DLSU Business & Economics Review 34(2) 2025 p. 99-120

REVIEW ARTICLE

A Review of Climate Change and Its Financial Impact on the Transportation Sector

Ray Anthony L. Almonares
Thammasat Business School, Thammasat University, Bangkok, Thailand
ray-ant61@tbs.tu.ac.th

In this paper, I review the existing literature on climate risks—both transition and physical—and their relationship with firm performance, with a specific focus on transportation finance. I find that the broad literature on carbon emissions and firm performance overlooks two critical characteristics of the global transportation sector: its heavy reliance on fossil fuels and the international scope of its operations. As a result, the conclusions drawn from this body of work may not be directly applicable to global transportation companies. Furthermore, I examine existing studies on extreme sea levels and the global maritime transportation sector, noting that these studies have not yet quantified the economic impact of extreme sea levels on the firm performance of seaports and shipping companies. Similarly, the nascent climate finance literature on the physical impacts of climate change has yet to address this issue. Filling these gaps is crucial, given the sector's central role in global trade and its heightened vulnerability to climate risks. The research gaps I identified in this review underscore the need for future studies at the intersection of climate change and transportation finance.

Keywords: climate change, transportation finance, climate risks

JEL Classifications: G3, Q54, L91

The global transportation sector plays an important role in facilitating international trade and travel. Following the Global Industry Classification Standard (GICS), global transportation can be classified into five main industries: air freight and logistics, airlines, marine, road and rail, and transportation infrastructure. Global maritime transportation, which includes seaports and shipping companies, supports about 80% of the world trade volume (United Nations Conference on Trade and Development, 2021). Air travel, which includes airports and airline companies, is the most common mode of international passenger transportation. The returns that global transportation companies derive from supporting the global economy make the sector an attractive asset class. Indices and funds, such as the MSCI World Transportation Index and the BlackRock Future of Transport Fund, allow investors and other financing providers to track the performance of this sector.

One interesting characteristic of the sector is that even if the five industries are grouped under global transportation, each one of them has its own nuanced properties which may uniquely influence each of the industry's performance. For example, the earnings and asset value in the shipping industry are affected by factors such as the global supply and demand for shipping services, and movements in freight rates and vessel prices (Alexandridis et al., 2018). In the aviation industry, airline companies turn to operating leases (instead of the direct acquisition of assets) to manage their fleet. Under this setup, airline companies operate the fleet that lessors lend to them. They lease to manage their capacity in response to fluctuating global traffic. Under this scheme, they expense, instead of capitalizing, their assets (Oum et al., 2000). Infrastructure for transportation systems is also becoming a viable asset class for investors. Mechanisms such as project finance and public-private partnerships (PPP) facilitate private participation in funding infrastructure projects that support the functioning of society (a function that the government traditionally performs). Infrastructure is generally characterized by long-lived and large-scale public structures. The returns to investors and other private sources of financing (i.e., pension funds) are linked to contracts or concessions that the government awards to private entities (Courtois, 2013; Gifford, 2012). The complex nature of the global transportation sector underscores the importance of understanding the financial management decisions that are unique to this industry. Transportation finance, as defined by Gifford (2012), involves the funding and management of transportation infrastructure and services, including highways, transit systems, airports, and ports. This field considers the distinctive characteristics of the global transportation industry, making it an interesting setting for studying the factors that influence firm performance.

The rising importance of addressing climate change has recently increased the attention that top financial journals have given to studying climate risks by having special issues on climate finance in the last five years[1]. The broad finance literature now includes a growing number of studies on the effects of carbon emissions and extreme weather events on firm performance. However, there remains a gap in understanding how these climate risks impact firm performance in the global transportation sector. As Gong et al. (2016) noted, the industry's unique and complex characteristics make it essential to test financial theories within this context. In my review, I address this gap through three key contributions. First, I look at the well-established literature from finance, environmental economics, and sustainability on the relationship between carbon emissions and firm performance. I evaluate the methodologies used and the theme of the findings from these studies. Second, I examine the emerging climate finance literature on the physical impacts of climate change on firm performance, identifying its current focus and potential areas for future exploration. Last, I synthesize these findings to propose future research directions at the intersection of climate change and transportation finance.

In this review, I identify critical gaps in the literature on climate risks and firm performance, particularly as they relate to the global transportation sector. Studies on the relationship between carbon emissions and firm performance often fail to account for the heavy-emitting and international characteristics of this sector, limiting their applicability. Additionally, research in transportation and finance has yet to quantify the economic impacts of extreme sea levels on the global maritime transportation sector, despite its direct exposure to this risk and its central role in facilitating global trade. Understanding these relationships is essential, given the significant implications for both industry resilience and the global economy. These gaps underscore the need for future research to explore these underexamined areas.

I structure the rest of the paper as follows. I provide a background discussion on climate risks in the global transportation sector in the next section. I then review the existing literature on carbon emissions and firm performance and examine the available research on extreme sea levels and global maritime transportation in the succeeding sections. I conclude the study in the last section.

Climate Risks in the Global Transportation Sector

There are two types of climate risks that can affect firm performance. One is transition climate risk, which is linked to the firm's carbon emissions. Firms with higher carbon emissions face higher transition risks because of regulations and changing consumer behavior, which penalize firms if they do not manage their carbon emissions (Bolton & Kacperczyk, 2023).

The other type is physical climate risk. Physical risk is related to the actual manifestation of climate change. It can be acute or event-driven (i.e., heat wave, drought, extreme rainfall, and storms), or it can be chronic or long-term (i.e., increases in average temperature, changes in rainfall pattern, and sea level rise; Ginglinger & Moreau, 2023).

The global transportation sector is highly vulnerable to both transition and physical climate risks. The industry faces transition risks because it heavily relies on fossil fuels. It accounts for 25% of the world's GHG emissions (Deumier et al., 2021) and maintaining business-as-usual will only lead to higher transportation-related emissions in the future. Hence, different stakeholders are taking various measures to minimize the sector's carbon emissions. These actions, however, have financial consequences on transportation companies. One example is the inclusion of the aviation industry in the European Union Emissions Trading Scheme (EU ETS) in 2012. The EU ETS, launched in 2005, is one of the EU's policies to reduce carbon emissions. It follows a "cap and trade" principle. This means that industries included in the EU ETS have a cap on their carbon emissions and that the allowances they need for their emissions are traded (Faber & Brinke, 2011). To meet the climate goals of the EU ETS, the cap per industry is designed to decrease over time. The cap in the aviation industry from 2013 onwards is 95% of the average emissions from 2004 to 2006. This is equivalent to 209 million tons of CO2 (European Union, n.d.). The EU ETS affects the financials of airline companies in two ways. First, the purchase of carbon allowances increases their operating expenses (OPEX). Based on Italian data, Meleo et al. (2016) estimated that an allowance price of EUR 25 per ton of CO2 costs the industry from EUR 12.87 to 15.14 million. In 2022, the average price of emission allowance in the EU ETS was EUR 81 per ton (Statista, 2023). The price of carbon allowances can also increase in the future with the growth of the industry. The other financial impact is on the firm's capital expenditure (CAPEX). Airline companies may need to invest in assets that reduce their carbon emissions because their industry emission limit is progressively capped (Nava et al., 2018).

The global shipping industry provides another example of transition risk in global transportation. In this industry, the International Maritime Organization (IMO) sets standards that manage the sector's emissions. The IMO is the United Nations's (UN) specialized agency that is tasked to set the standards for the safety, security, and environmental performance of international shipping. The standards they set also affect the shipping companies' OPEX and CAPEX. For example, they introduced a regulation in 2020 (known as "IMO 2020") to reduce the sulfur oxide (SOx) from ships by lowering the upper limit of the sulfur content of the ships' fuel oil from 3.50% to 0.50% (IMO, 2019). To comply, the company can either (a) switch from using high sulfur fuel oil (HSFO) to either low sulfur fuel oil (LSFO) or liquefied natural gas (LNG) or (b) they can keep using HSFO and install an exhaust gas cleaning system (EGCS), more commonly known as "scrubbers." Using LSFO increases their costs because LSFO is more expensive than HSFO. An increased demand for LSFO can also widen this price gap further. Meanwhile, installing LNG engines or scrubbers requires multimillion-dollar upfront CAPEX. The company also incurs a one-off loss in revenue when the ships are docked for weeks during retrofitting and a permanent opportunity cost due to the lost deck space allocated to the new equipment (Halff et al., 2019).

