability of firms, where shadow structures of the organizations support governance policies to achieve reduction in Co₂. Therefore governance reduces vulnerability to control scope 3 carbon

emissions. This study contributes in advancing sustainability discourse where governance structure should be resilient to address climate changes especially in vulnerable regions.

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