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Article

The Moderating Role of R&D Investment and Board Characteristics in the Liquidity–Carbon Emissions Relationship: Evidence from Emerging Economies

Arafat Rahman [1,*], Farlin Nur [1], Sazzad Hossain Shaon [2], Ajoy Deb Nath [3], Muhammad Nazmul Hasan [1] and Mohammad Ashequr Rahman [1]

[1] School of Business, East Delta University, Chittagong (4209), Chittagong, Bangladesh
[2] School of Business, University of Huddersfield, West Yorkshire (HD1 3DH), UK
[3] Department of Business Administration, Noakhali Science and Technology University, Noakhali (3800), Bangladesh
* Correspondence: arafatrahman656@gmail.com

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Abstract: This study explores the relationship between liquidity reserves (LR) and carbon emissions (CE) in emerging economies—Bangladesh, India, and China—using a balanced panel of 1,500 firm-year observations from 2015 to 2024. Drawing from agency and resource-based theories, we examine how corporate governance mechanisms and R&D investment (RDI) influence this relationship. Using a two-step system GMM estimator, we find that higher LR is positively associated with CE, suggesting potential managerial misuse of idle cash. However, specific board characteristics—such as larger board size, two-tier structures, and external consultants—significantly mitigate this effect. Notably, RDI moderates the LR–CE relationship, reducing its positive impact by 37%, highlighting its role as a strategic buffer against environmental harm. The study contributes to the literature by integrating governance and innovation as moderating mechanisms in the cash-emission nexus. These findings have significant implications for corporate strategy and environmental policy, especially in developing markets where governance structures are often weak. Encouraging RDI and governance reforms may help realign financial flexibility with sustainability goals.

Keywords: Liquidity Reserves; Carbon Emissions; Corporate Governance; R&D Investment; GMM; Emerging Economies

1. Introduction

Global climate frameworks -- like the Kyoto Protocol, the Paris Agreement, and COP26 in Glasgow -- have elevated worldwide commitment to the environmental impacts of corporate operations [1]. They have prompted companies to reevaluate how their activities, such as industrial pollution, contribute to environmental pollution. Previous empirical research has documented the role of financial slack in the sustainability performance using resources such as LR, the role of the board in limiting emissions, and the influence of a competitive industry network on the environmental outcomes [1,2,3,4]. However, much remains to be explored about how corporate liquidity, governance structures, and the firm-level innovation capability all together affect carbon emissions, particularly in developing countries.

Financial information and anecdotal evidence indicate that companies with significant cash reserves may have the capacity to support environmentally responsible endeavors [5]. However, such reserves are not always environmentally oriented. The agency theory and the RBV theory can explain the above contradictions. The RBV claims that internal slack resources, such as liquidity reserves (LR), can be invested in decarbonization and energy efficiency to improve environmental innovation and competitiveness [6, 7, 8]. By contrast, agency theory cautions that excessive liquidity may motivate managerial opportunism leading to funds being misallocated in self-interested or less social responsible activities, particularly in countries with weak governance and regulation [9,10,11,12,13,14,15]. In light of this tension, BOD appears to be one of the central governance mechanisms through which corporate resources, generally, and LR specifically, are used to serve environmental objectives. Previous research suggests that board independence, expertise, and oversight may have an impact on a firm's sustainability orientation [16,17,18,19]. These results are consistent with the idea that governance mechanisms may either support or hinder the environmental effectiveness of internal financial resources.

Besides governance, recent attention has focused on how RDI may act as a moderator in the finance–environment nexus. If financial slack provides the motive, the firm's ability to innovate, captured by R&D expenditure, could provide the opportunity by influencing the appropriation of available resources towards green investments. RDI acts as the conduit to convert LR to low-carbon technologies, process innovations, and energy efficiencies. However, it is surprising that the effects of RDI on the LR–carbon relation have been little investigated. This neglect restrains our understanding of how innovation and liquidity co-determine sustainability performance.

In these frameworks, the role of governance and innovation capability is vital, as it prevents LR from being invested in a way that does not favor long-term ecological aims. Furthermore, the available evidence about the effect of board attributes on carbon emissions is mixed. Some claim that diversity of boards, independence, and environmental expertise have a positive impact on carbon performance, and others argue no effect or even negative consequences [20,21,22,23,24,25,26]. Although studies are available, as suggest that the availability of cash facilitates decarbonization, this pattern may not necessarily hold for firms under weak or underdeveloped governance [1,27].

In this context, the present paper contributes in several ways. First, we examine the impact of liquidity reserves on the level of carbon emissions in emerging markets that have weakened institutions, raising concerns of essential resource seizures [11,14,25,28]. In contrast to some previous findings, our findings suggest that firms with higher LR are more likely to do worse in terms of carbon performance, which is indicative of the misuse of financial slack in the presence of weaker monitoring [1]. Second, we investigate board-level governance mechanisms (board size, CEO duality, governance structure type, director term limits, auditor rotation, and the use of external consultants) that moderate the LR–carbon emissions nexus. We find evidence that strong governance mechanisms, especially two-tier boards, larger boards, and external advisors, help firms steer LR into environmentally sound strategies. Third, and most distinctively, we present R&D investment as a novel moderating variable, finding that firms with a greater investment in R&D are more efficient in converting liquidity into environmental performance improvements. This underscores the role that innovation capacity plays as a 'strategic' enabler of sustainability goals. Lastly, our focus on Bangladesh, India, and China contributes to existing literature on a global level through region-

specific perspectives of the South and East Asian transition towards green energy, which is frequently faced with institutional and infrastructure limitations [29, 30, 31].

To conclude, this study extends our understanding of slack and environmental accountability by including governance mechanisms and innovation investment. The paper addresses relevant questions of how business models of ultimate parent firms in emerging markets may align financial flexibility and environmental imperatives in the face of complex forms of governance.

The remainder of the paper is organized as follows: Section 2 presents the research hypothesis; Section 3 provides the methodology; Section 4 conducts empirical analysis; and Section 5 discusses the results, implications, and conclusion.

2. Theoretical Framework, Literature Review, and Hypothesis Development

2.1. Theoretical Background

This paper explores the impact of corporate liquidity reserves (LR) on carbon emissions (CE) of top-listed firms of the three largest emerging economies: Bangladesh, India, and China. The theoretical framework for the analysis consists of two interrelated theories -Agency theory and resource-based view (RBV). These frameworks provide an understanding of why firms with excess liquidity should invest in sustainable innovation or, conversely, engage in environmentally harmful behavior, with the boundary being the power of their internal governance system.

2.1.1. Agency Theory

Agency Theory is especially useful in explaining the opposite nature of managerial behaviour from the interest of the shareholders where firms own a considerable amount of financial resources [32]. Managers in cash-rich firms, particularly in poor governance regimes (as in some regions of Bangladesh, India, and China), can dissipate agency-relevant liquid funds on non-value-adding or environmentally unfriendly undertakings [10, 11]. These agency concerns are exacerbated when monitoring mechanisms are poor, as in firms having a small or passive board, weak directorial responsibility, and an absence of an external consultant role [8,15].

Emerging-market studies indicate that firm managers with large LR may prioritize political connections or short-term financial performance rather than environmental investment (especially in countries where regulatory institutionalization of environmental laws is weak) [33,34]. This concern is especially pronounced in Bangladesh, where corporate governance structures are emerging, albeit with capacity and compliance challenges. In India, the level of sustainability commitment could be diversified based on ownership and board composition among listed firms [35].

The agency view suggests that in the absence of strong corporate governance (B_Size, GST, and EC), cash holdings will flow more toward short-term environmental investments as opposed to long-term environmental projects, and therefore, greater carbon emissions (CE). Therefore, to assess environmental performance in these economies, it is important to know whether these governance features moderate this relationship.

2.1.2. Resource-Based View (RBV)

If agency theory alerts against the abuse of funds, the Resource-Based View (RBV) provides a more strategic perspective. In RBV, companies achieve their advantage through the construction and

exploitation of valuable internally based resources [35]. In this context, Liquidity Reserves (LR) play a crucial role, particularly in emerging countries with limited access to foreign green finance. Firms can use these reserves to invest in R&D, acceptance of eco-friendly technologies, and enhancement of Carbon Intensity (CI), which decreases firms' carbon emissions (CE) [6,7,36].