On top of regulations and standards, increasing environmental awareness among consumers is another source of transition risk for global transportation companies. For example, retailers are receiving increased attention for the carbon emissions of the maritime cargo carriers they use in shipping their products (Robertson, 2021). The scrutiny that consumers impose on the carbon footprint of their purchases has prompted large retailers to commit to reducing their supply chain emissions[2] , which include those of the shipping services they employ. In the aviation industry, the passengers' environmental views are reflected in their willingness to pay (WTP) for climate-related measures that increase their airfare. This premium is based on the polluter-pays principle and compensates for the environmental damage caused by flights (Brouwer et al., 2008). Search results from Google also provide information on the carbon emissions of flights to guide passengers on the environmental impact of their itineraries.

The global transportation sector is also vulnerable and sensitive to physical climate risks. Extreme weather events interrupt the operations of transportation companies. Thunderstorms, heavy rainfall, and snowstorms disrupt high-speed rail (HSR) and aviation services (Chen & Wang, 2019). Increased lightning incidences cause flight delays, cancellations, and route disruptions (Yair, 2018). Climate change can also damage infrastructure (Becker et al., 2018), which can lead to costs amounting to billions of dollars (Blake et al., 2011). For example, the State of Mississippi (2006) assessed the damage of Hurricane Katrina to its ports to be at USD 100 million. In Japan, the Kansai International Airport, situated on reclaimed land in Osaka Bay, experienced severe flooding and other infrastructure damages after Typhoon Jebi hit the country in 2018. The airport closed for three days and resumed full operations after 17 days. The impact of the airport closure on the Kansai region is estimated at JPY 60 billion or USD 500 million (Lacoin, 2019). The effects of acute physical climate risks can even be worsened by the onset of chronic physical climate risks. Sea level rise (SLR), an example of a chronic physical risk, increases the frequency of coastal storm surges and flooding incidences (Bosello et al., 2007).

Carbon Emissions and the Global Transportation Sector

The existing financial, environmental economics, and sustainability literature provide the relationship between carbon emissions and firm performance. Table 1 presents the key details of these studies on the effect of carbon emissions on firm performance. I expand Y. Wang et al.'s (2022) discussion by including the industries that the papers in their review covered and adding papers on carbon emissions and firm performance that are not on their list.

The studies employ diverse measures of carbon emissions, reflecting varying methodologies and research objectives. A common measure is a firm's total carbon emissions (Bouaddi et al., 2023; Guastella et al., 2022; Lewandowski, 2017; Liu et al., 2023; Sun et al., 2022). L. Wang et al. (2014), Matsumura et al. (2014), Clarkson et al. (2015), Delmas et al. (2015), Choi et al. (2021) and Bolton and Kacperczyk (2021, 2023) distinguished the firm's absolute carbon and carbon-equivalent GHG emissions through scopes defined by the Greenhouse Gas (GHG) Protocol—Scope 1 (direct emissions), Scope 2 (indirect emissions from purchased energy), and Scope 3 (indirect emissions from supply chains). Together, these measures capture both direct and indirect environmental impacts of the company because they measure the firm's carbon emissions from its own operations and its supply chain.

Other studies use carbon intensity (emissions scaled by assets or revenues) to evaluate emissions relative to firm size or financial performance, highlighting resource-use efficiency (Aswani et al., 2024; Bendig et al., 2023; Brouwers et al., 2018; Busch et al., 2022; Busch & Hoffmann, 2011; Ferrat, 2021; Ganda & Milondzo, 2018; Homroy, 2023; Lee et al., 2015; Oestreich & Tsiakas, 2024; Russo et al., 2021; Saikia & Maji, 2024; Saka & Oshika, 2014). Trumpp and Guenther (2017) used the negative value of the firm's carbon intensity to proxy its carbon performance. Meanwhile, other studies focus on carbon efficiency to assess relative performance. Trinks et al. (2020) compared a firm's emissions with those of best-practice peers, whereas J. Wang et al. (2021) used a data envelopment analysis (DEA) model to estimate carbon efficiency. On the other hand, Nishitani and Kokubu (2012) and Ghose et al. (2023) explored carbon productivity (net sales per unit of carbon emissions) to illustrate the economic value generated per unit of emissions.

In addition to these metrics, some studies analyze changes in emissions to track a firm's reduction initiatives. For example, Alvarez (2012) and Gallego-Álvarez et al. (2015) investigated the impact of emission reduction efforts on performance. Ferrat (2021) used the Carbon Emission Performance (CEP) metric from MSCI, which links carbon performance to an ESG framework to assess its financial and strategic impacts. Categorical approaches are also used, such as dummy variables, to classify firms by their association with high-emission industries (Nguyen, 2017) or their alignment with climate initiatives like the science-based targets (SBT) (Ben-Amar et al., 2024).

The data for these analyses come from a variety of sources. These sources include company disclosures like corporate social responsibility (CSR) reports (Sun et al., 2022) or carbon disclosure project (CDP) disclosures (Homroy, 2023; L. Wang et al., 2014), regional databases such as the EU ETS (Brouwers et al., 2018) and the European Pollutant Release and Transfer Register (E-PRTR; Homroy, 2023), financial databases such as Thomson Reuters ASSET4 (Liu et al., 2023) and MSCI ESG Research (Ferrat, 2021), and national records (Nishitani & Kokubu, 2012).

Firm performance is measured using market-based and accounting-based indicators, with some studies combining both to examine the multidimensional impact of carbon emissions. Market-based measures

Table 1. *The Financial Literature on the Effects of Carbon Emissions on Firm Performance*

Paper	Carbon Emission Measure	Firm Performance Measure	Country	Industry	Study Period	Key Findings
Alvarez (2012)	Carbon emission variation from 2006 – 2007	ROA and ROE	Global	Multiple	2007 – 2010	Firms reducing CO2 emissions experienced a negative impact on operating performance (ROA) in the short term due to the upfront costs of emission mitigation. This effect was particularly evident during the financial crisis years of 2008–2009, as firms prioritized financial stability over environmental investments. The findings suggest that emission reductions could yield longer-term financial benefits once economic conditions improve.
Aswani et al. (2024)	Scope 1, Scope 2, and Scope 3 carbon emissions and carbon emission intensity (carbon emissions scaled by net sales)	Stock return, ROA, ROS, EBIT margin, and EBITDA margin	USA	Multiple	2005 – 2015	Carbon emissions are positive and significant in terms of stock return, ROA, ROS, EBIT margin, and EBITDA margin. However, carbon emission intensity is not significant against all measures of firm performance. They concluded in their study that the results from previous studies are driven by measurement and research design specifications. Bolton & Kacperczyk (2024) argued that the results of Aswani et al. (2024) corroborate their previous findings and that the latter decided to choose a different interpretation.

Ben-Amar et al. (2024)	A dummy variable equal to 1 if the firm sets carbon emissions reduction targets in line with the Science-Based Targets initiative (SBTi) framework	Stock return (raw and market model-adjusted)	USA	Multiple	2020	Firms with SBTi-aligned emission targets experience higher raw and market-adjusted stock returns during the COVID-19 crash period. This suggests that investors reward proactive climate commitments amidst economic uncertainty.
Bendig et al. (2023)	Carbon intensity (Scope 1 + Scope 2 emissions divided by total sales) and change in carbon intensity	ROA and Tobin's q	Global	Multiple	2015 – 2020	Carbon emissions reduction and lower carbon intensity have a positive effect on both ROA and Tobin's q. Findings suggest that firms committing to science-based emission reduction targets (SBTs) benefit from increased market confidence and improved operational efficiency. Investors appear to reward firms for mitigating carbon risks and demonstrating strong environmental stewardship.
Bolton & Kacperczyk (2021)	Scope 1, Scope 2, and Scope 3 carbon emissions and carbon emission growth rate	Stock return	USA	Multiple	2005 – 2017	Carbon emissions and carbon emission growth have a positive effect on stock return. Findings suggest that investors are demanding compensation for the firm's carbon risk.
Bolton & Kacperczyk (2023)	Scope 1, Scope 2, and Scope 3 carbon emissions and carbon emission growth rate	Stock return	Global	Multiple	2005 – 2018	Carbon emissions and carbon emission growth have a positive effect on stock return. Investors are demanding a carbon premium for their exposure to carbon risk. This premium is higher in countries with lower economic development, larger energy sectors, and less inclusive political systems.

