

# Corporate Environmental Performance: A Multi-Dimensional Analysis of GHG, Energy, Water, and Waste Management in Taiwanese Industries

*Badingatus Solikhah*<sup>1\*</sup> and *Edi Sarwono*<sup>1</sup>

<sup>1</sup>Universitas Negeri Semarang, Semarang, Indonesia

**Abstract.** This study examines the environmental performance of Taiwanese listed companies using 18,054 firm-year observations from 2016–2023. This study uses five indicators to examine changes in corporate environmental behavior over time. These indicators include GHG emissions, energy management, water and wastewater practices, waste and hazardous materials, and a composite environmental score. This study uses descriptive statistics, annual trend analysis, and comparisons between high-carbon and low-carbon industries. The results are supported by visual tools such as radar charts to highlight differences across environmental dimensions. Environmental indicators are generally stable over time, with a temporary decline in 2022 that may reflect post-pandemic effects. Industry results reveal uneven performance, with resource-intensive sectors stronger in energy and water management, and service and technology sectors performing better in GHG-related disclosure. Overall, the findings suggest that environmental performance is shaped by both operational conditions and reporting capacity, offering useful insights for policymakers seeking to strengthen environmental management across sectors.

## 1 Introduction

Debates on corporate environmental responsibility have increased in recent years, particularly since climate risks and greenhouse gas (GHG) emissions continue to rise across industries [1]. The urgency of green economics is no longer just an idea. Global warming, the push for clean energy, and increasing public scrutiny are now driving companies to respond more seriously to environmental challenges. Academia also contends that environmental performance is more than a symbolic label because it is measurable, monitorable, and comparable across sectors when supported by credible disclosure frameworks [2,3].

In Taiwan, industrial activity plays an important role in driving economic growth. As industrial expansion raises environmental concerns, environmental disclosure has increasingly become a key mechanism for evaluating corporate responsibility and

---

\* Corresponding author: [badingatusbety@mail.unnes.ac.id](mailto:badingatusbety@mail.unnes.ac.id)

alignment with a low-carbon economy [4]. But, on the other hand, corporate responses to sustainability commitments are varied. Some companies have invested in energy efficiency and waste reduction systems, while others remain dependent on resource-intensive processes that produce high emissions. This condition motivates researchers to re-examine how environmental indicators work overtime. Studies highlight that disclosure transparency encourages firms to adopt cleaner practices and improve performance in a more consistent way [5,6]. However, many companies still find it difficult to balance environmental spending with their short-term financial goals, which leads to unequal progress in areas like water use, waste management, and GHG reduction. Evidence from other countries also points in the same direction, although with its own nuances. Environmental efforts to strengthen environmental disclosure, for example, show that greater transparency can help firms improve carbon efficiency and support the shift toward cleaner operations [2]. These increases tend to be more pronounced when regulatory enforcement is strong enough to influence managerial decisions [2,7]. Insights from Indonesia also help broaden the picture. Research on carbon emissions in Indonesia shows that factors such as industry type, governance strength, and legitimacy pressures influence how companies disclose and manage their carbon emissions [8,9].

Research on emission trading provides a similar lesson. Market-based policies often encourage companies to disclose more, innovate more, and gradually reduce emissions, although the speed across industries are different [7,10]. At the same time, studies in climate modelling highlight that combining renewable energy development with machine-learning-based forecasting could strengthen future reductions in GHG emissions [11]. So, the broader discussion is not only about reporting itself, but also about how reporting interacts with incentives, regulatory signals, and the industrial environment that shapes corporate behavior.

