TOWARDS CARBON NEUTRALITY IN OPERATIONS AND SUPPLY CHAIN MANAGEMENT

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CERTIFICATE OF ORIGINALITY

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Abstract

This dissertation integrates insights from three complementary studies to explore the impacts of announcing and implementing corporate carbon neutrality goal setting and on firms' environmental performance. The first study demonstrates that ambitious carbon neutrality goals can trigger shareholder concerns and reduce firm value, particularly in the absence of effective operational and green capabilities. The second study examines the environmental outcomes of carbon neutrality goal announcements, revealing a reduction in firms' internal carbon emissions (Scopes 1 and 2) but identifying significant carbon leakage in supply chains (Scope 3). However, supply chain integration and sustainable supplier selection mitigate these unintended consequences. The third study investigates the role of customer base complexity (horizontal, vertical, and spatial dimensions) in shaping firms' environmental performance. The findings highlight that customer base complexity exerts negative pressures on environmental outcomes, but these effects can be alleviated through robust environmental management systems. Together, these studies provide a comprehensive understanding of how goal setting, stakeholder concern, and supply chain dynamics influence firms' environmental sustainability efforts. The dissertation offers theoretical insights and actionable guidance for researchers, managers and policymakers aiming to balance stakeholder pressures, improve emissions performance, and achieve sustainable operations.

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1. Chapter 1: Introduction

1.1 Research background

In recent years, sustainability and ethical consumption have emerged as critical global concerns. Within the industrial landscape, the adoption of the Environmental, Social, and Governance (ESG) management framework has become imperative, particularly in the fashion industry with large amounts of pollution. Research and Markets (2021) reports that the global conscious fashion market is projected to grow from USD 5.84 billion in 2021 to USD 8.3 billion by 2025. However, Pucker (2022) highlighted that, despite the increasing adoption of environmentally sustainable production and distribution practices among fashion companies, significant gaps remain. The challenges are primarily due to the complex structure of the fashion and textile industry, including intricate supply chain networks and the unavoidable accumulation of excessive inventory. In fact, over the past decade, the reduction in carbon emissions achieved through the buying and selling of second-hand goods has averaged less than 0.01% annually (Kim, 2022).

A growing body of literature underscores the profound ESG challenges posed by the manufacturing industry and a gradual shift toward a more sustainable and ethical paradigm (Kim & Suh, 2022). The concept of sustainable consumption, which emphasizes the consideration of ESG impacts during purchasing decisions, has gained traction among consumers. A report by Accenture, one of worldly famous consulting firms, reveals that consumers are increasingly adopting mindful and cost-conscious shopping behaviors, with a rising demand for local, sustainable, and value-oriented brands (Standish, 2020). Notably, it was reported that 61% of consumers preferred green purchases since the start of the COVID-19 pandemic, and 89% indicated their intention to maintain these consumption habits post-pandemic. Furthermore, McKinsey highlighted that 90% of Generation Z consumers, representing the next wave of purchasing power, expect brands in the fashion industry to clearly communicate their stance on environmental issues (Amed et al., 2019). It is crucial to implement and effectively communicate sustainable commitments and practices for the manufacturing industry to align with evolving consumer expectations.

With the intensification of global warming, there is increasing concern about understanding and addressing greenhouse gas emissions throughout the life cycle of consumption goods used in everyday life, including clothing, footwear, bedding, and electronics (Leal Filho et al., 2024). According to ISO 14067, the carbon footprint of a product represents the total greenhouse gas emissions and removals associated with a product system, expressed in carbon dioxide (CO_2) equivalents, and is based on life cycle assessment (LCA) methodologies (Liu et al., 2022). This term is used to measure the cumulative greenhouse gas emissions directly and indirectly caused by an activity or accumulated across the entire life cycle of a product (Galli et al., 2012). To date, researchers and companies have calculated the carbon footprint of various consumption products, including cotton fabric (Cheng & Liang, 2021), batteries (Perocillo et al., 2025), etc.

The manufacturing industry’s significant carbon footprint makes it a critical target for climate action, especially in the fashion industry that is known for its extensive use of resources, high emissions, and globalized supply chains. The Fashion Industry Charter for Climate Action was launched in 2018, with over 100 companies committing to align with the Paris Agreement's goals (Cristina, 2018). The 2010s marked a turning point as the fashion industry began to directly address the issue of carbon emissions. Major brands like Adidas, Burberry, Gucci, and H&M introduced sustainability goals, including commitments to carbon neutrality. The push for carbon neutrality in the fashion and textile industry has intensified in recent years due to consumer pressure, regulatory requirements, and global climate goals. More fashion brands have set net-zero carbon emission goals, such as Nike and Zara's parent company, Inditex.

Carbon neutrality refers to balancing the amount of CO_2 and other greenhouse gases (GHG) released into the atmosphere with an equivalent amount removed or offset (de Sousa Jabbour et al., 2019). For the manufacturing industry, carbon neutrality encompasses emissions at all stages of the supply chain, including material sourcing, manufacturing, transportation, retail, and post-consumer disposal (Chun et al., 2018). Governments and international organizations are introducing stricter environmental regulations, such as the EU's Carbon Border Adjustment Mechanism (CBAM) which penalize companies for high emissions, incentivizing them to pursue neutrality (Siy et al., 2023). Firms that fail to comply may face financial penalties, restricted market access, or reputational damage. Advances in material science, renewable energy adoption in manufacturing, and digital solutions such as blockchain and lifecycle assessment tools have made carbon neutrality more achievable (Wan et al., 2021). Carbon neutrality efforts often involve adopting renewable energy, energy-efficient machinery, and high-tech adoption, which can also benefit the firm by reducing operational costs in the long term.

Carbon neutrality is increasingly critical for organizations, not only to mitigate climate change but also to fulfill the demands and expectations of key stakeholders (Serafeim & Yoon, 2022). A firm's pledge to carbon neutrality serves as an integral facet of a firm's sustainability communication, conveying essential information about its environmental management endeavors. Such information assists key stakeholders in gauging a company's aspirations and commitment to carbon neutrality and provides insights into the anticipated intensity of its green initiatives. By aligning with the growing preference for socially responsible investments, these commitments may bolster a firm's reputation and help to differentiate the firm in a crowded, competitive market (e.g., Dando & Swift, 2003; Kim & Park, 2011).

1.2 Research motivation

A firm's pledge to achieve carbon neutrality signals a strong commitment to environmental stewardship, which constitutes a critical component of its ESG communication. While existing studies have examined the implications of carbon neutrality announcements, their findings have often been inconclusive (Dong et al., 2022). This inconsistency may arise from insufficient attention to and differentiation of the specific content within these announcements. After reviewing the carbon neutrality announcements of various companies, we observed an intriguing phenomenon: the target years for achieving carbon neutrality vary significantly across firms. For instance, the Inditex Group (owner of Zara) has announced its goal of achieving net-zero carbon emissions by 2040, whereas Nike has set a less ambitious target year of 2050.

Firms may announce carbon neutrality goals as part of their ESG communication to engage stakeholders and convey critical information about their environmental management strategies (Eccles et al., 2014). Such announcements also provide insights into a firm's sustainability orientation, as well as its future strategic and operational trajectory (Connelly et al., 2011). However, the actual impact of a company's carbon neutrality goal announcement on its performance and stakeholder perceptions remains largely unexplored. The extent to which these announcements serve as effective signals of environmental commitment has received limited attention in prior research. Additionally, the short-term and long-term effects of carbon neutrality goals on firm performance remain uncertain. Investigating how firms generate positive or negative impacts on themselves and their stakeholders after setting and announcing carbon neutrality goals represents a significant research gap that warrants further exploration.

Carbon neutrality goal setting helps consumers and shareholders assess the firm's dedication to carbon neutrality and the intensity of its green initiatives. Aligning with the growing demand for socially responsible investments, such signals may enhance a firm's reputation, leading to strengthened stakeholder support (e.g., Ji et al., 2021; Kim & Park, 2011). However, the path to realize ESG commitment is challenging, requiring substantial operational changes that can increase costs related to innovation, training and eco-friendly materials (e.g. Goebel et al., 2018), leading to increased stakeholder concern.

Therefore, our first study in Chapter 2 sets the foundation by exploring the immediate implications of carbon neutrality goal setting on firm value. It identifies a critical tension: although ambitious goals signal strong environmental commitment, they can also raise shareholder concerns and reduce firm value due to the operational and financial challenges associated with achieving these targets. However, firms with better operational efficiency, flexibility, and stronger momentum in carbon reduction are able to mitigate these negative effects. Ambitious environmental goals are like a double-edged sword, requiring firms to carefully balance their commitments with operational and green capabilities to manage risks and achieve meaningful outcomes effectively.

Numerous studies provide robust evidence supporting a positive and significant relationship between corporate green ESG commitments and its performance (Luzzini et al., 2015; Nath and Ramanathan, 2016). However, a growing stream of literature has raised debates about the possibilities for deliberate greenwashing or deceptive practices in ESG commitments (Bothello et al., 2023; Nemes et al., 2022), highlighting the prevalence of misleading claims in ESG advertising.

Thus, building on the insights from Study one, the second study in Chapter 3 investigates how carbon neutrality goal setting influences environmental performance, particularly in terms of emissions reductions. Though firms achieve reductions in internal emissions (Scopes 1 and 2), the study reveals a significant increase in supply chain emissions (Scope 3), highlighting the unintended consequence of carbon leakage. Importantly, better supply chain integration and sustainable supplier management are shown to effectively mitigate these challenges. The findings in Study 2 extend the discussion of the challenges hinted at in Study 1. Achieving ambitious goals not only affects the firm internally but also has far-reaching implications for supply chain management. It underscores the need for firms to expand their focus beyond internal operations to include external supply chain dynamics.

Effective management of supply chain emissions (Scope 3) necessitates the active involvement of supply chain partners that are crucial for enhancing corporate social responsibility (CSR) (Klassen & Vachon, 2003). The current literature of green OSCM has extensively explored the environmental impacts of suppliers (Gualandris & Kalchschmidt, 2016) and customers (Villena et al., 2021) on firms' ESG performance. Although the complexity perspective has garnered attention in green OSCM research focusing on suppliers (e.g., Adhikary et al., 2020), its application to understanding the impact of customers on environmental sustainability remains underexplored (Xiao et al., 2019).

Finally, our third study in Chapter 4 further broadens the analysis by introducing the role of customer base complexity in shaping environmental performance. Customers, as key stakeholders, exert pressures that drive firms to adopt sustainability initiatives. However, horizontal, vertical, and spatial complexities in customer bases negatively influence firms' environmental outcomes, as they add layers of operational and strategic challenges. The study emphasizes the importance of environmental management systems and innovation as tools to mitigate these negative effects.

Study 3 adds a critical stakeholder perspective of customers to the discussion initiated in Studies 1 and 2. In summary, Study 1 focuses on shareholder concerns about ambitious ESG commitments and Study 2 highlights utilizing supplier control to address supply chain carbon leakage, Study 3 identifies the strategies for managing customer base complexity, another dimension that can complicate efforts to achieve environmental goals. Together, these three studies illustrate the interconnected pressures from internal operations, supply chains, and external stakeholders that firms must navigate in their sustainability journeys. Together, they highlight the importance of OSCM in driving meaningful environmental performance. This integrated perspective provides actionable insights for both theory and practice in sustainable OSCM.

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2. Study one: Mitigating Shareholder Concerns About Ambitious Corporate Carbon Neutrality Goals

2.1 Introduction

In answering calls from the Conferences of the Parties of the United Nations to tackle climate change (Tobin et al., 2018), developed countries such as France, the United Kingdom, and New Zealand have passed legislation aimed at achieving carbon neutrality by 2050, whereas developing countries such as Brazil and China aim for this target by 2060. National carbon neutrality goals inevitably pressure the private sector to reduce carbon emissions. For example, BP and Shell have targeted zero emissions by 2050, even though they are in the oil and gas industry, which is the world's largest polluter (Beck et al., 2020). The fashion industry is also among the top polluting industries; the Inditex group (owner of Zara) has announced its goal of achieving net-zero carbon emissions by 2040, whereas Nike has targeted 2050, which seems comparatively less ambitious.

Goal setting is vital for a firm's strategy formulation. An environmental goal is an essential link between a firm's environmental strategy and sustainable operations management. Therefore, setting a carbon neutrality goal can demonstrate a firm's strategic commitment to environmental protection to its stakeholders. An ambitious goal can send a strong signal of commitment, fulfilling stakeholders' urgent expectations for environmental, social, and governance (ESG) investment, which some investors perceive as benefiting firm value or avoiding future costs to the firm (e.g., Flammer, 2013; Russo & Fouts, 1997).

Achieving carbon neutrality can involve substantial efforts in sustainable operations management (OM) to neutralize emissions, including implementing a continuously improved environmental management system (Melnyk et al., 2003), engaging in environmental management innovation (Montabon et al., 2007), and addressing supplier and customer base concerns (Song et al., 2023; Zhu & Sarkis, 2004). The estimated annual cost of achieving carbon neutrality is projected to reach 9.2 trillion GBP (10.5 trillion USD), equivalent to half of all corporate profits in 2020 (BBC, 2020). Climate-related environmental investments can be viewed as a cost to the firm with no offsetting benefit by some investors (Cañón-de-Francia & Garcés-Ayerbe, 2009). Hence, setting an ambitious carbon neutrality goal may increase shareholders' concerns that the cost of chasing carbon neutrality will greatly reduce operating cash flow and the subsequent value of firms.

Although the pioneering study by Fisher-Vanden and Thorburn (2011) revealed that voluntary corporate environmental commitments to reduce greenhouse gas emissions may conflict with firm value maximization, no studies have analyzed how different corporate environmental goal settings affect firm value. The establishment of a goal can reveal discrepancy between a firm's current state and its desired outcome (Locke & Latham, 1990). This divergence prompts organizations to focus their attention and allocate resources toward bridging the gap, often leading to performance enhancements and the realization of the specified objective. Setting a particularly ambitious goal necessitates higher investments or shorter time frame by a firm to attain the goal and can guide shareholder perception of the firm's future strategic and operational trajectory (Connelly et al., 2011). Shareholders may support the pursuit of carbon neutrality goals, particularly ambitious ones, and/or may become apprehensive regarding the potential impacts on future cash flows stemming from the chase for carbon neutrality because of the robust ESG commitments they entail. The research gap motivated us to examine the research question (**RQ1-1**): *How does the ambitiousness of a carbon neutrality goal affect firm value?*

As emphasized by Albertini (2013), Ambec and Lanoie (2008), and King and Lenox (2001), "When and how does it pay to be green?" is more important than "Does it pay to be green?" Securing shareholder recognition and support directly influences firm's acquisition of financial resources for operational improvement. It is imperative to investigate how firms garner this recognition and support when strongly committing to carbon neutrality. A firm's capabilities, strategic approaches, and experience are essential determinants of performance improvement and subsequent goal attainment (Latham & Locke, 2002, 2007, 2019). In the context of carbon neutrality, operational efficiency is a critical capability for addressing the complexities associated with carbon neutrality. The flexibility of carbon reduction and offsetting is a strategic approach to achieving carbon neutrality, and the momentum of emission reductions reflects the experience of past practices. We extend this understanding to explore whether these factors can enhance shareholder confidence and alleviate shareholder concerns when setting ambitious carbon neutrality goals. Such an alignment could result in a combined outcome that reconciles both public and shareholder expectations, positively facilitating firms' pursuit of carbon neutrality. Therefore, we propose our second research question (**RQ1-2**) as: *In what circumstances can setting an ambitious carbon neutrality goal enhance firm value?*

To address the research questions, we conducted our analysis on a sample of 146 U.S.-listed manufacturing firms (the treated firms) that announced their carbon neutrality goals. In this treated–control event study, we compared immediate changes in firm value between the treated firms and those that had not announced carbon neutrality goals (the control firms). The findings reveal that shareholders typically respond negatively to the announcement of carbon neutrality goals, consequently diminishing the firm's value, which is more pronounced when the announced goals are more ambitious. However, shareholder apprehension regarding an ambitious carbon neutrality goal is less pronounced in firms that exhibit greater operational efficiency, demonstrate flexibility in their approaches to achieving carbon neutrality, and show substantial momentum in reducing emissions prior to the goal announcement.

This study contributes valuable insights to both theory and practice. While goal setting is a fundamental aspect of a firm's environmental strategy formulation, the current sustainable OM literature has often neglected the specific effects of environmental goal setting. By introducing a fresh perspective on goal setting in the timely context of carbon neutrality, this research adds a nuanced understanding to the theory and practice of sustainable OM. Furthermore, we enrich the ongoing discourse regarding the relationship between environmental management and firm performance by revealing the complex tension between the pursuit of carbon neutrality goals and shareholder apprehension and examine possible strategies to reconcile this tension. Consequently, this study provides practical implications for firms aiming to make significant environmental commitments without jeopardizing their appeal to shareholders.

2.2 Literature Review and Hypothesis Development

Carbon neutrality refers to a condition in which an organization or person achieves a balance between the quantity of greenhouse gas emissions they generate and those that are eliminated from the atmosphere (de Sousa Jabbour et al., 2019). Firms can neutralize the CO2 generated by their internal operations or external activities through carbon offset or reduction mechanisms (Koh et al., 2023). Carbon emissions are directly and indirectly generated by firm operations and OM is critical in forming a pathway to carbon neutrality. To attain carbon neutrality, a firm needs to adopt operational practices, including carbon footprint accounting, green purchasing, and energy savings (Wan et al., 2021). Compared with other environmental practices, the pursuit of carbon neutrality is uniquely demanding, challenging, and multifaceted, requiring an intricate alignment of policy, technology, and operational strategies (Koh et al., 2023).

In the current business landscape, shareholders exhibit increasing vigilance toward a firm's ESG commitments (Serafeim & Yoon, 2022). A firm's pledge to carbon neutrality serves as a robust signal, emphasizing its allegiance to environmental conservation. This commitment is an integral facet of a firm's ESG communication, conveying essential information about its environmental management endeavors. Such information assists consumers and shareholders in gauging a company's aspirations and commitment to carbon neutrality and provides insights into the anticipated intensity of its green initiatives. By aligning with the growing preference for socially responsible investments, these signals can bolster a firm's reputation (e.g., Dando & Swift, 2003; Kim & Park, 2011). Enhancing reputation facilitates firms in garnering support from stakeholders more effectively (Branco & Rodrigues, 2006).

Achieving carbon neutrality presents a favorable occasion for showcasing corporate responsibility and accountability, leading to potential positive ramifications for shareholder value (Ji et al., 2021). Jacobs (2014) emphasized that the establishment and rigorous upkeep of stringent carbon emission standards can cultivate a favorable reputation, ultimately augmenting the value of the corporation for its shareholders. Li et al. (2023) analyzed the carbon neutrality announcements of 226 Chinese companies and found significant positive effects of carbon neutrality initiatives on the announcement day (with an average abnormal return of 0.99%), leading to positive long-term impacts on shareholder value. On the basis of data from 188 carbon neutrality announcements, Liu et al. (2024) determined that carbon neutrality announcements enhance shareholder value in China, with strategic-level carbon neutrality announcements yielding more significant and positive effects.

The journey to carbon neutrality is particularly difficult because substantial operational changes are required to reduce emissions. Pursuing this path can escalate innovation, operational, training, and eco-friendly material acquisition costs (Bowen et al., 2001; Goebel et al., 2018; Wong et al., 2020; Zhu & Sarkis, 2004); such financial commitments can strain a firm’s future cash flows, and the return on investment is distant and uncertain. Recent studies suggest that shareholder reactions to ESG announcements are driven primarily by financial rather than nonpecuniary motives such as reputation (Serafeim & Yoon, 2022). Krüger (2015) supposed that the decline in market value following the announcement of ESG news can be primarily attributed to agency costs. Drawing from this understanding, previous research underscores the potential trade-off between green initiatives and financial performance (e.g., Cordeiro & Sarkis, 1997; Worrell et al., 1995). Liu et al. (2023) used a dataset comprising 354 publicly listed companies in A-shares and found the promulgation of the carbon neutrality policy resulted in a significant negative stock market reaction. Xie et al. (2022) analyzed 166 companies from the United Kingdom and the United States and reported that companies experienced market value losses ranging from −2.09% to −1.21% as a result of committing to carbon neutrality.

The conflicting stock market reactions to carbon neutrality announcements may be attributed to the fact that carbon neutrality commitments do not always yield immediate optimal outcomes (Dong et al., 2022). Specifically, carbon neutrality-related events with diverse content possess varying information values, which can result in different effects on shareholder value. Dong et al. (2022) further summarized that the action event led to a 0.04% increase in carbon neutrality-related stocks, whereas the vision event resulted in a −0.003% change, suggesting that investors' confidence grows when a carbon neutrality commitment is accompanied by specific and detailed guidelines. Because of the presence of policy uncertainty and associated risks, it may prove challenging for the vision event of carbon neutrality to elicit a positive response from the capital market (Zou et al., 2021). Setting a carbon neutrality goal stands out as decision-making to set clear, quantifiable, and timebound goals. This specificity, coupled with the significant operational changes required to attain carbon neutrality, renders a carbon neutrality goal a unique and consequential commitment for firms. When companies make announcements related to carbon neutrality goal setting, they inevitably need to disclose the timelines for achieving the status of carbon neutrality. The length of the time frame for reaching carbon neutrality represents the ambition level of the company's goals, which may subsequently influence how stakeholders interpret and respond to the company's objectives (Hahn et al., 2015). Although Fisher-Vanden and Thorburn (2011) observed that firms engaging in the voluntary EPA Climate Leaders program (a corporate environmental initiative aimed at reducing greenhouse gas emissions) experienced significant negative abnormal stock returns through their study of 117 announcements, the immediate impact of setting different levels of ambitious environmental goals as detailed guidelines on investors and the stock market remains unclear.

2.2.1 Ambitious Carbon Neutrality Goals and Firm Value

According to goal-setting theory, a goal is defined as a specific, intended outcome or objective of an action (Locke & Latham, 1990). A core concept in this theory is discrepancy creation, which involves the deliberate establishment of a gap between an individual's or organization's current performance and a desired outcome (Bandura, 1989; Bandura & Locke, 2003). The literature on goal-setting theory has consistently demonstrated that specific and challenging goals can enhance motivation and lead to improved performance outcomes (Latham & Locke, 1975; Locke, 1968; Locke & Latham, 1990). Although Fisher-Vanden and Thorburn's (2011) exploratory research revealed that firms participating in programs requiring the announcement of specific greenhouse gas emission reduction targets experienced further stock price declines compared with those joining initiatives emphasizing more general environmental principles across all domains (not just climate change), the influence of environmental goal difficulty remains unknown.

The perceived difficulty of a goal can be characterized in two main ways. First, this difficulty refers to the discrepancy between the present state and the goal itself, with a larger gap signaling a more challenging objective (Locke & Latham, 1990). Second, the set deadline for the goal plays a pivotal role in gauging its difficulty. A tighter deadline suggests a compressed time frame for achievement, thus demanding more rapid performance enhancements (Fried & Slowik, 2004). Such ambitious goal-setting decisions reflect a preference for swift, significant progress.

Ambitious goals, characterized by a high discrepancy-to-time-frame ratio, demand increased effort and dedication. Attaining these goals necessitates focused attention on goal-related tasks (Locke & Bryan, 1969), heightened and sustained effort (Latham & Locke, 1975; Locke, 1968), enduring motivation (Huber, 1985), and the cultivation and application of pertinent knowledge and strategies (Wood & Locke, 1990).

The traditional perspective on goal-setting theory views it as a motivational mechanism. However, goals set by entities, especially firms, can also serve as signals to a broader set of stakeholders, indicating future strategic and operational trajectories. Stakeholder reactions to these signals can be instrumental in determining firm performance (Bosse et al., 2009). Therefore, integrating signaling theory with goal-setting theory offers a richer understanding of how stakeholders might interpret and respond to a firm's goals, thereby influencing its overall performance. This integration serves as the theoretical foundation for answering the research questions.

Setting ambitious carbon neutrality goals inherently implies that the firm is committed to achieving larger emission reductions in a shorter time frame. While shareholders may interpret this ambition as a testament to the firm's robust commitment to swiftly achieving these stringent benchmarks, it simultaneously highlights the firm's imminent need for increased resources and investments. Such goals demand significant advancements within constrained periods, escalating costs related to innovation, operations, training, and eco-friendly material acquisition (e.g., Bowen et al., 2001; Goebel et al., 2018; Wong et al., 2020; Zhu & Sarkis, 2004). These financial commitments can strain a firm's future cash flows, and the return on investment is distant and uncertain (Erekson et al., 2008; Fisher-Vanden & Thorburn, 2011; Jaggi & Freedman, 1992).

An intensified focus on carbon neutrality might push firms to allocate more to green projects, potentially raising concerns about the immediate economic implications and financial stability (Cañón-de-Francia & Garcés-Ayerbe, 2009). Investors may question the firm's ability to generate sufficient cash flow to fund these initiatives, especially in the short term. Without a clear financial plan or evidence of cost-effective strategies, investors may hesitate to support ambitious carbon neutrality goals. Given shareholders' heightened attention to financial outcomes post-ESG announcements (Serafeim & Yoon, 2022), setting a more ambitious carbon neutrality goal may further undermine firm value. Consequently, we posit that setting a more ambitious carbon neutrality goal can further undermine firm value.