Bouaddi et al. (2023)	Carbon-equivalent emissions	ROA, ROE, Tobin's, and market-to-book value (MTBV)	Emerging Economies	Multiple	2008 – 2021	Carbon emissions have a negative effect across all performance measures. This effect is more pronounced in smaller firms and low-performing companies. For high-performing large firms, carbon emissions are positively associated with performance. These firms tend to prioritize profitability over environmental considerations, accepting carbon-related costs such as taxes or fines rather than investing in emissions reduction.
Brouwers et al. (2018)	Industry- and year-adjusted carbon intensity (verified emissions from the EU ETS over a certain year divided by sales, minus the corresponding industry median of this carbon intensity)	ROA, ROE, and Tobin's q	EU	Multiple	2005 – 2012	Carbon emissions have a negative effect on firms that cannot pass on their carbon costs to their customers. The effect is insignificant for firms with cost pass-through mechanisms as their carbon costs are transferred to end consumers.
Busch & Hoffmann (2011)	Negative carbon intensity	Tobin's q, ROA, and ROA	Global	Multiple	2006	Better carbon performance leads to higher Tobin's q.
Busch et al. (2022)	Scope 1, Scope 2, and Scope 3 carbon-equivalent GHG emissions in the part where they replicate Delmas et al. (2015); Carbon intensity (Scope 1 GHG emissions divided by sales in the second part	ROA and Tobin's q	USA (in the replication of Delmas et al. (2015); USA and Europe in the second part	Multiple	2005 – 2014	Replication of Delmas et al. (2015): Higher carbon emissions are positively associated with ROA, indicating better short-term financial performance as firms avoid the immediate costs of emissions mitigation. However, there was no significant link between carbon emissions and Tobin's q., suggesting mixed long-term investor perceptions of emissions. Second part of the For high-performing large firms, carbon emissions are positively associated with performance.

						For high-performing large firms, carbon emissions are positively associated with performance.
Choi & Luo (2021)	Scope 1 and Scope 2 carbon emissions scaled by common shares outstanding	Market value of common equity scaled by common shares outstanding	Global	Multiple	2008 – 2015	Carbon emissions have a negative effect on firm value. The effect is more negative in countries with emission trading schemes and strict environmental regulations.
Choi et al. (2021)	Scope 1 and Scope 2 emissions	Market value of common equity	Australia	Multiple	2008 – 2015	Carbon emissions negatively impact firm value.
Clarkson et al. (2015)	Scope 1, Scope 2, and Scope 3 carbon emissions	Market value of common equity	EU	Multiple	2006 – 2009	Carbon emissions have a negative effect on firm value. This negative effect is mitigated in industries with lower competition because firms can pass on their carbon-related costs.
Delmas et al. (2015)	Scope 1, Scope 2, and Scope 3 carbon-equivalent GHG emissions	ROA and Tobin's q	USA	Multiple	2004 – 2008	GHG emission reduction negatively impacts ROA, which shows the immediate upfront costs of emission mitigation. However, GHG emission reduction has a positive effect on Tobin's q, which reflects the long-term financial benefits of emission management. Findings suggest that investors value proactive emissions reductions as a signal of preparedness for future regulations and market shifts.
Ferrat (2021)	Carbon emission performance (CEP) from the MSCI ESG Research database	ROA and stock return	Europe, North America, and the Pacific	Multiple	2015 – 2020	CEP negatively affects short-term financial performance, measured by ROA, especially for high-materiality industries and in regions with strict regulations. In the long term, firms in high-materiality

						industries can achieve competitive advantages through emissions reductions, particularly in markets that reward superior CEP. For low-materiality industries, CEP improvements often yield no significant financial impact, as they are perceived as symbolic and neither rewarded nor penalized by equity markets.
Gallego-Álvarez et al. (2015)	GHG emission variation	ROE and ROA	Global	Multiple	2006 – 2009	A reduction in carbon emissions positively impacts financial performance (ROE), supporting the notion that environmental strategies yield competitive advantages. However, emission reductions did not significantly affect operational performance (ROA), especially during the economic crisis of 2008-2009, suggesting limited short-term benefits for operational metrics.
Ganda & Milondzo (2018)	Carbon emission intensity (carbon emissions divided by net assets)	ROE, ROI, and ROS	South Africa	Multiple	2015	Carbon emissions have a negative effect on financial performance. This negative effect is more pronounced in heavy-emitting industries due to higher regulatory and environmental scrutiny.
Ghose et al. (2023)	Carbon productivity (net sales divided by the sum of Scope 1 and Scope 2 carbon emissions)	ROA and market-to-book ratio (MBR) of equity	India	Multiple	2015 – 2020	Carbon productivity has a positive effect on financial performance, particularly on MBR. This positive effect is more pronounced in carbon-intensive industries, where firms benefit from reduced regulatory risks and improved stakeholder confidence.
Griffin et al. (2017)	Scope 1 and Scope 2 carbon emissions	Value of common equity per share	USA	Multiple	2006 – 2012	GHG emissions have a negative effect on the value of the firm's equity shares.

Guastella et al. (2022)	GHG emissions	Tobin's q	Global	Utilities, Energy, Materials, and Transportation	2011 – 2017	High GHG emissions negatively impact firm performance, particularly in energy-intensive industries with stricter regulations. Sectoral variations highlight that transportation and utilities show weaker negative impacts than the energy and materials industries.
Homroy (2023)	GHG emissions data from the European Pollutant Release and Transfer Register (E-PRTR), Eikon and Carbon Disclosure Project (CDP)	ROA and market-to-book value (MTBV) of the firm	UK	Multiple	2007 – 2017	Lower GHG emissions have a positive effect on ROA and MTBV through improved operational efficiency and reduced energy costs. This positive effect is more pronounced in firms led by CEOs with daughters, as they are more likely to adopt climate-integrated business strategies. The effects are strongest for direct (Scope 1) and indirect (Scope 2) emissions, highlighting the financial benefits of proactive emission management.
Iwata & Okada (2011)	Greenhouse gas emissions (measured as 1,000 tons of CO2 equivalents) scaled by sales and operating revenue	ROE, ROA, ROI, ROIC, ROS, and Tobin's q – 1	Japan	Manufacturing	2004 – 2008	Greenhouse gas emissions have a negative and significant effect on accounting-based measures of firm performance (ROA, ROI, and ROIC).
Lee et al. (2015)	Carbon intensity (carbon emissions scaled by assets)	Tobin's q and ROA	Japan	Manufacturing	2003 – 2010	Carbon emissions weaken firm value. The market's penalty for the firm's negative actions (carbon emissions) is more consistent compared to its rewards towards the firm's positive actions (green R&D).

Lewandowski (2017)	Annual carbon emissions and changes in carbon emissions	ROA, ROE, ROS, ROIC and Tobin's q	Global	Multiple	2003 – 2015	A curvilinear relationship exists between annually reported carbon emissions and financial performance. Firms with superior carbon performance experience positive financial impacts, while those with inferior performance face negative outcomes. This suggests that financial benefits from carbon management are realized only after surpassing a threshold level of carbon performance. There is no curvilinear relationship between changes in carbon emissions and firm performance.
Liu et al. (2023)	Total carbon emissions from Thomson Reuters ASSET4	Tobin's q	UK	Multiple	2010 – 2017	Carbon emissions negatively affect Tobin's q due to regulatory costs, reputational risks, and upfront costs from complying with emissions reduction mandates. Carbon disclosure mediates this relationship, mitigating the negative impact of emissions and enhancing performance.
Makridou et al. (2019)	Verified emissions per sales	EBITDA	EU	Multiple	2006 – 2014	Lower emissions intensity (verified emissions relative to sales) is associated with higher profitability, as it reflects better operational efficiency and resource management. Firms in countries with strong energy efficiency policies benefit from reduced energy costs, translating efficiency gains into increased profits over time.
Matsumura et al. (2014)	Scope 1, Scope 2, and Scope 3 carbon emissions	Market value of common equity	USA	Multiple	2006 – 2008	An additional thousand metric tons of carbon emissions reduces the firm value by USD 212,000.