Taiwan presents an interesting context for this analysis. Since its major industrial clusters, namely electronics, petrochemicals, steel, and construction, have played a central role in national economic growth. But at the same time, these industries also contributed significantly to total emissions. In recent years, some firms have begun taking steps to lower their environmental footprint. One visible example is the increasing use of green building materials [4]. The pace and direction of these sustainability efforts, however, vary widely across companies. Some firms show progress in waste reduction and recycling, while others advance more quickly in energy efficiency or water conservation. Although aggregate “environmental scores” provide a general overview, they often fail to capture why certain sectors improve faster in specific areas. These variations highlight the need for a closer, more detailed analysis. Although Taiwan operates under a different institutional system, the main idea appears consistent: disclosure becomes meaningful only when it is linked with real behavioral improvements. An ESG score without tangible actions does not say much. Qian and Schaltegger (2017) [12] also remind us that firms disclose their sustainability practices for different reasons, sometimes to maintain legitimacy and sometimes because they genuinely improve their environmental practices, making it important to overview beyond the score itself.

The present study examines environmental performance in Taiwan using a multi-dimensional set of indicators, including GHG emissions, energy management, water and

wastewater management, waste and hazardous materials handling, as well as an overall environmental score. The analysis is based on 18,054 firm-year observations from 2016 to 2023. Employing an in-depth descriptive and visual approach, the study traces annual trends, compares industries with different levels of carbon intensity, and utilizes radar charts to illustrate how environmental improvements manifest across sectors. This approach enables a more nuanced understanding of environmental performance patterns that may not be fully captured by aggregate ESG or environmental scores.

Despite the growing body of research on environmental disclosure and carbon reporting, comprehensive cross-industry analyses of environmental performance within a single country over long periods remain limited. In Taiwan, studies integrating greenhouse gas (GHG) emissions, energy, water, and waste indicators are still scarce. Addressing this gap, this study maps environmental performance patterns across industries and carbon-intensity classifications using a large longitudinal dataset. Accordingly, this study seeks to answer three key research questions: (1) how environmental performance evolves over time, (2) how it differs across industries, and (3) whether high-carbon and low-carbon sectors exhibit systematic differences across specific environmental dimensions.

This study contributes to the literature on corporate environmental responsibility by providing a comprehensive overview of environmental performance across industries. The findings indicate that different environmental dimensions evolve at different rates, suggesting that improvement in one area does not necessarily correspond with progress in others. These results highlight the limitations of relying solely on single scores to capture corporate environmental performance. From a practical perspective, the findings provide insights for managers and policymakers in identifying environmental areas that require greater attention and more targeted sustainability strategies.

In addition, this study makes three specific contributions. First, it employs a multi-dimensional framework that integrates five environmental indicators: GHG emissions, energy management, water and wastewater management, waste and hazardous materials management, and an overall environmental score. This framework enables a more comprehensive assessment compared with studies that focus only on carbon disclosure. Second, the study draws on a large longitudinal dataset of 18,054 firm-year observations from 2016 to 2023, allowing the examination of changes in environmental performance over time, including the post-pandemic period. Third, by comparing high-carbon and low-carbon industries across multiple environmental indicators, the study provides a more differentiated understanding of sectoral patterns in corporate environmental performance and governance priorities.

## **2 Material and methods**

This study uses environmental performance data from the Taiwan Economic Journal (TEJ) covering listed firms from 2016 to 2023. After removing incomplete entries, the panel data includes 18,054 observations, which is sufficient for a descriptive exploration of environmental patterns. Five indicators are analyzed because they represent the core dimensions of environmental behaviour commonly used in ESG evaluations: (1) GHG Emissions Score, which reflects reporting and mitigation efforts related to greenhouse

gases; (2) Energy Management Score, capturing policies and practices that aim to improve energy efficiency; (3) Water and Wastewater Management Score, indicating how firms monitor and reduce water-related impacts; (4) Waste and Hazardous Materials Management Score, which relates to waste handling and pollution prevention; and finally (5) the composite Environment Score, summarizing overall performance across the environmental dimension. All indicator values range from 0 to 100, allowing direct comparison across firms, years, and sectors without additional rescaling.

The selection of these five indicators is grounded in widely recognized GRI-based environmental reporting dimensions, which categorize environmental performance into emissions, energy, water, waste, and overall environmental management practices. By adopting these dimensions simultaneously, the study ensures coverage of both impact-related indicators (e.g., GHG emissions) and resource-efficiency indicators (e.g., energy and water management), thereby providing a balanced representation of corporate environmental behavior.