H1-1: The market reaction to corporate carbon neutrality goal setting is more negative when the goal is more ambitious.

2.2.2 Mitigating Shareholder Concerns About Ambitious Carbon Neutrality Goals

Although an ambitious carbon neutrality goal may negatively affect firm value, it signals strong environmental commitment and can enhance the firm's reputation. As emphasized by Albertini (2013), Ambec and Lanoie (2008), and King and Lenox (2001), the question "When and how does it pay to be green?" is more salient than the more general inquiry of "Does it pay to be green?". This shift in focus underscores the importance of exploring the contextual conditions and key factors that can lead to more positive financial impacts of corporate environmental initiatives rather than simply seeking to establish an overall link between environmental commitment and financial performance. The “when and how” question recognizes that the relationship between environmental stewardship and financial outcomes is complex and nuanced and may vary depending on factors such as the type of environmental strategy, operation management, the regulatory landscape, stakeholder pressures, and the time horizon considered (Delmas & Toffel, 2008; Orsato, 2006).

Successful firms often balance diverse stakeholder, operational, and marketing needs, effectively managing tensions between carbon neutrality goals and shareholder value (Hahn et al., 2018; Pinto, 2019). As Lüscher and Lewis (2008) posited, organizations gain traction not by eliminating paradoxes but by navigating them. Thus, we delve into strategies whereby managers can harmonize ambitious carbon neutrality aspirations with shareholder expectations. Goal-setting theory emphasizes that a firm’s capabilities, strategic approaches, and experience are essential determinants of performance improvement and subsequent goal attainment (Locke & Latham, 2019). Proficiency in green operations not only bolsters confidence in achieving carbon neutrality but also boosts shareholder trust. Thus, shareholders may anticipate that these firms can offset short-term green operation costs by leveraging operational expertise, thus paving a smoother path to carbon neutrality. These potentially contributing factors motivated us to explore our second research question, which examines whether greater operational efficiency, flexibility to offset emissions, and stronger momentum in reducing carbon emissions help enhance firm value when setting an ambitious carbon neutrality goal.

Operational efficiency is a crucial capability for navigating the complex landscape of carbon neutrality. Efficient firms excel in reducing waste, optimizing resource utilization, and maximizing output (Lee & Johnson, 2014; Madhavan & Grover, 1998; Priem & Butler, 2001). Operational efficiency is not merely about cost savings but also intrinsically aligned with environmental stewardship, enabling firms to substantially reduce their carbon footprint and make the path to carbon neutrality shorter and more achievable.

Shareholders in today's ESG-focused investment landscape are keenly aware of the dual benefits of operational efficiency: the direct financial gains from optimized processes and the longer-term advantages of sustainable, environmentally friendly operations. For instance, Aroul et al. (2022) concluded that higher operational efficiency enhances firms' ESG scores and facilitates a positive effect of ESG scores on operational performance. Li et al. (2021) also indicated that companies with higher operational efficiency can achieve greater optimal benefits by improving corporate social responsibility. When a firm showcases its operational efficiency, it not only demonstrates its prowess in waste reduction but also underscores its strategic positioning for a carbon-neutral future. Consequently, these firms are likely to attract and maintain the confidence of shareholders as they demonstrate a greater ability to achieve ambitious carbon neutrality goals with lower costs. Thus, we set the following hypothesis:

H1-2: The negative impact of ambitious goals on the market reaction to setting a carbon neutrality goal is mitigated when firms have higher operational efficiency.

Flexibility as an asset has received extensive attention in OM literature (Gerwin, 1993; Koste et al., 2004). In the carbon neutrality context, flexibility in the approach, whether solely to reduce emissions or to combine reduction with offsetting, can markedly influence the feasibility and efficiency of the neutrality journey. Some firms opt to commit solely to reducing emissions internally to demonstrate a stronger environmental commitment, whereas others maintain flexibility to offset emissions externally. As firms approach their emission reduction targets, the marginal cost of further reductions escalates, often becoming economically challenging (Blanco et al., 2020; Blanco, 2022). In such scenarios, the ability to purchase carbon offsets emerges as a viable alternative, expediting the path to carbon neutrality (Roemer et al., 2023). Firms with the flexibility to integrate internal emission reduction and external emission offset can navigate the carbon neutrality landscape with reduced financial and resource burdens. Conversely, a rigid approach anchored only in direct emission reduction may demand hefty investments in green innovation, risking stagnation if not pursued effectively. Thus, flexibility not only eases the green transition but also alleviates shareholder apprehensions about financial implications. These arguments led us to our third hypothesis:

H1-3: The negative impact of ambitious goals on the market reaction to setting carbon neutrality goals is mitigated when firms maintain the flexibility to offset emissions.

Momentum represents a consistent performance experience over time, either ascending (positive momentum) or descending (negative momentum) based on a series of outcomes (Lehman & Hahn, 2013). Studies across various fields have demonstrated that managers often project past trends into the future, supposing that established status will persist (Bar-Eli et al., 2006; Gilovich et al., 1985). Furthermore, momentum directly influences the collective efficacy of an organization's members because positive momentum cultivates collective confidence in accomplishing set tasks (Audia et al., 2000; Lindsley et al., 1995).

Regarding carbon neutrality, the momentum of emission reduction prior to goal setting is a potent demonstration of a firm's effective abatement strategies. Shareholders observing an organization with substantial positive momentum in carbon reduction are likely to project this past success onto the organization's follow-up efforts, enhancing their confidence for the organization's commitment and capabilities. Specifically, Xie et al. (2022) discovered that companies with a history of better ESG performance can alleviate the adverse market reactions resulting from commitments toward carbon neutrality. This prior momentum not only promotes a more positive shareholder outlook but also bolsters the self-efficacy of organizational members in their carbon reduction endeavors. This dual reinforcement (internally among staff and externally among shareholders) serves to alleviate potential concerns associated with ambitious carbon neutrality goals, fostering a more favorable environment for green operations and investments. Hence, we proposed the following hypothesis:

H1-4: The negative impact of ambitious goals on the market reaction to setting a carbon neutrality goal is mitigated when firms show greater momentum to reduce carbon emissions prior to goal setting.

2.3 Methodology

The manufacturing sector is a major contributor to global greenhouse gas emissions, accounting for a significant share of total industrial emissions (International Energy Agency, 2022). To test our hypotheses, we focused on U.S.-listed manufacturing firms categorized under Standard Industry Classification (SIC) codes 2000–3990. Data collection was conducted using archival sources from three databases. First, following Monfort et al. (2021), we extracted announcements of carbon neutrality goal-setting from the Factiva database, a reputable source for corporate announcements offering both real-time updates and archival data from global news outlets. Second, financial data, including stock prices and accounting records, were sourced from the COMPUSTAT database, which provides standardized, comprehensive historical financial information on U.S.-listed companies (Lo et al., 2014). Third, environmental data were obtained from Thomson Reuters' Refinitiv Eikon database, which aggregates data voluntarily disclosed by firms via websites and sustainability reports (Dahlmann et al., 2023).

2.3.1 Sample Collection and Description

We conducted an event study to assess the immediate stock market reactions of U.S.-listed manufacturing firms to carbon neutrality goal-setting announcements. Given that firms may revise their carbon neutrality goals over time, and that shareholder responses may vary across successive announcements, we limited our analysis to each firm's initial public announcement of its carbon neutrality goal. This approach follows established event study practices (Corbett et al., 2005; Harris & Bromiley, 2007). We defined the event as the first public announcement by a firm declaring its intention to achieve carbon neutrality.

The data collection process began with compiling a list of 3,024 active U.S.-listed manufacturing firms from the COMPUSTAT database. We then searched for relevant media reports in the Factiva database using keywords such as "carbon neutral*" and "net zero," combined with firm names. For each identified announcement, we carefully reviewed the content to retain only the first announcements explicitly targeting carbon neutrality or net zero. Announcements associated with confounding events, such as earnings releases, leadership changes, or mergers and acquisitions, were excluded. This process yielded 273 unique announcements made between 2002 and January 2022.

Key details were extracted from the announcements, including the target year for achieving carbon neutrality, the scope of the goals (e.g., Scope 1, Scope 2, and Scope 3 emissions), and the strategies for achieving carbon neutrality (e.g., the use of carbon offsets). These details were used to measure key variables outlined in Section 4.4.1. Examples of key sentences from the announcements include:

- *General Motors Co. said Thursday it plans to be carbon neutral by 2040.*
- *Honda has decided to strive for the realization of carbon neutrality by 2050.*
- *Reach carbon neutrality and zero waste in HP operations by 2025.*

A direct comparison of firm performance before and after carbon neutrality goal-setting announcements is problematic, as counterfactual outcomes cannot be directly observed or calculated (Caliendo & Kopeinig, 2008). To address this issue, we employed propensity score matching (PSM) to conduct a natural experiment using a treated–control matching approach (Fan et al., 2022). Firms that announced carbon neutrality goals were designated as treated firms. To construct the matched sample, we first excluded treated firms with incomplete financial or environmental data. We then matched each treated firm with a control firm selected from the pool of active U.S.-listed manufacturing firms that had not made such announcements. Matching was performed based on propensity scores, ensuring that treated and control firms were comparable on relevant covariates. This process resulted in a final sample of 146 matched pairs (treated and control firms) for data analysis. The detailed sample screening procedures are outlined in Table 2-1.

Table 2-1 Detailed procedures for sample screening

Procedure	Deletion	Numbers of firms
Number of listed U.S. active manufacturing firms with carbon neutrality goal setting announcements		273
With sufficient financial data (including stock data)	-95	178
With sufficient environmental data	-32	146
Conducting propensity score matching	+ 146 (control firms)	146 (pairs)

2.3.2 Propensity Score Matching

The heterogeneity between treated and control firms may confound the observed effects of carbon neutrality goal-setting announcements. For instance, if a treated firm exhibits a significantly lower return on sales (ROS) than its matched control firm, the negative outcomes in the treated firm could stem from its limited adaptability to changing conditions rather than the direct impact of the carbon neutrality announcement. To mitigate this potential endogeneity, we adopted a propensity score matching (PSM) approach, as recommended by Ding et al. (2018) and Paulraj and de Jong (2011). This method allowed us to construct a control group that functioned as a counterfactual for comparison with the treated firms. The objective of the PSM approach was to estimate the propensity score, or the likelihood of a firm announcing a carbon neutrality goal, based on observable characteristics.

We initiated PSM by coding a binary variable, assigning a value of "1" to treated firms (those announcing carbon neutrality goals) and "0" to potential control firms. A probit regression was then conducted, with the binary variable as the dependent variable and a set of potential determinants of carbon neutrality goal-setting announcements as the independent variables. Sales-to-Property, Plant, and Equipment Ratio (SOP) measures capital investment efficiency, defined as the amount of sales generated per dollar invested in property, plant, and equipment (PPE). Firms with higher SOPs are more likely to convert production resources into green operations, reducing operational slack (Hendricks et al., 2009; Modi & Mishra, 2011; Wiengarten et al., 2017). R&D intensity is measured as the expense of Research & Development divided by sales and normalized by industry and year. This variable captures a firm's innovation capability. Firms with higher innovation capability are better positioned to engage in green innovations. Return on Sales (ROS), calculated as earnings before interest and taxes divided by sales, represent a firm's operating profit margin. Higher ROS indicates stronger financial efficiency, reducing concerns about financial risks associated with green investments. We also introduce Mean_IndAnnouncing to capture the average number of carbon neutrality goal-setting announcements within a firm's industry, included as an exogenous factor.

All independent variables were lagged by one year to account for temporal effects. Additionally, year and industry (two-digit SIC) dummy variables were included to control for unobserved heterogeneity across time periods and industries (Lo et al., 2018). This ensured that the results were not biased by variations in general industry or year-specific conditions.

Using the regression coefficients reported in Table 2-2, we calculated propensity scores for each treated and control firm. Each treated firm was matched with a control firm from the same industry and year, using the nearest propensity score. Post-matching analyses revealed no significant systematic differences between treated and control firms before and after sample exclusion, ensuring comparability.

The systematic differences in the independent variables were statistically insignificant, indicating a well-balanced match between groups. Moreover, we analyzed cumulative abnormal returns (CARs) for treated and control firms prior to the carbon neutrality announcements and found no significant differences, suggesting parallel stock price trends between the two groups before the event. Based on these robustness checks, we concluded that the treated and control firms were statistically comparable.

Our empirical strategy involved estimating the treatment effect of carbon neutrality goal setting by analyzing the abnormal cumulative abnormal returns ($Abnm\_CAR_i$). Specifically, the variable $Abnm\_CAR_i$ represents the abnormal difference between the CAR of a treated firm and that of its matched control firm. We tested whether $Abnm\_CAR_i$ was significantly different from zero, as detailed in Section 2.3.3. Furthermore, we investigated the relationship between $Abnm\_CAR_i$ and goal ambitiousness, as well as the interaction effects between goal ambitiousness and three operational factors: high operational efficiency, flexibility in achieving carbon neutrality, and momentum to reduce emissions prior to goal setting. These analyses, explained in detail in Section 2.3.4, provide insights into how firms can mitigate shareholder concerns through operational strategies while pursuing ambitious carbon neutrality goals.

Table 2-2 Estimated coefficients of the probit model for PSM

	Dependent Variable: Carbon Neutrality Goal Setting Announcing			
Independent variables	Coefficient	S.E.	p	VIF
SOP	-0.087	0.020	0.000	1.000
R&D intensity	-0.312	0.227	0.169	1.006
ROS	0.024	0.005	0.000	1.001
Mean_IndAnnoucing	0.374	2.034	0.854	1.004
Year dummy	Included			
Industry dummy	Included			
R^2	32.15%			
N	22,197			
Firms	3024			

2.3.3 Event Analysis

Shareholder reactions to carbon neutrality goal-setting announcements are critical, as they directly influence firm value and future cash flow. According to the efficient-market hypothesis (Fama, 1970), shareholders respond quickly to public announcements because these provide new information that shapes their assessments of a firm's prospects. These adjustments in shareholder evaluations are reflected almost immediately in stock price changes. Based on this theory, the event study approach assumes that market prices adapt instantaneously to incorporate newly available information (MacKinlay, 1997). Short-horizon event studies are particularly effective in capturing immediate shareholder reactions to such announcements (Ding et al., 2018).

To examine shareholder responses to carbon neutrality goal-setting announcements, we adopted the event study methodology (e.g., Brown & Warner, 1980; MacKinlay, 1997). Using this approach, we calculated abnormal returns (ARs), which measure stock price deviations from expected performance following a corporate announcement. The event announcement date was designated as day 0, allowing calendar days to be aligned with event days. In accordance with the efficient-market hypothesis, any immediate effects of an announcement should be observable in stock price changes on day 0. However, it is possible for event-related information to leak through informal channels prior to the formal announcement. To account for this, we used a two-day event period that included the announcement day (day 0) and the trading day preceding it (day −1) (e.g., Hendricks & Singhal, 2009; Jacobs & Singhal, 2014). This approach ensures that potential information leakage is captured in the analysis.

We employed Fama and French's (1993) three-factor model to estimate abnormal returns. Expected returns for each firm's stock price were calculated using a 200-day estimation period, spanning from day −210 to day −11 relative to the event day (Jacobs & Singhal, 2014; Lo et al., 2018). Firms with fewer than 40 days of stock price data during the estimation period were excluded from the sample to ensure reliability. Additionally, the estimation period was terminated at day -10 to prevent the announcement from influencing the estimates and to minimize concerns about non-stationarity (Jacobs et al., 2010; Lo et al., 2018).

We first assessed the impact of carbon neutrality goal-setting announcements on the mean AR for both day −1 and day 0 of the event period. Subsequently, we calculated cumulative abnormal returns (CARs) as the sum of daily mean ARs over the two-day event period (day −1 to day 0). To test whether the mean ARs and CARs were significantly different from zero, we conducted a parametric paired t-test. Specifically, we analyzed the treated firms, the control firms, and the abnormal changes between the two groups using Equation (1) as below. To ensure the robustness of our findings, we complemented t-tests with Wilcoxon signed-rank test, which examines the median differences, and the binomial sign test, which assesses the direction of changes. These additional tests provide further confidence in the validity of our analysis.

$$Abnm\_CAR_i = MatchedTreated\_CAR_i - MatchedControl\_CAR_i. \quad (1)$$

2.3.4 Regression Analysis

As mentioned above, we focused on each company's initial announcement of carbon neutrality goal setting; our event study thus relies on these singular instances. Because of this approach, this study lacked repeated observations for each sample, resulting in a cross-sectional analysis. This methodology aligns with similar event studies in the field (e.g. Arora et al., 2020; Lo et al., 2018). We developed an ordinary least squares regression model to analyse whether the variations of abnormal stock price changes (CAR from day -1 to 0), as calculated in Eq. (1), were influenced by the hypothesised factors of goal ambitiousness, operational efficiency, flexibility in offsetting emissions and momentum of reducing carbon emissions. The regression model with control variables (discussed below in Section 3.4.1) can be expressed as Eq. (2):

$$Abnm\_CAR_i = \beta_0 + \beta_1 Goal\ ambitiousness_i + \beta_2 Goal\ ambitiousness_i * Operational\ efficiency_i + \beta_3 Operational\ efficiency_i + \beta_4 Goal\ ambitiousness_i * Flexibility_i + \beta_5 Flexibility_i + \beta_6 Goal\ ambitiousness_i * Momentum_i + \beta_7 Momentum_i + \beta_8 IMR_i + \beta_9 Controls_i + \varepsilon_{i.} \qquad (2)$$

2.3.4.1 Measures

Except for goal ambitiousness, flexibility and the scope dummy obtained from the carbon neutrality goal-setting announcements, all independent variables and control variables in Eq. (2) for firm *i* had a one-year lag on the dependent variable. The variable measurements and data sources are summarised in Table A.1 in Appendix A.

Goal Ambitiousness. The perceived difficulty of a goal can be characterised in two main ways. First, this difficulty refers to the discrepancy between the present state and the goal itself, with a large gap signalling a challenging objective (Locke & Latham, 1990). Second, the set deadline for the goal plays a pivotal role in gauging its difficulty. A tight deadline suggests a compressed timeframe for achievement, thus demanding rapid performance enhancements (Fried & Slowik, 2004). Setting a goal creates a discrepancy between the firm's status quo and the goal (Bandura & Locke, 2003). Attaining the goal requires attention, effort and resources, driving performance improvement to reduce the discrepancy to zero (Latham & Locke, 2007). In our research context, setting a corporate carbon neutrality goal creates a discrepancy between the firm's current emission level (status quo) and carbon neutrality (the goal) and defines the openly committed timeframe of goal attainment. Thus, we incorporated both the volume of emissions to be compensated (scaled by the number of employees to control for firm size) and the timeline for achieving carbon neutrality. Achieving carbon neutrality involves reducing or offsetting carbon emissions to zero, making the current emission level an indicator of the discrepancy between the present state and the goal. The higher the current emission level, the greater the accomplishment needed to reduce this discrepancy. The year set for achieving carbon neutrality (e.g. 2040 or 2050) served as a deadline for reducing or offsetting carbon emissions to zero. A short timeframe implies that firms must exert effort annually to offset emissions. The formula for calculating goal ambitiousness is as follows:

$$Goal\ ambitiousness = \frac{{}^{Carbon\ emmision-0}/_{Employees}}{Goal\ year-Goal\ announce\ year}. \quad (3)$$

Operational Efficiency. We applied the stochastic frontier estimation (SFE) methodology to measure this variable (Dutta et al., 2005; Li et al., 2010). In contrast to traditional efficiency measures that rely on a single financial indicator, SFE offers a more comprehensive assessment of overall operational efficiency (Lam et al., 2016), measures a firm's relative operational efficiency in its industry and compares this efficiency across industries (Dutta et al., 2005). Following Lam et al. (2016), we implemented SFE and first developed a stochastic production function to represent the correlation between a company's operational resources and its operational output, as shown in Eq. (4):

$$\ln\ (Operating\ Income)_{ijt} = \beta_0 + \beta_1 \ln\ (Number\ of\ Employees)_{ijt} + \beta_2 \ln\ (Cost\ of\ Goods\ Sold)_{ijt} + \beta_3 \ln\ (Capital\ Ecpenditure)_{ijt} + \varepsilon_{ijt} - \mu_{ijt}, \quad (4)$$

where ε_{ijt} captures the stochastic random error term, and μ_{ijt} represents the technical inefficiency that relatively measures the inefficiency level of a firm in relation to the corresponding frontier in the same industry within the same year. Thus, we calculated the operational efficiency of firm i in industry j in year t as below in Eq. (5). We further multiplied this variable by 100 for consistency in the scale of regression coefficients across variables.

$$Operational\ Efficiency_{ijt} = 1 - \widehat{\mu_{ijt}}. \qquad (5)$$

We then introduced *flexibility* in achieving carbon neutrality. There are two mechanisms for achieving carbon neutrality. The choice of net zero requires an internal measure to reduce carbon emissions directly to zero, which involves operational changes, while some firms may also accept carbon offset as one of the methods to realise carbon neutrality. The flexibility of using the two combined mechanisms may relieve shareholder concerns about goal attainment. Therefore, we coded '0' for firms that announced net zero; otherwise, we coded '1'.

Momentum to reduce emissions prior to setting the goal was measured in terms of whether the firm demonstrated a strong momentum in reducing carbon dioxide emissions when announcing its carbon neutrality goal and the magnitude of that momentum in terms of the volume of reductions in a two-year period. Thus, we calculated momentum in year t as the difference between the change in carbon dioxide emissions per employee in year t and the change in emissions per employee in year t–1. We specifically supposed the momentum to be positive if a firm had low carbon dioxide emissions because it was on a reduction track. The contrasting relationship between these two variables prompted us to employ Formula 6 for calculating momentum:

$$\text{Momentum}_t = \left(\frac{CO2\ emission_{t-1}}{employee_{t-1}} - \frac{CO2\ emission_t}{employee_t}\right) - \left(\frac{CO2\ emission_{t-2}}{employee_{t-2}} - \frac{CO2\ emission_{t-1}}{employee_{t-1}}\right).$$

(6)

To enhance the robustness of our analysis, we included several control variables that account for firm-level characteristics influencing green operational practices and financial performance. Labor intensity, which reflects the availability of labor resources to support the adoption of green operational practices, was operationalized as the total number of employees divided by total assets (Dewenter & Malatesta, 2001; Hardcopf et al., 2019). We also controlled production efficiency using labour productivity, measured as earnings before interest and taxes (EBIT) per employee (Hendricks et al., 2009; Wiengarten et al., 2017). Including these variables accounts for the possibility that firms with greater labor resources or higher production efficiency may face fewer shareholder concerns about cash flow when pursuing carbon neutrality goals.

Sales growth, measured as the annual percentage change in sales, was included to capture a firm's ability to increase revenue over time. Leverage, calculated as total debt divided by total assets, was included to account for a firm's capacity to undertake high-risk investments through borrowing (Dai et al., 2021). These variables help control a firm's financial flexibility and risk profile, which may influence its ability to implement green operational strategies. We controlled for tangibility, which reflects the proportion of tangible assets in a firm's total assets, calculated as gross property, plant, and equipment (PPE) divided by total assets. We also included CapEx, measured as capital expenditure scaled by total assets, to account for a firm's liquidity and its ability to allocate financial resources efficiently. Firms with higher levels of tangible assets or capital reserves are better positioned to manage risks and invest in green operations to achieve carbon neutrality (Dai et al., 2021). R&D intensity, which indicates a firm's innovation capacity, was measured as R&D expenses divided by sales and normalized by industry and year to address variation across industries and time periods. Innovation capability can significantly influence a firm's performance and its ability to adopt green practices.

We also included three dummy variables. Year and industry (two-digit SIC) dummy variables were included to control for general conditions that varied between years and industries (Lo et al., 2018). The scope of a firm's carbon neutrality goals can influence the relationship between goal ambitiousness and firm performance. Some firms may limit their goals to internal operations (Scope 1), others may include energy consumption (Scope 2), and some may extend to the entire supply chain and product life cycle (Scope 3). To account for these differences, we coded the scope of each firm's carbon neutrality goal and included scope dummies. This ensures that variations in goal scope are isolated, allowing us to better estimate the impact of goal ambitiousness on firm value.

2.3.4.2 Correcting for Selection Bias

Although the propensity score matching (PSM) design and inclusion of multiple control variables help mitigate endogeneity concerns, issues may still arise due to factors such as selection bias from unobserved omitted variables (Wooldridge, 2015). For instance, firms that set carbon neutrality goals may differ systematically from those that do not. Although the risk of reverse causality was minimized by introducing a time lag between the independent and dependent variables (Wiengarten et al., 2017), selection bias remains a potential concern. Thus, we employed the Heckman selection two-stage analysis model (Heckman, 1979) that corrects for selection bias by accounting for the factors influencing a firm's likelihood of announcing carbon neutrality goals.

In the first stage, we identified the predictors of a firm's probability of announcing carbon neutrality goals. Firms that announced carbon neutrality goals at year t were coded as "1," while firms without such announcements were coded as "0." To satisfy the exclusion restriction—the requirement that at least one independent variable in the selection model be exogenous and unrelated to the outcome variable—we followed prior research (Fisman & Svensson, 2007; Lo et al., 2018) and included an industry-level variable, Mean_IndAnnouncing, as an exogenous predictor.