Miah et al. (2021)	Total, direct, and indirect absolute carbon emissions	ROE, EPS, Tobin's q, credit rating, and Z-score	Emerging Economies	Financial and non-financial	2011 – 2020	Carbon emissions significantly reduce ROA and Tobin's q for both types of firms. This impact is more pronounced for non-financial firms, which tend to emit more carbon compared to financial firms.
Nguyen (2017)	Dummy variable that indicates if the firm belongs to a heavy-emitting industry	Probability of negative net income, Tobin's q, and ROE	Australia	Multiple	2000 – 2014	Firms in heavy-emitting industries have lower firm performance because of their higher carbon risk. The negative relationship strengthens when stricter carbon policies, such as the Kyoto Protocol, are implemented.
Nishitani & Kokubu (2012)	Carbon dioxide productivity (net sales scaled by carbon emissions)	Tobin's q	Japan	Manufacturing	2006 – 2008	Firms that reduce their carbon emissions have better firm performance.
Oestreich & Tsiakas (2024)	Carbon emission intensity (carbon emissions divided by revenue)	Gross profitability (gross profits divided by total assets)	USA	Multiple	2005 – 2019	Firms with higher carbon emission intensity show significantly lower profitability. The result suggests that high emissions impose direct and indirect costs that negatively affect firm performance.
Russo et al. (2021)	Ratio of a firm's greenhouse gas emissions to its total sales, normalized against the industry average (a value of 1 indicates emissions per dollar of revenue equal to the industry average, while a value below 1 reflects better environmental performance)	ROA, ROE, ROS, Tobin's q	Global	Multiple	2004 – 2016	Firms that reduce their GHG emissions experience improved operating performance, as indicated by higher ROA and ROS, reflecting greater operational efficiency. However, the positive relationship with financial profitability, measured by ROE, is limited due to the capital intensity of emission reduction investments. Firms with sustained environmental

						improvements also benefit from higher market valuations, as reflected in Tobin's q, signaling strong investor confidence in their long-term sustainability commitments.
Saikia & Maji (2024)	Emission intensity (Scope 1 + Scope 2 emissions divided by sales)	Tobin's q	India	Multiple	2019 – 2023	Firms with higher carbon emissions exhibit lower market performance due to increased regulatory risks and reputational challenges. The negative relationship is more pronounced for firms adopting SBTi-aligned emission targets, and this corporate initiative enhances their market valuation.
Saka & Oshika (2014)	Carbon emissions scaled by revenue	Market value of equity	Japan	Manufacturing	2006 – 2008	Carbon emissions have a negative effect on firm value.
Sun et al. (2022)	Total carbon emissions in CSR reports	Market value of equity	China	Multiple	2017 – 2020	Insignificant regression results between carbon emissions and firm value.
Trinks et al. (2020)	Carbon efficiency (carbon emissions compared with best-practice peers)	Tobin's q and ROA	Global	Multiple	2009 - 2017	Carbon-efficient firms have better firm performance (0.1 carbon efficiency translates to 1% higher profitability).
Trumpp & Guenther (2017)	Carbon performance (negative total Scope 1 and Scope 2 emissions divided by sales)	ROA and stock return	Global	Multiple	2008 – 2012	A U-shaped relationship exists between carbon emissions and profitability. The results suggest that "it pays to be green" after exceeding a minimum level of environmental performance.
L. Wang et al. (2014)	Scope 1 and Scope 2 emissions from CDP	Tobin's q	Australia	Multiple	2010	GHG emissions have a positive effect on firm performance. This relationship is attributed to Australia's economic reliance on emission-intensive industries like mining and limited socially responsible investment (SRI) pressures in the country.

J. Wang et al. (2021)	Carbon efficiency (estimated using a DEA model)	CR, TAT, ROA, P/E ratio, and Tobin's q	China	Multiple	2015 – 2019	Carbon efficiency has a positive and significant effect on TAT and Tobin's q.
Yan et al. (2020)	Inverse of carbon emissions scaled by revenue	Tobin's q	China	Manufacturing	2009 - 2017	Better carbon performance translates to better firm value. This relationship is more prominent among non-state-owned companies and firms with high levels of corporate governance.
Yu et al. (2022)	Carbon intensity (industry CO2 emissions multiplied by the ratio of the firm's cost of sales to the industry's cost of sales, scaled by the firm's revenue)	ROA	China	Industrial	2010 – 2017	With the introduction of a pilot ETS, firms with lower carbon emissions have better profitability.

include Tobin's q and stock returns. Tobin's q reflects the firm's forward-looking value, whereas stock returns capture investors' perceptions of expected future cash flows and associated risks. Matsumura et al. (2014) and Clarkson et al. (2015) used the market value of equity, whereas Griffin et al. (2017) focused on the value of common equity per share. These metrics assess how carbon emissions influence overall firm valuation in financial markets. Accounting-based measures include Return on Assets (ROA), Return on Equity (ROE), Return on Investment (ROI), and Return on Sales (ROS), which assess profitability and operational efficiency. Some studies combine market-based and accounting-based measures in their analysis to provide a holistic view of firm performance as they capture the effects of carbon management on their operational efficiency and profitability and the market's perception and expected future performance of the company (Aswani et al., 2024; Busch et al., 2022; Delmas et al., 2015; Ferrat, 2021).

A common theme in the literature is the negative impact of carbon emissions on firm performance. For instance, studies by Choi and Luo (2021) and Clarkson et al. (2015) showed that carbon emissions reduce the market value of the firm in markets with stringent environmental regulations or emission trading schemes. Similarly, Ganda and Milondzo (2018) highlighted the challenges faced by heavy-emitting industries, where regulatory and environmental scrutiny leads to negative financial outcomes. Other studies, such as those by Nishitani and Kokubu (2012) and Oestreich and Tsiakas (2024), reported that higher emissions weaken profitability and operational efficiency. Nguyen (2017) noted that firms in high-emission industries face lower performance metrics due to elevated carbon risks, whereas Yu et al. (2022) demonstrated that lower emissions enhance profitability under China's pilot emissions trading scheme. The seminal work of Matsumura et al. (2014) estimated that every additional 1,000 metric tons of carbon emissions reduce firm value by approximately USD 212,000.

In contrast, some studies suggest a positive relationship between carbon emissions and firm performance in certain contexts. For example, Bolton and Kacperczyk (2021, 2023) found that carbon emissions are associated with higher stock returns. In this context, the positive relationship is explained by asset pricing foundations, where investors demand to be compensated for the higher risk they incur from the company's carbon emissions. Similarly, L. Wang et al. (2014) reported positive effects of emissions in emission-intensive industries like mining, where socially responsible investment pressures are limited. Busch et al. (2022) noted that firms benefit from higher emissions in the short term by avoiding the immediate costs of emission mitigation efforts, leading to improved ROA. From this perspective, lowering carbon emissions can hurt a firm's profitability, and firms that delay carbon-abating investments may experience better financial performance in the short term.

Other studies reveal mixed or conditional effects of carbon emissions, often depending on firm characteristics, industry, or external conditions. Delmas et al. (2015) observed that emission reductions negatively affect ROA in the short term due to upfront costs but positively influence Tobin's q, indicating long-term benefits from regulatory preparedness. Ferrat (2021) identified short-term financial challenges associated with emissions reduction in high-materiality industries but noted long-term rewards in markets that value superior carbon performance. Bouaddi et al. (2023) reported that smaller firms and low-performing companies experience negative impacts from emissions, while high-performing, large firms see positive effects due to their ability to absorb carbon-related costs. Lewandowski (2017) identified a curvilinear relationship, which suggests that the financial benefits from carbon management are realized only after surpassing a threshold level of carbon performance.