The first analysis is descriptive statistics. We compute summary statistics for each indicator to give a general overview of the environmental performance of Taiwanese listed firms. Then we continue to examine differences across industrial structures, and firms are grouped into two carbon-intensity categories, namely high-carbon and low-carbon categories. The high-carbon group includes cement, iron and steel, glass and ceramic, paper pulp, plastics, rubber, shipping, and the chemical industry, sectors commonly recognized as carbon-intensive because they rely on combustion-based processes and generate substantial direct emissions [6,7,10]. The remaining sectors, for example, electronics, tourism, trade, finance, construction, food processing, electric appliances, automotive, textiles, machinery, and others, are treated as low-carbon industries, as their emissions mostly stem from electricity use and building operations rather than high-temperature production. This two-level classification aligns with prior studies that distinguish between carbon-intensive and non-carbon-intensive sectors, while still allowing meaningful comparison of environmental performance across different industrial structures.

This study is designed as a structured descriptive and comparative analysis. The objective is to map environmental performance patterns across industries and over time using a multi-dimensional framework. The present study focuses on providing a comprehensive empirical baseline that can support subsequent causal analyses.

### **3 Results and discussion**

Before examining the numerical patterns, it is helpful to note how the environmental indicators in this dataset are defined. TEJ evaluates each dimension using a 0–100 scale, where higher scores reflect better environmental practices or disclosure. The GHG Emissions Score captures how companies monitor, report, and manage their greenhouse gas output. Energy Management Score reflects efforts to improve energy efficiency and reduce energy consumption. The Water and Wastewater Management Score assess how firms handle water use and wastewater discharge, while the Waste and Hazardous Materials Management Score focuses on solid waste, hazardous substances, and pollution prevention. The composite Environment Score summarizes the overall performance

across the environmental dimension. Disclosure-related items are aligned with GRI standards, although TEJ only began converting disclosure lists into environmental scores starting in 2020, making some indicators more complete in later years.

### 3.1 Statistic descriptive

**Table 1** summarizes the basic distribution of the four environmental sub-indicators and the composite Environment Score. Among the four sub-indicators, the GHG Emissions Score shows the largest variation, with a standard deviation above 25. This signals substantial differences in carbon-related performance, which is not surprising given how diverse industrial processes are. The Energy Management Score varies less, perhaps because energy-saving programs tend to be more standardized across sectors. Meanwhile, the Environment Score (Composite) has the smallest deviation, which makes sense: combining multiple dimensions generally produces a more stable distribution. These descriptive results offer a basic sense of the landscape before we move into comparisons between high-carbon and low-carbon industries in the next subsection.

**Table 1.** Descriptive statistics for environmental indicators and composite score

Indicators	Mean	Min	Max	Std. Dev
GHG Emissions Score	50.084	0.06	99.94	25.156
Energy Management Score	50.098	0.16	99.94	17.032
Water & Wastewater Management Score	50.063	0.06	99.94	23.781
Waste & Hazardous Materials Management Score	50.024	0.06	99.94	23.108
Environment Score (Composite)	53.097	23.32	90.96	11.036

### 3.2 Industry level comparison

As shown in **Table 2**, the environmental performance of each industry forms a rather uneven landscape, with some sectors demonstrating consistently stronger disclosure and management practices than others. Paper pulp, glass & ceramic, plastics, and rubber record some of the highest averages in energy and water-related indicators, an outcome that reflects years of operational efficiency improvements in industries that rely heavily on heat, fuel, and raw materials. On the opposite side, cement and tourism show weaker patterns across several indicators, suggesting slower adoption of environmental management systems or more fragmented disclosure practices. These contrasts appear repeatedly across the sub-indicators, creating a picture where performance is shaped not only by operational characteristics but also by how actively each sector engages with environmental reporting requirements.

