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Research paper

The Impact of Changes in Carbon Emissions on Firm Value: Focusing on Voluntary Disclosure of Water Resources

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Abstract

This study investigates how changes in carbon emissions influence firm value and the extent to which voluntary water resource disclosure moderates this relationship. Analyzing a sample of 702 South Korean listed firms from 2017 to 2021, increases in carbon emissions are negatively associated with firm value, signaling to the market potential operational inefficiencies or heightened regulatory risk in a carbon-constrained economy. More critically, our findings reveal a significant moderating effect of voluntary water disclosure. This suggests that transparent water reporting allows firms to contextualize their carbon performance, mitigating the adverse valuation impact of rising emissions by signaling a holistic commitment to environmental responsibility. From a signaling theory perspective, this integrated transparency reframes investor perceptions, transforming isolated emission concerns into components of a broader, more credible sustainability narrative, thereby reinforcing stakeholder trust and offering a strategic pathway to enhancing firm value amidst environmental challenges.

Keywords: *Changes in Carbon Emissions; Firm Value; Voluntary Disclosure of Water Resource.*

1. Introduction

The escalating global concern over climate change has significantly intensified the pressure on corporations to demonstrate environmental responsibility and accountability. According to World Population Review (2025), South Korea's global ranking for carbon emissions rose from 20th in 2010 to 11th, ranking 4th among OECD (Organization for Economic Cooperation and Development) nations. Despite having no legal obligations under the Kyoto Protocol, South Korea has faced persistent pressure to curtail its carbon emissions. In response, South Korea implemented the Greenhouse Gas and Energy Target Management System in 2010. Subsequently, to specifically address emissions from major industrial sources, South Korea transitioned to an Emissions Trading Scheme (ETS) in 2015, thereby promoting carbon emission reduction within the industrial sector (Kim and Yoo, 2023).

Amid increasing global scrutiny, carbon emissions extend from national totals to individual corporations. Growing awareness of climate change, pandemics, and international conflicts has led to a continual rise in demand not only from investors but also from other stakeholders for sustainable and responsible corporate practice (Kolk and Van Tulder, 2010). As a result, firms are facing growing pressure to disclose information regarding their environmental activities voluntarily (Amel-Zadeh and Serafeim, 2018).

Central to this discourse is the impact of carbon emissions, not merely as static figures but as dynamic indicators of a firm's adaptive capacity and commitment to sustainability (Matsumura et al. 2014). Changes in a company's carbon footprint can signal evolving operational efficiencies, responses to impending regulatory frameworks, or shifts in reputational standing, all of which carry substantial potential implications for firm value. Investors and stakeholders increasingly scrutinize these changes, recognizing them as proxies for a firm's resilience to transition risks and its long-term viability in a carbon-constrained economy (Cho et al., 2012).

Alongside the focus on carbon, the critical issue of water resource management has gained considerable prominence. Growing awareness of water scarcity has led stakeholders to demand greater transparency regarding how companies manage their water consumption, risks, and stewardship efforts (Farooq et al., 2024). The disclosure of water-related information serves as a vital channel for companies to communicate their commitment to responsible water management (Adhariani, 2021; Bunclark and Scott, 2021; Zhou et al., 2018). Such transparency can act as a positive signal to the market, indicating proactive risk mitigation and a dedication to sustainable operational practices, thereby potentially enhancing stakeholder trust and confidence (Liu et al., 2022).

This study examines the moderating effect of voluntary water disclosure on the relationship between changes in carbon emissions and firm value, analyzing 702 Korean listed firms from 2017 to 2021. The findings show that while carbon emissions negatively affect firm value, voluntary water disclosure mitigates these effects.

This study contributes to the literature by focusing on changes in emissions rather than static levels, capturing firms' dynamic environmental adjustments, and integrating voluntary water disclosures as a moderating factor. Prior studies mostly examined static carbon emission levels (Matsumura et al., 2014; Lemma et al., 2020; Xie et al., 2023), potentially missing nuanced market valuations of firms' adaptability. Research on water disclosure's moderating role remains limited.