Aswani et al. (2024) argued that the mixed results on the relationship between carbon emissions and stock returns or firm value reported in previous studies are primarily influenced by two factors: (a) how data vendors estimate emissions and (b) the focus on unscaled emissions, which are naturally tied to firm size and productivity. They caution researchers, practitioners, and policymakers to carefully interpret the statistical associations between carbon emissions and returns.

Studies also show that firm, industry, and country factors can moderate the relationship between carbon emissions and firm performance. For example, large firms with stronger financial performance are less likely to experience the negative effect of carbon emissions because they can absorb the required upfront mitigation costs and are better equipped to invest in mitigation strategies for carbon reduction (Bouaddi et al., 2023). Similarly, firms with climate-conscious leaders are also less likely to be negatively affected by carbon emissions (Homroy, 2023).

At the industry level, sectors with low product market competition (PMC) can often pass carbon-related costs onto consumers, mitigating the financial burden of carbon emissions. For example, Clarkson et al. (2015) found that industries with low PMC experience weaker negative effects of carbon emissions on firm performance. Likewise, Brouwers et al. (2018) demonstrated that industries capable of passing on carbon costs are less vulnerable to the financial impacts of carbon emissions.

On a country level, regulatory frameworks targeting carbon emissions influence firm performance significantly. Governments employ mechanisms such as emissions trading systems (ETSs) and carbon taxes to penalize high-emitting firms. An ETS sets a cap on emissions by allocating allowances to industries, creating financial incentives for firms to reduce emissions. Similarly, carbon taxes, which are based on the carbon content of fossil fuels, encourage firms to transition to low-carbon energy sources. Consequently, firms domiciled in countries with strict ETS or carbon tax policies face higher costs, intensifying the negative financial impact of carbon emissions on their performance (Choi & Luo, 2021).

Although the existing literature provides a broad understanding of how carbon emissions affect firm performance, they are unable to capture in their discussion some emission-related issues that are distinct and relevant to the global transportation sector. One key example is the heavy reliance of the business operations of global transportation companies on fossil fuels. Reducing carbon emissions in this sector entails substantial expenses for fuel switching and capital for carbon-abating technologies (Kiuila & Rutherford, 2013). There is a possibility that the benefits of reducing carbon emissions do not exceed the costs of reducing carbon emissions. Hence, the documented negative effect of carbon emissions on firm performance may not apply in this sector. Nguyen (2017) provided a discussion that focused on the industry's emissions. In his study, he identified nine heavy-emitting industries[3] and classified them as polluters. Firms belonging to these industries are hypothesized to have higher carbon risk and have weaker firm performance compared with non-polluters. Although his study focused on the emitting nature of the industry, his results cannot seem to fully apply to the global transportation sector. For one, he did not include the transportation industry among his heavy-emitting industries. Furthermore, his sample only included firms from Australia, so it did not capture the international nature of global transportation. He did not control for global macroeconomic variables that influence the demand and supply for global transportation services (and, consequently, affect the performance of transportation companies). Guastella et al. (2022) partially addressed this gap by including the transportation sector in their analysis of high-emission industries, recognizing its significant contribution to carbon emissions. However, their study did not account for the international scope of transportation firms or global trade's influence on carbon emissions and firm performance. The same reasoning can be said as to why the studies that focus on the Japanese manufacturing sector are insufficient in providing insights into the global transportation sector (Iwata & Okada, 2011; Lee et al., 2015; Nishitani & Kokubu, 2012; Saka & Oshika, 2014). The manufacturing sector is like the transportation sector in the sense that they both traditionally rely on fossil fuels, so their carbon emissions increase with their business activities. However, the existing studies on the manufacturing sector only look at Japanese firms, so they also fail to capture the international nature of the global transportation sector.

Overall, there is a need to study the relationship between carbon emissions and firm performance in global transportation companies for two key reasons. First, existing studies yield inconsistent findings on this relationship, making it difficult to draw definitive conclusions. These mixed results suggest that the unique characteristics of the global transportation sector may not have been adequately considered, highlighting the need for further investigation. Second, most studies offer generalized insights into the relationship between carbon emissions and firm performance but fail to consider critical features of the global transportation industry. These include the sector's heavy reliance on fossil fuels, its high levels of emissions, and the international scope of its operations, which subject firms to macroeconomic factors such as fluctuating fuel prices, cross-border trade dynamics, and varying regulatory frameworks. Addressing these distinctive aspects is essential to gain a deeper understanding of how carbon emissions impact the financial performance of transportation firms, emphasizing the need for focused research in this industry.

Extreme Sea Levels and the Global Maritime Transportation Sector

The global transportation sector is highly vulnerable to climate change and extreme weather events (Melkonyan et al., 2024). Among physical climate risks, the rise of sea level has gained significant attention in media and international policy discussions. This chronic risk exacerbates the effects of acute climate events, increasing its potential impact. Rising sea levels particularly threaten the global maritime industry due to its direct exposure to the oceans, with significant implications for the global economy. Variability in sea levels, whether extremely high or low, can disrupt seaport and shipping operations, increasing operational costs (Lam & Su, 2015; Moon & Woo, 2014; Dero et al., 2020). Global maritime transportation companies can pass on these costs to their customers through higher freight rates. Because this segment supports 80% of the international trade volume (United Nations Conference on Trade and Development, 2022), increases in shipping costs have inflationary effects on the global prices of goods (Carrière-Swallow et al., 2023). Hence, it is important to estimate the economic impact of extreme sea levels on seaports and shipping companies.

Existing studies in transportation and finance journals, however, have not addressed this literature gap. Becker et al. (2018) reviewed the transportation literature on how climate change effects, such as extreme sea levels, will affect seaports and shipping companies. The discussions revolve around qualitative and case-based studies that assess the impact on global maritime transportation. Izaguirre et al. (2021) quantified the impact of climate change on seaports. However, they focused on operational aspects such as the maneuverability of ships in docks, berthing and loading/unloading operations, visibility during rains, seaport staff's ability to work outdoors, and potential disruption of terminal operations due to flooding. Transportation studies have yet to quantify the corresponding economic costs that exposure to extreme sea levels brings.

The impact of extreme sea levels on firm performance is also a topic that the nascent literature on climate finance has yet to cover. Table 2 shows the different physical climate risks that the existing literature has studied. The two commonly used measures in the literature are the Climate Risk Index (CRI) from

Germanwatch (Huang et al., 2018; Ozkan et al., 2023) and temperature data obtained from the PRISM Climate Group of the US Department of Agriculture (Addoum et al., 2020, 2023) and the European Center for Medium-Term Weather Forecasts (Pankratz et al., 2023). These variables capture different aspects of physical climate risks. The CRI represents the country's relative position in terms of the following dimensions of physical climate risk: (a) number of deaths, (b) deaths per 10,000 inhabitants, (c) losses in purchasing power, and (d) losses per unit of GDP (Huang et al., 2018). On the other hand, studies that use climate data identify a threshold to define extreme values. For example, extreme temperatures are defined as being above 30° and below 0°C. These studies found that extreme temperatures affect the operations and productivity of companies. Hence, exposure to temperature shocks reduces their profitability (Addoum et al., 2023; Pankratz et al., 2023). Studying the impact of extreme sea levels on seaports and shipping companies can extend the literature on the impact of physical climate risks on firm performance. The global maritime transportation industry is an appropriate setting for studying extreme sea levels because the sector operates with direct exposure to the oceans.