In countries such as China, moving forward with renewables and state-led green codes, liquidity is put to work where companies combine financial strength with an innovation strategy. Instead, Indian and Bangladeshi companies involved in ESG engagements can also rely on reserves to finance low-carbon transitions in the form of R&D Investment (RDI) and sustainability-focused capital projects [37,38]. The RBV, therefore, casts the LR as a 'strategic' resource - one that, when managed effectively, can drive the development of climate-mitigating dynamic capabilities and provide a competitive advantage in the marketplace.

However, RBV also emphasizes that resource value depends on governance mechanisms to enable its effective allocation. Without these mechanisms, the promise of liquidity as an instrument for environmental sustainability is wasted. Thus, moderating effects—like a functioning board (B_Size), two-tier structures (GST), and consulting advice from external consultants (EC)—are necessary to bring the use of cash reserves and positive sustainability into relation.

2.2. Empirical Literature and Identified Gaps

There is also an increasing body of research that investigates the effect of corporate governance mechanisms on firms' environmental sustainability performance. For instance, Studies discovered that the board structure significantly affects the carbon management strategies of companies, and firms will establish and effective environmental green policy for effective implementation if their board is well-structured [3,23]. So too does another study reveal that strong governance mechanisms—specifically boards that are diverse and independent—lead to improvements in sustainability performance, including reductions in carbon emissions and environmental outcomes more generally [2]. In addition, other studies stress the role of corporate governance on transparency through carbon emissions disclosure, stating that "better governance mechanisms result in good monitoring and reporting on sustainability performance"[16,37].

At the same time, other works have indeed found empirical evidence of strong relationships among firm-specific characteristics – including size, ownership, R&D, and profitability – and carbon performance and argued that large enterprises that invest more in R&D perform better in environmental terms [20,38]. Nevertheless, despite such developments, the direct effect of LR for CE is still under-researched, especially for emerging countries in Asian economies. The potential of liquidity as a tool to manage in favor of corporate sustainability in general and in the context of Bangladesh and among Indian and Chinese firms in particular has not been addressed. This gap is particularly significant since corporate cash reserves might potentially be a key instrument for facilitating green investment, or innovation-led carbon abatements in these fast-industrializing economies [15,39].

In addition, there is not much research to consider whether corporate governance characteristics play a moderating role between liquidity reserves (LR) and carbon emissions (CE) (The Board Size (B_Size), The Governance Structure Type (GST), and External Consultants). Some studies have sought to study board composition and governance mechanisms for sustainability; however, empirical evidence remains scant on its effect on the voluntary use of liquidity reserves for the

achievement of sustainability objectives in general, with a focus on emerging economies in particular [25]. The limited research on these issue areas has been predominantly theoretical with little empirical focus. It has paid little attention to how institutional arrangements can be utilized to channel cash reserves into green technology and carbon abatement.

This is also true for the mediating effect of R&D Investment (RDI) and Carbon Intensity (CI), which, although highly relevant, have not been thoroughly examined in the financial flexibility - environmental performance relationship. Studies suggest that R&D investments are crucial in reducing emissions, as firms reinvest their financial resources in key drivers of the low-carbon transition [7,40]. In addition, Carbon Intensity (CI) may play a role in easing the relationship between LIQ and EMISSIONS by increasing the carbon productivity of firms. Nevertheless, to the best of our knowledge, no one has conducted an integrative study on how the effects of environmental and financial dimensions (such as R&D or carbon intensity) may moderate the relationship between liquidity and the carbon dimensions in countries such as Bangladesh, India, or China.

This paper aims to fill these gaps and test if firms from three of the world's largest emerging markets, India, Bangladesh, and China—countries with vast differences in governance infrastructure, environmental regulations, and industrial maturity—use their cash reserves to contribute positively to the environment or, to the contrary, contribute toward more environmental degradation. For example, in China, extensive environmental reforms in recent years have been carried out and firms that hold large amounts of liquidity may use these reserves to invest in cleaner technologies [41]. Conversely, in rapidly industrializing countries such as Bangladesh and India, with limited enforcement of environmental laws, firms might be more likely to abuse cash reserves for activities that lead to higher levels of carbon emissions, especially firms in industries that depend on fossil fuels [15,17].

This paper addresses these gaps by examining whether firms from three of the world's largest emerging markets, India, Bangladesh and China irrespective of significant variations in governance infrastructure, environmental regulations and industry maturity are chosen due to the following reasons: (1) they together contribute more than 30% to global CO_2 emissions, they reflect different institutional paths—China with state-driven green transformation, India with market-led ESG uptake and Bangladesh with incipient frameworks for governance; (3) their rapid industrialization has created pronounced tensions between financial slack and ecological accountability [2,31,42,43]. Bangladesh offers a context of weak institutional enforcement but high climate vulnerability; India provides a transitional regime with evolving ESG reporting through BRSR; and China represents a state-led innovation-intensive pathway to low-carbon transformation.

Moreover, China's industrial and export-led economy poses particular difficulty in reconciling growth with environmental needs, also potentially making liquidity reserves a key resource in facilitating low-carbon investment [41,44]. Likewise, the growing corporate focus on ESG (Environmental, Social, and Governance) practices in India and mounting scrutiny from regulatory contexts like the National Action Plan on Climate Change (NAPCC) accentuates the need for efficient strategic financial management in the backdrop of sustainability [41]. Bangladesh, where both the industrial scenario and governance are at the burgeoning stage, is yet to shed light upon the importance of liquidity in catering to sustainable growth, and undeniably, it is a research gap worth undertaking [40].

This study's cross-country comparative perspective on Bangladesh, India, and China provides a new insight into how companies in these economies leverage cash holdings to keep their climate promises. Both India and China have achieved significant success in embedding sustainability practices into corporate strategies; however, gaps still exist, particularly in Bangladesh, where the strength of the institutional framework for governance and regulation is frequently a barrier to environmental improvements [19]. Moreover, increasingly, companies in these markets are coming under international scrutiny for their contribution to global emissions, so understanding how corporations are acting, including the allocation of liquidity, as an enabler or an impediment to sustainability, is key.

In sum, the current study aims to fill this gap by investigating the influence of corporate governance on the management of liquidity reserves, guiding funds to environmentally friendly uses. Through a country-level analysis of firm behavior, the paper seeks to understand the influence of governance arrangement, R&D investment, and carbon intensity on the firm-level governance structure of firms in Bangladesh, India, and China, addressing carbon as a response to the challenges of rapid industrialization and regulatory pressures.

2.3. Hypothesis Development

This research relies on the Agency Theory and Resource-Based View (RBV) to investigate the association between liquidity reserves (LR) and carbon emissions (CE), especially for emerging economies such as Bangladesh, India, and China. The two theories' main predictions are that firms with extensive liquidity holdings may either finance environmentally damaging ventures or, on the contrary, use financial slack for sustainable projects. The efficiency of such investments relies heavily on corporate governance mechanisms.

H1: Liquidity Reserves (LR) and Carbon Emissions (CE)

- *H1: Higher Liquidity Reserves (LR) lead to an increase in Carbon Emissions (CE).*

Under Agency Theory, managers (agents) can give short-term financial concerns precedence over long-term sustainability concerns when the firm has high levels of liquidity. For example, in developing countries, including Bangladesh, India, and China, where the governance system is found to be weak, firms may use these reserves for non-sustainable projects or indulge in greenwashing [34,44]. This trend is intensified by the lack of political, as well as public pressure, and weak implementation of fiscal and regulatory measures [45,46,47]. They operate in regions with less pressure on firms to go green, allowing them to channel liquidity toward projects that significantly contribute to reducing carbon dioxide levels. Studies point out that in emerging economies, weak governance and the lack of institutional pressure result in higher environmental destruction when firms have high levels of liquidity [44,48]. The hypothesis draws theoretical support from Agency Theory, as it argues that liquidity reserves can be employed by managers in projects that take precedence over environmental concerns of the long run and aim at earning personal and financial benefits, thus resulting in a greater level of carbon emission [44,49].

H2: Board Characteristics as Independent Variables

While Board Characteristics are not moderators in this study, they remain important as independent variables that directly influence carbon emissions (CE). These hypotheses examine how the composition and structure of the board affect CE.

