IPRPD
International Journal of Business & Management Studies
ISSN 2694-1430 (Print), 2694-1449 (Online)
Volume 06; Issue no 01: January, 2025
DOI: 10.56734/ijbms.v6n1a10

EXPLORING THE FINANCIAL IMPACT OF ENVIRONMENTAL SUSTAINABILITY: A STUDY OF TAIWAN'S SEMICONDUCTOR SECTOR

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Abstract

In the era of global low-carbon transformation, corporate management of carbon emissions, environmental performance disclosures, and water resource utilization have become critical focal points for capital markets. This study investigates the relationship between the stock returns of Taiwanese semiconductor companies and variables such as total carbon emissions, TESG scores, corporate water consumption, and corporate social responsibility (CSR) during 2016–2022. Specifically, the study evaluates the influence of these factors in the context of international sustainability trends and Taiwan's mandatory carbon inventory policies. The findings reveal significant negative effects of total carbon emissions and corporate water consumption on stock returns, whereas TESG scores exhibit a positive correlation with stock returns. By integrating these elements, the study provides a comprehensive understanding of how environmental sustainability influences financial performance within the semiconductor sector. These insights underscore the importance of corporate environmental efforts in enhancing both sustainability and competitiveness.

Keywords

Stock Returns, Carbon Emissions, ESG Scores

1. Introduction

The 2015 United Nations Climate Change Conference led to the adoption of the Paris Agreement, requiring all parties to submit carbon emission data, devise reduction plans, and conduct carbon inventories every five years. Under this international trend, the Taiwanese government announced mandatory carbon inventory reporting in 2016 for major carbon emitters. Companies emitting more than 25,000 metric tons of carbon dioxide equivalent (CO_2e) annually were required to complete and register their greenhouse gas emissions by the end of August each year for the previous year. By 2022, the Greenhouse Gas Reduction and Management Act was updated to include both direct and indirect carbon emissions in calculations. These measures significantly strengthened corporate environmental disclosures, highlighting their importance and necessity.

According to the World Economic Forum's Global Risks Report 2023 (GSR2023), the failure of climate mitigation actions is projected to be the greatest global risk over the next decade. This indicates that while global attention to environmental issues is increasing, corporate environmental disclosures still have room for improvement. Sustainability reports should be more comprehensive to reflect companies' environmental efforts and achievements. Companies should regularly disclose environmental impact data, establish and maintain environmental management systems, set clear emission reduction targets, publish sustainability reports, and effectively manage environmental risks within their supply chains. By doing so, companies can not only comply with environmental regulations but also enhance their social image and competitiveness, achieving long-term sustainability goals. Efforts in environmental disclosure positively affect corporate sustainability and competitiveness while contributing to environmental conservation.

This study aims to explore the relationship between stock returns and variables such as total carbon emissions, TESG scores, total corporate water consumption, and CSR in Taiwanese semiconductor companies from 2016 to 2022, against the backdrop of international sustainability trends and Taiwan's mandatory carbon inventory policies.

First, the study analyzes the relationship between total carbon emissions, TESG scores, and stock returns in semiconductor companies. With increasingly stringent global carbon emission requirements, total carbon emissions

have become a critical metric for evaluating environmental performance and market reputation. Bolton and Kacperczyk (2021) found that carbon emissions significantly impact stock returns, while Aswani et al. (2023) suggested that stock returns are related to total carbon emissions. Moreover, the environmental dimension of ESG scores has a positive relationship with stock returns. Liao Jia-Man (2022) also reported that the environmental dimension of ESG scores positively affects stock returns. This study integrates these findings to examine whether total carbon emissions and TESG scores influence corporate stock returns.

Second, the study focuses on the relationship between total corporate water consumption and stock returns. As the semiconductor industry is water-intensive, water resource management efficiency directly affects operational costs and environmental reputation. Therefore, this study incorporates total water consumption as a variable to analyze its impact on stock returns.

Additionally, this study considers environmental disclosure as part of corporate social responsibility (CSR). As societal expectations for CSR increase, corporate performance in areas such as environmental protection has become a key factor influencing market value. The research investigates the relationship between CSR investments and stock returns in semiconductor companies, analyzing whether strong CSR strategies enhance market trust and investment attractiveness.To achieve these objectives, the study employs regression models to examine the effects of total carbon emissions, TESG scores, total corporate water consumption, and CSR scores on stock returns..