Other sectors show a more balanced profile. Finance, food processing, and electric appliances achieve some of the highest composite environment scores in **Table 2**, driven partly by more mature governance structures and relatively straightforward reporting processes. Electronics and trade also appear relatively steady, neither leading nor lagging, which hints at consistent, but not necessarily aggressive, environmental practices across multiple dimensions. Automotive, machinery, and several mid-range manufacturing industries sit in the middle of the distribution, with no extreme highs or lows. Taken

together, these patterns illustrate that sectors differ not just in environmental impact but also in how they prioritize, manage, and report the various components of environmental performance.

**Table 2.** Average environmental performance scores by industry

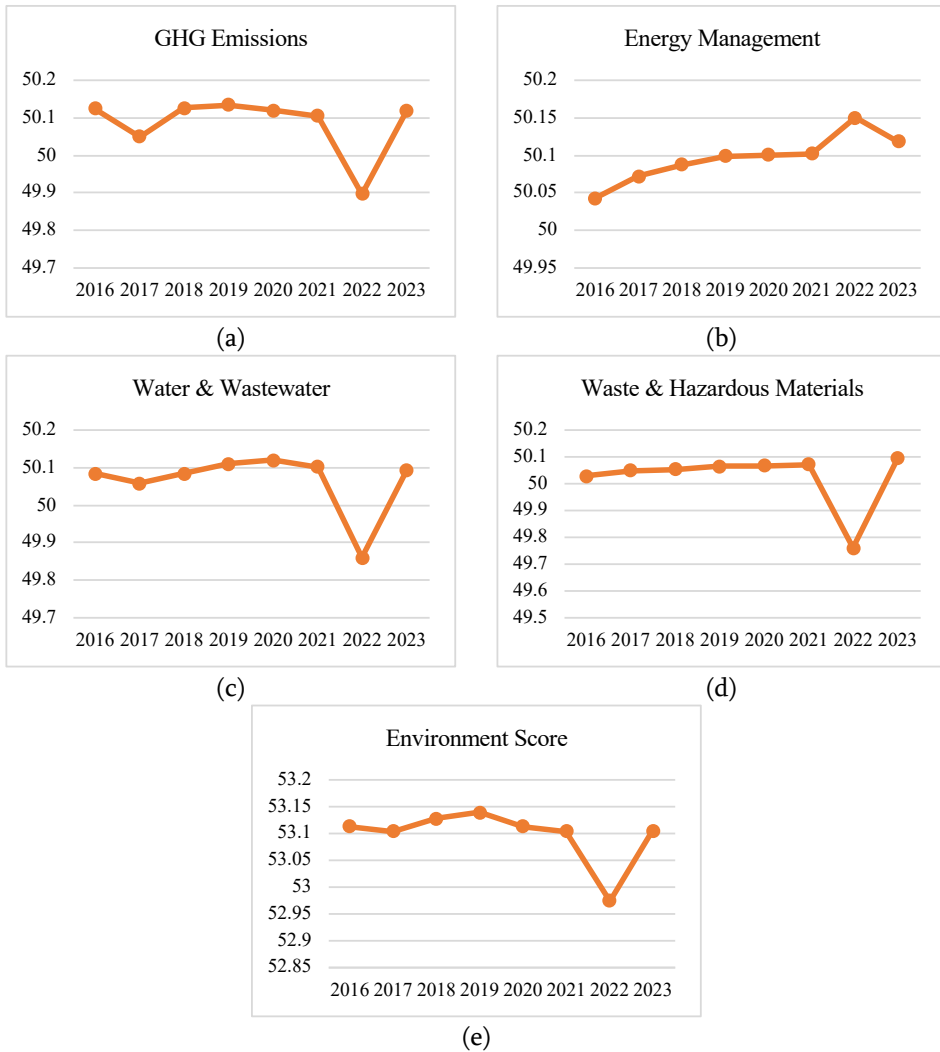
Industry	GHG	Energy	Water	Waste	Env Score
Tourism	50.253	49.524	48.537	49.215	49.9
Shipping	46.424	55.514	51.871	50.412	50.076
Trade	50.731	50.458	49.176	50.257	51.997
Others	48.45	49.29	48.296	48.648	52.222
Motor Machinery	50.005	47.803	47.295	48.33	52.36
Iron and Steel	50.097	46.676	46.119	47.682	52.592
Automotive	53.438	46.478	47.241	48.306	53.026
Construction	51.783	48.729	48.213	49.726	53.026
Electronics	51.108	49.454	49.017	49.533	53.164
Electric Appliance	52.508	47.705	47.664	48.408	54.087
Cement	40.574	65.402	56.13	55.516	54.349
Chemical Industry	50.294	50.03	47.905	48.841	54.434
Textile and Fiber	50.064	49.883	50.093	50.296	54.561
Plastics	41.507	62.104	57.183	53.594	55.004
Finance	53.559	54.519	53.402	53.101	55.797
Food	50.632	53.874	51.621	51.676	55.911
Paper Pulp	35.331	74.029	66.281	58.648	56.003
Rubber	44.07	64.008	58.382	54.308	56.566
Glass & Ceramic	45.908	64.244	59.216	55.261	58.125