Mean_IndAnnouncing measures the average number of carbon neutrality goal-setting announcements within a firm's industry. This variable reflects the level of industry-wide attention to carbon neutrality and captures peer effects consistent with institutional theory and the diffusion of innovation theory. Firms in industries with a higher prevalence of carbon neutrality announcements are more likely to adopt similar goals, driven by industry norms and competitive pressures. Importantly, as an aggregate industry-level measure, this variable is exogenous to firm-specific outcomes and does not introduce firm-level biases.

To enhance the explanatory power of the selection model, we also included firm-level variables such as the sales-to-property, plant, and equipment ratio (SOP), R&D intensity, return on sales (ROS), and year and industry dummies, consistent with the variables used in the probit model (see Section 2.3.2). The results from the probit model are presented in Table 2-2 before. From this probit regression, we calculated the inverse Mills ratio (IMR) for each observation. The IMR is derived as the ratio of the probability density function to the cumulative distribution function within the context of the standard normal distribution (Chen et al., 2009). This ratio adjusts for the non-randomness of the sample by capturing the likelihood of a firm's inclusion in the treated group, based on observable characteristics.

In next stage, we incorporated the IMR as an additional regressor for outcome equation to correct for self-selection bias. By including the IMR, we accounted for the influence of unobserved factors that might systematically affect both the likelihood of announcing carbon neutrality goals and the outcome variables. This adjustment ensures that the coefficients in the outcome model are unbiased and consistent, as the IMR corrects for the non-random nature of the treated subsample. This two-stage approach strengthens the validity of our hypothesis testing by addressing endogeneity concerns and ensuring that the estimated relationships between carbon neutrality goal-setting announcements and firm outcomes are robust and reliable.

2.4 Results

2.4.1 Event Analysis Results

We conducted parametric paired t-test nonparametric, nonparametric Wilcoxon signed-rank tests and binomial sign tests to examine stock market reactions to carbon neutrality goal-setting announcements, and the results are shown in Table 2-3. We calculated the ARs between each pair of matched treated and control firms, and the mean AR of day 0 and the mean CAR of the two-day window (day –1 to day 0) were both significantly negative (–0.484%, $p < 0.05$; –0.599%, $p < 0.05$). Similarly, in the treated firm group, the mean AR of day 0 and the average CAR of day –1 to day 0 were both significantly negative (–0.599%, $p < 0.01$; –0.840%, $p < 0.01$), whereas for the control firms, the mean AR of day −1 and day 0 and the mean CAR of day −1 to day 0 were nonsignificant. Thus, the endogeneity of the event study model should be partly addressed because there were no significant changes in the control firms' stock prices. The significant changes in stock prices in both treated firms and the ARs between the treated and control firms should be caused by the carbon neutrality goal-setting announcements. These results indicated that the direction of the relations was negative. We then conducted nonparametric Wilcoxon signed-rank tests and binomial sign tests, and the results remained robust.

Table 2-3 Abnormal returns of the carbon neutrality goal setting announcements

Short-term event study	Data	AR day -1	AR day 0	CAR day -1 to day 0
	n	146	146	146
Treated – Control	Mean	-0.115%	-0.484%	-0.599%
	T-statistic	-0.500	-1.959**	-2.128**
	Median AR	-0.315%	-0.471%	-0.581%
	Wilcoxon signed-rank Z-statistic	-0.820	-2.767***	-2.504**
	% negative	58.220%	59.590%	56.850%
	Binomial sign test Z-statistic	-1.903*	-2.235**	-1.572
Matched treated	Mean	-0.241%	-0.599%	-0.840%
	T-statistic	-1.511	-3.236***	-3.673***
	Median AR	-0.168%	-0.263%	-0.523%
	Wilcoxon signed-rank Z-statistic	-1.312	-2.990***	-3.691***
	% negative	55.480%	58.900%	63.010%
	Binomial sign test Z-statistic	-1.241	-2.069**	-3.062***
Matched control	Mean	-0.126%	-0.116%	-0.241%
	T-statistic	-0.718	-0.515	-0.904
	Median AR	-0.067%	-0.002%	-0.083%
	Wilcoxon signed-rank Z-statistic	-0.435	0.124	-0.726
	% negative	52.740%	50.000%	52.740%
	Binomial sign test Z-statistic	-0.579	0.000	-0.579

*** p<0.01, ** p<0.05, * p<0.1

2.4.2 Regression Results

We then conducted regression analyses using Stata 16.0. We present the descriptive statistics and correlations of variables in the regression analysis in Table A.2 in Appendix A. To assess collinearity, variance inflation factors (VIF) were calculated for all independent variables. The maximum VIF was 1.51, and the mean VIF was 1.265 (details presented Table A.3 in Appendix A). Thus, multicollinearity was not a significant concern in our analysis.

Table 2-4 presents the regression results indicating under what circumstances the shareholders' reaction to carbon neutrality goal setting announcements would be influenced. The dependent variable of all models in Table 2-4 is the abnormal CAR of day -1 to day 0. The coefficients of the inverse Mills ratio were all insignificant ($p > 0.1$), suggesting that event selection bias was not a severe concern in our models. The coefficient of goal ambitiousness in Model 1 is -0.031 ($p < 0.05$). A deviation of one standard deviation above the mean of goal ambitiousness (0.08) decreases the abnormal CARs by 2.48 percent. Thus, H1-1 is supported, and we posit that markets react more negatively to carbon neutrality goal setting announcements with higher goal ambitiousness.

To test H1-2, the interaction term was added to test the moderating effects of operating efficiency on the relationship between carbon neutrality goal ambitiousness and market reactions. The results of Model 2 showed that the coefficient of interacting operating efficiency with carbon neutrality goal ambitiousness (5.529, $p < 0.01$) was significantly positive. Thus, the negative market reactions to carbon neutrality goal ambitiousness are mitigated when the firms have higher operating efficiency.

Model 3 in Table 2-4 included the interaction between carbon neutrality goal ambitiousness and the flexibility to offset emissions. The results show that the coefficient of goal ambitiousness * flexibility (1.423, $p < 0.05$) is significantly positive. The results supported H1-3 and indicated that maintaining flexibility to offset emissions could mitigate negative shareholder reactions to ambitious carbon neutrality goal setting.

Table 2-4 Results of cross-sectional regression analysis

VARIABLES	(1) Abnm_CAR of day -1 to day 0	(2) Abnm_CAR of day -1 to day 0	(3) Abnm_CAR of day -1 to day 0	(4) Abnm_CAR of day -1 to day 0	(5) Abnm_CAR of day -1 to day 0
Goal ambitiousness	-0.031**	-0.031**	-1.454**	0.189**	-1.394*
	(0.015)	(0.015)	(0.682)	(0.080)	(0.787)
Goal ambitiousness * Operational efficiency		5.529***			5.604***
		(1.786)			(1.834)
Operational efficiency		-0.001			-0.001
		(0.000)			(0.000)
Goal ambitiousness * Flexibility			1.423**		1.598**
			(0.678)		(0.774)
Flexibility			-0.005		-0.004
			(0.006)		(0.007)
Goal ambitiousness * Momentum				0.389***	0.419***
				(0.141)	(0.135)
Momentum				0.000	0.000
				(0.000)	(0.000)
IMR	-0.008	-0.015	-0.011	-0.014	-0.024
	(0.040)	(0.040)	(0.040)	(0.040)	(0.041)
Labor productivity	-0.004	-0.004	-0.004	-0.005	-0.005
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Leverage	0.045	0.046*	0.045*	0.041	0.043
	(0.027)	(0.027)	(0.026)	(0.028)	(0.027)
Tangibility	-0.027**	-0.029**	-0.027**	-0.029***	-0.031***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
CapEX	0.177***	0.186***	0.170***	0.195***	0.199***
	(0.063)	(0.067)	(0.062)	(0.073)	(0.075)
Sales growth	-0.011***	-0.011***	-0.011***	-0.012***	-0.012***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Labor intensity	-0.824	-1.018	-0.878	-0.820	-1.083
	(0.676)	(0.652)	(0.682)	(0.684)	(0.659)
R&D intensity	-0.014	-0.015	-0.014	-0.011	-0.013
	(0.026)	(0.025)	(0.026)	(0.026)	(0.025)
Year, industry, scope dummy	YES	YES	YES	YES	YES
Constant	0.007	0.031	0.022	0.023	0.062
	(0.120)	(0.121)	(0.119)	(0.123)	(0.123)
Observations	146	146	146	146	146
Chi-squared (/100)	107.10	128.48	105.47	88.68	109.08
R-squared	35.10%	37.00%	35.90%	36.20%	39.00%
Adjusted R-squared	18.79%	19.67%	18.98%	18.66%	20.03%

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

H1-4 posits that the negative market reactions to carbon neutrality goal ambitiousness are mitigated when firms have more momentum to abate carbon emissions prior to goal setting. The coefficient of interacting carbon neutrality goal ambitiousness with momentum in Model 4 (0.389, $p < 0.01$) was significantly positive. Therefore, H1-4 is supported.

We also included all moderators in an integrated model (Model 5) to test when other moderators and their interactions with carbon neutrality goal ambitiousness are controlled for and how a particular interaction affects the firm's stock price, and our results remain robust.

2.4.3 Robustness Checks and Additional Analysis

To ensure the validity and reliability of our findings, we conducted several robustness checks and supplementary analyses, summarized in Table 2-5. Results of additional analyses are not included in the thesis but are available upon request. First, we examined the cumulative abnormal returns (CAR) from day –31 to day –2 and found no significant changes during this period. This indicates that information leakage prior to the event window was minimal (Wiengarten et al., 2020). The parallel trend test confirmed the satisfactory matching achieved through propensity score matching (PSM), alleviating concerns about the endogeneity of the event study model.

We also analyzed the long-term impact of carbon neutrality goal-setting announcements on stock prices. The results indicate that the negative influence on firm value persisted within one year of the announcement, suggesting that the adverse stock market reaction extends beyond short-term horizons.

To address concerns regarding the independence assumption in ordinary least squares (OLS) estimation, we followed the two-stage approach outlined by Lo et al. (2018). This method confirmed the robustness of the primary regression results. Furthermore, we applied bootstrap analysis to mitigate small sample bias, and the results further validated the reliability of our findings.

We also tested three alternative measures of goal ambitiousness. The consistent results reinforce our conclusion that the negative stock market reaction to carbon neutrality goal-setting announcements is more pronounced when the goal is more ambitious. However, this negative impact can be mitigated by enhancing operational efficiency, increasing flexibility in carbon offsetting, and building momentum in emissions reductions prior to goal setting.

Finally, we tested for a curvilinear relationship between carbon neutrality goal ambitiousness and shareholder reaction but found no evidence of a U-shaped relationship. This result underscores the straightforward negative association between goal ambitiousness and stock market reactions, further solidifying the robustness of our conclusions.

Table 2-5 Summary of robustness checks and additional analysis

Motivations	Analyses	Results
The concern of information leakage and parallel test for the period prior to the event window in the event study	Examining the CAR from day –31 to day –2 in the event study	No significant difference before carbon neutrality goal setting announcements
To explore the long-term effect of carbon neutrality goal setting announcements.	Examining the CAR from day 1to day 251 in the event study	Negative influence on the firm's stock price in a one-year-period
The potential correlation between independent variables and control variables in the regression analysis	Developing a two-stage regression model	Not falsifying hypotheses
The concern of small sample bias	Applying bootstrap analysis	Not falsifying hypotheses
Alternative measurement for carbon neutrality goal setting ambitiousness	Changing measurement of independent variable	Not falsifying hypotheses
The curvilinear relationship between carbon neutrality goal ambitiousness and shareholder reaction	Adding the squared terms of goal ambitiousness in the regression	The U-shape relationship could not be found

2.5 Discussion and Conclusion

This study investigates the impact of carbon neutrality goal setting on firm value. Using a matched sample of 146 pairs of U.S.-listed manufacturing firms, we find that announcements of carbon neutrality goals are associated with a decline in firm value. The negative effect is particularly pronounced when the goals are more ambitious. This decline can be attributed to shareholder concerns over the cash flow implications of corporate efforts to reduce carbon emissions, as such efforts often entail significant labor, time, or budgetary investments (Cañón-de-Francia & Garcés-Ayerbe, 2009;

Erekson et al., 2008; Jaggi & Freedman, 1992). These results align with broader economic concerns related to carbon neutrality, such as its potential to hinder economic recovery and employment in Japan (Sakai, 2021) or the substantial annual financial requirements for the European Union's green initiatives, estimated at approximately €520 billion from 2021 to 2030 (Ferdinandusse et al., 2022).

Ambitious carbon neutrality goals appear to heighten shareholder concerns. From an operations management (OM) perspective, we examined how firms might alleviate this tension. Our findings indicate that companies demonstrating superior operational efficiency, flexibility in achieving carbon neutrality, and consistent reductions in carbon emissions prior to goal setting are better positioned to mitigate shareholder apprehensions. This approach to reconciling ambitious environmental goals with shareholder interests contributes meaningfully to both theoretical discourse and practical applications in OM literature.

2.5.1 Implications for Theory

This research advances the sustainable operations management literature (e.g., Atasu et al., 2020; Kleindorfer et al., 2005), particularly by contributing to the emerging body of work examining immediate U.S. market reactions to carbon neutrality goal-setting announcements. While environmental goal setting has long been recognized as a cornerstone of corporate environmental strategy (Maxwell et al., 1997), we argue that its positive impact on firm value is contingent, as conflicts can arise between environmental commitments and shareholder interests (as identified in RQ1-1). To address these tensions, we provide actionable insights for firms to balance their environmental objectives with shareholder expectations by leveraging operational tools (as explored in RQ1-2).

This study investigates how the level of difficulty associated with environmental goal setting impacts firm value. While prior research has broadly examined the relationship between environmental and financial performance (Albertini, 2013; Ambec & Lanoie, 2008), it has not adequately addressed how the specific characteristics of environmental goals influence firm value. By focusing on this gap, we identify a negative association between ambitious environmental goals and firm value, attributing this to shareholders' preference for financial over non-financial considerations (Serafeim & Yoon, 2022). Our findings suggest that heightened shareholder concerns about ambitious goals are primarily driven by apprehensions regarding cash flow, highlighting the financial risks associated with ambitious sustainability commitments.

As societal, governmental, and consumer expectations for firms to create environmental value continue to grow, companies face increasing pressure to transition toward greener operations. However, our results reveal that shareholder concerns can act as a constraint, limiting the implementation of green strategies. This underscores the need for future research to examine the long-term financial and operational benefits of green initiatives, which may alleviate shareholder apprehensions and better align environmental goals with economic performance.

Our findings reveal a tension between carbon neutrality goal setting and shareholder reactions, and we propose strategies to mitigate this conflict from an operations management (OM) perspective. Achieving ESG commitments such as carbon neutrality generates substantial value for a firm's reputation, environmental outcomes, and societal well-being. By highlighting operational levers, such as efficiency improvements and flexible goal-setting approaches, we provide firms with practical guidance on balancing environmental and financial priorities.

Building on prior research, we emphasize that the question, "When and how does it pay to be green?" is far more relevant than simply asking, "Does it pay to be green?" (Albertini, 2013; Ambec & Lanoie, 2008; King & Lenox, 2001). By investigating the conditions, timing, and mechanisms through which green initiatives contribute to financial success, this study shifts the focus from a binary debate to a nuanced understanding of how firms can align environmental and economic objectives. Additionally, we underscore the importance of exploring trade-offs and risks associated with environmental commitments (King & Lenox, 2001; Orsato, 2006). Firms that successfully navigate these tensions can better manage the diverse needs of stakeholders, including reconciling carbon neutrality goals with shareholder value.

Future research should further explore methods for addressing conflicts among diverse stakeholder demands.

Unlike much of the existing OM research, this study examines environmental management through the lens of goal-setting theory. Although goal setting is a fundamental aspect of management practice, its role in green operations management remains underexplored. While previous studies, such as Fisher-Vanden and Thorburn (2011), have shown that firms announcing specific green goals experience greater stock price declines compared to general goals, the effects of other goal-setting characteristics, such as goal difficulty, goal commitment, and self-efficacy, remain unclear. By focusing on carbon neutrality goal setting, we emphasize the strategic nature of such commitments and identify goal ambitiousness as a critical dimension influencing shareholder reactions.

This study contributes to understanding how the characteristics of environmental goals shape firm value and highlights the importance of strategic goal-setting in achieving sustainability objectives. Exploring the consequences of carbon neutrality goal setting deepens our understanding of its role in operations management and offers new avenues for future research. Future OM studies should investigate the influence of additional goal-setting attributes on firm performance, drawing further insights from goal-setting theory.

2.5.2 Implications for Practice and Policy

Our findings suggest that management teams must acknowledge the potential short-term negative impact that announcing certain commitments, such as carbon neutrality goals, may have on firm value. This effect arises from the differing expectations, requirements, and influences of various stakeholders (Friedman & Miles, 2002). While public attention to ESG (Environmental, Social, and Governance) performance—particularly in environmental protection and human rights—has intensified (Behl et al., 2022), shareholders often prioritize risk assessment and potential financial returns (Frank, 1989; Serafeim & Yoon, 2022). When establishing ESG goals, management should carefully evaluate the influence of all stakeholder groups and strive to make balanced trade-offs to optimize operational and strategic outcomes.

By identifying factors that can mitigate shareholder concerns over ambitious carbon neutrality goals, this study provides actionable insights for firms aiming to pursue significant environmental commitments without alienating shareholders. Specifically, we highlight operational efficiency, flexibility in achieving carbon neutrality, and pre-existing momentum in emissions reduction as key levers under managerial control. These factors can be strategically utilized to positively influence shareholder perceptions. For instance, operations managers should first focus on enhancing operational efficiency through innovative technologies and practices that reduce carbon emissions while simultaneously optimizing performance. These improvements should be in place before committing to ambitious but flexible carbon neutrality goals. This approach ensures that firms can align their sustainability efforts with shareholder interests, thereby informing the strategic design and implementation of corporate sustainability initiatives.

The findings also carry important implications for policymakers. Firms may experience a short-term reduction in investment when setting non-financial goals, such as carbon neutrality goals. However, corporate engagement with ESG initiatives remains essential in light of increasing societal progress and environmental awareness. To support companies in this transition, policymakers should consider enacting stricter regulations to heighten institutional pressure while simultaneously offering policy-driven subsidies. While intensified institutional pressure is easier to implement and promotes accountability, subsidies can alleviate the financial burden on firms, helping them navigate the trade-offs between resource allocation for financial growth and ESG initiatives in the short term. These measures can enable companies to set and achieve meaningful ESG goals without compromising their economic viability.

2.5.3 Limitations

This study acknowledges several limitations that open avenues for future research. First, due to challenges in collecting unbiased primary data, we relied on secondary data to address the research questions. However, secondary data alone cannot comprehensively capture how shareholders integrate financial and environmental information into their investment decisions (March & Shapira, 1987; Wiengarten et al., 2017). Future experimental research, particularly scenario-based studies, could generate critical primary data to address this gap.

Second, a substantial proportion of the dataset (58%) comprised announcements made after 2021, restricting our ability to evaluate long-term effects. While our short-term event-study methodology effectively captures immediate shareholder reactions (Ding et al., 2018), the pursuit of carbon neutrality is inherently long-term. Future research should explore this topic using accounting-based performance metrics to assess the long-term implications of carbon neutrality goals. This study focuses exclusively on firms' initial announcements of carbon neutrality goals. As firms may revise their environmental commitments after initial goal setting, future research could investigate how such revisions influence shareholder perceptions and firm value.

Third, our empirical measure of ambition (based on timeline and emission scope) is objective, it may not fully capture how investors subjectively perceive and interpret these signals. Future research may explore the influence from linguistic analysis of CN announcements and firm-specific attributes like brand image and sustainability experience. Moreover, our focus on these three moderators is not exhaustive, and we encourage future research to explore additional moderators (e.g., firm reputation, regulatory context, and the linguistic framing of carbon neutrality announcements).

Last, our analysis is limited to publicly listed U.S. companies, raising questions about the generalizability of our findings to firms in other countries or regions. Comparative studies examining how reactions to carbon neutrality goals or other ESG commitments vary across different geographical and regulatory contexts would offer valuable insights.

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3. Study two: Moving Toward Carbon Neutrality Goal Without Leakage

3.1 Introduction

The escalating threat of climate change has intensified the scrutiny on corporate practices, particularly regarding the emission of carbon dioxide (CO2), which are significant contributors to global warming and environmental degradation. The repercussions of unchecked carbon emissions extend beyond ecological damage, impacting public health, economic stability, and social equity. Heightened stakeholder concerns regarding environmental impacts across the entire product lifecycle (Kohtala, 2015; Tate et al., 2011) have emerged as a key driver for organizations to integrate environmental priorities into their strategic supply chain management (SCM) initiatives (Joyce & Paquin, 2016; Saeidi et al., 2015). In response to escalating demands for accountability, firms are under growing pressure to implement sustainable practices aimed at mitigating these adverse environmental effects (Delmas & Toffel, 2008; Doda et al., 2016).

The urgent challenge of global warming has led to a trend for firms to adopt carbon neutrality goals as a central component of their sustainability commitments, serving as a structured approach to decreasing their carbon footprints. Carbon neutrality entails balancing the amount of emitted CO2 with an equivalent amount of carbon removal or offsetting (Wang et al., 2021). Committing to carbon neutrality aligns firms with global agreements and frameworks, such as the Paris Agreement adopted in 2015, which addresses stakeholder expectations and enhances firms' reputation. By setting carbon neutrality targets, firms are encouraged to implement strategies that catalyze internal operational changes and spur green innovation, thereby reducing CO2 emissions and contributing to global efforts against climate change (Wan et al., 2021).

Setting carbon neutrality goals signals a firm's commitment to reducing carbon emissions and taking responsibility for environmental stewardship. In spite of the number of companies pursuing carbon neutrality expanding, participation remains largely voluntary due to the lack of binding legal frameworks (Xie et al., 2023).

Furthermore, unlike prior climate policies with narrower scopes, carbon neutrality strategies represent long-term climate objectives that are hard to measure immediately. Setting carbon neutrality goals for realizing in several decades in the future, such as Nike's target for 2050, may raise concerns for firms, stakeholders, and the broader environmental context. Such long timelines may provide firms with opportunities to avoid tangible short-term action and delay emissions reductions, making it challenging for stakeholders to assess green commitments and performance over such an extended period. The practical realization and outcomes of carbon neutrality goal setting necessitates rigorous empirical analysis to assess their efficacy and uncover potential unintended consequences.

The effectiveness of carbon neutrality commitments in driving actual reductions in carbon emissions remains unclear. While the intention behind carbon neutrality is evident, translating these goals into tangible environmental outcomes may be complex. Prior research highlights that firms may struggle with aligning ambitious sustainability goals with operational realities, particularly when addressing emissions across all three scopes (e.g., Seuring & Müller, 2008; Klassen & Vachon, 2003). The ability to directly reduce carbon emissions is vital for firms aiming to pursue carbon neutrality, as direct reductions in scopes 1 (direct emissions in internal operations) and scope 2 (indirect emissions from energy) emissions are more transparent and easily measurable (Blanco, 2021), which enhances accountability and satisfies stakeholder expectations. However, scope 3 (indirect emissions from supply chain) emissions often involve complex supply chains and present significant challenges. Companies may subcontract certain high-emission activities to be performed elsewhere in the supply chain, thereby reducing their own emissions (Chen, 2017; Kolk and Pinkse, 2005). This shifting of carbon emissions within a company's supply chain is referred to supply chain carbon leakage (Song et al., 2023). Firms may outsource their carbon emissions to suppliers (Berry et al., 2021; Duan et al., 2021) to more easily and quickly achieve their carbon neutrality goals, which can impose a greater burden on the environment (Song et al., 2023) and contradict the original intention of sustainability. It is essential to investigate whether firms are responsibly addressing all relevant carbon emissions and enhancing overall environmental performance in their pursuit of carbon neutrality. This pressing issue leads the first research question (**RQ2-1**): *How does carbon neutrality goal setting influence a firm's environmental performance?*

Reducing carbon emissions throughout the entire product lifecycle is critically important, as it reflects a genuine commitment to environmental sustainability and contributes to the broader societal goal of sustainable development. Outsourcing carbon emissions to suppliers as a means of realizing the commitment to carbon neutrality and attracting stakeholder preference is an opportunistic and irresponsible practice. Although this behaviour may appear to reduce the company's own carbon emissions, it fundamentally contradicts the original intention of reducing overall carbon emissions for the sake of environmental protection on a global scale. Consequently, it is imperative to investigate how firms can extenuate supply chain carbon leakage and truly contribute to overall carbon reduction while ambitiously targeting to carbon neutrality. Therefore, we propose second research question (**RQ2-2**) as follows: *What operational tools can enable firms to make a more substantial contribution to sustainable development after establishing carbon neutrality goals?* Firms may be more likely to adopt sustainable SCM rather than carbon leakage when they possess stronger control mechanisms over the value chain of products. For example, vertical integration brings key production stages in-house, enabling direct oversight of emissions. Stringent supplier selection ensures that partners already meet a firm's environmental standards. Proactive supplier development builds suppliers' capabilities to reduce their own emissions.