By highlighting the strategic value of integrated environmental disclosures, this study advances understanding of how proactive transparency in water management offsets negative market perceptions due to rising carbon emissions. This underscores the importance of holistic environmental reporting for corporate valuation.
The rest of the research is organized as follows. The second section delineates the theoretical background and the development of hypotheses. The third part outlines the methodological approach adopted for this research. The fourth part shows the empirical results, and the final section provides the conclusion.

2. Theoretical Background and Hypothesis Development

2.1. changes in carbon emissions

Prior research has extensively documented the negative relationship between carbon emission levels and firm value. Matsumura et al. (2014) demonstrated that higher emissions correlate with discounted valuations, attributing this to investor concerns over regulatory risks and future liabilities. Similarly, Saka and Oshika (2014) found that Japanese firms with elevated emissions faced market penalties, while voluntary disclosure partially mitigated these effects. Furthermore, the study by Kim et al. (2023) revealed that a CEO's risk-averse tendency contributes to increased levels of carbon emissions in firms. Notably, the research found that this effect is more pronounced when board characteristics, such as a lower proportion of outside directors or a smaller board size, are present. This highlights the significant role of CEO compensation structures and board characteristics in influencing corporate environmental performance.
These studies, however, predominantly focus on static emission levels rather than dynamic changes over time. This study shifts the analytical focus to changes in carbon emissions, a critical yet underexplored dimension. Unlike levels, emission changes reflect firms' operational adaptability and responsiveness to evolving environmental pressures. For instance, Lemma et al. (2020) observed that firms with improving emission profiles that demonstrate year-over-year reductions experienced higher intangible asset valuations, as investors interpreted such trends as signals of proactive environmental governance. The rationale for this approach is further supported by temporal analyses. Kim (2024) revealed that pre-pandemic carbon emission reductions positively influenced firm value, whereas the post-COVID period erased these gains, underscoring how emission trends interact with external shocks. Additionally, while voluntary disclosure of emission levels enhances transparency (Matsumura et al., 2014), disclosing reductions amplifies this benefit.
By focusing on emission trends rather than absolute levels, this study fills a gap in the literature, offering insights into the broader implications of environmental performance on firm valuation. This perspective aligns with the hypothesis that carbon emissions, whether in levels or trends, hold significant influence on investor perceptions and corporate value. Based on this rationale, the first hypothesis is formulated as follows.
Hypothesis 1: Changes in carbon emissions negatively affect firm value.
As the intensifying impacts of climate change place unprecedented strain on global ecosystems, there is mounting demand for firms to provide transparent environmental disclosures, particularly regarding water-related risks. Zhu et al. (2023) highlight that corporate water risk, encompassing physical scarcity, regulatory changes, and reputational challenges, is an emerging critical issue that firms must address within their value chains to ensure sustainable operations under climate pressures. Further, Panteleev et al. (2024) highlight the vital role of ESG business reporting in water management, emphasizing that comprehensive and material ESG disclosures equip stakeholders with reliable information for decision-making and improve corporate competitiveness by aligning with sustainable development goals. The study underscores the need for comprehensive water risk assessment and integrated management as core strategic priorities for firms facing climate uncertainties. While corporate climate risk management has historically centered on carbon emissions, water is a critical yet often overlooked component of the greenhouse effect. The Intergovernmental Panel on Climate Change (IPCC) reports that seawater absorbs approximately 90% of the heat retained by the planet due to the greenhouse effect, underscoring water's central role in climate dynamics. Despite this significance, empirical research directly connecting water risks to financial and accounting outcomes remains limited.
In recent years, companies have begun to address this gap by voluntarily disclosing water-related risks and management strategies, often through standardized platforms such as the Carbon Disclosure Project (CDP) (CDP, 2025). The CDP's framework encourages firms to: (1) develop comprehensive water risk assessment systems, (2) establish and pursue company-wide water strategies and targets, and (3) implement concrete actions to mitigate water risks. Such voluntary disclosures enable investors, regulators, and other stakeholders to assess a firm's awareness of water-related challenges and its strategic response, while also reducing the potential for bias inherent in less standardized reporting channels such as annual or CSR reports (Datt et al., 2018).
Signaling theory further suggests that firms disclosing water risks proactively communicate their commitment to managing environmental challenges, sending a positive signal to the market and enhancing perceptions of responsible governance (Trueman, 1988). Consistent with Trueman's study (1988), Liu et al. (2022) asserted that voluntary environmental disclosures like water risk information signal their managerial talent and the firm's superior quality to investors, particularly in environments characterized by high information asymmetry and uncertainty. Additionally, Zhou et al. (2018) explicitly ground their analysis in signaling theory, positing that water disclosure serves as a crucial mechanism for firms to convey information about their water management and risk mitigation strategies to external stakeholders. They argue that such disclosures alleviate problems of adverse selection and moral hazard, ultimately influencing corporate risk-taking behavior and potentially leading to more efficient capital allocation by better-informed investors.
Empirical evidence indicates that corporate characteristics influence water disclosure practices, including financial performance (Yu et al., 2020; Wicaksono and Setiawan, 2022), firm size (Botha et al., 2022; Wicaksono and Setiawan, 2023), industry (Burritt et al., 2016; Zhang et al., 2021), and stakeholder pressure (Yu, 2022; Yu et al., 2020; Botha et al., 2022). Specifically, studies by Yu et al. (2020) and Wicaksono and Setiawan (2022) identified a negative correlation between a firm's profitability and the extent of its water-related disclosures. Conversely, Botha et al. (2022) and Wicaksono and Setiawan (2023) found a positive association between firm size and water disclosure practices. Furthermore, firms in water-sensitive industries are more likely to disclose water-related information due to increased pressure (Burritt et al., 2016; Zhang et al., 2021), demonstrating a commitment to water resource management and building stakeholder trust (Zhang et al., 2021; Yu, 2022). External factors, such as government shareholding (Yu, 2022), creditor pressure (Yu et al., 2020), and regulatory demands (Zeng et al., 2020), also affect water information disclosure. With this rationale, preemptive communication helps to build stakeholder trust and can be crucial in regaining confidence, especially when firms face negative media coverage or heightened community awareness regarding environmental issues (Mohamad and Taha, 2023).
Importantly, Zhu et al. (2023) emphasize that effective water risk disclosure should be integrated as part of firms' comprehensive environmental strategies to mitigate physical, regulatory, and reputational water risks. Such integrated disclosure contributes to enhancing firms' resilience and legitimacy in the face of climate change, complementing carbon emission disclosure and thereby strengthening the overall