### 3.3 Comparison between high- and low-carbon industries

The comparison in **Table 3** shows a pattern that is not entirely intuitive at first glance. Low-carbon industries record slightly higher averages for the GHG Emissions Score, which reflects stronger reporting and monitoring practices rather than higher levels of actual emissions. These sectors, mostly service-oriented or technology-based, tend to have simpler operational structures and more established ESG disclosure routines, making it easier for them to document GHG-related activities. High-carbon sectors, meanwhile, score lower on this dimension, a result that is likely shaped by the complexity of measuring direct emissions within energy-intensive production processes.

**Table 3.** Comparison Between High- and Low-Carbon Industries

Indicators	High-carbon industries	Low-carbon industries
GHG Emissions	48.21	50.558
Energy Management	52.266	49.549
Water & Wastewater	50.901	49.852
Waste & Hazardous Materials	49.88	50.06
Environment Score	53.424	53.015



**Fig. 1.** Trends in environmental performance indicators (2016–2023)

The opposite occurs for the Energy Management and Water & Wastewater indicators, where high-carbon industries show marginally stronger performance. Many firms in cement, steel, paper, plastics, and related sectors have long adopted efficiency programs simply because energy and water are major cost components in their operations. The averages in **Table 3** suggest that these efforts translate into moderately higher scores for these two indicators. Differences in the Waste & Hazardous Materials dimension are minimal, and the composite Environment Score ends up almost the same for both categories. All these points to a simple but important observation: environmental performance varies by dimension, and each group of industries seems to prioritize the area's most closely linked to their operational pressures and reporting capacity. **Fig 1** illustrates that the pattern observed over the eight years (2016-2023) is generally stable in terms of environmental performance indicators.

Indicators from 2016 to 2023 show stability, despite slight fluctuations, demonstrating consistent environmental management practices. Meanwhile, the decline in all dimensions in 2022 is a post-COVID-19 impact, as companies continue to adapt to operational disruptions and supply chain issues. Furthermore, delays in environmental monitoring and disclosure also contributed to the year. Therefore, these conditions may have temporarily weakened environmental performance and reporting intensity. Meanwhile, in 2023, indicators returned to normal and approached pre-2022 levels, suggesting that the decline was temporary, post-COVID-19, rather than structural. Overall, this trend demonstrates that the environmental management system is generally resilient but remains vulnerable to short-term external shocks or influences.

### **3.4 Discussion**

The stability across environmental scores, along with moderate sectoral differences found in this study, aligns with previous research suggesting that companies often engage in environmental disclosure as a structured, routine activity rather than as an evolving performance tool. Research on carbon reporting suggests that changes in disclosure behavior tend to occur slowly, unless companies face strong regulatory or market pressure [5,12]. The consistent mid-range scores across the four sub-indicators in our data support the perspective that many companies appear to meet baseline environmental management expectations, but few show substantial improvement year-over-year. The decline across all indicators in 2022 is also consistent with other research on external disruptions. Corporate responsiveness to climate and environmental issues can decline when companies prioritize operational stability, as widely documented during and immediately after the COVID-19 pandemic [6]. The rapid recovery in 2023 suggests that the decline likely reflected a slowdown in reporting or a reallocation of resources rather than a long-term shift in environmental commitments.