To address these research questions, we examined 212 announcements of carbon neutrality goals made by US-listed manufacturing firms. Employing a natural experiment, we examined environmental performance changes between treatment groups (firms that had announced carbon neutrality goals) and control groups (that had not). Using the propensity score matching (PSM) technique, we developed matched pairs to ensure the treatment and control firms shared similar characteristics. The results from the difference-in-differences (DID) regression analysis reveal that setting carbon neutrality goals leads to reductions in a firm's Scope 1 and Scope 2 carbon emissions (controlled by the firm itself), while increasing emissions in Scope 3 (which occur throughout the supply chain). Furthermore, higher vertical integration, better green SCM in supplier selection and supplier development can help extenuate the irresponsible practice of supply chain carbon leakage.

The results indicate that companies that excel in external resource control are more likely to responsibly and honestly fulfill their sustainability commitments regarding worldwide carbon neutrality. The findings of this study contribute to the green operations management literature and provide actionable insights for policymakers, corporate leaders, and other stakeholders. This research informs effective environmental management practices and promotes the adoption of green business strategies by elucidating the impacts of carbon neutrality goal setting on emissions reduction.

3.2 Literature Review and Hypotheses Development

Carbon neutrality refers to achieving a net-zero balance of carbon dioxide emissions by offsetting emissions through both positive and negative measures (Wang et al., 2021). Specifically, mechanisms such as carbon offsets, energy-saving technologies, and emission-reduction innovations enable to neutralize the carbon dioxide generated by countries, organizations, or products, either directly or indirectly (Wan et al., 2021). Whether driven by adherence to national policies or as a strategic effort to enhance their reputation, carbon neutrality has become an increasingly integral element of operation management.

Committing to carbon neutrality not only transforms firms' operational management practices but also positions these practices as key determinants of the efficiency of their carbon neutrality efforts. Recently, the topic of carbon neutrality has garnered significant attention from scholars in operation management. For instance, Linghu et al. (2022) examined the role of enterprise heterogeneity and societal "willingness to pay" in shaping carbon neutrality strategies; and Wang and Zhao (2022) investigated how process integration in resilient supply chains contributes to achieving carbon neutrality. Despite the substantial body of research exploring methods for firms to accomplish carbon neutrality, there remains a paucity of studies investigating the implications of setting carbon neutrality goals. Examining the long-term effects of carbon neutrality goal setting offers valuable insights into its significance and impact on operation management.

Carbon neutrality goal setting has emerged as a critical strategy for firms to demonstrate their commitment to addressing climate change and meeting stakeholder expectations. However, its impacts on carbon emissions are not clear across the three scopes of emissions defined by the Greenhouse Gas (GHG) Protocol: scope 1 (direct emissions from internal operations), scope 2 (indirect emissions from purchased energy), and scope 3 (indirect emissions from the supply chain) (Environmental Protection Agency, 2025). Firms have the highest level of control over scope 1 emissions, as these originate directly from their internal operations, such as manufacturing processes, on-site fuel combustion, and in-house logistics. Scope 2 emissions result from the generation of purchased electricity, heat, or steam. Scope 1&2 emissions are easier for firms to manage and take actions due to their direct operational control over these emissions (Blanco, 2021). Moreover, emissions in scope 1&2 are easier to measure due to direct control and availability of operational data (Blanco, 2021). Reporting for Scope 1&2 emissions is facilitated by established standards, such as the Greenhouse Gas Protocol and ISO 14064. These frameworks provide clear guidelines for calculating and disclosing emissions, reducing ambiguity and ensuring consistency across firms.

Unlike Scopes 1&2, Scope 3 emissions are generated across a firm's value chain, including upstream (e.g., suppliers) and downstream (e.g., product use and disposal) activities. Scope 3 is broader and often constitutes the largest portion of a company's total emissions (Song et al., 2022). These emissions often fall outside the firm’s direct operational control, making it difficult to manage and implement reduction strategies (Wilhelm et al., 2016). Furthermore, Scope 3 reporting requires firms to account for emissions across complex and often fragmented supply chain networks. However, the emission in scope 3 are not directly controlled by the company and occur throughout the supply chain, making them more challenging to measure. Accurate reporting of Scope 3 emissions relies on extensive data collection from external stakeholders, such as suppliers, distributors, and customers. However, many firms face data quality and availability issues, as suppliers may lack the resources, expertise, or motivation to measure and disclose their emissions (Jira & Toffel, 2013). Modern supply chains involve multiple tiers of suppliers, each with varying levels of environmental performance and data availability (Grimm et al., 2014). The lack of visibility into lower-tier suppliers and the absence of standardized reporting practices across the supply chain exacerbate the difficulty of quantifying Scope 3 emissions (Seuring & Müller, 2008).

Achieving carbon neutrality has become a critical objective for firms globally, with organizations increasingly tending to announce carbon neutrality to attract the preference from stakeholders. However, there are significant differences in the carbon neutrality goal setting announcement regarding the difficulty of emission reduction and reporting transparency of the three scopes. Scope 1 and Scope 2 emissions are relatively easy for companies to manage and disclose, while reducing Scope 3 emissions pose more complex challenges because they are beyond the control of the company itself. The current literature on operations management is insufficient to explore the improvement of different scopes involved when companies make green commitments, which motivated us to fill the research gap in exploring the influences on long term carbon emission of different scopes from carbon neutrality goal setting announcement.

3.2.1 Carbon reduction after carbon neutrality goals

When an organization commits to a carbon neutrality goal, it serves as a motivational driver, encouraging the organization to actively develop plans and take actions aimed at minimizing both emissions from Scope 1 and Scope 2 under its control. Such goals establish a clear and measurable target, fostering a proactive approach to reducing internal carbon emissions and promoting the adoption of sustainable practices throughout the organization's operations. Firms that demonstrate a robust commitment to ESG are more likely to implement operational strategies that enhance environmental performance (Nath & Ramanathan, 2016). Ioannou and Serafeim (2019) highlight that firms with public sustainability commitments are more likely to implement emissions-tracking systems and operational improvements.

Moreover, the availability of standardized methods to calculate Scope 1 and 2 emissions enables firms to implement direct intervention (Tang & Zhou, 2012). Past research provides a lot of guidance on technology improvements related to reducing Scope 1 and Scope 2 emissions. For example, to reduce carbon emission directly in scope 1 by adopting lean practices (e.g., King & Lenox, 2001; Rothenberg et al., 2001) or green technology innovations (e.g., Gillingham et al., 2016), and indirectly in scope 2 through transitioning to renewable energy (e.g., Kin et al., 2024) or improving energy efficiency (e.g., Boyd and Curtis, 2014).

Overall, internally, carbon neutrality goal setting serves as a guiding milestone in the internal operations management of an enterprise, providing impetus for carbon emission reduction; externally, carbon neutrality commitments raise stakeholders' green expectations, which puts pressure on companies to significantly improve environmental performance that can be seen by stakeholders. Therefore, it can serve as a catalyst for companies to implement comprehensive strategies to reduce their carbon footprint. In the context of scope 1 emissions and scope 2 emissions, setting carbon neutrality goals may drive firms to adopt existing and explore potential operational and technological improvements, enhance energy efficiency, and transition toward renewable energy sources.

Hypothesis 2-1: *Setting corporate carbon neutrality goals will lead to a reduction in Scope 1 and Scope 2 emissions.*

3.2.2 Supply chain carbon leakage after carbon neutrality goals

Stringent environmental regulations, combined with high implementation costs and carbon fees, frequently drive the relocation of pollution-intensive industries from developed to developing nations. This relocation occurs because developing countries often maintain less stringent environmental policies, which can exacerbate environmental degradation while pursuing financial performance. This phenomenon is conceptualized as the "pollution haven hypothesis" (Chichilnisky, 1994; Copeland & Taylor,1994).

Developing nations may deliberately adopt more lenient environmental standards as a competitive strategy to attract economic activity, particularly in light of their limited infrastructure capabilities. In alignment with the pollution haven hypothesis, firms may also simply outsource highly polluting manufacturing operations or products to supply chain partners in order to reduce costs and support financial growth (Berry et al., 2021). When the pollution haven hypothesis is applied to organizations, members of the supply chain are regarded as recipients of high emissions, as well as the entities to which focal firms, with stringent greenhouse gas emissions standards, relocate production activities (Berry et al., 2021). This type of supply chain leakage has minimal impact on reducing overall emissions within the supply chain and is therefore considered an environmental burden (Song et al., 2022). Outsourcing emissions to the supply chain, commonly known as supply chain carbon leakage, may occur when firms seek to preserve their reputation and capital without making significant efforts to address green requirements from local (Li & Zhou, 2017) and national institutions (Berry et al., 2021). As carbon emissions are an inherent byproduct of production activities, firms can redistribute their production processes throughout the supply chain and strategically regulating their level of outsourcing, thereby altering the carbon emissions for which they are directly responsible (Chen, 2017) and supply chain-wide carbon emissions (Fu & Su, 2020). However, this action can enable companies to appear socially responsible for environmental protection while potentially undermining genuine sustainability efforts (Dai et al., 2021).

While disclosing Scope 1 & 2 carbon emissions has become common practice, only about 10% of companies pursuing or committing to carbon neutrality targets disclose their Scope 3 emissions (Song et al., 2023). The limited attention and visibility given to supply chain emissions may encourage manufacturers to reduce their Scope 1 & 2 carbon emission by outsourcing "dirty production" (Duan, et al., 2021) to suppliers, thereby seems to look better in self-report of green data (Berry et al., 2021). This practice could potentially increase the overall carbon footprint that hinders the general achievement of global carbon neutrality.

Organizations may opt to relocate production activities to suppliers operating under less stringent environmental regulations, thereby reducing costs associated with internal carbon reduction innovations, to achieve carbon reductions within organizational boundaries. However, such suppliers often employ less efficient and more carbon-intensive production methods, leading to increased Scope 3 emissions. Nath and Ramanathan (2016) observed that organizations primarily focused on compliance and cost minimization tend to adopt a minimalist approach to green operational practices, showing limited willingness to exceed basic regulatory requirements or pursue higher standards of environmental performance. Furthermore, outsourcing Scope 1 and Scope 2 emissions to Scope 3 allows firms to circumvent the expenses and investments required to implement energy efficiency measures, innovate in clean technologies, or integrate renewable energy into their operations.

Although carbon neutrality frameworks typically require organizations to monitor and disclose Scope 1, 2, and 3 emissions, variations in accountability and visibility can occur. Challenges in measurement often arise due to issues related to data availability, reliability, and the complexities of defining boundaries for Scope 3 emissions. As a result, certain firms may engage in opportunistic practices by outsourcing their Scope 1 and 2 emissions to Scope 3 that which are less likely to be scrutinized (Duan et al., 2021). Yue et al. (2020) also noted that some firms disproportionately emphasize visible aspects of corporate social responsibility (CSR) while neglecting its less observable dimensions.

However, this approach neglects the broader environmental impact across the supply chain and runs counter to the fundamental goal of carbon neutrality, which seeks to achieve global low-carbon and environmentally sustainable outcomes. As firm businesses and their supply chains expand globally, supply chain carbon leakage has garnered increased attention in the field of operations management (e.g., Chen et al, 2011; Huang et al., 2021). It is viewed as a negative spillover effect that may lead to an overall increase in emissions and adverse social outcomes (Chen et al, 2011;

İşlegen et al., 2016; Song et al., 2022). Supply chain carbon leakage can significantly reduce a company's own carbon emissions and avoid related costs and investments in green operations, and such speculative behavior is difficult to detect due to the measurement and disclosure difficulties of Scope 3 emissions. Thus, we hypothesized the following:

Hypothesis 2-2: *Setting corporate carbon neutrality goals will result in an increase in Scope 3 emissions.*

Although Song et al. (2022) have innovatively suggested that supply chain carbon leakage may also be related to supply chain optimization and innovation, potentially yielding long-term benefits, current research in the field of operations management primarily focuses on analytical studies aimed at mitigating the negative impacts of supply chain carbon leakage through policy design and technology implementation. For instance, Huang et al. (2021) evaluated the implementation and effectiveness of two anti-leakage policies: border taxes and output-based allocations. Drake (2018) discussed the potential of carbon tariffs and border adjustments, as well as technology choices and "clean leakage," in alleviating supply chain carbon leakage. Additionally, Sunar and Plambeck (2016) examined the impact of carbon tariffs and border adjustments on carbon emissions allocation rules in collaborative supply chain production. While some literature has started to investigate emission allocation and responsibility within supply chains (e.g., Caro et al., 2013; Gopalakrishnan et al., 2021), there seems to be few research exploring operational levers that focal firms can adopt to reduce the negative impacts of supply chain carbon leakage.

Zhu and Sarkis (2004) categorized environmental management practices into two distinct areas: internal and external. Later, Fu and Su (2020) analyzed the impact of pollution prevention and waste management initiatives, and outsourcing on the reduction of focal firm and its supply chain carbon emissions. Current literature about internal green management has primarily focused on preventing pollution and minimizing waste within a firm's internal processes (Christmann, 2000; Zhu & Sarkis, 2004). In contrast, external green management emphasizes fostering green mindset for the entire supply chain and mitigating adverse environmental outcomes through collaboration with external stakeholders (Large & Gimenez Thomsen, 2011). Since scope 3 is beyond the control of the company, we mainly explore how companies can mitigate the adverse effects of carbon leakage by utilizing and managing external resources, thereby reducing carbon emissions overall.

3.2.3 External resource control to mitigate supply chain carbon leakage

Organizations are not self-sufficient, they depend on external entities for critical resources, and this dependency influences their behavior and strategies (Pfeffer & Salancik, 1978). Supply chain carbon leakage will become worse from the lack of direct control over the environmental practices of suppliers, which are major contributors to scope 3 emissions. When firms rely on suppliers with high-carbon operations, they indirectly increase their overall carbon footprint, undermining their carbon neutrality commitments. By strategically managing and controlling external resources, firms can reduce their exposure to supply chain carbon leakage or ally suppliers to implement more effective carbon reduction measures, thus aligning supply chain practices with their sustainability objectives. Specifically, firms can reduce their reliance on high-carbon suppliers or prioritize partnerships with environmentally certified suppliers by exerting control over sourcing and improve green supplier management.

3.2.3.1 Vertical Integration

Vertical integration refers to a firm's strategy of directly controlling more stages of its value chain, including upstream suppliers and downstream distribution and production processes. Firms that rely heavily on outsourcing are generally less vertically integrated, as outsourcing represents "the extent to which the vertical range of manufacturing is reduced" (Broedner et al., 2009). In the context of scope 3 emissions, reliance on suppliers with high-carbon operations increases a firm’s overall carbon footprint and undermines its carbon neutrality goals. Vertical integration helps to solve the problem of pollution haven hypothesis by reducing their dependency on outsourcing and gain a greater control over their production processes and supply chains (Lin et al., 2014). By internalizing activities that are traditionally outsourced, firms gain better control over operational efficiencies, resource utilization, process standardization, and supply chain sustainability oversight. By internalizing key processes, firms can proactively invest in green technologies and infrastructure, rather than relying on external suppliers to adapt to new environmental standards. This reduces reliance on external suppliers and allows firms to directly implement low-carbon technologies and practices.

Vertical integration enables firms to implement low-carbon practices across previously external operations, such as production, logistics, or energy generation. Higher vertical integration allows firms have a better control of environmental impacts (Carter & Rogers, 2008; Rao & Holt, 2005) by outsourcing less capacities to regions with weaker environmental regulations and diminishing corresponding transportation emissions as well. Besides, firms with high vertical integration can fully utilize their environmental technologies and production methods within their existing operations, reducing the need to relocate production to avoid pollution control costs. This enhanced control enables firms to address carbon emissions directly, particularly in scope 1 and scope 2, while also reducing carbon leakage risks in scope 3. Scope 3 emissions, which originate from upstream suppliers and downstream partners, are often beyond a firm's immediate control. Vertical integration helps mitigate these emissions by bringing more of the supply chain under the firm's direct influence. Integrated firms can design products and processes that require fewer carbon-intensive inputs, reducing emissions across the supply chain. Klassen and Vachon (2003) show that firms with greater control over their supply chains are better equipped to implement sustainable sourcing practices. By internalizing upstream activities (e.g., raw material sourcing), firms can bypass high-emission suppliers and adopt low-carbon alternatives. Pagell and Wu (2009) argue that vertical integration helps firms eliminate unsustainable practices from their supply chains by internalizing critical activities.

Supply chain carbon leakage occurs when firms shift emissions-intensive activities to external suppliers to achieve apparent reductions in scope 1 and 2 emissions. Vertical integration helps to mitigate this concern by in-house compliance with environmental standards and reduction of supply chain complexity. Integrated firms are less likely to outsource emissions-intensive activities to external suppliers, as these activities are now part of their internal operations and subject to their environmental policies. By consolidating supply chain activities, firms can reduce the complexity and fragmentation of their supply chains, which are often associated with higher scope 3 emissions. Gimenez and Sierra (2013) find that firms adopting vertical integration report lower scope 3 emissions due to reduced reliance on external suppliers.

Hypothesis 2-3: *Higher levels of vertical integration will attenuate the rise in Scope 3 emissions following the carbon neutrality goals.*

3.2.3.2 Interorganizational relationship management

Power dynamics plays a significant role in interorganizational relationships, where firms with greater control over critical resources can influence the behavior of dependent organizations (Pfeffer & Salancik, 1978). Firms with significant purchasing power can use this leverage to encourage or require suppliers to adopt low-carbon practices. By engaging suppliers in green efforts, firms can reduce their dependence on high-carbon practices, align supplier behavior with their carbon neutrality goals, and enhance environmental performance across the supply chain.

Information asymmetry between customers and suppliers is a common phenomenon (Ciliberti et al., 2011) and is particularly pertinent to sustainability issues, such as carbon emissions reduction. Suppliers often lack comprehensive information about the emissions performance expectations of their customers (Wilhelm et al., 2016). Additionally, because suppliers are typically positioned further upstream in supply chains, they are often less exposed to public scrutiny and market pressures to reduce carbon emissions (Li & Zhou, 2017). Consequently, firms are supposed to better manage supplier relationships to significantly influence the supplier's engagement in emissions reduction efforts. By fostering greener interorganizational relationships with suppliers, firms can reduce uncertainty, align goals, and build shared responsibility for emissions reduction.

In the context of supply chain carbon management, firms are dependent on suppliers for materials, components, and services, which directly influence their scope 3 emissions. However, this dependency creates vulnerabilities, as firms have limited control over the environmental practices of their suppliers. By setting stringent environmental criteria for supplier selection, firms can strategically manage these dependencies to ensure alignment with their carbon neutrality goals and reduce scope 3 emissions. Supplier selection is a critical decision-making process in a firm’s SCM strategy. By implementing stricter environmental criteria for supplier selection, firms can proactively screen out high-carbon suppliers and maintain the relationship with those upstream suppliers adhere to stringent environmental standards and adopt sustainable practices. Suppliers that fail to meet these criteria, or whose practices lead to excessive scope 3 emissions, can be terminated and replaced with more sustainable alternatives.

Before committing to costly and uncertain environmental initiatives, stricter supplier selection criteria can serve as clear and reliable signals of environmental commitment from their customers to assess the potential outcomes of their response (Jira & Toffel, 2013). Supplier selection incentivizes suppliers to adopt low-carbon technologies and sustainable practices to remain competitive. When environmental criteria are integrated into supplier selection processes, suppliers must compete not only with cost and quality but also with their ability to meet sustainability standards. This competition incentivizes suppliers to reduce their carbon footprints, adopt green technologies, and improve their environmental performance to remain competitive. Zhu and Sarkis (2004) highlight that green supplier selection encourages suppliers to adopt environmental practices, reducing emissions across the supply chain. Suppliers that meet stringent environmental criteria are more likely to use renewable energy, reduce waste, and adopt cleaner production technologies, contributing to lower upstream emissions. By selecting suppliers that align with the firm's sustainability objectives, firms can ensure consistency in carbon reduction efforts across the supply chain.

Carbon leakage in the supply chain often occurs when firms shift emissions-intensive activities to suppliers that do not adhere to stringent environmental standards. Supplier selection mitigates this risk by requiring suppliers to meet specific benchmarks, such as ISO 14001 certification, which ensures compliance with environmental management standards. Firms can also enforce environmental criteria through regular audits and terminate relationships with non-compliant suppliers, reducing the risk of outsourcing emissions-intensive activities. Especially, Pagell and Wu (2009) argue that collaboration with suppliers meeting criteria on sustainability initiatives reduces scope 3 emissions and fosters long-term environmental improvements. Rao and Holt (2005) show that firms engaging with suppliers on environmental performance achieve better alignment of sustainability goals across the supply chain. By establishing clear environmental criteria and linking supplier retention to compliance, firms can create a more sustainable supply chain that minimizes scope 3 carbon leakage. Therefore, we proposed the following hypothesis:

Hypothesis 2-4: *Conducting supplier selection will attenuate the rise in Scope 3 emissions following the carbon neutrality goals.*

Studies in supply chain management have demonstrated that supplier collaboration is a critical enabler of sustainable supply chain practices (Gimenez & Tachizawa, 2012; Paulraj et al., 2017). The literature on green OSCM emphasizes that collaboration enhances environmental performance by fostering trust, commitment, and information sharing between firms and their suppliers (Klassen & Vachon, 2003; Pagell & Wu, 2009). By engaging green supplier development, firms can reduce their dependence on high-carbon practices, align supplier behavior with their carbon neutrality goals, and enhance environmental performance across the supply chain (Klassen & Vachon, 2003; Zhu et al., 2013).

Firms may depend on external suppliers for resources, such as raw materials, components, and services, which directly impact scope 3 emissions. However, suppliers may lack the knowledge, capabilities, or incentives to adopt low-carbon practices, thereby increasing the firm's exposure to carbon leakage risks. By implementing green supplier development, such as conducting supplier training programs and collaborating on environmental initiatives, firms can build better green interorganizational relationships by transferring knowledge, building supplier capabilities, and fostering a shared commitment to sustainable practices.

Joint sustainability initiatives, such as co-developing low-carbon technologies or implementing circular economy practices, foster collaboration and shared responsibility for emissions reduction. These efforts may create opportunities for suppliers and buyers to jointly address emissions hotspots and achieve collective sustainability outcomes (Pagell & Wu, 2009). Green supplier development enhances information flow and transparency, enabling firms to monitor scope 3 emissions more effectively. For example, tracking suppliers' environmental performance creates accountability and ensures that suppliers remain committed to reducing their carbon footprints. When firms and suppliers engage in joint problem-solving and environmental initiatives, they create opportunities to align their goals and share resources to achieve mutual sustainability objectives. These collaborative efforts not only reduce emissions but also build long-term trust and commitment, reducing the likelihood of opportunistic behavior. We thus posit hypothesis as below:

> ***Hypothesis 2-5:*** *Conducting supplier development will attenuate the rise in Scope 3 emissions following the carbon neutrality goals.*

3.3 Sample and Variables

3.3.1 Data and Variables

This study focuses on U.S.-listed manufacturing firms classified under Standard Industry Classification (SIC) 2-digit codes 20–39 to examine the long-term impact of carbon neutrality goal setting on carbon emissions across different scopes.

Manufacturing firms were selected due to their significant contribution to global emissions; according to the International Energy Agency (IEA), direct emissions from the manufacturing sector account for 25% of global emissions, excluding indirect emissions from electricity consumption (Zacharia, 2024). As a result, manufacturing firms represent a primary target for carbon emission reduction initiatives and are a critical focus of this research.

Firms from other industry sectors, such as trade, finance, services, and public administration (SIC codes 50–99), were excluded from the sample. These industries and their suppliers are generally not primary targets for carbon emissions reduction efforts (Song et al., 2024). Additionally, operational and environmental, social, and governance (ESG) data for manufacturing firms are more readily available and comparable, further supporting their inclusion in this study. To ensure the validity and reliability of the analysis, data were collected from multiple sources, as detailed in the following sections. This multi-source approach enhances the robustness of the research findings and ensures consistency across key variables.

3.3.1.1 Carbon Neutrality Goal Settings.

Following previous research, we utilized the Factiva database to identify announcements of carbon neutrality targets. Factiva consolidates news and information from a wide range of sources, including The Wall Street Journal, The New York Times, and PR Newswire (Desai et al., 2023). Recognizing that firms may revise their carbon neutrality commitments over time, which could lead to varying shareholder reactions with each announcement, we followed Harris and Bromiley (2007) and focused exclusively on each firm's first public announcement of its carbon neutrality goal. We defined the event as the first instance where a listed firm publicly declared its commitment to achieving carbon neutrality or net-zero emissions.

Our data collection process involved several steps. First, we compiled a list of 3,024 active U.S.-listed manufacturing firms from the Compustat database. We then searched for media reports on these firms in the Factiva database, using keywords that combined firm names with terms such as “carbon neutral*” or “net zero.” Each announcement was carefully reviewed, and only the first announcement explicitly stating a firm’s carbon neutrality or net-zero commitment was retained. To avoid confounding effects, announcements associated with unrelated events—such as financial disclosures, leadership changes, or mergers and acquisitions—were excluded. This process yielded 268 firm announcements made between 2002 and 2022.

Next, we removed firms with missing financial data in Compustat or environmental data in Bloomberg ESG and Eikon, resulting in a final sample of 234 firm observations. The detailed data-cleaning process is illustrated in Figure B.1 in Appendix B, while the industry distribution of announcements is summarized in Table B.1 in Appendix B.