2. Literature review

This chapter reviews relevant literature, focusing on the impacts of total carbon emissions, TESG scores, and total corporate water consumption on stock returns, as well as the relationships between research variables and stock performance.

a. Total Carbon Emissions and Stock Return

Total carbon emissions refer to the quantity of greenhouse gases, including carbon dioxide, released into the atmosphere by a specific entity over a specific period. With the growing impact of global climate change, promoting green finance and achieving a zero-carbon economy have become recent governmental objectives. As a key representative of high-tech industries, Taiwan's semiconductor sector is characterized by manufacturing processes that may involve significant carbon emissions. In recent years, Taiwan's emphasis on carbon reduction has intensified, with the government actively promoting sustainable development, reducing carbon footprints, and implementing corresponding carbon reduction policies. This study explores the relationship between total carbon emissions and the stock returns of semiconductor companies. Research by Bolton and Kacperczyk (2021a, 2021b, 2022) suggests that total carbon emissions have a significant positive impact on stock returns.

b. TESG Scores and Stock Returns

The Taiwan Economic Journal (TEJ) has developed the TESG Sustainability Index to evaluate ESG trends, covering three core areas: Environment (E), Social (S), and Governance (G). These metrics provide standards for assessing corporate or portfolio performance in these domains. In today's financial markets, investors increasingly focus on how ESG factors influence stock performance. The TESG Index emphasizes Taiwan's pursuit of corporate sustainability. Shanaev and Ghimire (2022) observed that a decline in ESG ratings could significantly suppress stock prices.

c. Total Corporate Water Consumption and Stock Returns

Recent years have seen heightened attention from businesses and investors to environmental sustainability. Total corporate water consumption falls under the environmental dimension of sustainability and is considered a benchmark for assessing corporate commitment to environmental issues. Rudebusch (2021) demonstrated that climate change factors could lead to financial losses, reducing stock prices. Semiconductor manufacturing requires substantial water resources for cooling equipment and ensuring that chips remain free from dust and impurities. Consequently, the semiconductor industry's high demand for water resources and the management of recycled and reclaimed water have become critical topics. Research by Valentin Jouvenot (2022) indicated that effective water management enhances stock performance. Similarly, Qin Ruiqi (2023) found that greater attention to water usage correlates with higher stock returns. Based on these findings, this study includes total corporate water consumption as a variable to evaluate its relationship with stock returns.

d. Control Variables and Stock Returns

As a capital-intensive industry, Taiwan's semiconductor sector typically requires significant initial investments to maintain competitiveness. Jiang, John, and Larsen (2021) found a negative relationship between R&D intensity and stock returns. Substantial R&D expenditures on new technologies, processes, and products often lead to higher debt ratios, which reflect a company's financial leverage and debt repayment capacity. Dedek Sriulina Sihombing and Galumbang Hutagalung (2022) demonstrated through F-tests that debt ratios significantly influence stock returns. Additionally, as a highly technology-intensive sector operating in a rapidly evolving environment, semiconductor

industry revenue and earnings per share (EPS) tend to grow quickly. Amyulianthy and Ritonga (2016) showed that EPS significantly positively impacts stock returns. Therefore, this study incorporates market value, R&D expenditures, debt ratios, EPS, revenue growth rates, return on assets (ROA), and return on equity (ROE) as control variables, referencing the literature discussed above.

3. Research Design

a. Data and sample selection

The data for this study were obtained from the Taiwan Economic Journal (TEJ) database. Since the data for 2023 are incomplete, the study period spans from 2016 to 2022. The sample comprises publicly listed semiconductor companies in Taiwan with records available for total carbon emissions, TESG scores, total corporate water consumption, and CSR scores. Observations with incomplete data were excluded, resulting in a final sample of 203 listed companies.

The data on total carbon emissions utilized the most recently disclosed figures for the given year (or the first disclosure if recent data were unavailable). If carbon inventory disclosures were segmented, the study aggregated the disclosed data across all inventory scopes. TESG scores were derived from the TESG Sustainability Index. Total corporate water consumption included recycled water. CSR scores were based on whether the company prepared sustainability reports and whether those reports were verified by third parties. Any missing data were excluded from the analysis.

1.1. Methodology

This study employs the Ordinary Least Squares (OLS) regression model to examine the impact of environmental sustainability on Taiwan's semiconductor industry. Based on this approach, the following three regression models are established. Model 1 is as follows:

$$RET_{i,t} = \beta_0 + \beta_1 CO2_{i,t} + \beta_2 TESG_{i,t} + \beta_3 CSR_{i,t} + \beta_4 \log(MV_{i,t}) + \beta_5 \log(R\&D_{i,t}) + \beta_6 DR_{i,t} + \beta_7 EPS_{i,t} + \beta_8 YoY_{i,t} + \beta_9 ROA_{i,t} + \beta_{10} ROE_{i,t} + \epsilon_t$$