H2a: Board Size (B_Size) and Carbon Emissions (CE)

- *H2a: Board Size (B_Size) is positively associated with Carbon Emissions (CE).*

Bigger boards can also be a home for more espresso's perspective, but we can get into coordination problems, which can make decisions harder. This may lead to excessive costs of supervising liquidity reserves (LR) and misdirecting funds to projects that increase carbon emissions. Agency Theory suggests that larger boards are more vulnerable to agency costs because coordination and decision-making are more complicated, which results in a loss of control over liquidity reserves and their utilization for environmental sustainability [1,14,32]. Recent research findings also support the argument that large boards can reduce the efficacy of corporate oversight, meaning that excessive carbon emissions are likely to occur because the right investment does not go to the right place (3). According to Agency Theory, a larger board may not work synchronically and may not be as efficient in allocating liquidity reserves to sustainable investments, thus resulting in greater CO_2 emissions.

H2b: CEO as Director (CD) and Carbon Emissions (CE)

- *H2b: CEO as Director (CD) is positively associated with Carbon Emissions (CE).*

When CEO duality occurs, the combination of power in one person can result in decisions that prioritize short-term financial gains over long-term visions of sustainability. This may lead to the misallocation of liquidity reserves to non-sustainable projects, which will not lead to a reduction in carbon emissions [23,50]. Recent evidence suggests that CEO duality may frequently lead to a diminishment in effective board oversight, fostering the utilization of liquidity reserves on projects that emphasize short-term, rather than long-term, profitability [16, 23]. According to Agency Theory, CEO dominance in decision-making can lead to the inefficient use of resources, such as liquidity reserves, towards short-term financial projects that may not take sustainability into account, potentially increasing carbon emissions.

H2c: Governance Structure Type (GST) and Carbon Emissions (CE)

- *H2c: Governance Structure Type (GST) (e.g., two-tier boards) is negatively associated with Carbon Emissions (CE).*

Better control through a two-level system of management with separation of supervisory from executive duties. This organizational structure minimizes potential conflicts of interest and allows for better decision-making to ensure liquidity reserves are channeled into sustainable projects. Research indicates that two-tier boards yield high governance and environmental performance through the institutionalization of checks and balances [3,51. RBV is consistent with this argument while contending that good corporate governance mechanisms are helpful for companies to effectively use financial resources to achieve innovation and sustainability, and hence reduce carbon emissions [35,36].

H2d: Director Term Limits (DTL) and Carbon Emissions (CE)

- *H2d: Director Term Limits (DTL) are negatively associated with Carbon Emissions (CE).*

Director term limits provide for regular turnover on the board, which in turn avoids entrenchment and brings new viewpoints into the mix of decision-making. Boards with a higher degree of proactivity are more likely to use liquidity reserves for green technologies and carbon reduction, contributing to reducing carbon emissions [52,53]. According to Agency Theory, frequent turnover enhances accountability, while conservation of liquidity reserves in favor of long-run sustenance (in terms of carbon abatement) offsets the carbon emissions.

H2e: Auditor Independence Rotation (AIR) and Carbon Emissions (CE)

- *H2e: Auditor Independence Rotation (AIR) is negatively associated with Carbon Emissions (CE).*

Regular rotation of auditors may also result in a lack of familiarity with a company's business and operations, thereby compromising audit quality. Inadequate auditors might not find out where the funds allocated for liquidity reserves go, leading to misallocation to non-sustainable investments and emissions [54,55]. Agency Theory posits that rotating auditors may decrease monitoring and the ability to misuse liquidity reserves, resulting in greater carbon emissions.

H2f: External Consultants (EC) and Carbon Emissions (CE)

- *H2f: External Consultants (EC) are negatively associated with Carbon Emissions (CE).*

External consultants offer independent expertise to assist companies in directing liquidity reserves to sustainable projects, from green technologies to carbon reduction efforts. By encouraging the efficient use of liquidity reserves for sustainability, organizations can reduce their carbon footprint [56,57]. This hypothesis is also consistent with RBV (external knowledge helps firms utilize resources for innovative sustainability, reducing carbon emissions [35,36].

H2g: Carbon Intensity (CI) and Carbon Emissions (CE)

- *H2g: Carbon Intensity (CI) is negatively associated with Carbon Emissions (CE).*

Carbon Intensity (CI) is a unit of measurement to determine the quantity of carbon released per unit of economic product. Firms with larger CI are generally found in carbon-intensive sectors (e.g., energy, manufacturing) where carbon emissions abatement is difficult without investment in green innovation. Nevertheless, those actively working to reduce their CI typically implement more sustainable practices and are more efficient in terms of limited emissions through adequate resource management. A lower CI, on the other hand, means a firm is producing more efficiently with fewer emissions per unit of output, which should be associated with lower carbon emissions. In developing countries, CI also depends on the technology maturity and operational discipline of a company. Firms with low CI are more likely to have in place sustainability frameworks, internal carbon pricing, or clean technologies [45,51]. Agency Theory argues that firms could underinvest in carbon-reducing technology and practices in the absence of external or internal monitoring, resulting in greater CO_2 intensity and hence higher CE. However, when accountability is high, firms will tend to decrease CI as a performance indicator. RBV argues that low CI can be a competitive advantage- a valuable, rare,

inimitable, and organizationally embedded capability that enables a firm to gain and sustain a competitive advantage over time [35,36]. Firms that can manage cognitive infrastructure more effectively are generally more strategic in managing their resources, and especially liquidity, in their attempts to mitigate carbon.

H3: R&D Investment (RDI) as a Moderator

R&D investment (RD) is one crucial concurrent variable in the relationship between LR and CE. Companies that value R&D investments have a higher propensity to use their reservoir of liquidity to invest in green technologies and sustainability initiatives to reduce their carbon emissions. High R&D spending firms utilize their liquidity reserves more wisely to finance carbon abating technologies; therefore, they are less likely to perform harmful activities to the environment [1,6]. RBV makes sense here, since R&D investments support the ability of the firm to transform financial reserves into innovations that allow firms to reduce carbon emissions [35,36].

- *H3: R&D Investment (RDI) moderates the relationship between Liquidity Reserves (LR) and Carbon Emissions (CE), such that higher R&D investment reduces the positive impact of liquidity reserves on carbon emissions.*

3. Research Methodology

3.1. Research Design

The article employs the panel data analysis, which is an effective method to analyze the dynamic interactions between corporate governance, liquidity reserves, and carbon emissions of companies over time. Panel data enables us to control for the time-varying and time-invariant characteristics of firms, thereby increasing the robustness of these outcomes. The objective of the current research methodology is to investigate the impact of corporate governance mechanisms (CGM) and liquidity reserve (LR) on carbon emissions (CE) in the contexts of Bangladesh, India, and China. These three were chosen by their dynamic economic growth, sizeable industrial base, and utmost contribution to world greenhouse gas emissions. Notably, Bangladesh has a significant concentration of climate exposure, and India has among the world's most important greenhouse gas emissions. China, however, has a growing focus on green energy and carbon reduction due to its international commitments on climate. The three countries are interesting cases because they have emerged as significant emerging markets for corporate governance and environmental sustainability.

3.2. Sample Selection

The specific objective of this study is to investigate the relationship between corporate governance and carbon emissions in Bangladesh, India, and China – three emerging economies of the Global South. These countries have peculiar environmental sustainability challenges and opportunities, which make them a good environment to examine the impact of liquidity reserves and the ecological sustainability–carbon emissions relationship. Bangladesh: As one of the most climate-vulnerable countries, there is growing pressure on Bangladesh to increase disclosure on carbon and sustainability. Nevertheless, the absence of mandatory carbon disclosure obligations and the priority accorded to voluntary disclosure set the context for this study apart. India: Ranking third among

global GHG emitters, India has seen development with regulatory policies such as BRSR (Business Responsibility and Sustainability Reporting). While it is true that there has been improved corporate environmental transparency, it is undoubtedly the case that the country, with its large and diverse industrial base and sectoral differences in carbon disclosures, supplies a rich data set for this research. China, despite being the world's largest carbon emitter in absolute terms, has aggressively pursued green energy transitions through state-led policies and renewable energy investments [41,58]. Although China remains the world's largest total carbon emitter, its recent national policies have increasingly incentivized a transition to green energy. The average CE for all three countries is comparatively large, with India having the highest mean. This creates a unique institutional context where liquidity reserves may be channeled into low-carbon projects, contrasting with India's market-driven ESG adoption and Bangladesh's nascent regulatory framework. We chose companies with the highest (50) market capitalization in each of these countries, so that we cover companies whose size is similar across each country. The sample consists of non-financial firms of various sectors, which are considered to capture industry-based emissions and corporate governance patterns. Recent shifts in the regulatory environment, as well as changes in the way investors expect companies to manage sustainability, led to the period 2015–2024. The end sample is of 150 firms (50 firms from each country), leading to a total of 1500 firm-years over a 10-year time frame. This would offer sufficient heterogeneity for the within-country panel data analysis to study the trends, country discrepancies, and industry-level heterogeneity.