Table 2. *The Financial Literature on the Effect of Physical Climate Risks on Firm Performance*

Paper	Physical Climate Risk Measure	Firm Performance Measure	Country	Industry	Study Period	Key Findings
Addoum et al. (2020)	Number of days exposed to extreme temperature (above 30°C and below 0°C)	Sales, Productivity, Operating income, Net income, and Stock return (during earnings announcements)	USA	Multiple	1990 – 2015	Exposure to extreme temperatures does not affect sales, productivity, and profitability. They also do not obtain sufficient support for the possibility of corporate adaptation to temperature shocks.
Addoum et al. (2023)	Number of hours of exposure to extreme temperature (above 30°C and below 0°C)	EPS	USA	Multiple	1990 – 2015	Extreme temperature affects the earnings of different industries. The effect is bi-directional. Some industries are affected negatively, while others benefit from extreme temperatures.
Hsu et al. (2018)	Major disasters (e.g., hurricanes, earthquakes, wildfires, and floods) that last for fewer than 30 days and have a total estimated damage of over USD 1 billion	ROA	USA	Multiple	1988 – 2014	Firms with factories in states that are hit by natural disasters have lower profitability.
Huang et al. (2018)	Climate risk index from Germanwatch	ROA and cash flow from operations	Global	Multiple	1993–2012	Physical climate risk has a negative and significant effect on ROA and cash flow.
Ozkan et al. (2023)	Climate risk index from Germanwatch	EBITDA, ROA, Cash flow, and Tobin's q	Global	Multiple	2010–2017	Physical climate risk has a negative and significant effect on accounting-based measures of firm performance.
Pankratz et al. (2023)	Number of days exposed to heat (above 30°C and the 90th percentile of the location- and season-specific temperature distribution)	Sales and operating income	Global	Multiple	1995–2019	Exposure to hot days reduces sales and operating income. When the number of hot days increases by one standard deviation, revenue and operating income decrease by 0.6% and 1.8%, respectively.

Conclusion

In my review, I highlighted the diverse methodologies and findings on the relationship between carbon emissions and firm performance. The studies revealed mixed results. Some studies identified a negative impact of carbon emissions due to transitory costs associated with regulations, shifting market demands, and negative investor sentiment. In contrast, other studies reported positive or conditional effects, particularly in emission-intensive sectors or within specific financial frameworks. These differing outcomes are often influenced by moderating factors such as firm size, industry characteristics, and country-level policies like emissions trading systems and carbon taxes. Although carbon emissions remain a well-researched topic in understanding the impact of climate change on firm performance, the varying results underscore the complexity of this relationship and the need for continued exploration in underexamined contexts.

In contrast to the well-established literature on carbon emissions and firm performance, the climate finance literature on the physical impact of climate change is still emerging and limited in scope. Although it primarily examines physical climate risks, existing studies that directly use climate data only focus on extreme temperatures. It has yet to address the financial implications of critical phenomena such as extreme sea levels, particularly in sectors directly exposed to these risks, such as the global maritime transportation sector.

I also emphasize in my review the need to study the effects of different climate risks on the performance of the global transportation sector. Existing research on the relationship between carbon emissions and firm performance does not adequately capture the heavy-emitting and international characteristics of this sector. As such, the empirical relationship between carbon emissions and firm performance in global transportation should be investigated. Moreover, neither transportation nor finance research has quantified the economic impacts of extreme sea levels on the global maritime transportation sector. Addressing this question is crucial, as seaports and shipping companies play a central role in facilitating global trade. The two research gaps identified in this review highlight critical opportunities for future studies at the intersection of climate change and transportation finance.

Notes

[1] Stroebel & Wurgler (2021) noted these journals to be the Journal of Financial Economics, Finance Research Letters, International Review of Financial Analysis, Management Science, Review of Financial Studies, and Sustainability. The Journal of Corporate Finance also has a special volume on climate change (Calvet et al., 2022). This development among finance journals appears to be recent as Diaz-Rainey et al. (2017) observed that the top three finance journals (Journal of Finance, Journal of Financial Economics, and Review of Financial Studies) did not publish a single article on climate finance from 1998 to 2015.

[2] Walmart includes reducing its supply chain emissions in its climate change strategies at https://corporate.walmart.com/esgreport/environmental/climate-change, accessed on July 10, 2023.

[3] The industries included are: (1) Oil, Gas, and Consumable Fuels; (2) Electric Utilities; (3) Gas Utilities; (4) Independent Power Producers and Energy Traders; (5) Multi-Utilities; (6) Chemicals; (7) Construction Materials; (8) Metals and Mining; and (9) Paper and Forest Products. He used the GICS as his basis in identifying the firm's industry.

References

Addoum, J. M., Ng, D. T., & Ortiz-Bobea, A. (2020). Temperature shocks and establishment sales. *Review of Financial Studies*, *33*(3), 1331–1366. https://doi.org/10.1093/rfs/hhz126

Addoum, J. M., Ng, D. T., & Ortiz-Bobea, A. (2023). Temperature shocks and industry earnings news. *Journal of Financial Economics*, *150*(1), 1–45. https://doi.org/10.1016/j.jfineco.2023.07.002

Alexandridis, G., Kavussanos, M. G., Kim, C. Y., Tsouknidis, D. A., & Visvikis, I. D. (2018). A survey of shipping finance research: Setting the future research agenda. *Transportation Research Part E: Logistics and Transportation Review*, *115*, 164–212. https://doi.org/10.1016/j.tre.2018.04.001

Alvarez, I. G. (2012). Impact of CO2 emission variation on firm performance. *Business Strategy and the Environment*, *21*(7), 435–454. https://doi.org/10.1002/bse.1729

Aswani, J., Raghunandan, A., & Rajgopal, S. (2024). Are carbon emissions associated with stock returns? *Review of Finance*, *28*(1), 75–106. https://doi.org/10.1093/rof/rfad013

Becker, A., Ng, A. K. Y., McEvoy, D., & Mullett, J. (2018). Implications of climate change for shipping: Ports and supply chains. *Wiley Interdisciplinary Reviews: Climate Change*, *9*(2). https://doi.org/10.1002/wcc.508

Ben-Amar, W., Comyns, B., & Martinez, I. (2024). Firm commitments on climate change: Effects of science-based targets on financial outcomes during the COVID-19 crisis. *Business Strategy and the Environment, 33*(8), 7768–7787. https://doi.org/10.1002/bse.3890

Bendig, D., Wagner, A., & Lau, K. (2023). Does it pay to be science-based green? The impact of science-based emission-reduction targets on corporate financial performance. *Journal of Industrial Ecology*, *27*(1), 125–140. https://doi.org/10.1111/jiec.13341

Blake, E. S., Landsea, C. W., & Gibney, E. J. (2011). *The deadliest, costliest, and most intense United States tropical cyclones from 1851 to 2010 (and other frequently requested hurricane facts)*. https://repository.library.noaa.gov/view/noaa/6929

Bolton, P., & Kacperczyk, M. (2021). Do investors care about carbon risk? *Journal of Financial Economics*, *142*(2), 517–549. https://doi.org/10.1016/j.jfineco.2021.05.008

Bolton, P., & Kacperczyk, M. (2023). Global pricing of carbon-transition risk. *Journal of Finance*, *78*(6), 3677–3754. https://doi.org/10.1111/jofi.13272

Bolton, P., & Kacperczyk, M. (2024). Are carbon emissions associated with stock returns? Comment. *Review of Finance*, *28*(1), 107–109.