Research Model 1 explores the impact of total carbon emissions, TESG scores, and CSR scores on stock returns.In this model, RETi,t represents the stock return of company i in period t; CO2 i,t denotes the total carbon emissions of company i in period t; TESG i,t is the TESG score of company i in period t; CSR i,t indicates the CSR score of company i in period t; MV i,t is the market value of company i in period t; log(R&Di,t) represents the R&D expenditure of company i in period t; DR i,t refers to the debt ratio of company i in period t; EPS i,t denotes the earnings per share of company i in period t; YoY i,t is the year-on-year revenue growth rate of company i in period t; ROA i,t represents the return on assets of company i in period t; and ROE i,t indicates the return on equity of company i in period t.

Model 2 is as follows:

$$RET_{i,t} = \beta_0 + \beta_1 TWC_{i,t} + \beta_2 WI_{i,t} + \beta_3 (TWC_{i,t} \times WI_{i,t}) + \beta_4 CSR_{i,t} + \beta_5 \log(MV_{i,t}) + \beta_6 \log(R\&D_{i,t}) + \beta_7 DR_{i,t} + \beta_8 EPS_{i,t} + \beta_9 YoY_{i,t} + \beta_{10} ROA_{i,t} + \beta_{11} ROE_{i,t} + \epsilon_t$$

Research Model 2 examines the impact of corporate water usage and CSR scores on stock returns. In this model, TWC i,t represents the total water consumption of company i in period t.Water intensity WI i,t is included as an independent variable. WI i,t is calculated as the total water consumption divided by the company's total revenue in period t. Additionally, using the regression model technique, this study introduces an interaction term between total water consumption and water intensity. It is hypothesized that this interaction term enhances the moderating effect on stock returns and improves the explanatory power of the model.

Model 3 is as follows:

$$RET_{i,t} = \beta_0 + \beta_1 CO2 + \beta_2 TESG_{i,t} + \beta_3 ES_{i,t} + \beta_4 TWC_{i,t} + \beta_5 CSR_{i,t} + \beta_6 \log(MV_{i,t}) + \beta_7 \log(R\&D_{i,t}) + \beta_8 DR_{i,t} + \beta_9 EPS_{i,t} + \beta_{10} YoY_{i,t} + \beta_{11} ROA_{i,t} + \beta_{12} ROE_{i,t} + \epsilon_t$$

This study builds upon the previously mentioned models to establish Model 3, which further explores the environmental dimension by incorporating an environmental score as a new variable. This model considers corporate carbon emissions, total water consumption, and external evaluations to examine the impact of environmental sustainability on stock returns, providing a more comprehensive explanation of a company's sustainability performance. In this model, ES i,t represents the environmental score of company i in period t, derived from the environmental dimension of the TESG Sustainability Index in the Taiwan Economic Journal.

4. Empirical results and analysis

This study utilizes the regression results from Models 1, 2, and 3 to examine the relationship between environmental sustainability and stock returns.

The results of Model 1 indicate that total carbon emissions and TESG scores significantly impact a company's stock returns. Companies with lower carbon emissions and higher TESG scores tend to achieve higher stock returns, with these relationships being highly significant. Firms demonstrating low carbon emissions and high TESG scores are likely committed to environmental sustainability, which may open up additional investment opportunities and lead to greater stock returns.

At a 1% significance level, a 1% decrease in CSR scores is associated with a 0.174% increase in stock returns. This suggests that companies may allocate significant resources to CSR activities, which could otherwise be directed toward higher-return investments. When firms reduce CSR expenditures, they may reallocate these funds to projects that directly enhance profitability, thereby improving short-term stock returns.

Although companies with high CSR scores may experience reduced stock returns in the short term due to higher costs, research by Emirhan Ilhan et al. (2023) highlights that climate risk management, as part of CSR, has a significant impact on stock prices. Long-term investors tend to favor firms that prioritize climate risk management, enabling these companies to better withstand market volatility and uncertainties, ultimately achieving superior stock returns over the long term.

Thus, this study hypothesizes that over an extended time frame, CSR scores and stock returns may exhibit a significant positive relationship.

Dependent variable: RET	Coefficient	P-value
CO_2	-0.025	0.459
TESG	0.015	0.723
CSR	-0.174	$<0.001^{***}$
LOG(MV)	0.357	$<0.001^{***}$
LOG(R&D)	-0.155	0.008^{**}
DR	0.026	0.518
EPS	-0.189	$<0.001^{***}$
YoY	0.465	$<0.001^{***}$
ROA	0.017	0.906
ROE	0.015	0.712
R^2	0.31	$<0.001^{***}$

TABLE I: Regression Results Analysis of Model 1

The results of Model 2 reveal that total corporate water consumption significantly affects a company's stock returns. Companies with lower total water consumption and higher water intensity achieve relatively higher stock returns, with this relationship being highly significant. At a 1% significance level, a 1% reduction in total water consumption increases stock returns by 6.077%, indicating that effective water management can substantially enhance stock performance.