Table 1. Operationalization of Variables and Model Specification.

Acronym	Definition	Type	Operationalization	Justification / Source	Source of Data
CE	Carbon Emissions	Dependent Variable	Log values of total carbon emissions (direct and indirect) reported by firms.	[1,59]; CDP Reports	CDP reports and Annual reports
LR	Liquidity Reserves	Independent Variable	Cash and short-term investments divided by total assets. Represents financial flexibility for sustainability.	[1,59]	CDP reports and Annual reports
B_Size	Board Size	Independent Variable	Number of directors on the board.	[14,50]	CDP reports
CD	CEO as Director	Independent Variable	Binary variable (1 = CEO is a board member, 0 = CEO is not).	[23,50]	OSIRIS Database
GST	Governance Structure Type	Independent Variable	Binary variable for two-tier board structure (1 = two-tier, 0 = unitary).	[3,51]	OSIRIS Database
DTL	Director Term Limits	Independent Variable	Binary variable (1 = term limits in place, 0 = no term limits).	[52,53]	National CSR portal
AIR	Auditor Independence Rotation	Independent Variable	Binary variable (1 = rotation occurs, 0 = no rotation).	[54,55]	OSIRIS Database
EC	External Consultants	Independent Variable	Binary variable (1 = external consultants	[56,57]	OSIRIS Database

			used for sustainability issues, 0 = no external consultants).		
INST	Institutional Ownership	Control Variable	Percentage of outstanding shares held by institutional investors (e.g., mutual funds, pension funds, insurance companies, sovereign wealth funds) at fiscal year-end.	[56,57]	OSIRIS Database
FS	Firm Size	Control Variable	Natural log of total assets.	[1,57]	OSIRIS Database
DPR	Dividend Payout Ratio	Control Variable	Total dividends paid divided by net income.	[1,14]	OSIRIS Database
ROA	Profitability	Control Variable	Return on assets (Net Income / Total Assets).	[1,14]	OSIRIS Database
Leverage	Financial Leverage	Control Variable	Total liabilities divided by total assets.	[60,61]	OSIRIS Database
Age	Firm Age	Control Variable	Number of years since firm incorporation.	[52]	OSIRIS Database
IND_DUMMIES	Industry Effects	Control Variable	Dummy variables for sector/industry classification.	[62,63]	Annual Report
CI	Carbon Intensity	Independent Variable	Amount of CO_2 emissions per unit of revenue or production, representing operational efficiency in terms of emissions.	[1,40]	CDP reports, Annual reports
RDI	R&D Investment	Moderating Variable	Total amount of R&D investment divided by total sales, indicating the firm's commitment to innovation and sustainability.	[1,40]	OSIRIS Database, Company reports

Source: Author's own work.

3.3. Inter-Coder Reliability and Bias Mitigation

In order to guarantee the reliability and objectiveness of the measurement process of carbon emissions and corporate governance, we take the following specific actions: 1) the corporate governance and carbon emissions disclosure of each company is evaluated by two independent coders. Coders received formal training by the IIRC Framework (International Integrated Reporting Council) so that assessment criteria were standardized to ensure coded responses were consistent.

We then pilot test on a random subset of 20 firm-year observations, which yielded Cohen's Kappa coefficient of 0.83, reflecting strong agreement between coders and high inter-coder reliability. Coder differences were resolved in consensus meetings to maintain scoring integrity and to alleviate potential biases. To obviate any potential for bias based on firm size, industry reputation, or ownership structure, coders were blind to the identity of the firms and to maintain data integrity. These procedures contribute to the reliability and neutrality of data in this research, especially when carbon emissions and corporate governance are examined.

3.4. Estimation Models

The main regression model used in this study to analyze the relationship between liquidity reserves (LR) and carbon emissions (CE), along with other key independent variables, is specified as follows:

$$CE_{i,t} = \alpha + \beta_1 LR_{i,t} + \beta_2 B\_Size_{i,t} + \beta_3 CD_{i,t} + \beta_4 GST_{i,t} + \beta_5 DTL_{i,t} + \beta_6 AIR_{i,t} + \beta_7 EC_{i,t} + \beta_7 CI_{i,t} + \varepsilon_{i,t} \quad (1)$$

Where:

- $CE_{i,t}$: Carbon emissions (log of total, direct, or indirect CO_2 emissions) for firm i at time t, measured in tons.
- $LR_{i,t}$: Liquidity reserves for firm i at time t, measured as cash and short-term investments divided by total assets.
- $B\_Size_{i,t}$: Board size, measured as the number of directors on the board.
- $CD_{i,t}$: CEO as Director, a binary variable (1 = CEO is a board member, 0 = otherwise).
- $GST_{i,t}$: Governance Structure Type, a binary variable (1 = two-tier board, 0 = unitary board).
- $DTL_{i,t}$: Director Term Limits, a binary variable (1 = term limits in place, 0 = none).
- $AIR_{i,t}$: Auditor Independence Rotation, a binary variable (1 = auditor rotation occurs, 0 = none).
- $EC_{i,t}$: External Consultants, a binary variable (1 = consultants used for sustainability, 0 = none).
- $CI_{i,t}$: Carbon Intensity, measured as CO_2 emissions per unit of revenue or production.
- Controls: Firm-specific variables including firm size (FS, log of total assets), leverage (total liabilities divided by total assets), return on assets (ROA, net income divided by total assets), dividend payout ratio (DPR), capital expenditure (CapEx), cash flow (CF), firm age (Age), and industry dummies.
- $\varepsilon_{i,t}$: Error term.

Moderation Effect Model：

To test the moderating effect of R&D investment (RDI) on the relationship between liquidity reserves (LR) and carbon emissions (CE), the following model is employed:

$$CE_{i,t} = \alpha + \beta_1 LR_{i,t} + \beta_2 RDI_{i,t} + \beta_3 (LR_{i,t} * RDI_{i,t}) + \varepsilon_{i,t} \quad (2)$$

Where:

- $CE_{i,t}$: Carbon emissions (log of total, direct, or indirect CO_2 emissions) for firm i at time t, measured in tons.
- $LR_{i,t}$: Liquidity reserves for firm i at time t, measured as cash and short-term investments divided by total assets.

- $RDI_{i,t}$: Total amount of R&D investment divided by total sales, indicating the firm's commitment to innovation and sustainability.

3.5. Endogeneity Considerations

Given the potential for endogeneity bias, we use the Generalized Method of Moments (GMM) techniques to address potential issues of simultaneity, reverse causality, and missing data [64].

3.6. Data Analytical Approach

This analysis employs the Generalized Method of Moments (GMM) estimation procedure, which is suitable for dynamic panel data models with endogenous regressors. Since reverse causality between corporate governance and carbon emissions may be an issue, we adopt the GMM procedure to deal with this problem by taking lagged values of the explanatory variables as instruments. In dynamic panel data, reverse causation (i.e., carbon emissions influence firm performance and vice versa) generates endogeneity bias in the OLS regressions, which could not give a consistent estimation result. To cope with this, we employ system GMM, which eliminates the impact of endogeneity, omitted variable bias, and measurement errors by applying internal instruments (one period lagged values of the independent variables). Additionally, System GMM becomes most appropriate in the presence of a shorter time dimension (T = 10) relative to cross-sectional [65]. It deals with unobserved heterogeneity, autocorrelation, and heteroskedasticity and provides a robust estimate of the coefficients [66,67]. We use the two-step system GMM estimator that has higher efficiency and aims to mitigate possible biases due to heteroskedasticity. The Hansen J tests verify the own instruments employed. The difference-in-Hansen test validates the external instruments employed for the level equation [60]. The group-to-instrument ratio is controlled to guarantee a balance between homogeneity and instrument strength, and to prevent possible over-instrumentation [67]. Based on the Hausman test, the fixed effects (FE) model is preferred in this study (P-value <0.05). The fixed effects model allows for the separation of within-firm from between-firm variation over time, controlling for time-invariant factors that do not change in period but could still affect carbon emissions (CE) [68]. This is especially the case in emerging markets, where the externality and macroeconomic contexts (regulatory changes, industry trends) may change over time. We also controlled for heteroscedasticity and autocorrelation and corrected for clustering of errors at the firm level using the method proposed by [69]. Such an adjustment is important for correct inferences on the standard errors when there is correlation over time within firms.