sustainability profile perceived by stakeholders. Increased transparency regarding water management practices can reassure stakeholders that, even amidst significant carbon emissions, the firm is actively addressing its broader environmental impact and demonstrating a commitment to sustainable resource utilization. By providing detailed information on water-related risks, mitigation strategies, and performance metrics, companies can signal a holistic approach to environmental responsibility, offsetting potential concerns linked solely to carbon emissions and fostering a more comprehensive understanding of their environmental stewardship. Therefore, drawing from the arguments presented, the second hypothesis is formulated as follows.
Hypothesis 2: Firms that voluntarily disclose water resources affect the relationship between changes in carbon emissions and firm value.

3. Research Design

3.1. Data collection

This study analyzes publicly traded companies in South Korea from 2017 to 2021. Financial data for these firms was sourced from the KIS-Value database. Carbon emissions and water-related data were extracted from disclosures made to the CDP. These disclosures originate from survey responses, a process aimed at encouraging firms to address climate change. Following Kumar and Dua (2022), such voluntary CDP participation is considered an effective indicator of a firm's environmental footprint. To ensure consistency in the dataset, firms operating in the financial sector were excluded due to their distinct regulatory environment. Additionally, companies lacking available financial data were removed from the sample. Following these exclusions, the final dataset consists of 702 firm-year observations.