These patterns can be further interpreted through legitimacy and stakeholder perspectives. Firms operate within institutional environments in which environmental disclosure serves not only as a managerial tool but also as a mechanism to maintain social legitimacy. In carbon-intensive sectors, stronger public scrutiny and regulatory oversight may encourage firms to invest in efficiency-related dimensions, particularly energy and water management, which are closely tied to production costs and operational risk. On the other hand, industries with less direct environmental impact, such as finance, electronics, and commerce, may focus on the quality of disclosure and on governance alignment to meet investor expectations and reputational standards. This interpretation is consistent with legitimacy theory, which suggests that firms strategically adjust environmental practices and reporting behavior in response to societal and stakeholder pressures.

The differences between companies also align with prior literature showing that environmental performance is shaped by organizational context as much as physical emissions levels, with high-impact sectors often investing heavily in operational efficiency, particularly in areas like energy and water use, because these resources are directly linked to production costs. This pattern is consistent with evidence from carbon-intensive industries in China [2,7]. Meanwhile, sectors with a smaller operational

footprint, such as finance, electronics, or commerce, generally achieved higher scores on disclosure, reflecting stronger governance structures and smoother integration of reporting standards, in line with research by Liu et al. (2023) [10] linking carbon disclosure to organizational performance. Overall, these results highlight a common theme across much of the sustainability literature: companies are improving and disclosing unevenly across environmental dimensions, and their progress depends not only on environmental impacts but also on institutional expectations, reporting frameworks, and strategic priorities of their respective industries.

The sectoral differences identified in this study also align with broader international evidence. Research in China and other developing countries shows similar trends: industries that produce a lot of carbon focus on becoming more efficient due to regulations and costs, while service industries are better at sharing information because they have stronger management systems. These cross-country similarities indicate that national regulation, industrial composition, and institutional governance mechanisms shape environmental performance. The Taiwanese case, therefore, contributes to comparative sustainability discussions by illustrating how environmental dimensions evolve unevenly across sectors under varying operational and institutional conditions

From a strategic perspective, the findings imply that environmental performance should not be interpreted as a single aggregated outcome. Improvements in one dimension, such as energy efficiency, do not automatically translate into broader environmental progress. Corporate sustainability strategies require a more balanced and integrated methodology that concurrently addresses various environmental dimensions. From a regulatory perspective, the evidence suggests that environmental rules might work better if they focus on specific industries rather than rely solely on overall environmental scores. Different regulatory tools that account for the unique features of each industry might be more effective at promoting overall environmental progress than focusing solely on partial compliance.

Despite its broader scope, this study relies on GRI-based environmental scores as a proxy for environmental performance. These scores primarily reflect disclosure practices, management systems, and policy implementation, rather than direct physical measurements of emissions or environmental impacts. As a result, higher scores do not necessarily indicate lower absolute emissions but may instead reflect stronger environmental management and reporting practices. This limitation should therefore be considered when interpreting the findings, particularly when comparing industries with different operational characteristics.

## **4 Conclusion**

This study presents information on the environmental performance of Taiwan's industries over an eight-year period, from 2016 to 2023. The pattern is quite consistent, although there are differences between sectors, and there are small, gradual improvements from year to year. The post-COVID-19 pandemic in 2022 resulted in a small, temporary decline. It is also possible that operational and reporting disruptions are still facing many companies, but not a structural decline. A cross-industry comparison reveals higher scores in sectors focused on disclosure related to greenhouse gas (GHG)

emissions indicators, while progress is more evident in areas directly related to efficiency, particularly in resource-intensive industries such as energy and water management. Overall, the findings of this study demonstrate that environmental performance is shaped by a combination of operational realities and institutional expectations, which points to the need for policies that encourage not only disclosure but also continuous performance improvement across all dimensions.