3.3.1.2 Dependent Variables: Carbon Emissions

We collected carbon emissions data from the Bloomberg ESG database, following recent studies (Bellamy et al., 2020; Song et al., 2023, 2024). Bloomberg ESG collects emissions data under the Greenhouse Gas (GHG) Protocol, developed by the World Resources Institute (WRI). This data is compiled from a variety of sources, including 10-K filings, corporate responsibility or sustainability reports, regulatory documents, brochures, presentations, and company websites. Bloomberg researchers also engage directly with firms through sustainability surveys based on GRI standards to address gaps in publicly available information (Bloomberg ESG, 2018). As a result, all GHG emissions data are traceable to their sources and calculated using rigorous, standardized methods.

For this study, we combined Scope 1 and Scope 2 emissions to represent a firm’s total internal emissions, reflecting its operational and energy-related carbon footprint (Blanco, 2021). Scope 3 emissions, on the other hand, were used to capture emissions linked to the firm’s supply chain, with suppliers contributing significantly to these emissions (Villena & Dhanorkar, 2020). To ensure comparability across firms with varying scales of operation, we scaled each firm's carbon emissions by its total annual revenue. Logarithmic transformations were applied to normalize the data and reduce the influence of outliers, consistent with prior research (Song et al., 2024). Finally, we specify the formulas used to construct our scaled carbon emissions metrics, which serve as the dependent variables in this study:

$$Emission\ Scope12 = ln(\frac{Emission\ Scope1 + Emission\ Scope2}{Annual\ revenues})$$

$$Emission\ Scope3 = ln(\frac{Emission\ Scope3}{Annual\ revenues})$$

$$Emission\ Scope123 = ln(\frac{Emission\ Scope1 + Emission\ Scope2 + Emission\ Scope3}{Annual\ revenues})$$

3.3.1.3 Moderators

To examine the moderating effect of firms' vertical integration, we use the variable $Vertinteg$, which measures the degree of vertical integration for a given firm in a specific year. This metric indicates the extent to which a firm's products are vertically related to other products sold by the same firm, reflecting the potential for internal supply-and-demand linkages. Data for this measure were sourced from the Vertical Text-Based Network Industry Classification (VTNIC) developed by Frésard et al. (2020).

The VTNIC methodology combines product descriptions from firms' 10-K filings with Input-Output (IO) tables from the Bureau of Economic Analysis (BEA) to calculate vertical relatedness scores. These scores are derived using a triple matrix product that quantifies the likelihood of two firms forming a supply chain partnership. Specifically, if a firm's product description matches another firm's input requirements, the first firm is identified as a potential supplier to the second. The vertical integration score for each firm is extracted from the diagonal entries of the matrix, representing the degree of vertical correlation among the firm's own products. A higher $Vertinteg$ score suggests that the firm's products are more likely to form a closed-loop supply chain, reflecting greater vertical integration. This metric has been widely applied in recent research to analyze supply chain networks (Grieser et al., 2022), supplier relationships (Runge et al., 2022), and investment and acquisition strategies (Hoberg & Phillips, 2025).

To measure firms' external green supplier selection practices, we use the $Supplier\ Selection$ variable from the ESG section of the Thomson Reuters Refinitiv Eikon database (formerly ASSET4, now managed by LSEG). Refinitiv Eikon collects ESG data from a variety of public sources, including corporate annual reports, sustainability disclosures, NGO publications, ESG-related news, and industry journals (Su et al., 2024). Covering over 16,000 firms globally since 2002 and encompassing 90% of global market capitalization, Eikon provides a transparent, standardized, and systematic framework for ESG information, featuring more than 870 ESG metrics (LSEG, 2024). This database has been widely utilized in academic research (e.g., Cheng et al., 2014; Falcone et al., 2024; Hardcopf et al., 2021).

The $Supplier\ Selection$ variable is derived from the "Environmental Supply Chain Management" category in the Eikon database. It captures whether a firm incorporates environmental criteria, such as ISO 14000 certifications or energy consumption standards, in its supplier selection processes. This includes both the selection of new suppliers and the evaluation of existing suppliers based on environmental criteria. As an indicator of green supply chain management, $Supplier\ Selection$ reflects proactive risk mitigation and aligns with recent studies on sustainable sourcing (Mateska et al., 2024). It highlights the focal firm's commitment to ensuring that its supply chain partners meet rigorous environmental standards.

To measure firms' efforts in green supplier development, we use the $Supplier\ Development$ variable from the ESG section of the Eikon database. Specifically, this variable is based on the "Environmental Supply Chain Policy" category, which assesses whether a firm has policies aimed at including its supply chain in broader efforts to reduce environmental impact. This measure evaluates the extent to which a firm's environmental policy addresses supply chain emissions and reflects systematic efforts to co-develop the environmental capabilities of suppliers (Karaman et al., 2024). Examples of such efforts include joint initiatives, such as co-innovation in circular technologies, and the establishment of relational governance mechanisms, such as shared regulatory systems for emissions reduction. By fostering collaboration in supplier development, Supplier Development captures how firms internalize emissions responsibility through cooperative decarbonization strategies, rather than outsourcing carbon emissions.

3.3.1.4 Controls

The financial and operational data used in this study are mainly collected from the Compustat database. Detailed descriptions of the variables, their operationalization, and data sources are provided in Table B.2 of Appendix B. To account for organizational scale effects, we included the log-transformed number of employees ($Firm\ Size$) as a control variable to reflect firms' operational scale (Chen et al., 2023). Profitability was measured using return on assets (ROA), defined as the ratio of net income to total assets, which provides insight into the firm's financial performance (Diebel et al., 2024). We also used the ratio of sales to property, plant, and equipment (SOP) to capture the efficiency with which firms generate revenue from their fixed asset investments (Osadchiy et al., 2025). This metric is particularly relevant for capital-intensive operations, which often have distinct environmental footprints.

To assess corporate growth, we included the sales growth rate ($Sales\ Growth$), defined as the percentage increase in sales compared to the previous year (Brammer & Pavelin, 2006). This variable is a critical factor in environmental decision-making and corporate strategy (Ganda & Milondzo, 2018). Financial leverage ($Leverage$), calculated as the ratio of total debt to total assets, and tangibility ($Tangibility$), measured as the proportion of fixed assets to total assets, were also controlled for, as a firm's financial structure can influence its environmental decisions (Large & Gimenez Thomsen, 2011).

In addition, we included the inventory turnover ratio ($Inventory\ Turnover$), defined as the ratio of cost of goods sold to inventory, as a measure of operational efficiency. This variable captures the relationship between inventory management and energy efficiency, which can impact a firm's emissions (Sartal et al., 2020). Log-transformed Selling, General, and Administrative Expenses (SGA) were also controlled for, as this variable reflects operational efficiency and is closely linked to energy consumption patterns and emissions profiles. Recognizing the pivotal role of innovation in reducing emissions (Álvarez Fernández, 2018), we included research and development intensity ($R\&D\ Intensity$) as a proxy for technological advancement potential within a firm's supply chain. This variable captures the extent to which a firm's innovation capabilities, particularly in suppliers, can facilitate emissions reductions through product or process innovation.

3.3.2 Empirical Strategy

A key empirical challenge in estimating the effect of carbon neutrality announcements on corporate emissions is the issue of endogeneity. First, reverse causality may bias the results if firms with already favorable emissions trajectories are more likely to announce ambitious carbon neutrality goals. Second, omitted variable bias (self-selection bias) arises when unobserved factors influence both the decision to commit to neutrality and subsequent emission outcomes. For instance, firms with strong environmental leadership may be more inclined to announce neutrality targets and simultaneously reduce emissions, even in the absence of the announcement itself. Failure to account for such confounders could lead to an overestimation of the causal effect of the announcement.

To address these challenges, we adopt an event-study framework that integrates propensity score matching (PSM) with a difference-in-differences (DID) estimation. Specifically, we match each firm announcing a neutrality goal with a non-announcing peer that is similar in observable pre-announcement characteristics. This matching process balances the treatment and control groups on observable factors that could simultaneously influence the decision of announcement and future emissions, thereby mitigating confounding from these variables. Following the matching process, we apply DID to compare changes in emissions between treated and control firms before and after the announcement. The DID framework eliminates biases from time-invariant unobserved heterogeneity and common macroeconomic shocks. By focusing on within-firm changes relative to matched controls, this approach also mitigates reverse causality: if firms with superior emissions performance were already on a downward trend, such trends are captured during the pre-announcement period and are netted out of the estimated treatment effect.

Before implementing the DID estimation, key identification assumptions must be satisfied. First, the treatment and control groups must exhibit similar pre-treatment trends in emissions. This assumption is validated in our analysis, as demonstrated in the following section. Second, the stable unit treatment value assumption (SUTVA) requires that the treatment effects do not spill over to control firms or other treated firms, and that treatments are consistent and well-defined. SUTVA is satisfied in this context because carbon neutrality goal setting is an independent corporate strategy rather than direct market intervention. Adjustments to emission performance typically involve long-term investments and strategic decisions, making emissions less susceptible to short-term competitive responses. Moreover, by focusing on a three-year window post-announcement, the likelihood of spillover effects or external interventions is minimized.

Third, the homogeneous treatment effects assumption requires that the treatment effect is constant across firms and over time. While this assumption has been relaxed by time-varying methods in recent literature, it remains important to address potential biases arising from changes in treatment effects over time. To mitigate these concerns, we transform calendar years into event years to ensure temporal alignment in PSM matching and comparability in DID analysis. In the PSM process, we incorporate individual and time fixed effects and match treated firms with control firms over the same event window period. Last, to complement the baseline regression and ensure robustness, we employ alternative estimators, including the CSDID estimator proposed by Callaway and Sant'Anna (2021), the SADID estimator introduced by Sun and Abraham (2021), and the stacked DID approach developed by Cengiz et al. (2019). These methods account for potential biases arising from staggered treatment adoption and provide robust estimates of the treatment effects. The results and implications of these robustness checks are discussed in detail in the subsequent sections.

3.3.3 PSM

To minimize potential selection bias, we applied PSM to ensure that treatment groups and control groups were highly similar and comparable. Treatment firms were defined as those that announced carbon neutrality goals, while control firms were classified as never-treated firms that did not make such announcements. The mutually exclusive nature of these two groups satisfies the stable composition assumption required for our difference-in-differences (DID) analysis. This design also addresses concerns about contamination, where late-treated firms might otherwise serve as controls for early-treated firms, potentially biasing the estimated average treatment effect on the treated.

To implement the matching, we employed a logit model to calculate the propensity scores, representing the likelihood of a firm announcing a carbon neutrality goal. Using a 1:1 nearest neighbor matching approach with a caliper of 0.01, we matched a control firm to each treatment firm with the closest propensity score within the same industry (based on 2-digit SIC codes) and the same year. In the second stage, we ensured that the control group shared the same time window as the treatment group, achieving complete alignment in terms of industry and period. This design allowed for counterfactual comparisons while reducing the risk of cross-industry spillovers that could differentially affect control firms. The propensity scores were estimated using the following logit model:

$$Announcement_{i,t} = F(X_{i,t-1}, Industry_j, Year_k) \quad (1)$$

where $F(.)$ is logit function, $Announcement_{i,t}$ means whether the firm i set carbon neutrality goals or not in the first event year t. We incorporated treatment firms only in the first event year t and other control firms in PSM samples to improve matching efficiency. $X_{i,t-1}$ are firms' financial and operational characteristics (i.e., ROA, $Sales\ Growth$, $Invenotry\ Turnover$ and $Leverage$) and prior carbon emission trend (i.e., $D.Emission\ Scope123_{i.t-1}$ and $D.Emission\ Scope12_{i.t-1}$) , $Industry_j$ and $Year_k$ are dummies to give priority to calculating the scores for the same industry and year.

After excluding treatment firms with missing data or those that could not be matched to a control firm, we finalized a sample of 212 matched pairs of treatment and control firms, resulting in a total of 2,300 firm-year observations over the window period of [-3, 3] around the year of the announcement. Further details of the PSM process, including the logit regression results and balance tests, are provided in Tables B.3 and B.4 of Appendix B.

3.3.4 Summary Statistics

We present summary statistics for all variables used in our analysis based on a sample of 212 matched pairs of treatment and control firms. These statistics, reported in Table B.5 of Appendix B, include measures of central tendency (mean and median) and dispersion (standard deviation, minimum, and maximum). Additionally, we provide separate summary statistics for the treatment and control groups in Tables B.6 and B.7. The sample demonstrates a reasonable distribution, with relatively stable variance, which confirms the high quality of the data and enhances the reliability and interpretability of our subsequent regression analyses.

To ensure the robustness of our empirical tests, we conducted a correlation analysis among the firm-year variables as a preliminary diagnostic. The results, detailed in Table B.8 of Appendix B, show strong positive correlations among the three dependent variables. These findings support the validity of the empirical framework and indicate the need for further investigation into the relationships between variables.

We also assessed the independence of variables by calculating their variance inflation factors (VIFs), as shown in Table B.9 of Appendix B. The VIF values range from 1.040 to 3.590, indicating that multicollinearity is not a concern in this study. These results further validate the reliability of the dataset and contribute to the robustness of our analyses.

3.4 Analysis and Results

To evaluate the impact of carbon neutrality goal setting on firms' greenhouse gas (GHG) emissions, we employ a difference-in-differences (DID) approach. A parallel trends test is conducted to validate the applicability of this method. Furthermore, we introduce three moderating variables to identify effective strategies for mitigating supply-chain carbon leakage.

3.4.1 Direct Effect of Carbon Neutrality Goal Setting Announcement

To analyze the effect of carbon neutrality announcements on GHG emissions, we adopt the pooled DID approach as outlined by Li et al. (2019). This method is particularly appropriate due to the staggered timeline of carbon neutrality goal implementation across different firms. By comparing the changes in emissions between treatment firms (those committing to carbon neutrality) and control firms (those without such commitments), we isolate the causal effect of the announcements. This approach also mitigates the influence of external factors, such as macroeconomic conditions, that could confound the results. Using control firms as a counterfactual, we estimate how the emissions of treatment firms would have evolved in the absence of carbon neutrality announcements (Chu et al., 2021). The DID estimation is represented in Equation (2).

$$Y_{i,t} = \beta_0 + \beta_1 Announcement_{i,t} + X_{i,t-1}\beta + \delta_i + \theta_t + \epsilon_{i,t} \qquad (2)$$

Here, the subscript i denotes the specific firms, while the subscript t represents the period. $Y_{i,t}$ represents the dependent variables: $Emission12$ and $Emission3$. The independent variable $Announcement_{i,t}$ means whether firm i has set a carbon neutrality goal in Year t. β_0 is the intercept term, which represents the expected value of $Y_{i,t}$when all other variables are held constant at zero. β_1 represents the coefficients associated with the variable $Announcement_{i,t}$, which are also the key coefficients we focus on. $X_{i,t-1}$ is a vector of control variables. We use lagged 1 period variables to avoid reverse causality. The term $X_{i,t-1}$ represents the linear combination of these variables, where β represents the vector of corresponding coefficients. The error term $\epsilon_{i,t}$ captures the unobserved factors or random disturbances that affect $Y_{i,t}$ and that are not accounted for by the included variables. We employed the term δ_i, representing additional firms' fixed effects, to control unobserved heterogeneity among different firms, such as firm type, operations style, and other time-invariant omitted variables. The term θ_t representing additional-year fixed effects helps control for any unobserved and time-variant characteristics that may affect dependent variables. To account for potential correlations between different events for the same firms, we cluster the standard errors by the firms.

The baseline regression results, shown in Table 3-1, examine the influence of carbon neutrality goal setting on both direct and indirect GHG emissions at the firm level and across their supply chains. For $Emission\ Scope12$, which includes direct (Scope 1) and energy-related indirect (Scope 2) emissions, the coefficient for the $Announcement$ variable is negative and statistically significant at the 1% level (Column 1, coefficient = -0.166, $p < 0.01$). This finding indicates that, after announcing carbon neutrality goals, firms reduce their Scope 1 and Scope 2 emissions by 16.6%. The reduction in direct emissions reflects firms' proactive measures to decrease carbon emissions within their own operations, aligning with their net-zero commitments.

In contrast, for $Emission\ Scope3$, which captures supply-chain-related emissions, the coefficient for Announcement is positive and statistically significant at the 1% level (Column 3, coefficient = 0.249, $p < 0.01$). This result suggests that firms may engage in "outsourcing emissions" by shifting emissions from their own operations to their supply chains. While firms achieve reductions in directly controlled emissions, they may simultaneously increase emissions in less regulated or less visible areas of their supply chains. This behavior underscores the potential for carbon leakage within supply chains, complicating the achievement of overall sustainability goals.

Table 3-1 The results of the baseline model

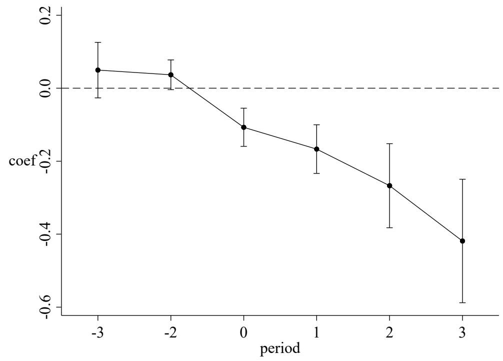
Variables	(1) $Emission\ Scope12$	(2) $Emission\ Scope3$
$Announcement$	-0.166***	0.249***
	(0.029)	(0.084)
$Firm\ Size$	-0.033	-0.012
	(0.025)	(0.047)
SGA	0.002	-0.019
	(0.020)	(0.031)
SOP	-0.024**	0.003
	(0.010)	(0.011)
ROA	-0.051	0.110
	(0.121)	(0.224)
$R\&D\ Intensity$	-0.094	-0.081
	(0.057)	(0.086)
$Sales\ Growth$	-0.010**	0.004
	(0.005)	(0.005)
$Leverage$	0.057	0.344
	(0.117)	(0.214)
$Inventory\ Turnover$	-0.002	0.014*
	(0.005)	(0.008)
$Tangibility$	0.194**	0.220*
	(0.083)	(0.118)
Constant	4.293***	4.732***
	(0.166)	(0.236)
Observations	2,300	2,300
$Adjusted\ R^2$	0.964	0.865
Firm FE	YES	YES
Year FE	YES	YES

*Note. *p<0.1, **p<0.05, ***p<0.01 using two-tailed tests. Robust standard errors clustered at the firm level are reported in parentheses. Controls, Firm FE, and Year FE are included.*

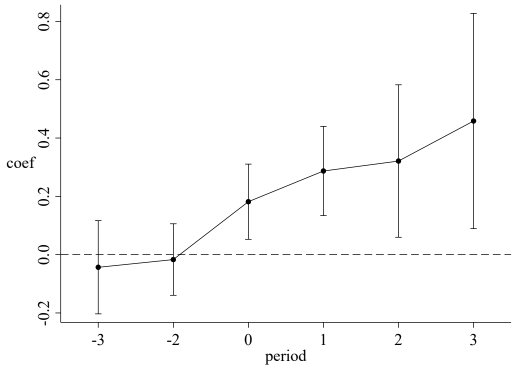
To prove the internal validity of the DID model, we test parallel trends assumptions on our matched sample. This test also mitigates the anticipatory behavioral concern that firms have a significant reduction in emissions compared with control firms before the announcement because they somehow anticipate it. We adopt a frequently used testing approach (Calvo et al., 2023). So, we formulate the data into Equation (3):

$$Y_{i,t} = \beta_0^* + \sum_{t=-3}^{t=3} \tau_t \times D_t \times Treated_i + X_{i,t-1}\beta^* + \delta_i^* + \theta_t^* + \epsilon_{i,t}^* \qquad (3)$$

We use D_t as an event time indicator, where $D_t = 1$ represents the t^{th} period relative to the treatment time. $Treated_i$ is a treatment group indicator, where $Treated_i = 1$ if firm i belongs to the treatment group and $= 0$ otherwise. If the parallel trends assumption holds, τ_t should remain insignificant for $t < 0$ (i.e., the pre-treatment periods). We also follow the convention to normalize τ_{-1} to 0 to avoid identification errors (Callaway & Sant'Anna, 2021). And $X_{i,t-1}$ contains the aforementioned control variables. Figure 1 presents the test results for the parallel trends assumption. The results show that the limits of the 95% confidence interval for the event window [-3, -2] have included zero, which suggests that the parallel trends assumption is satisfied for our data before treatment.



(a) $Emission\ Scope12$



(b) $Emission\ Scope3$

Figure 1 Testing for parallel trend assumption

3.4.2 Heterogeneity Analysis of Supply Chain Control Factors

We add moderators and their interaction terms into Equation (2) to examine moderating effects of impacts on carbon emissions for firms with different levels of external resource control:

$$Y_{i,t} = \beta_0 + \beta_1 Announcement_{i,t} + \beta_2 Moderator_{i,t-1} + \beta_3 Announcement_{i,t} \times Moderator_{i,t-1} + X_{i,t-1}\beta + \delta_i + \theta_t + \epsilon_{i,t} \qquad (4)$$

where $Moderator_{i,t-1}$ refers to three moderators ($Vertinteg$, $Supplier\ Selection$ and $Supplier\ Development$) of firms i in the year $t-1$, for testing the moderators, respectively. The other variables—independent variable $Announcement_{i,t}$, control variables $X_{i,t-1}$, firm fixed effect δ_i, time fixed effect θ_t, and error term $\epsilon_{i,t}$—are defined the same as those in Equation (2).

The moderating effect of vertical integration ($Vertinteg$) on the relationship between carbon neutrality goal announcements and subsequent carbon emissions is presented in Column (1) of Table 3-2. The interaction term ($Announcement * Vertinteg$) is negative and statistically significant for Scope 3 emissions, indicating that higher levels of vertical integration mitigate the increase in emissions associated with carbon neutrality goal setting. Specifically, the results suggest that the positive effect of carbon neutrality goal setting on Scope 3 emissions is attenuated by 35.64% when $Vertinteg$ increases by one standard deviation (0.045) above the mean (0.024).

This finding highlights that firms with greater internal process control through vertical integration are better positioned to manage emissions across the supply chain. By internalizing key processes, these firms achieve greater oversight of emissions-intensive activities that might otherwise be outsourced, thereby reducing the reliance on external suppliers and limiting carbon leakage. Vertical integration thus emerges as a critical strategic mechanism for firms to align their carbon neutrality commitments with verifiable reductions in overall carbon emissions, particularly in addressing the challenges posed by Scope 3 emissions outsourcing.

The influence of $Supplier\ Selection$ on Scope 3 emissions is shown in Column (2) of Table 3-2, where the interaction term is statistically significant ($\beta = -0.457$, $p < 0.01$). These findings provide robust evidence that integrating environmental criteria into supplier selection processes significantly offsets the positive impact of carbon neutrality goal setting on Scope 3 emissions. In fact, the analysis reveals that the increase in Scope 3 emissions is reduced by 80.18% when firms prioritize environmental considerations in sourcing strategies.

This result underscores the role of supplier selection as a key lever for reducing emissions outsourcing and managing the carbon footprints of supply chain partners. Unlike direct emissions, Scope 3 emissions require firms to extend their governance beyond organizational boundaries. By incorporating interorganizational environmental standards, firms can unify supply chain practices with sustainability goals. For instance, firms can exclude high-carbon suppliers or incentivize partners to adopt low-carbon technologies, thereby exerting greater control over indirect emissions. These efforts contribute to meaningful progress toward carbon neutrality and demonstrate that supplier selection is integral to addressing emissions challenges across the supply chain.

Table 3-2 The results of analysis on moderators

	(1)	(2)	(3)
Variables		$Emission\ Scope3$	
$Announcement$	0.300***	0.570***	0.577***
	(0.100)	(0.131)	(0.136)
$Announcement * Vertinteg$	-2.376*		
	(1.395)		
$Vertinteg$	0.873**		
	(0.426)		
$Announcement * Supplier\ Selection$		-0.457***	
		(0.148)	
$Supplier\ Selection$		0.053	
		(0.110)	
$Announcement * Supplier\ Development$			-0.447***
			(0.153)
$Supplier\ Development$			0.043
			(0.089)
Constant	4.740***	4.793***	4.785***
	(0.232)	(0.248)	(0.249)
Observations	2,300	2,300	2,300
$Adjusted\ R^2$	0.865	0.867	0.866
Controls	YES	YES	YES
Firm FE	YES	YES	YES
Year FE	YES	YES	YES

*Note. *p<0.1, **p<0.05, ***p<0.01 using two-tailed tests. Robust standard errors clustered at the firm level are reported in parentheses. Controls, Firm FE, and Year FE are included.*

The moderating effect of $Supplier\ Development$ on Scope 3 emissions is reported in Column (3) of Table 3-2, with a statistically significant interaction term (β = -0.447, p < 0.01). The analysis indicates that firms actively engaging in supplier development initiatives can reduce the positive impact of carbon neutrality goal setting on Scope 3 emissions by 77.47%.

Supplier development transforms supplier relationships from transactional to cooperative through shared accountability frameworks and long-term investments in trust and capability alignment. Unlike supplier selection, which excludes high-carbon partners, supplier development induces endogenous improvements in suppliers' environmental behaviors. By fostering collaborative relationships, firms empower suppliers to adopt sustainable practices, such as low-carbon production technologies, and address emissions from decentralized operations, including raw material extraction and logistics. These relational strategies are particularly effective for mitigating indirect emissions that are otherwise difficult to govern through unilateral measures.