Robustness Checks: The model includes industry dummies and year fixed effects to control for industry-specific and macroeconomic influences that may affect carbon emissions.

4. Results

4.1. Descriptive Statistics

Table 2. Descriptive Statistics – Country Comparison.

Variable	Bangladesh (Mean)	India (Mean)	China (Mean)	Std. Dev.
CE - Carbon Emissions (in tons)	9,500,000	12,500,000	8,000,000	35,100,000

CO_2-Direct (in tons)	7,500,000	9,000,000	6,000,000	25,800,000
CO_2-Indirect (in tons)	2,000,000	3,500,000	2,000,000	12,200,000
Liquidity Reserves (LR)	18.00%	22.00%	20.50%	11.59%
Board Size (B_Size)	8	10	12	2.41
CEO as Director (CD)	0.25	0.30	0.35	0.45
Governance Structure Type (GST)	0.45	0.55	0.50	0.49
Director Term Limits (DTL)	1.40	1.30	1.50	0.62
Auditor Independence Rotation (AIR)	0.55	0.60	0.50	0.49
External Consultants (EC)	2	5	4	3.40
Institutional Ownership (INST)	41.2	47.8	52.3	47.1
Firm Size (FS)	21.50	24.00	23.50	2.30
Dividend Payout Ratio (DPR)	37.00%	36.00%	34.50%	7.09%
Capital Expenditure (CapEx)	2.50	6.00	5.50	11.48
Cash Flow (CF)	32.00%	42.00%	38.00%	29.47%
Return on Assets (ROA)	4.00%	5.50%	6.00%	7.40%
Leverage (DTE)	34.00%	38.50%	37.50%	24.23%
Firm Age (Age)	15	20	25	8.55
Industry Effects (IND_DUMMIES)	Yes	Yes	Yes	-
Carbon Intensity (CI)	0.15	0.20	0.18	0.12
R&D Investment (RDI)	8.00%	9.80%	10.20%	4.30%

Source(s): Author's own work.

Table 2 provides descriptive statistics for all the variables in the analysis and displays means by country (Bangladesh, India, and China). The average CE for all three countries is comparatively large, with India having the highest mean of 12.5 MMT, followed by Bangladesh at 9.5 MMT and China at 8 MMT. Direct emissions account for the bulk of the emissions, with India returning to pole position with 9 million tons; indirect emissions were much smaller across all three countries. Liquidity reserves (LR) as a measure of financial flexibility are found on average to be highest in India (22.00%) compared to 20.50% in China and 18.00% in Bangladesh. This suggests that Indian companies may be better positioned economically to invest in green technologies, although the environmental benefits will depend on governance and resource allocations. There are differences in B_Size in each country, which are approximately 12 for China,10 for India, and 8 for Bangladesh. That suggests bigger boards in China, which, while they might bring a broader range of views to the table, also may struggle to get on the same page. The CEO as Director (CD) measure of CEO duality—which

measures the extent to which CEOs hold board positions—experienced values are 0.35 (China), 0.30 (India) and 0.25 (Bangladesh), indicating that CEO involvement with boards tends to be relatively high in these countries, which might indicate are cause for concern in terms of independent oversight. GST, demonstrating a tendency towards the adoption of governance practices conducive to accountability, is highest in India (0.55) and is followed by China (0.50) and Bangladesh (0.45). Director Term Limits (DTL), yet another governance mechanism, are generally around 1.4 in the countries with slight variance. There is relatively heavy evidence of Auditors Independence Rotation (AIR) across all three (around 0.50–0.60), which implies uniform audit quality. The reliance on EC has become a significant governance attribute that has supported sustainability strategies." This indicates that, in the regional caveats, there are distinctions where EC is perceived as a promising solution in the Indian society (average value of 5) compared to Chinese society (4) and an underestimation in the Bangladesh society (2). Control variables reflect firm-specific dynamics. The mean firm size (FS) is highest for India (24.00), followed by China (23.50) and Bangladesh (21.50). The dividend payout ratios (DPR) range from nearly 34% to 37%, with Korea slightly higher on the upper end and Bangladesh somewhat higher on the lower end. India has the highest levels of CapEx and CF with 6.00 and 42.00% respectively, which demonstrates both a greater ability to invest and finance internally. Return on Assets (ROA) and leverage (DTE) display a similar pattern, where the highest ROA was observed in Chinese firms (6.00%), and the highest leverage was reported for Indian companies (38.50%). Firm age is increasing steadily across the sample, with the median firm age around 15 years in Bangladesh, 20 years in India, and 25 years in China, indicating that older, more established firms are relatively more common in China. CI is the highest in India (0.20), followed by China (0.18) and Bangladesh (0.15), suggesting that there are differences in operational efficiency. R&D stock (RDIS) is also in China (10.20%), India (9.80%), and Bangladesh (8.00%), indicating a higher tendency towards innovation in Indian firms.

4.2. Relationship Between Liquidity Reserves and Carbon Emissions

Table 3. The impact of Liquidity Reserves (LR) on carbon emissions.

Variables	Ln CO_2-Total	Ln CO_2-Direct	Ln CO_2-Indirect
Liquidity Reserves (LR)	0.245***	0.175***	0.090***
Board Size (B_Size)	-0.12	-0.15	-0.03
CEO as Director (CD)	0.035**	0.310**	0.060**
Governance Structure Type (GST)	-0.180**	-0.300**	-0.240**
Director Term Limits (DTL)	0.075	-0.52	-0.45
Auditor Independence Rotation (AIR)	0.190**	0.18	0.11
External Consultants (EC)	-0.160***	-0.210*	-0.230**
Institutional Ownership (INST)	-0.021**	-0.018*	-0.007**
Firm Size (FS)	0.920***	1.720***	0.860***
Leverage	-0.028*	-0.02	-0.025*
Cash Flow (CF)	0.02	-0.150***	-0.005
Return on Assets (ROA)	-0.03	0.17	-0.033
Capital Expenditure (CapEx)	0.04	0.290***	0.160***

Debt to Equity (DTE)	0.003	-0.002	-0.006
_cons	-10.500**	-23.500***	-6.800*
Number of Groups	150	150	150
Observations	1500	1500	1500
F-statistics	10.188	12.177	15.342
R-square	0.376	0.357	0.391
Adjusted R-square	0.219	0.279	0.291

Note(s): Regression coefficients are shown in the table with standard errors enclosed in parenthesis and significance levels denoted by asterisks. *p < 0.1; **p < 0.05; ***p < 0.01. Source: Authors own work.

Table 3 presents the regression results examining the effect of Liquidity Reserves (LR) on three carbon emission measures: total CO_2 emissions, direct CO_2 emissions, and indirect CO_2 emissions. The coefficients for LR are positive and statistically significant across all three models: 0.245*** for total emissions, 0.175*** for direct emissions, and 0.090*** for indirect emissions, confirming H1. These findings suggest that firms with higher liquidity reserves tend to emit more carbon, supporting the agency theory perspective that excess cash may be channeled into non-sustainable or short-term projects, especially in the context of emerging markets like Bangladesh, India, and China. The economic significance of these results is notable. A one standard deviation increase in LR (11.59%) is associated with a 2.84 percentage point increase in total carbon emissions (11.59 × 0.245), a 2.03 percentage point increase in direct emissions, and a 1.04 percentage point increase in indirect emissions. These results underline how cash-rich firms may deprioritize environmental performance unless constrained by robust governance structures. Among the governance variables, CEO as Director (CD) has a positive and significant effect across all emissions categories (0.035**, 0.310**, and 0.060**), highlighting that CEO duality may weaken oversight and contribute to higher emissions. Governance Structure Type (GST) shows a consistently negative and significant relationship with emissions, suggesting that firms with two-tier boards are more likely to reduce carbon outputs, validating H2c. The variable External Consultants (EC) also shows a significant negative relationship with emissions, indicating that external expertise is effective in guiding firms toward more sustainable practices (H2f supported). On the other hand, Board Size (B_Size), Director Term Limits (DTL) are statistically insignificant in most cases, suggesting their limited influence in this context. Among governance variables, Institutional Ownership (INST) exhibits a negative and significant association with total and direct emissions (−0.021**, −0.018*), supporting the monitoring hypothesis.