3.2. Empirical model

To test the first hypothesis, which examines the relationship between changes in carbon emissions and firm value, the following equation is formulated. Firm value (FV) is measured as the sum of the book value of assets and the market value of equity, divided by the book value of assets (Lee and Jeon, 2019). The variable, Gas, is a dummy variable, assigned a value of 1 if gas emissions in the current year increase compared to the prior year, and 0 otherwise.

$$FV_t = \beta_0 + \beta_1 Gas_t + \beta_2 Size_t + \beta_3 Lev_t + \beta_4 Loss_t + \beta_5 Roe_t + \beta_6 Cfo_t + \beta_7 Inv_t + \beta_8 Da_t + YrD + IndD + \varepsilon \quad (1)$$

Where, FV = firm value, Tobin's Q = (book value of assets + market value of equity)/book value of assets; Gas = dummy variable, 1if changes in carbon emissions in year t increases, compared to year t-1, 0 otherwise; Size = natural logarithm of total assets; Lev = total debt divided by total assets; Loss = 1 if a company with loss, and 0 otherwise; Roe = net income divided by equity; Cfo = operating cash flow/total assets; Inv = plant, property, and equipment (except land and construction in the process)/total assets; Da = Discretionary accruals measured by the model in Kothari et al., (2005), as specified in equation (2); YrD = year dummies; IndD = industry dummies;
The calculation of discretionary accruals (Da) follows the methodology outlined by Kothari et al. (2005).

$$\frac{Ta_t}{A_t} = \alpha_0 + \beta_1 \frac{1}{A_t} + \beta_2 \left(\frac{\Delta Sales_t - \Delta Ar_t}{\Delta Ar_t}\right) + \beta_3 \frac{Ppe_t}{A_t} + \beta_4 Roa_t + \varepsilon_t \quad (2)$$

Where Ta = Net income − cash flow from operations; A = Total assets; Sale = Sales revenue; Ar = Accounts receivable; Ppe = Plant, property, and equipment; Roa = Return on assets; Net income/total assets.
To assess the effect of the voluntary disclosure of water on the relationship between changes in gas emissions and firm value, the second equation is established as follows.

$$FV_t = \beta_0 + \beta_1 Gas_t + \beta_2 Water_t + \beta_3 GW_t + \beta_4 Size_t + \beta_5 Lev_t + \beta_6 Loss_t + \beta_7 Roe_t + \beta_8 Cfo_t + \beta_9 Inv_t + \beta_{10} Da_t + YrD + IndD + \varepsilon (3)$$

Where, Water = Voluntary disclosure of carbon emission; GW = interaction term between Gas and Water; See equation (1) for the definition of other variables.

4. Empirical Results

4.1. Descriptive statistics

Table 1 presents the descriptive statistics for the key variables analyzed in the study. The variable Gas, which captures changes in gas emissions, has a mean of 0.022 and shows the proportion exhibiting increases. The variable Water, representing voluntary water disclosure, has a mean of 0.281. Overall, these statistics provide a preliminary understanding of the distribution and variability of the key variables under investigation.

Table 1: Descriptive Statistics

Variables	Mean	Std	Q1	Median	Q3
FV	2.042	2.178	0.803	1.331	2.227
Gas	0.022	0.148	0.000	0.000	0.000
Water	0.281	0.450	0.000	0.000	1.000

(1) See equations (1) and (3) for variable definitions.

Table 2 presents the correlation coefficients among the key variables. It is important to note that while a negative correlation is observed between firm value (FV) and changes in gas emissions (Gas), as well as between firm value and voluntary water disclosure (Water), these results do not account for other explanatory variables. Therefore, the observed associations may change when additional control variables are included, underscoring the necessity for further analysis to better understand the underlying relationships.

Table 2: Correlation Matrix of Main Variables

	FV	Gas	Water
FV	1.000	-0.225 0.000	-0.150 0.026
Gas		1.000	0.144 <.0001
Water			1.000

(1) See equations (1) and (3) for variable definitions.