3.4.3 Robustness Tests and Further Analyses

In this section, we have implemented several additional tests and further analyses to ensure the robustness of our results. Table 3-3 summarizes the motivation and processing method. The detailed analyses and results are not included in the thesis, but are available upon request. Further analysis includes five parts:

We evaluate the comprehensive effects of carbon neutrality commitments by employing Emission Scope123 as a substitute dependent variable to investigate the primary and moderating impacts of total emissions. The findings indicate that carbon neutrality commitments are associated with an average 18.3% increase in total emissions relative to current levels. However, this effect can be mitigated through strategies such as vertical integration, supplier selection, and supplier development. Furthermore, alternative measures of interorganizational relationship management, specifically supplier selection and supplier development, were utilized. The results consistently demonstrate similar patterns in terms of direction, magnitude, and statistical significance.

To address potential sample selection biases, we applied alternative propensity score matching (PSM) specifications, including matching ratios of 1:1, 1:2, and 1:4 nearest neighbors, as well as a 0.2 caliper. The robustness of the primary results was maintained across these variations in sample size.

To account for potential placebo effects, a placebo test was conducted as an additional robustness check. Firms with carbon neutrality goals were randomly reassigned 1,000 times, and the results confirmed the robustness of the observed effects. These findings provide further evidence supporting the causal impact of carbon neutrality goal setting on greenhouse gas (GHG) emissions, demonstrating that the results cannot be attributed to random or spurious factors.

To explore the dynamics of carbon leakage within supply chains, we constructed alternative measures of GHG emissions. Specifically, we examined the ratios between different emission scopes to identify potential shifts between direct and indirect emissions. The positive changes in the ratios of (Emission Scope3)/(Emission Scope12) and (Emission Scope3)/(Emission Scope123), alongside the negative change in (Emission Scope12)/(Emission Scope123), provide evidence of carbon leakage within supply chains. These shifts underscore the importance of analyzing emissions at the supply chain level. By employing alternative measures, we further validated the robustness of the primary results while uncovering mechanisms of emissions reallocation across scopes in global supply chains.

To assess the role of vertical integration, we utilized the natural logarithm of net property, plant, and equipment (PP&E) as a proxy for firms' level of production control. A significant decline in PP&E following the announcement of carbon neutrality commitments was observed, suggesting an increased reliance on outsourcing and external suppliers.

Recognizing concerns regarding potential biases in difference-in-differences (DID) studies with staggered treatment assignments, we employed advanced estimators developed by Callaway and Sant'Anna (2021), Sun and Abraham (2021), and Cengiz et al. (2019). These methods address potential estimation biases in traditional DID designs. Consistent with our baseline model, the dynamic effects for Emission Scope12 and Emission Scope3, estimated using CSDID, SADID, and Stacked DID approaches, revealed similar and statistically significant trends.

Table 3-3 Robustness tests and further analyses

Motivation	Processing method
Alternative measurements of carbon emissions	Changing the dependent variable to $Emission\ Scope123$
Alternative measurements of interorganizational relationship management	Using alternative measurements for *Supplier Selection* and *Supplier Development*
Alternative settings in PSM	Changing PSM settings to 1:2 and 1:4 nearest neighbor and to 0.2 caliper
Placebo test	Rearranging the firms with carbon neutrality goal setting randomly 1000 times
Mechanism test 1	Changing the dependent variable to emission ratio among scopes
Mechanism test 2	Changing the dependent variable to $PP\&E$
Alternative estimation	Using CSDID, SADID and Stacked DID to alleviate the heterogeneity in time-varying DID

3.5 Conclusion and discussion

This study investigates the impact of carbon neutrality goal setting on firms' carbon emissions across scopes 1, 2, and 3, with a particular focus on the differing outcomes across these categories. By analyzing 212 carbon neutrality goal-setting announcements made by US-listed manufacturing firms and employing a quasi-natural experiment with propensity score matching and difference-in-differences (DID) models, we provide robust empirical evidence of the consequences of these commitments. Our findings reveal that firms experience an average reduction of 16.6% in scope 1&2 emissions after setting carbon neutrality goals. However, the study also uncovers an average increase of 24.9% in scope 3 emissions beyond a firm's direct operational boundaries, highlighting the presence of supply chain carbon leakage when pursuing carbon neutrality. We further identify mechanisms to mitigate this carbon leakage, especially improving vertical integration, setting environmental criteria for supplier selection and better green supplier development. These findings provide a deeper understanding of how carbon neutrality goal setting can lead to better environmental performance and offer actionable green operational management guidance for firms and policymakers.

3.5.1 Theoretical implications

Our findings make several important contributions to the literature on corporate carbon neutrality, supply chain carbon leakage, and green operations management by providing novel insights into the long-term impacts of carbon neutrality goal setting on firms' environmental performance.

We extend existing research of corporate carbon neutrality to explore the overall long-term influences on corporate's environmental performance. This study deepens the understanding of the long-term effects of carbon neutrality goal setting by examining its impact on carbon emissions across scope 1, scope 2, and scope 3. By measuring emissions from all three dimensions, this research provides a more comprehensive evaluation of firms' environmental performance over time. Unlike prior studies that primarily focus on immediate or operational-level emissions reductions (e.g., scope 1 and scope 2) (e.g., King & Lenox, 2001), our findings reveal the unintended and often overlooked consequence of scope 3 carbon leakage in the supply chain. This holistic approach advances existing research on corporate carbon neutrality by offering a deeper understanding of the trade-offs and complexities associated with achieving meaningful, overall emissions reductions. This contribution aligns with existing calls in the literature for more integrated frameworks that consider emissions across all scopes (e.g., Seuring & Müller, 2008). By highlighting the interplay between scopes, this study encourages future research to move beyond narrowly defined boundaries of carbon accounting and focus on the interconnectedness of operational and supply chain emissions.

Our findings extend the body of research on supply chain carbon leakage by uncovering a key driver of this phenomenon: the adverse effects caused by firms' efforts to quickly demonstrate the effectiveness of their green commitments. Under pressure from stakeholders, firms often prioritize measurable reductions in scopes 1 and 2 emissions to showcase immediate progress toward their carbon neutrality goals. However, this myopic focus can lead to emissions-intensive activities being outsourced or shifted upstream in the supply chain, resulting in significant increases in scope 3 emissions. This insight adds a new dimension, following Song et al. (2022)'s view of supply chain optimization and innovation, to the literature on supply chain carbon leakage, which has traditionally focused on issues such as regulatory arbitrage (e.g., Drake, 2018; Huang et al., 2021) or supply chain complexity (Seuring & Müller, 2008). By identifying the unintended consequences of firms' desire to demonstrate improvements in self-carbon reduction, this study highlights the need for more balanced and strategically aligned approaches to carbon neutrality. This perspective contributes to the theoretical understanding of supply chain carbon leakage by linking it to organizational behavior and strategic decision-making under stakeholder pressure, offering a novel explanation for why it occurs even among firms committed to sustainability. Future research may explore more dimensions of the antecedences and consequences of supply chain carbon leakages to provide a more comprehensive understanding.

A key theoretical contribution of this study to the green operations management literature lies in its identification of three key moderators—vertical integration, supplier selection, and supplier development—that address supply chain carbon leakage and reduce scope 3 emissions. Vertical integration allows firms to internalize emissions-intensive processes, granting greater control over critical supply chain activities and reducing exposure to high-carbon suppliers. This extends prior work on supply chain governance (Pagell & Wu, 2009) by highlighting how vertical integration not only reduces operational uncertainty but also aligns supply chain practices with carbon neutrality objectives. Setting environmental criteria for supplier selection (establishment and termination) provides firms with a mechanism to exert influence over external suppliers, ensuring alignment with sustainability goals while addressing supply chain carbon leakage risks. Finally, green supplier development, such as through training programs and collaborative sustainability initiatives, fosters shared responsibility and enhances supplier capabilities for emissions reduction, aligning with the idea of managing interorganizational relationship through collaboration (Vachon & Klassen, 2006). The latter two moderators build upon the literature on supplier collaboration (Klassen & Vachon, 2003; Tachizawa & Wong, 2014) by demonstrating how firms can leverage their buyer power to incentivize lower emissions across supply chains.

By linking operational strategies to supply chain emissions reductions, this study contributes to the growing body of literature that integrates green SCM with broader goals of carbon neutrality (Seuring & Müller, 2008; Carter & Rogers, 2008). Our findings encourage researchers to further investigate more valid methods from both internal operations management and external resource control (Zhu & Sarkis, 2004; Fu & Su, 2020) for helping truly pursing carbon reduction. We also encourage future research to explore more from leveraging of environmental data from suppliers (e.g., via Internet of Things-enabled emission tracking, ESG audit data, or collaborative supply chain platforms) and practicalities of supplier monitoring (incentives and penalties, and third-party verification).

3.5.2 Practical implications

The findings of this study offer actionable guidance for managers, sustainability practitioners, and policymakers seeking to achieve true carbon neutrality. To ensure that firms' environmental commitments translate into meaningful and sustained reductions in their overall carbon footprint, it is essential to balance operational improvements, supply chain alignment, and stakeholder engagement.

To maintain stakeholder trust and preference, managers must demonstrate a genuine commitment to environmental protection that extends beyond scopes 1 and 2, which requires adopting a holistic approach to carbon neutrality. Firms could establish measurable reduction targets for scope 3 emissions alongside their scope 1 and 2 goals to ensure a balanced approach to decarbonization. By incorporating scope 3 into their carbon neutrality strategies, managers can showcase their commitment to addressing the full spectrum of emissions, which is increasingly important to investors, customers, and regulators. Managers might also clearly communicate their decarbonization efforts and progress across all three scopes to stakeholders. Transparent reporting builds trust and demonstrates accountability, which strengthens the firm’s reputation and competitive position. These strategies help to reinforce the firm’s environmental credibility and align with stakeholder expectations for comprehensive and authentic sustainability commitments.

Managers aiming to reduce their firms’ carbon emissions comprehensively should apply the following operational levers to address emissions across all three scopes, with particular attention to scope 3 emissions: leveraging vertical integration, implementing stricter supplier criteria, and conducting green supplier development. Vertical integration enables firms to internalize emissions-intensive supply chain activities, granting greater control over processes and reducing dependency on high-carbon suppliers (Pfeffer & Salancik, 1978; Pagell & Wu, 2009). By internalizing critical operations, managers can directly implement low-carbon technologies, enforce sustainability standards, and reduce the risk of outsourcing emissions to less regulated suppliers. Additionally, setting environmental criteria for supplier selection and termination ensures that suppliers align with the firm’s sustainability objectives. Managers should prioritize suppliers with verifiable low-carbon practices, renewable energy usage, and transparent emissions reporting. Such criteria not only mitigate the risk of scope 3 carbon leakage but also incentivize suppliers to adopt more sustainable practices, creating an industry-wide shift toward decarbonization (Klassen & Vachon, 2003; Tachizawa & Wong, 2014). Finally, managers should better involve suppliers in green efforts by providing training programs, sharing resources, and collaborating on emissions reduction initiatives. These efforts foster supplier capabilities and shared responsibility for sustainability outcomes, ensuring that suppliers actively contribute to the firm’s carbon neutrality goals (Vachon & Klassen, 2006). By implementing these three strategies, managers can address the complexities of supply chain carbon leakage while strengthening their overall environmental performance.

Moreover, policymakers may play a crucial role in promoting corporate decarbonization by creating an enabling environment that encourages firms to adopt more comprehensive carbon neutrality strategies. Governments should provide subsidies or tax incentives for supplier development programs that help firms and their partners transition to low-carbon practices. For example, financial support for suppliers to adopt renewable energy, invest in energy-efficient technologies, or develop carbon accounting capabilities can accelerate supply chain-wide emissions reductions. This aligns with research on the importance of collaborative supply chain decarbonization (e.g., Carter & Rogers, 2008; Seuring & Müller, 2008). And regulatory bodies should require firms to disclose emissions across all three scopes to ensure greater accountability and transparency. Standardized reporting frameworks, such as those provided by the Greenhouse Gas Protocol, can help firms identify and address emissions hotspots while enabling consistent comparisons across industries. Mandating scope 3 reporting will encourage firms to integrate supply chain emissions into their carbon neutrality strategies, thereby reducing the risk of supply chain carbon leakage. By adopting these policy measures, governments can create a supportive environment that incentivizes and supervises firms to address emissions comprehensively and fosters industry-wide progress toward carbon neutrality.

This study highlights the need for closer alignment between managerial practices and policy frameworks to achieve systemic sustainability outcomes. Managers and policymakers must work together to address the complexities of scope 3 emissions, which require collaboration across organizational boundaries. Policymakers can create the conditions for supply chain decarbonization through incentives and regulation, while managers can implement operational improvements and supply chain strategies that align with these broader goals. This interplay between operations and policy is critical for achieving meaningful and sustained reductions in firms' overall carbon footprint.

3.5.3 Limitations

First, this study focuses on US-listed manufacturing firms, which may limit the generalizability of the findings to other industries or regions. Future research could explore the impact of carbon neutrality goals in sectors with different emissions profiles, such as technology, services, or agriculture, and in firms operating in emerging economies. Second, scope 3 emissions are inherently complex to measure due to the development of multiple tiers of suppliers and downstream partners. While this study uses aggregated scope 3 data, future research could adopt a more granular approach, such as analyzing emissions by specific supply chain activities or groups. Third, we evaluate the long-term (3 years) impact of carbon neutrality goals on emissions using secondary data. Future research could examine the effects of these commitments in a longer period or using some first-hand data, particularly how firms sustain emissions reductions over time and adapt to evolving stakeholder expectations and regulatory environments. Fourth, our finding highlights the importance of external resource control in mitigating scope 3 emissions but does not explicitly consider the role of emerging technologies, such as blockchain and artificial intelligence, in enabling emissions tracking and management. Future research may explore how these technologies can enhance firms' ability to address supply chain carbon leakage.

3.6 References

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4. Study three: Greener operations amid a complex customer base: The role of environmental management systems and innovation

4.1 Introduction

In the business-to-business context, customers serve a crucial role in firms' environmental management. Due to their proximity to other consumers and their high market visibility, customers are often key drivers of a firm's environmental sustainability. Notably, many customers incorporate environmental standards into their procurement requirements (Maignan & McAlister, 2003), thereby exerting significant environmental pressures on firms (Villena et al., 2021). Simultaneously, customers can serve as valuable sources of knowledge for firms striving to enhance their sustainability (Gimenez & Tachizawa, 2012; Klassen & Vachon, 2003). However, manufacturing firms often serve a large number of customers with diverse environmental requirements (Bozarth et al., 2009; Akin Ateş et al., 2022). For instance, a Chinese manufacturer might need to comply with the Eco-Management and Audit Scheme (EMAS) for European customers, while also adhering to ISO 14001 standards for American customers. These differences in environmental requirements can create significant challenges for firms attempting to simultaneously adhere to multiple environmental standards. This study addresses the following critical question: *How can firms effectively manage the complex and diverse environmental requirements of a broad and varied customer base?*

This study utilizes the concept of customer base complexity to capture the diversity and complexity in customers' environmental requirements. This concept is based on the premise that in environmental management, dealing with a large and diverse customer base will likely be more challenging than dealing with a small and homogeneous customer base. Following the literature on supply chain complexity (e.g., Lu & Shang, 2017; Akin Ateş et al., 2022), we categorize customer base complexity into three dimensions: horizontal, vertical, and spatial. Horizontal complexity reflects the number of customers, while vertical complexity indicates the depth of customer relationships, and spatial complexity represents the geographical distribution of customers. We hypothesize that a firm's environmental outcome will be negatively affected by these dimensions of customer base complexity. Managing diverse customer-specific environmental demands can strain a firm's resources, thereby making it more difficult to minimize its environmental impact. As such, for a given level of output or sales, firms with lower customer base complexity are likely to achieve better environmental performance than those with higher customer base complexity.

When faced with complex environments, firms must develop adaptive capabilities (Cohen & Levinthal, 1990). Organizational routines form the foundation of such capabilities, particularly in the context of enhancing firms' absorptive capacities (Lewin et al., 2011). This study examines two environmental routines—environmental innovations (EI) and environmental management systems (EMSs)—to assess their potential for mitigating the negative effects of customer base complexity on environmental performance. Drawing on absorptive capacity theory (Cohen & Levinthal, 1990; Lewin et al., 2011), we propose that EI and EMS can boost a firm's absorptive capacity in the context of environmental management. EI can mitigate customer base complexity through systematic changes and adaptations (Berrone et al., 2013), while EMS can address customer base complexity by standardizing diverse requirements (Darnall & Edwards, 2006). This study explores the extent to which these routines can help to alleviate the negative effects of customer base complexity on a firm's energy use (as a key operational input) and CO_2 emissions (as a key environmental output) per unit of sales.

To evaluate our hypotheses, we sampled listed manufacturing firms in the United States and collected data from multiple databases. This resulted in a panel dataset comprising 940 firm-year observations from 236 firms. Using two-way fixed-effect panel model, we found that our three indicators of customer base complexity all caused negative influences on firms' environmental performance, as measured by energy consumption and CO2 emissions. Our analysis also revealed that environmental management systems (EMSs) are effective in mitigating the impact of horizontal customer base complexity on both energy consumption and CO2 emissions, as well as alleviating the impact of spatial complexity on CO2 emissions. While environmental innovation (EI) reduces the negative effects of vertical complexity on energy consumption and spatial complexity on CO_2 emissions. Collectively, EMSs and EI complement each other in addressing customer base complexity.

This study makes three significant theoretical and practical contributions to the green supply chain management (GSCM) area. First, unlike prior research (e.g., Foerstl et al., 2015; Huq et al., 2016; Chen & Ho, 2019), which predominantly treats customers as a homogeneous group of stakeholders, this study adopts a complexity perspective (Wijekoon et al., 2021) to capture the heterogeneity of customers. By recognizing customers as a diverse group of stakeholders, we provide a more accurate representation of their influence on a firm's environmental management, thereby advancing the GSCM literature with a nuanced understanding of customer impacts on environmental sustainability. Second, we developed a comprehensive database integrating multiple data sources to operationalize customer base complexity and link its three dimensions—horizontal, vertical, and spatial—to firms' energy use and CO_2 emissions. This represents a significant implication to the supply chain management literature, which has largely talked about supply base complexity (e.g., Bode & Wagner, 2015; Lu & Shang, 2017; Sharma et al., 2020) while neglecting the complexities of customer bases. Third, we extend and specify the theoretical discussion of complexity absorption capability (Boisot & Child, 1999) to identify strategies (EMSs and EI) that help firms mitigate the negative relationships between customer base complexity and environmental performance.

4.2 Theoretical Foundation

4.2.1 Customer base complexity

A firm's customers often employ a wide range of environmental standards and practices in supply chain sustainability. Consequently, it is not merely the extent or magnitude of customer pressure (Foerstl et al., 2015; Porteous et al., 2015) that influences a firm's green practices, but also the diversity among customers, particularly with respect to their environmental expectations. This research adopts a complexity framework (Choi et al., 2001) to conceptualize a firm and its customer base as an integrated system, examining three distinct dimensions of customer base complexity.

A recent review by Akin Ateş et al. (2022) highlights the limited research on downstream supply chain complexity. As such, the present study also draws upon the literature on upstream supply chain complexity (e.g., Bode & Wagner, 2015; Lu & Shang, 2017) and internal complexity (e.g., Bozarth et al., 2009; Gray & Handley, 2015) to properly define customer base complexity. Horizontal complexity refers to the breadth of the customer base, represented by the number of customers (Lu & Shang, 2017; Sharma et al., 2020). While a broad customer base can diversify risks and provide access to multiple markets, it can also have negative effects on a firm's performance. For example, Bozarth et al. (2009) found that having a larger number of customers can negatively affect manufacturing performance metrics such as schedule adherence and cost. It is presumed that managing a large customer base will likely complicate environmental management because the firm will need to address multiple different environmental requirements.

Vertical complexity captures the depth of a firm's customer relationships, which often extends beyond those with direct customers, especially as product complexity increases (Choi & Hong, 2002). Although the literature on downstream supply chain complexity only addresses vertical complexity to an extremely limited extent, the literature on green supply chain management does acknowledge the challenges of cascading environmental standards, as seen in the "green bullwhip effect" (Lee et al., 2014), which describes a situation in which environmental requirements become increasingly diversified and ambiguous in multi-tier supply chains. It is conjectured in this study that this type of complexity can cause confusion for firms, thereby making it more difficult for them to effectively deploy resources to improve their environmental performance.

Spatial complexity reflects the geographical dispersion of customers. As globalization intensifies, firms increasingly serve geographically dispersed customers (Gereffi & Lee, 2012). Serving a dispersed customer base often involves complying with diverse, and sometimes even conflicting, environmental standards. For example, a firm might face different environmental standards and requirements, such as EMAS for European customers and ISO 14001 for American customers. It is presumed that spatial complexity likely increases the heterogeneity of customer environmental requirements, thereby complicating the firm's environmental management processes. This implies that serving customers located in the same country will likely entail simpler environmental management processes than serving customers located in many different countries.

Collectively, these three dimensions of complexity offer a holistic perspective on the structure of a firm's customer base, encompassing both its size and diversity. Akin Ateş et al. (2022) note that customer base complexity could negatively affect firm performance due to reasons driven by structural and cognitive challenges (Rossetti et al., 2023). Structurally, complexity can disrupt efficient resource deployment; cognitively, complexity in the environment can hinder managers' ability to process and act on relevant information. As adaptive systems, firms must match the complexity of their environments (Boisot & Child, 1999). This study seeks to understand how firms adapt to cope with customer base complexity in the context of environmental management.

4.2.2 Absorptive capacity routines: EMS and EI

Complexity is a necessary yet challenging aspect of supply chain management that often leads to inefficiencies and disruptions (Bode & Wagner, 2015). To navigate complex environments, firms must build absorptive capacity, which is the "ability of a firm to recognize the value of new, external information, assimilate it, and apply it to commercial ends" (Cohen & Levinthal, 1990, p. 128). Organizational routines, such as standard operating procedures and rules guiding decisions, are fundamental to developing absorptive capacity since they represent the building blocks of organizational capabilities that evolve in response to past experiences and environmental changes (Teece et al., 1997; Zollo & Winter, 2002). Lewin et al. (2011) argue that the ability of firms to discover and implement complementarities between various routines may be key to sustainable competitive advantage.

Encompassing rules, heuristics, and norms, routines serve a crucial role in adaptation, innovation, and change, especially under bounded rationality constraints (Winter & Szulanski, 2001). Routines coordinate the actions of multiple organizational units or actions by individuals. Routines can also accelerate and simplify information processing tasks and decision-making processes. As routines evolve, they become integral to firms' absorptive capacity and help them respond to complex environments (Lewin et al., 2011). Importantly, routines are context-specific (Winter & Szulanski, 2001), which implies that firms need task-specific routines for managing different complexities. In the context of environmental management, it remains unclear what routines can be effective in developing a firm's absorptive capacity. Our thorough literature review on environmental management identified EMS and EI as key routines that may enhance a firm's absorptive capacity when confronted with customer base complexity.

EMSs are routines that "enable organizations to continually reduce their impact on the natural environment" (Darnall & Edwards, 2006, p. 302). They typically include policies and evaluation processes to assess and meet environmental goals. For example, ISO 14001 focuses on standardization and continuous improvement, which align with exploitative learning. Notably, Lewin et al. (2011) suggest that an EMS can be an effective absorptive capacity routine in the context of environmental management. EMSs are recurrent and a source of stability and continuity (Melnyk et al., 2003). Moreover, they can help to coordinate multiple organizational units and simplify information processing, thus enabling firms to handle customer base complexity more effectively.

EIs are routines for "the development of products, processes, or services aimed at reducing environmental harm through innovations like emissions treatment and cleaner energy use" (Berrone et al., 2013, p. 891). They are characterized by their broad environmental scope, exploratory learning, and organizational flexibility (Berrone et al., 2013; Nair et al., 2016). EIs also entail the invention of new designs and the creation of novel products and processes to reduce or eliminate the use of hazardous materials. Although EIs are generally riskier and require greater financial resources, they may accrue returns in the long term. These attributes make EI well-suited for navigating heterogeneous customer environmental requirements.

In this study, we argue that EMSs and EIs provide potentially effective sets of environmental routines that can enhance a firm's absorptive capacity in the context of environmental management, which can further enable it to cope with the challenges posed by customer base complexity.

4.3 Hypotheses Development

4.3.1 Customer Base Complexity and Environmental Management

Supply chain complexity is an inevitable reality, particularly in the context of globalization (Bode & Wagner, 2015). Empirical research has consistently demonstrated that such complexity negatively affects various aspects of firm performance, e.g., financial (Lu & Shang, 2017), environmental (Adhikary et al., 2020), innovation (Sharma et al., 2020), etc. Moreover, the complexity of a firm's supply base can impede a its ability to effectively harness its suppliers' innovation capabilities (Dong et al., 2020).