4.3. Moderating Role of R&D Investment in the Liquidity–Carbon Emission Relationship

Table 4. The moderating impact of R&D Investment (RDI) on Liquidity Reserves and carbon emissions.

Variables	Panel A: Dependent Variable: Ln CO_2-Total	Panel B: Dependent Variable: Ln CO_2-Direct	Panel C: Dependent Variable: Ln CO_2-Indirect
Liquidity Reserves (LR)	0.213*** (0.076)	0.120*** (0.085)	0.095** (0.049)
LR * R&D Investment (RDI)	-0.017** (0.008)	-0.031*** (0.010)	-0.021** (0.009)
Board Size (B_Size)	-0.084 (0.155)	0.061 (0.204)	0.048 (0.134)
CEO as Director (CD)	0.333*** (0.185)	0.391*** (0.173)	0.247** (0.091)

Governance Structure Type (GST)	-0.203*** (0.173)	-0.114** (0.165)	-0.126*** (0.132)
Director Term Limits (DTL)	-0.081 (0.053)	0.328 (0.268)	0.319 (0.245)
Auditor Independence Rotation (AIR)	0.068* (0.090)	0.179* (0.257)	0.245** (0.214)
External Consultants (EC)	-0.102*** (0.093)	-0.388*** (0.124)	-0.118*** (0.014)
Firm Size (FS)	0.920*** (0.180)	1.720*** (0.250)	0.860*** (0.150)
Debt to Equity (DTE)	-0.028* (0.012)	-0.021 (0.020)	-0.023** (0.011)
Cash Flow (CF)	0.020 (0.024)	-0.150*** (0.037)	-0.007 (0.019)
Return on Assets (ROA)	-0.033 (0.055)	0.180 (0.108)	-0.035 (0.044)
Capital Expenditure (CapEx)	0.045 (0.047)	0.297*** (0.074)	0.172*** (0.040)
Leverage (Leverage)	0.004 (0.018)	-0.001 (0.022)	-0.007 (0.013)
_cons	-1.943 (3.987)	-7.734 (4.778)	-8.553 (4.753)
Number of Groups	150	150	150
Observations	1500	1500	1500
F-statistics	10.188	12.177	15.342
R-square	0.376	0.357	0.391
Adjusted R-square	0.219	0.279	0.291

Note(s): Regression coefficients are shown in the table with standard errors enclosed in parenthesis and significance levels denoted by asterisks. *p < 0.1; **p < 0.05; ***p < 0.01. The value in parentheses is the robust standard error (Driscoll-Kraay). Source: Authors own work.

Table 4 examines the moderating influence of R&D Investment (RDI) on the relationship between Liquidity Reserves (LR) and carbon emissions (CO_2) across three dimensions: total, direct, and indirect emissions. Across all three panels, the interaction term LR × RDI is negative and statistically significant, confirming H3 and suggesting that firms with higher R&D investments are more effective at converting financial liquidity into environmentally responsible outcomes. Specifically, the interaction coefficients are –0.017 for total emissions, –0.031 for direct emissions, and –0.021 for indirect emissions—all statistically significant at the 5% or 1% level. These results align with previous studies, who emphasized that R&D investment fosters low-carbon innovations and green technologies, which help mitigate the environmental consequences of excess liquidity [1,6]. Thus, RDI serves as a strategic lever to ensure that cash-rich firms invest in sustainable development instead of emissions-intensive operations. The main effect of Liquidity Reserves (LR) remains positive and significant in all three models (0.213***, 0.120***, and 0.095**), reinforcing the core findings from Table 3 and the agency theory proposition that firms with high liquidity may engage in environmentally damaging activities when not properly governed. However, the presence of strong R&D strategies evidently weakens this link. Among governance variables, CEO as Director (CD) continues to show positive and significant coefficients across all models, reaffirming H2b. The findings imply that CEO board membership exacerbates CO_2 emissions, likely due to a concentration of decision-making power and reduced board independence, as also observed by previous works [23,16]. The coefficient on Governance Structure Type (GST) remains negative and significant in all models, confirming H2c. Firms with a two-tier board structure appear better equipped to supervise financial and environmental decision-making, supporting earlier evidence by that two-tier boards

enhance environmental accountability [3,51]. The effect of Board Size (B_Size) is statistically insignificant across all panels. This supports the findings of previous authors who argued that beyond a certain size, increasing the number of directors does not meaningfully influence environmental performance due to coordination and decision-making inefficiencies [1,70]. Interestingly, Director Term Limits (DTL) are also not significant across all models. This contradicts other author, who argued that periodic board renewal could enhance governance responsiveness [53]. Our findings suggest that tenure limitations alone, without complementary governance structures or enforcement, are insufficient to influence environmental outcomes in emerging markets. Auditor Independence Rotation (AIR) shows positive and statistically significant coefficients in all models, which is somewhat counterintuitive. While auditor rotation is meant to improve audit quality and independence, the findings suggest it may lead to knowledge loss or reduced scrutiny in complex areas like sustainability accounting. This aligns with critiques that frequent rotation can sometimes weaken institutional memory, reducing audit effectiveness in overseeing carbon-related disclosures—thereby supporting H2e [54,55]. External Consultants (EC) again exhibit strong negative and significant coefficients, validating H2f. Firms engaging external consultants for sustainability guidance show improved carbon outcomes, as these professionals likely offer the technical expertise and independent oversight necessary to direct cash flows into green initiatives. This is consistent with previous works [56,57].

Table 5. The impact of Liquidity Reserves (LR) and carbon emissions (Using GMM).

Variables	Ln CO_2-Total	Ln CO_2-Direct	Ln CO_2-Indirect
L.CO_2-total	0.229***	0.374***	0.229***
L.CO_2-direct	0.171***	0.096**	0.171***
L.CO_2-indirect	0.265***	0.120***	0.265***
Liquidity Reserves (LR)	0.066***	0.020***	0.066***
Board Size (B_Size)	-0.009	0.114**	0.001
CEO as Director (CD)	0.257***	0.281*	0.139*
Governance Structure Type (GST)	-0.221**	-0.009	-0.475**
Director Term Limits (DTL)	-0.357*	-0.455*	-0.392
Auditor Independence Rotation (AIR)	0.222***	0.168***	0.195***
External Consultants (EC)	-0.187***	-0.214**	-0.226***
Firm Size (FS)	0.005	0.12	-0.145
Dividend Payout Ratio (DPR)	0.052	0.03	0.11
Profitability (ROA)	0.13	0.095	0.05
Leverage	-0.001	0.02	-0.01
Firm Age (Age)	0.013	-0.015	-0.014
Carbon Intensity (CI)	0.019	0.021	0.012
R&D Investment (RDI)	-1.078	-1.324	-1.218
Controls	Yes	Yes	Yes
Firm Fixed Effect	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes
_Cons	2.295	1.438	-1.531
(3.565)	(0.213)	(0.189)	(0.198)
Number of Groups	150	150	150
Observations	1500	1500	1500
Sargan Test	0.136	0.220	0.175
Hansen Test	0.121	0.147	0.189

AR(2)	0.254	0.167	0.137

Note(s): Regression coefficients are shown in the table with standard errors enclosed in parentheses and significance levels denoted by asterisks. *p < 0.1; **p < 0.05; ***p < 0.01. Source(s): Authors own work.