Bosello, F., Roson, R., & Tol, R. S. J. (2007). Economy-wide estimates of the implications of climate change: Sea level rise. *Environmental and Resource Economics*, *37*(3), 549–571. https://doi.org/10.1007/s10640-006-9048-5

Bouaddi, M., Basuony, M. A. K., & Noureldin, N. (2023). The heterogenous effects of carbon emissions and board gender diversity on a firm's performance. *Sustainability*, *15*(19). https://doi.org/10.3390/su151914642

Brouwer, R., Brander, L., & Van Beukering, P. (2008). "A convenient truth": Air travel passengers' willingness to pay to offset their CO2 emissions. *Climatic Change, 90*(3), 299–313. https://doi.org/10.1007/s10584-008-9414-0

Brouwers, R., Schoubben, F., & Van Hulle, C. (2018). The influence of carbon cost pass through on the link between carbon emission and corporate financial performance in the context of the European Union Emission Trading Scheme. *Business Strategy and the Environment*, *27*(8), 1422–1436. https://doi.org/10.1002/bse.2193

Busch, T., Bassen, A., Lewandowski, S., & Sump, F. (2022). Corporate carbon and financial performance revisited. *Organization and Environment*, *35*(1), 154–171. https://doi.org/10.1177/1086026620935638

Busch, T., & Hoffmann, V. H. (2011). How hot is your bottom line? Linking carbon and financial performance. *Business and Society*, *50*(2), 233–265. https://doi.org/10.1177/0007650311398780

Calvet, L., Gianfrate, G., & Uppal, R. (2022). The finance of climate change. *Journal of Corporate Finance, 73*, Article no. 102163. https://doi.org/10.1016/j.jcorpfin.2022.102162

Carrière-Swallow, Y., Deb, P., Furceri, D., Jiménez, D., & Ostry, J. D. (2023). Shipping costs and inflation. *Journal of International Money and Finance*, *130*, Article no. 102771. https://doi.org/10.1016/j.jimonfin.2022.102771

Chen, Z., & Wang, Y. (2019). Impacts of severe weather events on high-speed rail and aviation delays. *Transportation Research Part D: Transport and Environment*, *69*, 168–183. https://doi.org/10.1016/j.trd.2019.01.030

Choi, B., & Luo, L. (2021). Does the market value greenhouse gas emissions? Evidence from multi-country firm data. *British Accounting Review*, *53*(1). https://doi.org/10.1016/j.bar.2020.100909

Choi, B., Luo, L., & Shrestha, P. (2021). The value relevance of carbon emissions information from Australian-listed companies. *Australian Journal of Management*, *46*(1), 3–23. https://doi.org/10.1177/0312896220918642

Clarkson, P. M., Li, Y., Pinnuck, M., & Richardson, G. D. (2015). The valuation relevance of greenhouse gas emissions under the European Union carbon emissions trading scheme. *European Accounting Review*, *24*(3), 551–580. https://doi.org/10.1080/09638180.2014.927782

Courtois, Y. (2013). Infrastructure: An emerging global asset class. *CFA Institute Magazine*, 16–19.

Delmas, M. A., Nairn-Birch, N., & Lim, J. (2015). Dynamics of environmental and financial performance: The case of greenhouse gas emissions. *Organization and Environment*, *28*(4), 374–393. https://doi.org/10.1177/1086026615620238

Dero, Q. Y., yari, E., & Charrahy, Z. (2020). Global warming, environmental security and its geo-economic dimensions case study: Caspian Sea level changes on the balance of transit channels. *Journal of Environmental Health Science and Engineering*, *18*(2), 541–557. https://doi.org/10.1007/s40201-020-00481-0

Deumier, G., Glade, P.-S., & Bapst, E. (2021). *Carbon impact analytics: 2020 Report on the transport sector*. https://www.carbon4finance.com/2020-report-on-the-transport-sector

Diaz-Rainey, I., Robertson, B., & Wilson, C. (2017). Stranded research? Leading finance journals are silent on climate change. *Climatic Change*, *143*(1–2), 243–260. https://doi.org/10.1007/s10584-017-1985-1

European Union. (n.d.). *Reducing emissions from aviation*. Retrieved March 20, 2023, from https://climate.ec.europa.eu/eu-action/transport-emissions/reducing-emissions-aviation_en

Faber, J., & Brinke, L. (2011). *The inclusion of aviation in the EU emissions trading system: An economic and environmental assessment*. https://www.files.ethz.ch/isn/133975/faber_aviation.pdf

Ferrat, Y. (2021). Carbon emissions and firm performance: A matter of horizon, materiality and regional specificities. *Journal of Cleaner Production*, *329*. Article no. 129743. https://doi.org/10.1016/j.jclepro.2021.129743

Gallego-Álvarez, I., Segura, L., & Martínez-Ferrero, J. (2015). Carbon emission reduction: The impact on the financial and operational performance of international companies. *Journal of Cleaner Production*, *103*, 149–159. https://doi.org/10.1016/j.jclepro.2014.08.047

Ganda, F., & Milondzo, K. S. (2018). The impact of carbon emissions on corporate financial performance: Evidence from the South African Firms. *Sustainability*, *10*(7), Article no. 2398. https://doi.org/10.3390/su10072398

Ghose, B., Makan, L. T., & Kabra, K. C. (2023). Impact of carbon productivity on firm performance: Moderating role of industry type and firm size. *Managerial Finance*, *49*(5), 866–883. https://doi.org/10.1108/MF-07-2022-0319

Gifford, J. L. (2012). Transportation finance. In R. D. Ebel & J. E. Petersen (Eds.), *The Oxford Handbook of State and Local Government Finance* (pp. 594–623). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199765362.013.0022

Ginglinger, E., & Moreau, Q. (2023). Climate risk and capital structure. *Management Science*, *69*(12), 7492–7516. https://doi.org/10.1287/mnsc.2023.4952

Gong, S. X. H., Firth, M., & Cullinane, K. (2016). Choice of financing and governance structures in transport industry: Theory and practice. In P. T.-W. Lee & K. Cullinane (Eds.), *Dynamic shipping and port development in the globalized economy (Volume 1: Applying theory to practice in maritime logistics)* (pp. 150–177). Palgrave Macmillan.

Griffin, P. A., Lont, D. H., & Sun, E. Y. (2017). The relevance to investors of greenhouse gas emission disclosures. *Contemporary Accounting Research*, *34*(2), 1265–1297. https://doi.org/10.1111/1911-3846.12298

Guastella, G., Mazzarano, M., Pareglio, S., & Spani, R. C. (2022). Do environmental and emission disclosure affect firms' performance?: Evidence from sectorial micro data. *Eurasian Business Review*, *12*(4), 695–718. https://doi.org/10.1007/s40821-021-00195-9

Halff, A., Younes, L., & Boersma, T. (2019). The likely implications of the new IMO standards on the shipping industry. *Energy Policy*, *126*, 277–286. https://doi.org/10.1016/j.enpol.2018.11.033

Homroy, S. (2023). GHG emissions and firm performance: The role of CEO gender socialization. *Journal of Banking and Finance*, *148*, Article no. 106721. https://doi.org/10.1016/j.jbankfin.2022.106721

Hsu, P.-H., Lee, H.-H., Peng, S.-C., & Yi, L. (2018). Natural Disasters, Technology Diversity, and Operating Performance. *Review of Economics and Statistics*, *100*(4), 619–630. https://doi.org/10.1162/rest_a_00738

Huang, H. H., Kerstein, J., & Wang, C. (2018). The impact of climate risk on firm performance and financing choices: An international comparison. *Journal of International Business Studies*, *49*(5), 633–656. https://doi.org/10.1057/s41267-017-0125-5

International Maritime Organization. (2019). *IMO 2020 - cleaner shipping for cleaner air*. https://www.imo.org/en/MediaCentre/PressBriefings/pages/34-IMO-2020-sulphur-limit-.aspx

Iwata, H., & Okada, K. (2011). How does environmental performance affect financial performance? Evidence from Japanese manufacturing firms. *Ecological Economics*, *70*(9), 1691–1700. https://doi.org/10.1016/j.ecolecon.2011.05.010

Izaguirre, C., Losada, I. J., Camus, P., Vigh, J. L., & Stenek, V. (2021). Climate change risk to global port operations. *Nature Climate Change*, *11*(1), 14–20. https://doi.org/10.1038/s41558-020-00937-z

Kiuila, O., & Rutherford, T. F. (2013). The cost of reducing CO2 emissions: Integrating abatement technologies into economic modeling. *Ecological Economics*, *87*, 62–71. https://doi.org/10.1016/j.ecolecon.2012.12.006

Lacoin, S. (2019). *Climate change resilience strategy - Redefining flood protection at Kansai International Airport*. https://www.icao.int/environmental-protection/Documents/EnvironmentalReports/2019/ENVReport2019_pg263-267.pdf

Lam, J. S. L., & Su, S. (2015). Disruption risks and mitigation strategies: An analysis of Asian ports. *Maritime Policy and Management*, *42*(5), 415–435. https://doi.org/10.1080/03088839.2015.1016560