While empirical studies on the complexity of supply networks considering downstream are scarce, evidence suggests that customer base complexity is an integral aspect of the modern business landscape, especially in the context of environmental management. For instance, L-Bridge, a printed circuit board manufacturer based in Dongguan, serves a customer base comprising over 100 major companies across Europe, North America, East Asia, and Southeast Asia. These customers impose diverse and stringent environmental requirements, posing significant challenges for L-Bridge in integrating these standards into its daily operations efficiently and cost-effectively.

Given the limited direct investigations of customer base complexity in the OSCM literature, this study draws on research related to supply base complexity (e.g., Bode & Wagner, 2015; Dong et al., 2020; Lu & Shang, 2017), transaction cost economics (Grover & Malhotra, 2003), and social network theory (Ahuja, 2000). These perspectives are utilized to examine the potential effects of horizontal, vertical, and spatial customer base complexity on a firm's environmental performance, specifically focusing on energy consumption and CO_2 emissions.

Horizontal complexity reflects the breadth of a firm's customer base (cf. Lu & Shang, 2017; Sharma et al., 2020). Firms often aim to maintain more customers to reduce dependency on any single customer and to diversify their market access. For instance, Weizhen, a Shenzhen-based electric motor manufacturer, supplies over 60 major customers globally, including Sony, Philips, Samsung, and Microsoft. The company enforces an implicit policy to ensure that single customer accounts for less than 10% of its total production capacity.

Horizontal complexity can influence a firm's environmental performance in various ways. First, serving a large customer base exposes firms to heightened environmental pressures, as extending social and environmental sustainability across supply chains has become both a norm and a requirement (Gimenez & Tachizawa, 2012; Xiao et al., 2019). Second, a diverse customer base can serve as a valuable source of environmental knowledge and information, including advanced standards and innovative practices (Lee & Klassen, 2008; Villena et al., 2021).

However, bounded rationality imposes significant constraints, leading us to argue that horizontal complexity can also impede effective environmental management. A large customer base often brings diverse and sometimes conflicting environmental requirements, which are challenging to integrate into daily operations. For example, Weizhen faces varied customer demands: some require adherence to ISO 14001 for environmental management, Sony enforces its proprietary "Sony Green Partner" environmental standards, and Philips mandates compliance with the Electronics Industry Citizenship Coalition Code of Conduct (authors' notes). When a firm with limited cognitive and managerial resources encounters multiple, divergent environmental requirements, it is likely to experience delays and difficulties in making the necessary environmental investments.

In summary, while engaging with a large number of customers can provide access to critical information and intangible resources, the diversity of environmental requirements across the customer base may create significant challenges and confusion for effective environmental management.

***Hypothesis 3-1**: A firm's horizontal customer base complexity positively influences its energy use **(H3-1a)** and CO_2 emissions **(H3-1b)**.*

The depth of a firm's customer base plays a significant role in green practice. Assessing vertical complexity has posed challenges for supply chain researchers. Building on prior studies (e.g., Choi & Krause, 2006; Lu & Shang, 2017), this study defines vertical complexity as the average number of lower-tier customers linked to a firm's Tier-1 customers.

We posit that vertical complexity can negatively affect a firm's green practice due to the "green bullwhip effect" (Lee et al., 2014; Seles et al., 2016). This effect describes how environmental requirements intensify and change as they propagate along supply chains. From a transaction cost economics (TCE) perspective, the bounded rationality of supply chain partners, coupled with uncertainties surrounding environmental technologies (Shrivastava, 1995), exacerbates challenges in cascading environmental requirements across long and complex supply chains.

Vertical complexity is likely to amplify this green bullwhip effect further. A higher number of lower-tier customers increases the confusion and difficulty experienced by Tier-1 customers in managing environmental requirements, which are then passed along to the focal firm. This cascading effect complicates environmental management and hinders the firm's ability to meet sustainability objectives.

***Hypothesis 3-2**: A firm's vertical customer base complexity positively influences its energy use **(H3-2a)** and CO_2 emissions **(H3-2b)**.*

Spatial complexity pertains to the geographical distribution of a firm's customer base and is commonly quantified by the number of countries or regions where its customers are located (Lu & Shang, 2017). This dimension of complexity can have both positive and negative implications for a firm's green practice.

From the perspective of social network theory (SNT), a geographically diverse customer base allows a firm to access a wide range of nonredundant knowledge and a unique combination of intangible resources that can strengthen green practice efforts (Kim, 2013). However, from the perspective of transaction cost economics (TCE), the geographical dispersion of customers significantly increases the transaction costs associated with green practice in two key ways.

First, countries exhibit substantial variation in environmental standards (Orcos et al., 2018), shaped by both formal and informal institutional factors influencing the development and dissemination of these standards (Xiao et al., 2018; Xiao et al., 2019). For instance, the European Union (EU) enforces the Eco-Management and Audit Scheme, which represents some of the world's most stringent environmental regulations. When serving a diverse customer base across multiple countries, firms often face conflicting environmental requirements that are difficult to integrate into daily operations. These differences in standards can lead to confusion or even operational challenges. For instance, while the EU generally maintains stricter environmental standards compared to the United States, compliance with EU standards does not guarantee full alignment with U.S. regulations, further complicating environmental management.

Second, from the SNT perspective, spatial complexity increases both geographical and cultural distances between focal firm and customers (Dong et al., 2020), complicating efforts to engage with them effectively on environmental management initiatives.

In summary, although a geographically dispersed customer base provides access to valuable resources and knowledge, the difficulties associated with coordination, compliance, and collaboration with such a diverse customer base may hinder a firm's ability to fully leverage these resources for environmental improvements.

Hypothesis 3-3*: A firm's spatial customer base complexity positively influences its energy use* ***(H3-3a)*** *and CO_2 emissions* ***(H3-3b)****.*

4.3.2 Environmental Innovation and Complexity Absorption

EI encompasses various types, including innovations in product, process, and managerial (Berrone et al., 2013). EI represents a proactive, long-term strategy that goes beyond regulatory compliance, demanding substantial resources and management commitment. Compared to other environmental practices, EI involves higher risks and resource commitments. Firms that pursue EIs often view environmental challenges as opportunities rather than threats (Porter & Van der Linde, 1995), which helps to explore transformative changes and address critical environmental concerns such as global warming (Slawinski & Bansal, 2015).

EI can enhance a firm’s absorptive capacity by shifting from exploitative to exploratory learning and fostering a more strategical organizational structure (e.g., Berrone et al., 2013; Nair et al., 2016). EI often involves adopting new technologies, processes, and practices aimed at sustainability. This requires the firm to invest in learning, both internally and externally. By focusing on green technologies, sustainability practices, or resource-efficient systems, a firm can develop a culture that encourages continuous learning (Berrone et al., 2013), which strengthens its absorptive capacity. Moreover, EI often requires collaboration with external partners, including suppliers, customers, and research institutions. By engaging with different stakeholders on sustainability-related projects, firms can enhance their ability to absorb new knowledge from various sources, thereby broadening their knowledge base (Sharma & Vredenburg, 1998). Finally, a firm engaged in EI is likely to develop more flexible processes, thereby enhancing its capacity to absorb external knowledge and rapidly implement new ideas and solutions (Sharma & Vredenburg, 1998). This flexibility is an important aspect of absorptive capacity, which enables firms to retain an advantageous position in rapidly changing markets.

Based on these observations, we propose that EI can mitigate the challenges posed by customer base complexity in two main ways. First, firms that engage in EI are likely to view customer base complexity as a kind of valuable intangible assets to learn from customer's knowledge and technical (Porter & Van der Linde, 1995; Slawinski & Bansal, 2015). For example, such firms may actively involve engineers from customer companies in their environmental initiatives. This positive view enables firms to leverage their customer base for ideas and inspiration (c.f. Lewin et al., 2011). Second, firms experienced in EI are more capable of finding creative solutions that integrate diverse environmental requirements from various customers, aided by their exploratory learning orientation and adaptable structures (Berrone et al., 2013; Nair et al., 2016). Thus, for firms actively investing in EI, customer base complexity may become a benefit instead of a burden. These observations lead to our fourth, fifth, and sixth hypotheses, which are presented as follows:

Hypothesis 3-4: *EI mitigates the positive effect of horizontal customer base complexity on a firm's energy use* ***(H3-4a)*** *and* CO_2 *emissions* ***(H3-4b)***.

Hypothesis 3-5: *EI mitigates the positive effect of vertical customer base complexity on a firm's energy use* ***(H3-5a)*** *and* CO_2 *emissions* ***(H3-5b)***.

Hypothesis 3-6: *EI mitigates the positive effect of spatial customer base complexity on a firm's energy use* ***(H3-6a)*** *and* CO_2 *emissions* ***(H3-6b)***.

4.3.3 Environmental Management System and Complexity Absorption

Environmental management system, which outlines formal processes for training personnel, monitoring environmental performance, and reporting data to stakeholders, is a process-oriented routine for systematically managing a firm's environmental impact (Melnyk et al., 2003). The use of an EMS can lead to significant performance gains, particularly when certified under standards such as ISO 14001. Certification helps to ensure that an EMS is effectively implemented, allowing firms to regularly evaluate and improve their environmental performance based on established policies and objectives (Melnyk et al., 2003; Sroufe, 2003).

An EMS can contribute to a firm's absorptive capacity in multiple ways. First, it can assist the firm in acquiring knowledge of environmental management. An EMS typically involves standardized procedures for identifying, evaluating, and managing environmental risks and opportunities (an example of such an EMS is one conforming to the ISO 14001 standard). By establishing formal processes for data collection and the monitoring and review of environmental performance, firms can acquire knowledge from various internal and external sources (Delmas, 2001). This enables them to understand new environmental regulations, market shifts toward sustainable practices, and develop new technological innovations.

Second, EMSs require continuous monitoring and evaluation of environmental practices. By regularly assessing their environmental impact, firms can absorb and integrate relevant external knowledge (e.g., green technologies or sustainability practices) into their operations. Over time, this can improve the firm's capacity to assimilate new knowledge and adapt it to its specific needs.

Third, the continuous improvement aspect of EMSs (often linked to Plan-Do-Check-Act cycles) encourages firms to adopt innovative practices, whether through improving resource efficiency, reducing emissions, or creating innovative sustainable product designs. This constant cycle of review and improvement fosters knowledge transformation, which is an essential element of absorptive capacity (Dangelico & Pujari, 2010).

Based on these observations, we argue that an EMS can serve as an absorptive capacity routine to help firms manage customer base complexity. Our synthesis of the literature identified two main mechanisms in this regard. First, a mature EMS provides systematic procedures for collecting, processing, and verifying information relevant to environmental management (Darnall & Edwards, 2006; Ziegler & Nogareda, 2009). This structure minimizes ad hoc responses to customer environmental requirements, thereby reducing the effects of bounded rationality and enabling the more effective handling of diverse requirements. Next, an EMS supports continuous improvement and exploitative learning, encouraging firms to find synergies between financial and ESG targets (Melnyk et al., 2003; Sroufe, 2003). As a result, firms with a well-functioning EMS can more easily access the information, knowledge, and best practices embedded throughout a complex customer base, which can facilitate ongoing environmental improvement. These facts lead us to our seventh, eighth, and ninth hypotheses, which are presented as follows:

Hypothesis 3-7*: An EMS mitigates the positive effect of horizontal customer base complexity on a firm's energy use* ***(H3-7a)*** *and CO_2 emissions* ***(H3-7b)****.*

Hypothesis 3-8*: An EMS mitigates the positive effect of vertical customer base complexity on a firm's energy use* ***(H3-8a)*** *and CO_2 emissions* ***(H3-8b)****.*

Hypothesis 3-9*: An EMS mitigates the positive effect of spatial customer base* *complexity on a firm's energy use **(H3-9a)** and CO_2 emissions **(H3-9b)**.*

4.4 Methods

4.4.1 Sample

The study utilized data from four secondary sources: Thomson Reuters Environmental, Social, and Governance (ESG) database, Kinder, Lydenberg, Domini Inc. (KLD) database, Bloomberg Supply Chain Analysis (SPLC), and Compustat. The data collection process began with identifying 338 manufacturing firms (classified under the Standard Industrial Classification [SIC] codes 20-39) with available data of environmental performance in the Thomson Reuters ESG and KLD databases. After integrating the environmental data with financial information collected from the Compustat database, the sample size was reduced to 330 firms. Subsequently, supply chain data were retrieved from Bloomberg SPLC, further reducing our sample to 236 firms due to missing data.

The dependent variable, environmental performance, was measured over the period 2012-2019, while the independent variables were lagged by one year (2011-2018) to account for potential endogeneity. This resulted in a final panel dataset comprising 236 manufacturing firms and 940 firm-year observations for analysis. Detailed information about the sample distribution is provided in Table C1 of Appendix C. The industry composition demonstrates a diverse representation of manufacturing sectors, with no single sector dominating the dataset. Additionally, the temporal distribution of firm-year observations is balanced across the study period.

4.4.2 Measurement

4.4.2.1 Dependent variables

The study employs CO2 emissions and energy use as indicators of a firm's environmental performance, consistent with prior research (Adhikary et al., 2020; Pil & Rothenberg, 2003). CO2 emissions serve as a key measure of overall environmental performance (Chaabane et al., 2012; Miemczyk et al., 2012). This variable is calculated as the ratio of a firm's total carbon dioxide emissions (scope 1 and 2, in kilograms) to its net sales (in millions of U.S. dollars). For the purpose of analysis, this metric is referred to as "*emissions*," with higher values indicating poorer environmental performance.

Angell and Klassen (1999) emphasized the need to assess environmental performance at the operational level in addition to the firm level. In response, Pil and Rothenberg (2003) incorporated raw material inputs into their framework for evaluating environmental performance within manufacturing. To capture operational-level environmental performance, energy use is included as a secondary measure. This variable is defined as the ratio of total energy consumption (direct and indirect, in gigajoules) to net sales (in millions of U.S. dollars). For analysis, this metric is referred to as "*energy use*," with higher values indicating a decline in environmental performance.

Both CO2 emissions and energy use data were sourced from the Thomson Reuters ESG database. An increase in either metric (emissions or energy use per unit of sales) reflects a deterioration in the firm's environmental performance.

4.4.2.2 Independent variables and moderators

Horizontal customer base complexity was quantified as the total count of Tier-1 customers linked to the focal firm. A greater number of Tier-1 customers heightens the difficulty of aligning and integrating their diverse requirements into production processes.

Vertical customer base complexity was operationalized as the average number of Tier-2 customers associated with each Tier-1 customer. Since Tier-2 customers are less directly visible to the focal firm, discrepancies in their environmental demands may be exacerbated by the green bullwhip effect (Lee et al., 2014). A higher number of Tier-2 customers amplifies this effect, making supply chain coordination significantly more difficult.

Spatial customer base complexity was assessed based on the number of countries in which the firm's customers are located. This measure captures the heterogeneity in customer environmental requirements due to geographical dispersion. However, one could argue that customers from multiple countries may exhibit similar and stable environmental requirements (e.g., within the European Union). To more accurately reflect the heterogeneity of customer countries, we used the variance in the Environmental Performance Index (EPI) of the countries as an enhanced measure of spatial complexity. The EPI evaluates a country's environmental performance across 11 categories (Wendling et al., 2020). Customers from countries with higher EPI scores are likely to have different environmental requirements compared to those from countries with lower scores. To quantify the heterogeneity and instability of customers' environmental requirements, we calculated the annual change in the standard deviation of the EPI scores for the Tier-1 customers' countries. Given that the distributions of all three complexity indicators (horizontal, vertical, and spatial) were highly skewed to the right, we applied a natural logarithmic transformation to normalize the data and correct for skewness.

The first routine of absorptive capacity, *environmental innovation*, was assessed using the environmental innovation score from the Thomson Reuters ESG database. This composite score is derived from 36 indicators sourced from various channels including corporate annual reports, NGO websites, and news outlets. The score reflects a firm's ability to develop new environmental technologies, such as green production processes and eco-designed products (Xie et al., 2019). Thus, it captures the firm's proficiency in both process and product innovation for environmental purposes.

The implementation and experience of EMSs were assessed based on a firm's certification against ISO 14001, as recorded in the KLD database. As ISO 14001 is designed to promote continuous improvement, the timing and duration of certification are critical factors. Research has shown that prolonged experience with ISO 14001 significantly influences the selection and deployment of environmental initiatives (Melnyk et al., 2003). Accordingly, this study measured *environmental management system* as the number of years (log-transformed) that a firm had maintained an ISO 14001 certification as of year t. This metric captures the firm's accumulated expertise and practical experience in implementing environmental management practices.

4.4.2.3 Control variables

To account for supply chain structure, we incorporated measures of customer and supplier concentration, with data obtained from Bloomberg SPLC. *Customer concentration* and *supplier concentration* were calculated by scaling the transaction values between the focal firm and its top four customers or suppliers respectively. Highly concentrated supply chains are more likely to help a firm maintain close relationships with important customers and suppliers, which thus bring benefits to supply chain coordination (Ak & Patatoukas, 2016). Additionally, two variables were included to control for supply base complexity: the number of direct suppliers (*horizontal supply base complexity*) and the number of Tier-2 suppliers per direct supplier (*vertical supply base complexity*). Both variables were natural-logarithm transformed to account for skewness. Prior research (e.g., Adhikary et al., 2020) has shown that supply base complexity can significantly affect a firm's greenhouse gas emissions.

Firm performance, measured as return-on-assets (*ROA*), was included as a control variable, with data sourced from the Compustat database. *Firm size*, proxied by the natural log of the number of employees, was also included. Larger and better-performing firms often have more resources available to invest in environmental practices (de Villiers et al., 2011). *Financial leverage*, calculated as the debt-to-equity ratio, was included to account for financial stress, which may influence the allocation of resources to environmental initiatives (Modi & Cantor, 2021). Research and development (R&D) intensity, defined as *R&D expenses* per employee, was added to control for the level of personnel support for environmental innovation (Alam et al., 2019).

Several variables related to green supply chain practices were included, with data sourced from the Thomson Reuters ESG database. First, the performance of the firm's partnership programs with external stakeholders to address environmental issues was controlled for (*environmental partnership*). Second, the presence of a dedicated team responsible for implementing environmental strategies (*environmental management team*) was included. Third, the existence of a formal policy for managing environmental issues within the supply chain (*environmental supply chain policy*) was controlled for. These variables were distinct from the dependent and independent variables measured in this study.

To account for environmental pressures originating from the customer base, this study included several customer-related variables. *Average customer energy use* and *average customer CO2 emissions*, both scaled by customer revenues, were included to capture the average environmental performance of customers. Furthermore, the proportion of customers with a dedicated environmental management team (*average customer environmental management team*) was included as a proxy for customers' commitment to environmental management. Finally, the year of observation was included as a control variable to account for potential temporal effects caused by changes over time. Detailed descriptions of all measurements are provided in Table C2 in Appendix C.

4.4.3 Estimation methods

Testing the proposed hypotheses involves several empirical challenges that must be addressed to ensure robust results. First, there is a potential issue of reverse causality, as a firm's environmental performance may influence its customer structure. For instance, firms with poor environmental performance might face reduced competitiveness in attracting and retaining customers. To mitigate this concern, the study employed a one-year lag for the independent and control variables compared to the dependent variable, following the approach outlined by Wiengarten et al. (2017). Additionally, the analysis may be biased by both observable and unobservable factors. To address confounding effects from observable factors, the study incorporated control variables as recommended by Lu and Shang (2017). For unobservable confounding factors, a two-way fixed-effects regression approach was adopted, which helps mitigate their potential influence (Ketokivi & McIntosh, 2017).

In a fixed-effects model, each subject serves as its own control. The underlying assumption is that any effects from omitted variables influencing a subject at one point in time will manifest in a consistent manner over time, resulting in constant or “fixed” effects (Pesaran et al., 2018). By applying firm-level fixed effects, the model facilitates “within” estimation by demeaning variables at the firm level (Wowak et al., 2021). This fixed-effects approach eliminates variations across firms that might otherwise bias the results. Consequently, the coefficients in a fixed-effects model capture how changes in customer base complexity within a firm over time affect subsequent shifts in environmental performance. The coefficients derived from this fixed-effects model reflect intra-firm dynamics. Specifically, they measure the effect of temporal changes in customer base complexity on future environmental outcomes within the same firm (Wowak et al., 2021).

Thus, the models were estimated using the “xtreg” function with the “fe” option in STATA (version 16), which supports fixed-effects regression analysis. The following models were specified to test the hypotheses, where *controls* are those control variables mentioned above and ε is the error term.

$$Environmental\ performance_{it} = \beta_0 + \beta_1 horizontal\ customer\ base\ complexity_{it-1} + \beta_2 vertical\ customer\ base\ complexity_{it-1} + \beta_3 spatial\ customer\ base\ complexity_{it-1} + \beta_4 Moderators_{it-1}{*}horizontal\ customer\ base\ complexity_{it-1} + \beta_{54} Moderators_{it\ it-1}{*}vertical\ customer\ base\ complexity_{it-1} + \beta_{64} Moderators_{it\ it-1}{*}spatial\ customer\ base\ complexity_{it-1} + + \beta_{74} Moderators_{it\ it-1} + \beta_{8\sim n} controls_{it-1} + \varepsilon_{it} \quad (1)$$

4.4.4 Selection bias

We conducted the sample selection process based on the availability of original environmental performance data, specifically energy use and emissions, as reported in the Thomson Reuters ESG database. However, some U.S.-listed manufacturing firms might be absent in this database. Firms with superior environmental performance may be more transparent in disclosing their environmental practices, increasing the likelihood of their inclusion in the database. This potential bias, where inclusion in the ESG database is influenced by a firm’s environmental performance, can be represented as a binary variable.

To address concerns about selection bias, this study employed the Heckman two-stage analysis (Pagell et al., 2019). In the first stage, a probit regression was conducted to model the likelihood of a firm being included in the ESG database. The results of the probit regression are presented in Table 4-1. Based on these results, the inverse Mills ratio (*IMR*) was calculated, representing the probability of firm *i* being included in the ESG database and having environmental data available for year *t*. Often referred to as the selection hazard, the IMR is derived from probit analysis and is computed as the ratio of the probability density function to the cumulative distribution function of the standard normal distribution (Chen et al., 2009). In the second stage, the *IMR* was incorporated into the our regression models to account for potential selection bias arising from the availability of environmental performance data. This approach ensures that the findings are not distorted by selection effects.

Table 4-1 Selection model

	Dependent Variable: Environmental Data Reporting		
Independent variables	Coefficient	S.E.	p
ROA	0.41446	0.17049	0.015
Firm size	0.41491	0.01327	0.000
Leverage	-0.00017	0.00039	0.669
R&D intensity	0.00086	0.00032	0.008
EnvTeamScore	0.01222	0.00045	0.000
N_IndReport	1.89049	0.21579	0.000
YearDummy	Included		
IndustryDummy	Included		
R^2	36.38%		
N	10106		

4.5 Results

We summarize the descriptive statistics and correlations among all variables included in the analysis in Table C3 in Appendix C. The results of the two-way fixed-effects regression analyses for energy use and emissions are detailed in Table 4-2 and Table 4-3 as below, respectively. To assess collinearity, variance inflation factors (VIF) were calculated for all independent variables. The maximum VIF was 3.93, and the mean VIF was 1.57 (as presented in Table C4 in Appendix C), indicating that multicollinearity is not a significant concern in this study (Kutner et al., 2005).

4.5.1 Direct effects of customer base complexity

The dependent variables of Model 1 in Tables 4-2 and 4-3 are *energy use* and *CO_2 emission (per unit of sales),* respectively. These two tables include all three dimensions of customer base complexity and control variables. In Table 4-2, the coefficients of horizontal customer base complexity (893.576, $p < 0.05$) and vertical customer base complexity (760.041, $p < 0.05$) are significantly positive, while the coefficient of spatial customer base complexity is not significantly different from zero ($p > 0.1$). In Table 4-3, all coefficients of horizontal customer base complexity (0.675, $p < 0.05$), vertical customer base complexity (0.554, $p < 0.1$), and spatial customer base complexity (0.269, $p < 0.05$) are significantly positive. These results fully support H3-1a, H3-1b, H3-2a, H3-2b, and H3-3b, but do not support H3-3a.

4.5.2 Moderating effects

Models 2-4 in Table 4-2 examine the dependent variable of energy use, including interaction terms between EI and the three dimensions of customer base complexity: horizontal, vertical, and spatial. The results indicate that the interaction between EI and vertical customer base complexity is significantly negative (-17.341, $p < 0.1$). Specifically, increasing EI from its mean value (45.53) to one standard deviation above the mean (77.72) mitigates the positive effect of vertical customer base complexity on energy use by 33.62%. However, no significant moderating effect of EI was found for horizontal or spatial customer base complexity. Therefore, H3-5a is supported, while H3-4a and H3-6a are not supported.

Models 5-7 in Table 4-2 also use energy use as the dependent variable, incorporating interaction terms between EMS and the three complexities. The results show that the interaction of EMS with horizontal customer base complexity (-753.079, $p < 0.05$) and vertical customer base complexity (-789.666, $p < 0.1$) is significantly negative. This suggests that implementing EMS mitigates the positive effect of horizontal customer base complexity on energy use by 47.92% and vertical customer base complexity by 66.06%. However, no significant moderating effect of EMS was found for spatial customer base complexity. Accordingly, H3-7a and H3-8a are supported, while H3-9a is not supported.