Additionally, the regression results from Model 2 show that the interaction term between total water consumption and water intensity has a p-value of less than 0.001, demonstrating high significance. This finding suggests that the inclusion of the interaction term provides a moderating effect, strengthening the negative impact of total water consumption on stock returns. The higher the water intensity, the more significantly reductions in total water consumption improve stock returns.

Dependent variable: RET	Coefficient	P-value
TWC	-6.077	$<0.001^{***}$
WI	3.155	$<0.001^{***}$
TWCxWI	2.141	$<0.001^{***}$
CSR	-1.151	$<0.001^{***}$
LOG(MV)	2.901	$<0.001^{***}$
LOG(R&D)	-0.404	$<0.001^{***}$
DR	0.303	$<0.001^{***}$
EPS	-0.794	$<0.001^{***}$
YoY	0.215	$<0.001^{***}$
ROA	-0.418	$<0.001^{***}$
ROE	-0.057	0.345^{*}
R^2	-6.077	$<0.001^{***}$

TABLE II: Regression Results Analysis of Model 2

Lastly, the results of Model 3 confirm that environmental sustainability factors significantly influence stock returns. Companies with higher carbon emissions, higher TESG scores, or lower total water consumption exhibit relatively higher stock returns. This indicates that investors are increasingly valuing corporate performance in environmental sustainability. Environmental indicators such as carbon emissions, TESG scores, and water usage are considered critical metrics for assessing a company's sustainability. Investors may perceive these factors as not only providing insights into the company's long-term stability and growth potential but also influencing its financial performance and risk management, thereby driving stock returns.

Dependent variable: RET	Coefficient	P-value
CO_2	1.86	$<0.001^{***}$
TESG	0.414	$<0.001^{***}$
ES	-0.288	$<0.001^{***}$
TWC	-2.5	$<0.001^{***}$
CSR	-0.849	$<0.001^{***}$
LOG(MV)	2.322	$<0.001^{***}$
LOG(R&D)	-0.441	$<0.001^{***}$
DR	0.096	$<0.001^{***}$
EPS	-0.548	0.004^{**}
YoY	0.114	$<0.001^{***}$
ROA	-0.156	$<0.001^{***}$
ROE	-0.049	0.031^{**}
R^2	0.486	0.447

TABLE III: Regression Results Analysis of Model 3

5. Conclusion and policy implications

This study uses total carbon emissions, TESG scores, CSR scores, and total corporate water consumption as indicators of environmental sustainability to examine their impact on stock returns. The findings reveal that these factors significantly affect stock returns.

Regarding water resources, the study confirms that lower total water consumption is associated with higher stock returns. The semiconductor manufacturing industry, being water-intensive, places a premium on water efficiency and resource management, which are critical to operational costs and environmental impact. Lower water usage is typically linked to efficient production and operations, enabling companies to control costs in other areas. Moreover, resource-efficient companies often maintain a competitive advantage, enhancing investor confidence in their future profitability and, consequently, boosting stock returns. By reducing total water consumption, firms not only lower production costs but also establish a strong image of environmental responsibility and sustainable development.

TESG scores, as a comprehensive environmental evaluation tool, also show a positive relationship with stock returns. It is suggested that international sustainability trends have influenced investors to increasingly value corporate carbon emission management and environmental disclosures. Companies with higher TESG scores typically demonstrate better resource utilization and environmental protection practices, which drive up stock returns.

For carbon emissions, the results indicate a highly significant positive relationship between total carbon emissions and stock returns. This finding may be attributed to the nature of semiconductor wafer manufacturing processes, which are inherently carbon-intensive. The technological maturity of Taiwan's semiconductor industry enables it to secure orders from across the globe, thereby increasing stock returns. Additionally, as international attention on carbon management grows, total carbon emissions have become a crucial metric for investors evaluating corporate environmental performance and growth potential. Companies with robust carbon management capabilities and proactive disclosure of emission data are likely to gain higher valuation and stock returns in the capital market.

The findings of this study provide empirical evidence to guide Taiwan's semiconductor companies in developing sustainable strategies. Firms should continue to enhance their carbon management practices, improve the transparency of environmental performance information, and effectively manage water and other resources. By doing so, they can strengthen their environmental image and long-term competitive advantage, ensuring sustainable growth.

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