Figure 1 compares firm value changes corresponding to an increase in gas emission for two groups: firms that voluntarily disclose water usage, denoted as water =1 in black, and those that do not, denoted as water = 0 in gray. The firm value decreases as gas emissions increase for both groups; however, the decline is less steep for firms disclosing water information, suggesting that voluntary water disclosure mitigates the negative impact of increased gas emissions on firm value.

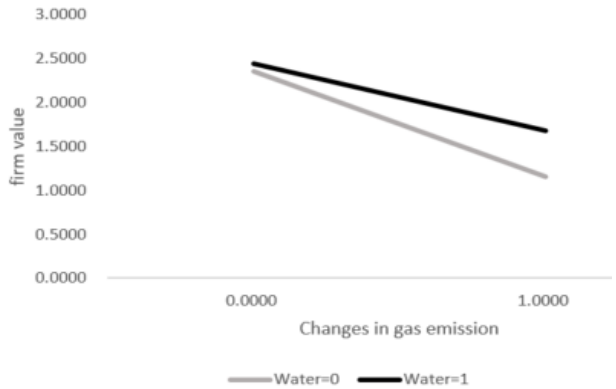

Fig. 1: Effect of Changes in Gas Emission on Firm Value by Voluntary Water Disclosure Status.

Where Water =1 denotes firms with voluntary water disclosure; Water=0 denotes firms without voluntary water disclosure.

4.2. Regression results

Table 3 presents the regression results testing the first hypothesis, which examines the relationship between changes in gas emissions (Gas) and firm value (FV). The coefficient of -0.898 for the Gas variable and statistically significant at the 1% level. This indicates that when a firm's carbon emissions increase, its firm value tends to decrease by about 0.9 units, holding other factors constant. This means that investors view rising carbon emissions as a risk, possibly due to higher regulatory costs or operational challenges, which negatively affect the company's market valuation.

The result distinguishes itself from prior literature, which has predominantly focused on static emission levels (Matsumura et al., 2014), by shifting the analytical focus to temporal adjustments. This dynamic perspective captures how a firm's adaptive capacity in managing its environmental footprint influences market perception. While Lemma et al. (2020) identified that firms demonstrating emission reductions gained intangible asset premiums, the result of this research complements this by highlighting that emission increases appear to trigger valuation discounts. Taken together, these findings underscore the financial materiality of emission trends, suggesting a need for firms to prioritize not only absolute carbon reduction but also the transparent communication of their emission patterns to potentially address investor concerns regarding environmental risk management.

Table 3: Regression Results of the First Hypothesis

Variables	Est.	t-value
Intercept	-9.668	-3.490***
Gas	-0.898	-3.040***
Size	0.367	3.880***
Lev	0.042	0.220
Loss	-0.544	-1.310
Roe	-2.710	-1.930*
Cfo	1.743	2.260**
Inv	6.850	5.860***
Da	3.127	3.280***
YrD	Included	
IndD	Included	
F-value	9.96	
Adj-R^2	0.23	

(1) ***, **, and * denote significance at the 1 %, 5 %, and 10 % level, respectively.
(2) See equation (1) for variable definitions

Table 4 presents the regression results for the second hypothesis, which investigates the moderating effect of voluntary water disclosure (Water) on the relationship between changes in gas emissions (Gas) and firm value (FV). The interaction term of variable GW is the focal point of this analysis. The coefficient for Gas is -1.525, significant at the 1% level, reaffirming the negative relationship between increased gas emissions and firm value. Similarly, the coefficient for Water is -1.463 is also significant at the 1% level, indicating that voluntary water disclosure, on its own, is negatively associated with firm value. This may reflect the costs or increased scrutiny associated with such disclosures. However, the interaction term (GW) shows a positive coefficient of 1.188, significant at the 5% level.