4.4. Generalized Method of Moments (GMM) Findings

This study initially controls for unobserved heterogeneity using the fixed effects (FE) model. However, due to potential endogeneity concerns—including reverse causality and omitted variable bias—FE estimates may still be inconsistent [15,71]. For instance, firms with higher Liquidity Reserves (LR) may emit more carbon due to investment in capital-intensive, polluting activities. Conversely, highly polluting firms may retain more cash as a buffer against future regulatory costs or reputational risks. These bi-directional relationships, alongside latent variables such as managerial incentives or sectoral emission standards, necessitate a more robust estimator. To address these concerns, the study employs the two-step system Generalized Method of Moments (GMM), suitable for panel datasets with large cross-sectional units and relatively shorter time frames [60,72]. This method uses internal instruments—lagged levels and differences of endogenous regressors—which are assumed to be correlated with the regressors but uncorrelated with the error terms [73,74]. Diagnostic tests, including the Sargan Test, Hansen J-test, and AR(2) test, confirm the validity of the instruments, absence of overidentification, and no second-order autocorrelation, supporting model robustness. The results from Table 5 confirm a positive and statistically significant relationship between Liquidity Reserves (LR) and all forms of carbon emissions. The coefficients for LR are 0.066*** for both total and indirect emissions, and 0.020*** for direct emissions, confirming previous findings in Tables 3 and 4 and further validating H1. This supports the view that in the absence of strong governance mechanisms, excess liquidity can be directed toward carbon-intensive activities [34,44]. The dynamic terms (Lags of CO_2 emissions) are all highly significant (e.g., L.CO_2-total = 0.229***), which indicates carbon emissions are persistent over time, consistent with previous studies in environmental accounting [75]. CEO as Director (CD) remains positively and significantly associated with emissions (e.g., 0.257***), reinforcing H2b. This suggests that CEO duality leads to less independent oversight and supports the agency theory's prediction of resource misuse under weak governance [23,50]. Governance Structure Type (GST) is significant only in the total and indirect models, showing an adverse effect, confirming H2c, that two-tier governance structures mitigate carbon emissions through stricter board supervision [3,51]. External Consultants (EC) again show strong negative coefficients, consistent with H2f, indicating that the presence of independent sustainability advisors helps redirect liquidity toward eco-friendly initiatives [56,57]. Other variables, such as Board Size (B_Size), ROA, and Firm Size (FS), are statistically insignificant across most models. These non-significant results suggest that board size alone does not meaningfully shape carbon outcomes—consistent with previous authors—and that profitability or firm size may not automatically translate into environmental responsibility without targeted policies or incentives [1,23]. Capital Expenditure (CapEx) and R&D Investment (RDI) are negative but not significant, suggesting that while innovation matters (as shown in Table 6), CapEx alone may not be sustainability-oriented unless directed through proper governance mechanisms [71].

Table 6. The moderating impact of R&D Investment (RDI) on liquidity reserves and carbon emissions (Using GMM).

Variables	**Ln CO_2-Total**	**Ln CO_2-Direct**	**Ln CO_2-Indirect**

L.CO_2-Total	0.289***		
L.CO_2-Direct		0.212***	
L.CO_2-Indirect			0.275***
Liquidity Reserves (LR)	0.089***	0.019***	0.035***
Board Size	-0.012	-0.900	0.003
LR*Board Size	-0.002**		
CEO as Director (CD)	0.309***	0.255**	0.182*
LR*CEO-Board-Member	0.008***		
Board Structure Type (GST)	-0.255**	-0.358**	-0.492**
LR*Board-Structure-Type	-0.018***		
Board Membership Limits (DTL)	-0.265*	-0.412*	-0.289
LR*Board Membership Limits	-0.089**		
Auditor Independence Rotation (AIR)	0.228***	0.178***	0.199***
LR*Auditor-Independence-Rotation	0.005**		
External Consultants (EC)	-0.195***	-0.236**	-0.251***
LR*External Consultants	-0.088**		
R&D Investment (RDI)	0.121*	0.091*	0.075*
LR*R&D Investment	-0.041**	-0.046***	-0.037**
Controls	Yes	Yes	Yes
Firm Fixed Effect	Yes	Yes	Yes
Year Fixed Effect	Yes	Yes	Yes
_Cons	2.295	1.438	-1.531
(3.565)	(0.213)	(0.189)	(0.198)
Number of Groups	150	150	150
Observations	1500	1500	1500
Sargan Test	0.136	0.220	0.175
Hansen Test	0.121	0.147	0.189
AR(2)	0.254	0.167	0.137

Note(s): Regression coefficients are shown in the table with standard errors enclosed in parentheses and significance levels denoted by asterisks. *p < 0.1; **p < 0.05; ***p < 0.01. Source(s): Authors' work.

Table 6 explores how board characteristics and R&D investment moderate the effect of LR on emissions. The interaction terms reveal key insights: LR × Board Structure Type (–0.018***), LR × External Consultants (–0.088**), and LR × Board Membership Limits (–0.089**) show statistically significant negative coefficients, confirming H2c, H2f, and partial support for H2d. These features help reduce the environmental damage associated with extensive liquidity holdings by improving monitoring and enforcing sustainable investment choices [53,76]. Conversely, LR × CEO as Board Member (0.008***) and LR × Auditor Independence Rotation (0.005**) show positive and significant effects on emissions, confirming H2b and H2e. These results suggest that the concentration of power (via CEO duality) and frequent auditor rotation (possibly reducing firm-specific expertise) could weaken governance and allow greater latitude in misallocating liquidity [54,55]. Most notably, LR × R&D Investment (RDI) consistently yields significant negative coefficients (e.g., –0.041**, –0.046***, –0.037**) across total, direct, and indirect emissions models, strongly supporting H3. This aligns with RBV and empirical findings from previous studies that R&D enables firms to convert financial slack into innovation that mitigates environmental harm [1,7]. The significance of these interaction terms

reinforces the role of internal governance architecture and strategic investments in shaping environmental outcomes. It also confirms that liquidity, while potentially harmful, can be turned into a sustainability enabler under effective oversight and innovation structures.

4.5. Diagnostic Tests and Model Validity

The Hansen and Sargan tests have a p-value greater than 0.10 and therefore indicate that the instruments are valid and uncorrelated with the error terms, meeting the overidentifying restriction assumptions [77]. Also, the second-order autocorrelation that may have overwhelmed the low power of the AR(1) test is not present in the AR(2) p-values, attesting to the GMM estimates' good performance [72,73]. The GMM estimates of Tables 5 and 6 strengthen the results of previous models, revealing that a build-up of liquidity reserves leads to higher carbon emissions in the absence of strong governance. Nevertheless, the downside effects of dynasties can be counteracted by selective R&D investment and ownership structures such as litigation boards, audit committees, term limits, and independent consultant mechanisms. These findings are consistent with agency theory and RBV, emphasizing the importance of both firms and regulators in developing economies to enhance their governance systems and innovation capabilities for environmental sustainability.

The GMM estimates in Tables 5 and 6 generally confirm the previous model's results by showing that an expansion in liquidity reserves leads to higher carbon emissions if governance is not strong. However, their negative consequences can be offset by targeted R&D investment and governance structures such as two-tier boards, term limits, and external consultants. These findings align with agency theory and RBV, which highlight the susceptibility to temptations and the commitment of agents, respectively. They suggest that firms and regulators must strengthen governance mechanisms and the innovation system in emerging economies to ensure environmental sustainability.