From a practical perspective, the findings suggest that improving environmental performance requires not only disclosure practices but also consistent operational efforts across multiple environmental dimensions. For policymakers, this highlights the importance of regulatory frameworks that encourage both transparency and continuous environmental improvements across industries. For managers, the results indicate the need to integrate environmental management more systematically into operational decision-making rather than focusing primarily on reporting compliance. Future research may further examine the drivers behind these patterns and explore how governance mechanisms and policy interventions can better support tangible environmental improvements.

## References

1. Solikhah, B.; Wahyudin, A.; Subowo Carbon Emissions of Manufacturing Companies in Indonesia Stock Exchange: A Sustainable Business Perspective. *J. Phys. Conf. Ser.* **2020**, *1567*, 42086, doi:10.1088/1742-6596/1567/4/042086.
2. Lan, J.; Wang, P. An Efficiency Perspective on Low Carbon Pilot City Policy and Carbon Emission Performance of Listed Enterprises: Quasi-Experimental Evidence from China. *Energy Econ.* **2025**, *145*, 108454, doi:10.1016/j.eneco.2025.108454.
3. Sharaf-Addin, H.H. Towards Net-Zero Carbon Emissions: A Systematic Review of Carbon Sustainability Reporting Based on GHG Protocol Framework. *Environ. Sustain. Indic.* **2024**, *24*, 100516, doi:10.1016/j.indic.2024.100516.
4. Tsai, W.-T.; Tsai, C.-H. Interactive Analysis of Green Building Materials Promotion with Relevance to Energy Consumption and Greenhouse Gas Emissions from Taiwan's Building Sector. *Energy Build.* **2022**, *261*, 111959, doi:10.1016/j.enbuild.2022.111959.
5. Frankovic, I.; Kolb, B. The Role of Emission Disclosure for the Low-Carbon Transition. *Eur. Econ. Rev.* **2024**, *167*, 104792, doi:10.1016/j.euroecorev.2024.104792.
6. Wang, Z.; Fu, H.; Ren, X.; Gozgor, G. Exploring the Carbon Emission Reduction Effects of Corporate Climate Risk Disclosure: Empirical Evidence Based on Chinese A-Share Listed Enterprises. *Int. Rev. Financ. Anal.* **2024**, *92*, 103072, doi:10.1016/j.irfa.2024.103072.
7. Li, D.; Zhang, Z.; Gao, X. The Impact of Carbon Emission Trading System on the Implied Cost of Equity Capital. *Int. Rev. Econ. Financ.* **2025**, *101*, 104157, doi:10.1016/j.iref.2025.104157.
8. Solikhah, B.; Wahyuningrum, I.F.S.; Yulianto, A.; Sarwono, E.; Widiatami, A.K. Carbon Emission Report: A Review Based on Environmental Performance, Company Age and Corporate Governance. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *623*, 12042, doi:10.1088/1755-1315/623/1/012042.
9. Solikhah, B.; Yulianto, A.; Suryarini, T. Legitimacy Theory Perspective on the Quality of Carbon Emission Disclosure: Case Study on Manufacturing Companies in Indonesia

- Stock Exchange. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *448*, 12063, doi:10.1088/1755-1315/448/1/012063.
10. Liu, Y.S.; Zhou, X.; Yang, J.H.; Hoepner, A.G.F.; Kakabadse, N. Carbon Emissions, Carbon Disclosure and Organizational Performance. *Int. Rev. Financ. Anal.* **2023**, *90*, 102846, doi:10.1016/j.irfa.2023.102846.
  11. Darwish, H.; AlHmoud, I.W.; Turlapaty, A.C.; Gokaraju, B. Predicting the Future Climate: Integrating Renewable Energy and Machine Learning to Address Temperature and GHG Emissions. *Energy Reports* **2025**, *14*, 2399–2419, doi:10.1016/j.egy.2025.09.004.
  12. Qian, W.; Schaltegger, S. Revisiting Carbon Disclosure and Performance: Legitimacy and Management Views. *Br. Account. Rev.* **2017**, *49*, 365–379, doi:10.1016/j.bar.2017.05.005.