The result supports the second hypothesis. Consistent with prior literature, an increase in carbon emissions is slightly associated with a decline in firm value, reflecting investor concerns regarding environmental risks and potential regulatory costs. This finding suggests that

voluntary disclosure may introduce additional information that highlights potential operational or regulatory risks related to water management. Such disclosures could be interpreted as costly signals, possibly increasing investor scrutiny and perceived firm risk in the short term (Clarkson et al., 2008; Hummel and Schlick, 2016). Empirical evidence from emerging economies supports this view, showing that although sustainable development motivates firms to disclose water information, the negative market impact of such disclosure reflects the underlying risk exposure highlighted to investors (Yu et al., 2024).

Nonetheless, the interaction term between carbon emission changes and voluntary water disclosure is positive and significant. This indicates that voluntary water disclosure, when combined with changes in carbon emissions, mitigates the adverse effect of rising emissions on firm valuation. From the standpoint of signaling theory, providing transparent and integrated environmental information enables firms to present a more comprehensive profile of their environmental stewardship. This multidimensional disclosure strategy strengthens the credibility of reported information and alleviates concerns about isolated carbon emission increases (Zhou et al., 2018). Moreover, it signals a firm's proactive approach to managing environmental risks holistically, which is recognized favorably by the market (Liu et al., 2022).

Therefore, while voluntary water disclosure may initially convey negative implications due to disclosure costs and risk exposure, its strategic integration with carbon emission information represents an effective mechanism to enhance market trust and firm value. This underscores the importance for firms to align environmental disclosures to present a coherent and credible narrative of environmental accountability, which is increasingly valued in financial markets.

Table 4: Regression Results of the Second Hypothesis

Variables	Est.	t-value
Intercept	-12.015	-3.680***
Gas	-1.525	-3.810***
Water	-1.463	-4.330***
GW	1.188	2.090**
Size	0.466	4.140***
Lev	0.177	0.890
Loss	-0.601	-1.410
Roe	-3.455	-2.310**
Cfo	1.389	1.760*
Inv	7.715	6.290***
Da	3.325	3.360***
YrD	Included	
IndD	Included	
F-value	9.88***	
Adj-R^2	0.29	

1) ***, **, and * denote significance at the 1 %, 5 %, and 10 % level, respectively.
2) See equations (1) and (3) for variable definitions

5. Conclusion

This paper examines the moderating effect of voluntary disclosure of water resources on the relationship between changes in carbon emissions and firm value. After investigating Korean firms from 2017 to 2021, the analysis confirms that changes in carbon emissions exert a significant negative impact on firm value, which is interpreted as a signal of operational inefficiency and regulatory non-compliance to a carbon-constrained economy. At the same time, voluntary disclosure of carbon emissions moderates such a relationship, suggesting that transparent water reporting reframes investor perceptions, contextualizing carbon performance within a broader sustainability framework. From a signaling theory perspective, firms combining emissions trends with water transparency send credible signals of holistic environmental stewardship, offsetting concerns about carbon risks and reinforcing stakeholder trust.

This study contributes to existing literature. Using changes in carbon emissions is an advanced methodology for evaluating corporate adaptability. Also, the interaction effect highlights the need for integrated environmental reporting. Firms should pair carbon management with water transparency to signal comprehensive risk mitigation. Regulators should incentivize multi-dimensional disclosures, such as linking carbon and water metrics in sustainable frameworks, to enhance accountability and comparability.

This study focuses on South Korean firms within the context of Korea's national target to reduce greenhouse gas emissions by 37% from projected levels by 2030 (Climate Action Tracker). The proactive and responsive role of firms is critical to achieving this goal. Accordingly, policymakers should closely consider corporate perceptions and behaviors when designing effective climate policies to encourage active corporate engagement. While this research offers important insights into the relationship between carbon emissions, voluntary water disclosure, and firm value in Korea's specific institutional setting, caution is needed when generalizing these results to different countries or industries. Variations in regulatory frameworks, market conditions, and stakeholder expectations may produce different disclosure practices and valuation effects. Future studies in diverse institutional contexts will be essential to evaluate the broader applicability of these findings

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