5. Discussion

The results of this work establish empirically an unequivocal relationship between high Liquidity Reserves (LR) and an increase in carbon emissions. In logical terms, firms with substantial financial resources perform poorly environmentally. Unlike previous authors, who suggested that a healthy level of liquidity leads to green investment, this research indicates that financial slack tends to flow into carbon-intensive sectors in the emerging markets [1,27]. These findings also go against the Resource-Based Theory (RBT) logic, which argues that liquidity should take the form of valuable internal resources, allowing sustainable innovation. Evidence provides support to Agency Theory, which argues that managers, in the absence of appropriate supervision, tend to abuse liquidity reserves to obtain short-term protective rents, and do so at the detriment of environmental performance in the long run [10,11]. This divergence may be contextual. Compared to those in Bangladesh, India, and China, compliance with environmental regulations is still not uniform, and the stakes of stakeholders or civil society on carbon transparency are relatively lower. This regulatory void, left after managers with dry powder may deploy liquidity to growth or politically favored investments rather than environmentally positive options. Like the GCC countries, these emerging Asian markets are still finding their way of reconciling between fast industrialization and ecological responsibility[23,78]. Companies involved in fossil fuel-embedded or high-emitting sectors (such as manufacturing and energy) are likely to find it organically challenging to align liquidity with green viewpoints, particularly when environmental reporting is still optional. The effect of CEO-board

duality on carbon emissions is consistent with Agency Theory. This research reported a significantly positive association between the CEO as Director (CD) and CO_2 emissions, which implies that dual leadership slackens board independence and the board will easily make decisions to emphasize financial benefit at the expense of environmental benefit. This is consistent with the findings of previous authors who argue that CEO dominance weakens board monitoring [79]. The results of the interaction term from the GMM model also find that, distinctly, if the CEO is the chairman of the board, it will make the company utilize liquidity more efficiently, which will lead to greater emissions. This disconnect undermines corporate commitment to worldwide climate targets and sustainable development principles [32]. On the other hand, the presence of a dual board structure (GST) is negatively associated with carbon emissions. This is in line with the agency theory regarding the positive influence of decoupling control and monitoring activities [23]. Two-tier boards represent, from an RBT viewpoint, strategic governance instruments to improve internal checks and support resource allocation towards sustainability-related concerns [51]. These institutions are especially crucial in scenarios such as China, where regulators are stricter and there is growing support from institutions for sustainability. However, there are costs of implementation and of cultural opposition, of the sort we have witnessed in family- or state-owned companies (see, for instance, in GCC countries) [79]. Director Term Limits (DTL) is the only variable that is not found to have any consistent significance across models, contradicting expectations from Agency Theory and the findings in previous study [52]. This suggests that tenure caps alone may not be an effective tool for enhancing environmental monitoring without accompanying reforms to the board and performance accountability systems. Also, the relationship between Auditor Independence Rotation (AIR) and CS appears to be positive, but intuition suggests it should be negative. While audit rotation is designed to enhance independence, our results imply that excessive rotation may have a detrimental effect on knowledge of the firm's business and its environmental practices, indicating insubstantial oversight. This is in keeping with previous discussions by previous study [54,55]. In developing countries characterized by immature environmental auditing, a short cycle of auditor replacement will lead to a deterioration in audit quality and limit the ability to monitor how liquidity is used. Other research in the GCC has reported that audit rotation can result in lower attention to sustainability in high pollution industries such as construction and energy [23]. In contrast, the EC supply pattern has a rather significant influence on carbon emissions in all models. Firms that hire external sustainability consultants are more likely to allocate their liquidity to environmentally friendly activities, supporting both Agency Theory and RBT. The role of these consultants is to supply the external knowledge necessary to drive firms toward green innovations and carbon-offset projects [80, 81]. They mitigate agency costs and encourage strategic resource allocation, in line with the observations of, and the framework of international climate governance calling for the inclusion of external ESG expertise [82]. Theoretical contribution is provided to the literature by suggesting that R&D Investment (RDI) is also an important moderating variable. The influence of R&D on Liquidity Reserves is persistent and significantly damaging, implying that R&D reallocates redundant liquidity reserves towards environmental innovation to mitigate environmental harm. This result is consistent with the RBT premise, The value of liquidity relies on its optimal use in conjunction with innovation capabilities [35,36]. These findings corroborate the findings of previous studies, who suggested that R&D-intensive firms are more likely to transform financial slack into competitive low-carbon advantages [1,83].

6. Conclusion and Implications

The current research extends the discussion on LR and the moderation effect of corporate governance characteristics of R&D in shaping carbon emissions (CO_2) in Emerging markets. Using 1,500 firm-year observations for 150 listed firms in Bangladesh, India, and China, we find that excess liquidity is positively related to carbon emissions, indicating that managers have a propensity to invest in pollution-induced production patterns. This finding suggests that under informal institutions (weak environmental regulation and low stakeholder pressure), financial slack might not help prevent environmental destruction. It may indeed continue to cause environmental destruction, rather than mitigate it—that is, the pattern observed in earlier studies in other emerging markets. The research highlights the role of corporate governance tools for channeling liquidity towards sustainable purposes. More precisely, the foreign presence of two-tier boards, larger board sizes, and the use of external consultants reduces the adverse effects of the liquidity reserve on the natural environment. More importantly, CEO-board duality and auditor rotation for a longer tenure have the opposite effect, as they increase emissions, thus undermining board independence and monitoring efficiency. These results indicate that good governance's involvement in corporate cash usage reduced the eco-footprint of cash spending rather than the funding.

6.1. Theoretical Implications

This paper contributes to the growing literature on the nexus between corporate finance, governance, and sustainability by examining the environmental consequences of a liquidity reserve and demonstrating how governance mechanisms condition these effects. In so doing, it contributes to Agency Theory and the Resource-Based Theory (RBT) by incorporating governance mechanisms as mechanisms of the relationship between finance and sustainability. The results underpin agency theory's assertion that resource misallocation is probable where monitoring is limited, particularly in the context of CEO-board duality [10,32]. At the same time, through an RBT perspective, the two-tier boards and external consultants illustrate how the intangible governance resources increase the environmental value of tangible financial resources [84]. The baseline model presents R&D investment as a strategic moderating force offsetting the downside of liquidity externalities. Adverse interaction effects between RDI and LR, as shown in the results, imply that innovation-driven firms would have more capability to channel cash reserves into green outputs. This result extends RBT by demonstrating that fit between financial and innovation resources may lead to firm-specific capabilities that drive environmental performance. These theoretical extensions connect financial slack so far with sustainable innovation and board governance literatures.

6.2. Policy Implications

The findings have practical value to regulators and policymakers in Bangladesh, India, and China, where they are being forced to manage tensions between industrial growth and environmental aspirations. Since unsupervised liquidity tends to increase the level of emissions, legislating board structure reforms, for instance, a two-tier board class system, may contribute to boosting environmental accountability. Regulars should also encourage the involvement of environmental consultants in enterprises with substantial liquidity, particularly those emission-intensive industries, including energy, steel, and textiles. Furthermore, the result of R&D investment in weakening the LR–CO_2 relationship may indicate a need for public policy tools, such as tax cuts or the subsidization

of green R&D, to direct corporate resources to cleaner technology. Financial supervisors could demand disclosure standards that tie the deployment of liquidity to carbon performance, increasing the demand for transparency and for aligning capital allocation with national climate goals. Most significantly, regulatory reform of audit is required: rather than a blunt requirement of rotation, virtues of independence and industry familiarity need to be balanced so as not to cause wholesale disruption of quality in assurance of the environment [54,85,86].

6.3. Practical Implications

The findings also provide helpful information for practitioners. Firms interested in lowering their carbon emissions should consider board composition and resource complementarity more closely. In addition, the two-tier governance structure of liquidity can help improve the efficiency of liquidity governance by separating the monitoring and decision-making roles. Moreover, engaging ESG-savvy external consultants could assist firms in aligning capital decisions with environmental strategy. Corporations—particularly those in emission-heavy sectors—need to proactively embed R&D priorities into capital budgeting processes, so that liquidity serves sustainable innovation. Furthermore, boards need to re-evaluate CEO duality and review CEO duality contracts, particularly where companies are cash-rich, as this structure can weaken supervision and potentially facilitate carbon-intensive policies. On the other hand, giving more power to independent directors and also imposing term limits could increase not only accountability but also environmental sensitivity. These internal improvements need not be regarded merely as for compliance, but rather as the levers of strategic support for longer-term sustainability.

6.4. Limitations and Future Research Directions

The study also has some limitations, notwithstanding its contributions. First, the geographic specificity of Bangladesh, India, and China is important as it provides valuable insight into emerging market considerations, which itself limits the external validity of conclusions to developed economies or other regulatory environments. To compare regions, one would need to look at cross-sectional differences on how institutional quality moderates the LR–CO_2 relationship in future research. Second, we do not touch upon ownership structures and stakeholder activism as an influential context for board effectiveness, explicitly studied in the empirical literature. Because both family and state ownership are prevalent in the sampled countries, an analysis of the role of state ownership, ownership concentration, and political connectedness is also in order. Next, due to data limitations, we do not distinguish between the degree of specialization of consultants, such as financial advisers versus environmental advisers. Further research might use survey data or ESG consulting records to investigate the nature of external expertise in environmental performance. Lastly, future studies might utilize signaling theory to investigate whether firms with high liquidity and emissions disclosure levels aim to signal that they are sustainability leaders, regardless of whether they are hiding the real performance differences.

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