Lee, K. H., Min, B., & Yook, K.-H. (2015). The impacts of carbon (CO2) emissions and environmental research and development (R&D) investment on firm performance. *International Journal of Production Economics*, *167*, 1–11. https://doi.org/10.1016/j.ijpe.2015.05.018

Lewandowski, S. (2017). Corporate carbon and financial performance: The role of emission reductions. *Business Strategy and the Environment*, *26*(8), 1196–1211. https://doi.org/10.1002/bse.1978

Liu, Y. S., Zhou, X., Yang, J. H., Hoepner, A. G. F., & Kakabadse, N. (2023). Carbon emissions, carbon disclosure and organizational performance. *International Review of Financial Analysis*, *90*, Article no. 102846. https://doi.org/10.1016/j.irfa.2023.102846

Makridou, G., Doumpos, M., & Galariotis, E. (2019). The financial performance of firms participating in the EU emissions trading scheme. *Energy Policy*, *129*, 250–259. https://doi.org/10.1016/j.enpol.2019.02.026

Matsumura, E. M., Prakash, R., & Vera-Muñoz, S. C. (2014). Firm-value effects of carbon emissions and carbon disclosures. *Accounting Review*, *89*(2), 695–724. https://doi.org/10.2308/accr-50629

Meleo, L., Nava, C. R., & Pozzi, C. (2016). Aviation and the costs of the European Emission Trading Scheme: The case of Italy. *Energy Policy*, *88*, 138–147. https://doi.org/10.1016/j.enpol.2015.10.008

Melkonyan, A., Hollmann, R., Gruchmann, T., & Daus, D. (2024). Climate mitigation and adaptation strategies in the transport sector: An empirical investigation in Germany. *Transportation Research Interdisciplinary Perspectives*, *25*, Article no. 101102. https://doi.org/10.1016/j.trip.2024.101102

Miah, M. D., Hasan, R., & Usman, M. (2021). Carbon emissions and firm performance: Evidence from financial and non-financial firms from selected emerging economies. *Sustainability*, *13*(23), Article no. 13281. https://doi.org/10.3390/su132313281

Moon, D. S. H., & Woo, J. K. (2014). The impact of port operations on efficient ship operation from both economic and environmental perspectives. *Maritime Policy and Management*, *41*(5), 444–461. https://doi.org/10.1080/03088839.2014.931607

Nava, C. R., Meleo, L., Cassetta, E., & Morelli, G. (2018). The impact of the EU-ETS on the aviation sector: Competitive effects of abatement efforts by airlines. *Transportation Research Part A: Policy and Practice*, *113*, 20–34. https://doi.org/10.1016/j.tra.2018.03.032

Nguyen, J. H. (2017). Carbon risk and firm performance: Evidence from a quasi-natural experiment. *Australian Journal of Management*, *43*(1), 65–90. https://doi.org/10.1177/0312896217709328

Nishitani, K., & Kokubu, K. (2012). Why does the reduction of greenhouse gas emissions enhance firm value? The case of Japanese manufacturing firms. *Business Strategy and the Environment*, *21*(8), 517–529. https://doi.org/10.1002/bse.734

Oestreich, A. M., & Tsiakas, I. (2024). Carbon emissions and firm profitability. *Journal of Sustainable Finance and Investment*. https://doi.org/10.1080/20430795.2024.2386476

Oum, T. H., Zhang, A., & Zhang, Y. (2000). Optimal demand for operating lease of aircraft. *Transportation Research Part B: Methodological*, *34*(1), 17–29. www.elsevier.com/locate/trb

Ozkan, A., Temiz, H., & Yildiz, Y. (2023). Climate risk, corporate social responsibility, and firm performance. *British Journal of Management*, *34*(4), 1791–1810. https://doi.org/10.1111/1467-8551.12665

Pankratz, N., Bauer, R., & Derwall, J. (2023). Climate change, firm performance, and investor surprises. *Management Science, 69*(12), 7352–7398. https://doi.org/10.1287/mnsc.2023.4685

Robertson, A. (2021). *Shady routes: How big retail and their carriers pollute along key ocean shipping corridors*. https://shipitzero.org/wp-content/uploads/2021/11/FINAL-Ship-it-Zero-Campaign-Report.pdf

Russo, A., Pogutz, S., & Misani, N. (2021). Paving the road toward eco-effectiveness: Exploring the link between greenhouse gas emissions and firm performance. *Business Strategy and the Environment*, *30*(7), 3065–3078. https://doi.org/10.1002/bse.2789

Saikia, M. B., & Maji, S. G. (2024). Corporate carbon emissions, science-based targets initiatives and firm performance: Evidence from India. *International Journal of Law and Management*. https://doi.org/10.1108/IJLMA-05-2024-0161

Saka, C., & Oshika, T. (2014). Disclosure effects, carbon emissions and corporate value. *Sustainability Accounting, Management and Policy Journal*, *5*(1), 22–45. https://doi.org/10.1108/SAMPJ-09-2012-0030

State of Mississippi. (2006). *The Impact of Hurricane Katrina on Mississippi's commercial public ports and opportunities for expansion of the ports*. https://www.peer.ms.gov/reports/rpt487.pdf

Statista. (2023). *European Union Emission Trading System (EU-ETS) carbon pricing in 2022*. https://www.statista.com/statistics/1322214/carbon-prices-european-union-emission-trading-scheme/

Stroebel, J., & Wurgler, J. (2021). What do you think about climate finance? *Journal of Financial Economics*, *142*(2), 487–498. https://doi.org/10.1016/j.jfineco.2021.08.004

Sun, Z.-Y., Wang, S.-N., & Li, D. (2022). The impacts of carbon emissions and voluntary carbon disclosure on firm value. *Environmental Science and Pollution Research*, *29*(40), 60189–60197. https://doi.org/10.1007/s11356-022-20006-6

Trinks, A., Mulder, M., & Scholtens, B. (2020). An efficiency perspective on carbon emissions and financial performance. *Ecological Economics*, *175*, Article no. 106632. https://doi.org/10.1016/j.ecolecon.2020.106632

Trumpp, C., & Guenther, T. (2017). Too little or too much? Exploring U-shaped relationships between corporate environmental performance and corporate financial performance. *Business Strategy and the Environment*, *26*(1), 49–68. https://doi.org/10.1002/bse.1900

United Nations Conference on Trade and Development. (2021). *Review of maritime transport 2021*. https://unctad.org/system/files/official-document/rmt2021_en_0.pdf

United Nations Conference on Trade and Development. (2022). *Review of maritime transport 2022*. https://unctad.org/rmt2022

Wang, J., Li, J., & Zhang, Q. (2021). Does carbon efficiency improve financial performance? Evidence from Chinese firms. *Energy Economics*, *104*, Article no. 105658. https://doi.org/10.1016/j.eneco.2021.105658

Wang, L., Li, S., & Gao, S. (2014). Do greenhouse gas emissions affect financial performance? - An empirical examination of Australian public firms. *Business*

Strategy and the Environment, *23*(8), 505–519. https://doi.org/10.1002/bse.1790

Wang, Y., Wu, Z., & Zhang, G. (2022). Firms and climate change: A review of carbon risk in corporate finance. *Carbon Neutrality*, *1*(1), Article no. 6. https://doi.org/10.1007/s43979-022-00005-9

Yair, Y. (2018). Lightning hazards to human societies in a changing climate. *Environmental Research Letters*, *13*(12), Article no. 123002. https://doi.org/10.1088/1748-9326/aaea86

Yan, H., Li, X., Huang, Y., & Li, Y. (2020). The impact of the consistency of carbon performance and carbon information disclosure on enterprise value. *Finance Research Letters*, *37*, Article no. 101680. https://doi.org/10.1016/j.frl.2020.101680

Yu, P., Hao, R., Cai, Z., Sun, Y., & Zhang, X. (2022). Does emission trading system achieve the win-win of carbon emission reduction and financial performance improvement? —Evidence from Chinese A-share listed firms in industrial sector. *Journal of Cleaner Production*, *333*, Article no. 130121. https://doi.org/10.1016/j.jclepro.2021.130121