Models 2-4 in Table 4-3 analyze the dependent variable of CO2 emissions, including interaction terms between EI and the three moderators. The results reveal that the interaction between EI and spatial customer base complexity is significantly negative (-0.008, $p < 0.05$). Increasing EI from its mean (45.53) to one standard deviation above the mean (77.72) mitigates the positive effect of spatial customer base complexity on CO2 emissions by 43.13%. However, no significant moderating effects of EI were identified for horizontal or vertical customer base complexity. Therefore, H3-6b is supported, while H3-4b and H3-5b are not supported.

Models 5-7 in Table 4-3 examine the dependent variable of CO2 emissions, incorporating interaction terms between EMS and customer base complexity. The findings indicate that the interaction of EMS with horizontal customer base complexity (-0.837, $p < 0.01$) is significantly negative. This indicates that having an EMS mitigates the positive effect of horizontal customer base complexity on CO2 emissions by 60.29%. However, no significant moderating effects of EMS were observed for vertical or spatial customer base complexity. Thus, H3-7b is supported, while H3-8b and H3-9b are not supported.

In summary, for energy use, EI mitigates the effect of vertical customer base complexity (H3-5a supported), while EMS mitigates the effects of both horizontal and vertical customer base complexities (H3-7a and H3-8a supported). For CO2 emissions, EI mitigates the effect of spatial customer base complexity (H3-6b supported), while EMS mitigates the effect of horizontal customer base complexity (H3-7b supported). While no significant moderating effects were found for the remaining hypotheses (H3-4a, H3-4b, H3-6a, H3-8b, H3-9a, H3-9b not supported).

Table 4-2 Results of two-way fixed effects regression analysis on energy use

VARIABLES	Model 1 Energy use	Model 2 Energy use	Model 3 Energy use	Model 4 Energy use	Model 5 Energy use	Model 6 Energy use	Model 7 Energy use
Horizontal customer base complexity	893.576**	1,309.047**	859.450**	893.729**	1,571.409***	990.771**	924.956**
	(0.026)	(0.026)	(0.032)	(0.026)	(0.003)	(0.014)	(0.022)
Vertical customer base complexity	760.041**	751.937**	1,660.532***	762.209**	772.777**	1,195.254***	762.206**
	(0.045)	(0.047)	(0.009)	(0.044)	(0.041)	(0.007)	(0.045)
Spatial customer base complexity	87.882	77.433	83.600	172.432	62.203	63.895	114.148
	(0.533)	(0.584)	(0.553)	(0.437)	(0.660)	(0.651)	(0.531)
Environmental innovation * Horizontal customer base complexity		-9.062					
		(0.334)					
Environmental innovation * Vertical customer base complexity			-17.341*				
			(0.079)				
Environmental innovation * Spatial customer base complexity				-1.986			
				(0.622)			
Environmental management system * Horizontal customer base complexity					-753.079**		
					(0.050)		
Environmental management system * Vertical customer base complexity						-789.666*	
						(0.063)	
Environmental management system * Spatial customer base complexity							-62.370
							(0.748)

Environmental innovation		32.613	36.010	8.890			
		(0.366)	(0.131)	(0.686)			
Environmental management system					2,253.571	1,271.268	-299.896
					(0.173)	(0.319)	(0.817)
IMR	1,240.174	1,168.295	1,182.221	1,240.209	1,196.645	1,289.537	1,207.100
	(0.291)	(0.321)	(0.314)	(0.292)	(0.307)	(0.271)	(0.305)
ROA	6,001.064	6,048.174	5,532.921	6,176.771	5,935.302	6,734.734	6,053.281
	(0.241)	(0.238)	(0.280)	(0.230)	(0.246)	(0.189)	(0.238)
Firm size	1,057.559	1,056.817	1,138.387	1,064.990	803.719	1,009.482	1,037.504
	(0.241)	(0.243)	(0.208)	(0.239)	(0.376)	(0.262)	(0.250)
Leverage	0.398	0.416	0.299	0.355	0.287	0.171	0.268
	(0.900)	(0.896)	(0.925)	(0.911)	(0.928)	(0.957)	(0.933)
R&D intensity	4.800	5.830	6.004	4.699	3.802	5.155	4.404
	(0.652)	(0.590)	(0.578)	(0.663)	(0.720)	(0.628)	(0.679)
Environmental partnership	-5.870	-6.383	-5.963	-5.971	-5.847	-6.508	-5.704
	(0.494)	(0.459)	(0.487)	(0.488)	(0.495)	(0.448)	(0.507)
Environmental management team	-17.984*	-17.526*	-16.567*	-18.115*	-17.684*	-18.470*	-17.477*
	(0.067)	(0.075)	(0.093)	(0.066)	(0.071)	(0.060)	(0.075)
Environmental supply chain policy	5.671	5.582	5.372	5.688	4.831	3.932	4.579
	(0.553)	(0.559)	(0.574)	(0.552)	(0.616)	(0.683)	(0.635)
Horizontal supply base complexity	-415.928	-428.689	-437.631	-434.589	-423.901	-493.552	-413.516
	(0.437)	(0.424)	(0.414)	(0.419)	(0.428)	(0.357)	(0.441)
Vertical supply base complexity	509.694	482.604	531.342	511.422	434.350	521.757	513.401
	(0.207)	(0.234)	(0.188)	(0.206)	(0.283)	(0.196)	(0.204)
Supplier concentration	46.089	43.976	40.273	47.672	53.131	51.190	50.986
	(0.621)	(0.637)	(0.666)	(0.610)	(0.569)	(0.583)	(0.585)
Average customer energy use	0.035	0.047	0.032	0.033	0.045	0.030	0.034
	(0.849)	(0.800)	(0.861)	(0.860)	(0.809)	(0.869)	(0.854)
Average customer CO2 emission	2.839***	2.786***	2.690**	2.848***	2.650**	2.908***	2.770***

	(0.008)	(0.009)	(0.012)	(0.008)	(0.013)	(0.007)	(0.010)
Average customer environmental management team	-31.457	-33.479	-37.215	-32.434	-24.729	-36.789	-33.304
	(0.382)	(0.354)	(0.303)	(0.369)	(0.496)	(0.308)	(0.357)
Customer concentration	-38.196	-38.412	-38.457	-38.867	-25.778	-32.958	-33.747
	(0.562)	(0.560)	(0.559)	(0.556)	(0.696)	(0.617)	(0.610)
Firm FE & Year FE	Included	Included	Included	Included	Included	Included	Included
Constant	-6,581.634	-7,747.139	-8,563.056*	-6,906.468	-7,866.423*	-7,374.561	-6,557.786
	(0.156)	(0.107)	(0.073)	(0.142)	(0.095)	(0.115)	(0.163)
Firm-year observations	940	940	940	940	940	940	940
R-squared	7.70%	7.80%	8.10%	7.70%	8.30%	8.20%	7.80%
Number of firms	236	236	236	236	236	236	236

p-value in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 4-3 Results of two-way fixed effects regression analysis on CO_2 emission

VARIABLES	Model 1 Emission	Model 2 Emission	Model 3 Emission	Model 4 Emission	Model 5 Emission	Model 6 Emission	Model 7 Emission
Horizontal customer base complexity	0.675**	0.431	0.660*	0.668**	1.389***	0.703**	0.682**
	(0.045)	(0.382)	(0.050)	(0.047)	(0.001)	(0.038)	(0.044)
Vertical customer base complexity	0.554*	0.557*	0.734	0.561*	0.550*	0.774**	0.515
	(0.081)	(0.079)	(0.170)	(0.076)	(0.082)	(0.037)	(0.106)
Spatial customer base complexity	0.269**	0.279**	0.272**	0.597***	0.256**	0.266**	0.404***
	(0.023)	(0.019)	(0.022)	(0.001)	(0.031)	(0.026)	(0.008)
Environmental innovation * Horizontal customer base complexity		0.005					
		(0.514)					
Environmental innovation * Vertical customer base complexity			-0.003				
			(0.673)				
Environmental innovation * Spatial customer base complexity				-0.008**			
				(0.024)			
Environmental management system * Horizontal customer base complexity					-0.837***		
					(0.009)		
Environmental management system * Vertical customer base complexity						-0.418	
						(0.241)	
Environmental management system * Spatial customer base complexity							-0.221
							(0.174)

Environmental innovation		-0.031	-0.005	0.022			
		(0.303)	(0.791)	(0.229)			
Environmental management system					3.446**	1.244	1.426
					(0.013)	(0.246)	(0.189)
IMR	-0.172	-0.087	-0.140	-0.130	-0.210	-0.140	-0.261
	(0.861)	(0.930)	(0.887)	(0.894)	(0.831)	(0.887)	(0.791)
ROA	2.690	2.520	2.454	3.228	2.551	3.038	2.700
	(0.531)	(0.558)	(0.569)	(0.452)	(0.552)	(0.481)	(0.530)
Firm size	-2.241***	-2.164***	-2.149***	-2.141***	-2.499***	-2.252***	-2.247***
	(0.003)	(0.004)	(0.005)	(0.005)	(0.001)	(0.003)	(0.003)
Leverage	0.001	0.000	0.000	0.000	0.001	0.001	0.001
	(0.835)	(0.920)	(0.922)	(0.962)	(0.824)	(0.842)	(0.846)
R&D intensity	-0.001	-0.003	-0.002	-0.003	-0.001	-0.000	-0.001
	(0.935)	(0.732)	(0.803)	(0.756)	(0.883)	(0.980)	(0.933)
Environmental partnership	0.002	0.003	0.003	0.003	0.002	0.002	0.003
	(0.735)	(0.653)	(0.684)	(0.724)	(0.745)	(0.780)	(0.710)
Environmental management team	0.006	0.006	0.007	0.006	0.006	0.005	0.006
	(0.476)	(0.439)	(0.403)	(0.458)	(0.500)	(0.528)	(0.472)
Environmental supply chain policy	0.017**	0.017**	0.017**	0.017**	0.018**	0.017**	0.017**
	(0.034)	(0.036)	(0.037)	(0.035)	(0.029)	(0.035)	(0.032)
Horizontal supply base complexity	-1.042**	-1.023**	-1.035**	-1.103**	-1.039**	-1.076**	-1.001**
	(0.021)	(0.023)	(0.022)	(0.014)	(0.021)	(0.017)	(0.026)
Vertical supply base complexity	0.844**	0.861**	0.850**	0.852**	0.758**	0.849**	0.852**
	(0.013)	(0.011)	(0.012)	(0.012)	(0.026)	(0.012)	(0.012)
Supplier concentration	-0.015	-0.013	-0.016	-0.008	-0.015	-0.017	-0.017
	(0.844)	(0.866)	(0.842)	(0.914)	(0.852)	(0.829)	(0.832)
Average customer energy use	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000
	(0.295)	(0.275)	(0.292)	(0.264)	(0.342)	(0.297)	(0.325)
Average customer CO2 emission	0.002*	0.002*	0.002*	0.002*	0.001	0.002*	0.002*

	(0.080)	(0.076)	(0.088)	(0.073)	(0.108)	(0.066)	(0.087)
Average customer environmental management team	0.005	0.007	0.004	0.002	0.016	0.004	0.008
	(0.873)	(0.828)	(0.888)	(0.957)	(0.604)	(0.892)	(0.805)
Customer concentration	-0.037	-0.036	-0.037	-0.039	-0.028	-0.037	-0.035
	(0.508)	(0.510)	(0.508)	(0.477)	(0.612)	(0.504)	(0.531)
Firm FE & Year FE	Included	Included	Included	Included	Included	Included	Included
Constant	5.832	6.746*	5.683	4.824	4.070	5.210	5.033
	(0.135)	(0.095)	(0.157)	(0.220)	(0.302)	(0.185)	(0.201)
Firm-year observations	940	940	940	940	940	940	940
R-squared	8.40%	8.60%	8.60%	9.30%	9.30%	8.60%	8.60%
Number of firms	236	236	236	236	236	236	236

p-value in parentheses

*** p<0.01, ** p<0.05, * p<0.1

4.5.3 Robustness checks and additional analyses

To enhance the validity of our findings, several additional tests were conducted, and the results of these robustness checks and supplementary analyses are summarized in Table 4-4. Results of additional analyses are not included in the thesis but are available upon request.

We incorporated the two moderating effects, environmental innovation (EI) and environmental management systems (EMS), into an integrated model to account for potential interaction effects between the moderating variables. The presence of correlations between independent and control variables poses a risk of violating the assumption of independence in estimation. To address this concern and ensure the robustness of the results, a two-stage model was implemented, following the approach of Lo et al. (2018).

We proposed an alternative metric for spatial customer base complexity, defined as the proportion of Tier-1 customers distributed across multiple countries, normalized by the total number of Tier-1 customers. Given the relatively high correlation between horizontal and spatial supply base complexities in the dataset, spatial supply base complexity was added to the regression model to mitigate omitted variable bias. Subsequently, horizontal supply base complexity was replaced with spatial supply base complexity in the analysis. All tests demonstrated that the primary results remained consistent.

Inspired by Lu and Shang (2017), this study investigated the curvilinear relationships between a firm's customer base complexity and its environmental performance. The analysis revealed one U-shaped relationship and two reverse U-shaped relationships, suggesting that the impact of customer base complexity on environmental performance may vary non-linearly. The potential mitigating role of the interaction between EI and EMS on the effects of all three types of customer base complexity was also explored. However, the results did not indicate any significant moderating effects.

Table 4-4 Robustness checks and further analyses

Motivations	Analyses	Results
The concern of how a particular interaction affects the firm's environmental performance when others are controlled	Including all moderation effects in an integrated model	The results keep robust
The potential correlation between independent variables and control variables in the regression analysis	Developing a two-stage regression model	The results keep robust
Alternative measurement for spatial customer base complexity.	Changing measurement of spatial customer base complexity.	The results keep robust.
Omitting supply base complexity may introduce omitted variable bias.	Adding spatial supply base complexity in the regression.	The results keep robust.
	Replacing the horizontal supply base complexity by the spatial supply base complexity.	The results keep robust.
The curvilinear relationship between a firm's customer base complexity and environmental performance.	Adding the squared terms of customer base complexity in the regression.	One U-shape and two reverse U-shape relationships are found.
The potential interaction of EI and EMS in their mitigating effects.	Interacting EI and EMS to see if the interaction term can play a mitigating role	No significant results are found.
Customer base complexities may affect the focal firm's operational efficiency, with environmental performance simply as a by-product of these inefficiencies.	Replacing the dependent variable by operational efficiency.	No significant results are found.
The negative relationship between focal firm environmental performance and customer base complexities may be due to diversity in customer environmental standards.	Replacing the spatial customer base complexity by environmental customer base complexity (measured as variation of customer's environmental criteria in sourcing and material).	We found environmental customer base complexity could also significantly increase both focal firm's energy use and emissions.

Lastly, we conducted two mechanism tests to provide empirical evidence supporting our key arguments. We examined the relationships between all three types of customer base complexity and operational efficiency. Following the methodology of Song et al. (2024), inventory days were used as one indicator of operational efficiency, and total factor productivity (TFP), calculated using the classic Cobb-

Douglas production function (Jiang et al., 2023), was used as another. The results indicated that customer base complexity did not significantly negatively affect operational efficiency, rejecting the possibility that environmental performance is merely a by-product of inefficiencies. To directly reflect the complexity of environmental requirements, we also introduced a measure of environmental customer base complexity, defined as the variation in customers' environmental criteria for sourcing and materials. The results showed that higher environmental customer base complexity significantly increased both the energy use and emissions of the focal firm. The results provide strong support for the key argument that customer base complexity exposes firms to a wide range of environmental standards, creating significant challenges for their environmental performance.

4.6 Discussion

Customers play a pivotal role in a firm's environmental management by exerting substantial pressure for enhanced environmental performance and serving as critical knowledge base, such as industrial standards, emerging trends, and innovation practices (Chen & Ho, 2019; Villena et al., 2021). Drawing on the complexity perspective (Choi et al., 2001), this study conceptualizes a firm's customer base as a integrated system and examines how three dimensions of customer base complexity (horizontal, vertical, and spatial) impact energy consumption and CO_2 emissions, two primary indicators of environmental performance. The findings reveal that both horizontal and vertical complexity exhibit a positive association with energy consumption, whereas spatial complexity does not have a statistically significant effect on energy use. Additionally, all three dimensions of customer base complexity are positively correlated with CO_2 emissions. These results underscore the challenge that customer base complexity poses to firms in their efforts to enhance environmental performance.

Beyond investigating the direct impact of customer base complexity on environmental performance, this study also examines the potential of two key green practices to absorb complexity: Environmental Management Systems (EMSs) and

Environmental Innovations (EIs) (Ziegler & Nogareda, 2009). The findings indicate that EMSs effectively attenuate the effect of horizontal customer base complexity on both energy consumption and CO2 emissions. Furthermore, EMSs are effective in reducing the influence of vertical customer base complexity on energy use. Conversely, EIs are shown to mitigate the effects of vertical customer base complexity on energy use and spatial customer base complexity on CO2 emissions. However, neither EMSs nor EIs are entirely sufficient to counteract the adverse effects of customer base complexity on a firm's environmental performance. Nevertheless, these two strategies largely complement one another in absorbing complexity when targeting better environmental performance. For instance, EMSs are effective in mitigating the effect of horizontal customer base complexity on CO2 emissions, where EIs are ineffective. Conversely, EIs are effective in mitigating the influence of spatial customer base complexity on CO2 emissions, where EMSs are not. Similarly, EMSs and EIs complement each other in addressing the effects of horizontal customer base complexity on energy consumption.

4.6.1 Theoretical Implications

First, the green OSCM literature (Gimenez & Tachizawa, 2012) has consistently highlighted the critical roles of key stakeholders in fostering green supply chains. However, prior studies predominantly treated various stakeholder groups as uniform, failing to consider the heterogeneity within these groups. To address this gap, Adhikary et al. (2020) recently examine how supply base complexity influences a firm's carbon emissions. Building on this, this study adopts the complexity perspective to investigate the nuanced effects of customer base complexity on a firm's environmental performance. By conceptualizing the customer base as a complex system, we uncover new insights into the influence of customers on a firm's green practices. Linking with studies like Adhikary et al. (2020), our findings provide empirical support for applying the complexity perspective in green OSCM.

Second, this research contributes to the literature on EMSs by investigating how they can mitigate the adverse effects of customer base complexity on environmental performance. Although EMSs like ISO 14001 are widely adopted, their effectiveness remains a topic of debate (e.g., Darnall et al., 2008; Sroufe, 2003). This study takes an innovative approach by examining the ability of EMSs to absorb and manage customer base complexity. The findings suggest that a mature and well-functioning EMS can effectively reduce the negative impacts of customer base complexity on environmental performance, including energy consumption and CO_2 emissions. This underscores the importance of moving beyond merely testing the direct influences between EMSs and environmental performance. A more insightful approach involves exploring how EMSs enable firms to address and resolve critical challenges in environmental and green supply chain management.

Third, our findings significantly advance the literature on EI. Since the 1990s, Michael Porter has championed environmental innovation, emphasizing its role in helping firms build valuable capabilities that cannot be achieved through mere compliance with environmental regulations (Porter & Van der Linde, 1995). Later, Sharma & Vredenburg (1998) identified three competitively valuable capabilities (stakeholder engagement, higher-order learning, and continuous improvement) that are fostered by proactive environmental strategies such as innovation. Our results reveal that EI can mitigate the adverse effects of both vertical and spatial customer base complexities on environmental performance. This demonstrates that EI not only enhances the three aforementioned capabilities but also contributes to a firm's ability to absorb complexity (Boisot & Child, 1999). This finding represents a major addition to the body of research on EI.

Lastly, this study extends the application of the complexity perspective within the context of OSCM. Since its introduction to the field by Choi et al. (2001), subsequent research (e.g., Dong et al., 2020; Lu & Shang, 2017; Sharma et al., 2020) has concentrated on supply base complexity, with limited effort put to customer base complexity. To the best of our knowledge, this study innovatively differentiates the dimensions of customer base complexity and examines their distinct impacts on a firm's environmental performance. Our findings demonstrate the value of this differentiation, as the three dimensions of customer base complexity exert varying influences on environmental performance. Furthermore, EMSs and EI were proved to have distinct mitigating effects on the different dimensions of customer base complexity, highlighting the importance of tailored approaches to managing environmental challenges.

4.6.2 Managerial Implications

First, as firms increasingly operate in global and diverse markets, they often serve a large and geographically dispersed customer base. Managers are advised to carefully consider the potential adverse effects of customer base complexity on environmental performance, particularly when making strategic decisions involving diversified customer bases. Second, it is important for managers to recognize that the three dimensions of customer base complexity do not have uniform effects. Vertical complexity, compared to horizontal complexity, poses greater challenges for managing environmental performance and is often less apparent to firms. We recommend that managers enhance supply chain transparency to better anticipate and address evolving environmental regulations, especially given the amplification of environmental challenges through the green bullwhip effect.

Third, although environmental management systems, such as ISO 14001, are widely adopted, our findings indicate that their effectiveness in mitigating the adverse effects of customer base complexity on environmental performance is limited. Managers are supposed to be mindful that if their customer bases are geographically diverse, ISO 14001 alone may not sufficiently address the complexities arising from varying environmental regulations across regions. Finally, we highlight that firms may actively invest in EMSs and EI that contributes to the development of both firms' competitively valuable capabilities and firms' capabilities to absorb complexity. Neither EI nor EMSs can individually address the diverse (horizontal, vertical, and spatial) customer base complexities. Therefore, manufacturers can adopt more effective strategies based on the specific characteristics of their customer base's complexity—considering their horizontal, vertical, and spatial dimensions—to achieve their desired improvements in environmental performance (e.g., reducing energy consumption or lowering carbon emissions). Alternatively, they may choose to combine both routines to tackle the complexities presented by all three dimensions of the customer base.

4.6.3 Limitations and Future Research

First, this study did not incorporate cooperative and eliminative complexity, which are two dynamic dimensions identified by Lu and Shang (2017). Investigating how these two additional customer base complexities may influence a firm's green practice should be a valuable direction of future research which could expand on our work. Second, this study focused on internal environmental performance and management, while customer expectations often extend to social performance improvements. Future research could broaden the scope to include the social contributions of sustainable OSCM, such as occupational health and safety, diversity and equity.

Third, our sample consisted of U.S. manufacturing firms. Thus, our implications may not be generalizable to other industries or developing countries where regulations tend to be less stringent. Future studies may enrich the samples from various industries and emerging economies to test the generalization and boundary of our findings. Fourth, the use of secondary data in this study presents limitations in terms of analytical granularity. To address this, future research could employ primary data collection methods, such as surveys and interviews, to validate and expand upon our findings. Finally, our analysis focused exclusively on customer base complexity, future research could adopt a multi-stakeholder perspective to explore the impacts and interactions of other stakeholders, such as governments, communities, and suppliers, that may collectively influence a firm's environmental outcomes.

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5. Conclusions and Suggestions for Future Research

This dissertation integrates insights from three complementary studies to provide a comprehensive understanding of how carbon neutrality goal setting brings influence, both short-term and long-term, on firm’s performance and how to better improve the firm's performance from the perspective of OSCM. Study 1 in Chapter 2 highlights the tension between ambitious sustainability goal setting and short-term firm value, while firm’s operational and green capabilities are critical to mitigating shareholder concerns. Study 2 in Chapter 3 extends the discussion by demonstrating the unintended carbon leakage in supply chains (long-term environmental performance) after sustainability goal setting and emphasizing the importance of supplier control to address these challenges. Study 3 in Chapter 4 deepens the understandings of supply chain management by examining the role of customer base complexity, revealing how horizontal, vertical, and spatial dimensions of complexity can negatively impact environmental outcomes, and robust environmental management systems and innovation can mitigate these effects.

By combining insights across multiple contexts and dimensions, this dissertation offers a unified framework for understanding the complexities of setting and achieving carbon neutrality goals and improving environmental performance. The findings underscore the need for firms to balance goal ambition with feasibility, adopt holistic strategies that integrate internal operations with external supply chain management to respond effectively to diverse stakeholder pressures when pursuing ESG commitment. This integrated perspective not only bridges critical gaps in sustainable OSCM literature but also highlights promising avenues for future research. It also provides a foundation for practical applications, enabling firms and stakeholders to navigate the challenges of sustainability with greater effectiveness and resilience.

5.1 Theoretical implications

This dissertation contributes to the sustainable OSCM literature by offering a multidimensional framework that links internal, inter-organizational, and external stakeholder dynamics. We underscore the need for firms to adopt holistic strategies that balance goal ambition, supply chain integration, and stakeholder complexity to achieve meaningful and sustainable environmental performance. This dissertation advances theoretical understanding of the mechanisms that drive sustainable outcomes under complex stakeholder pressures.

First, we offer a holistic perspective on the interactions between internal operations and external stakeholders (shareholders, suppliers and customers). We highlight that sustainability efforts cannot be fully understood or optimized without considering the complex pressures from multiple stakeholders. Future research may explore more about the multi-stakeholder perspective in sustainability development by investigating how the interactions among different stakeholders influence firms' sustainability strategies and examining how stakeholder attitudes and behaviors evolve over time and how these dynamics affect firms' environmental strategies and performance. These dynamics are particularly relevant to the fashion and textile industry, where sustainability efforts must often address not only supply chain pressures but also consumer perceptions from multiple stakeholders. Future research may explore more about the multi-stakeholder perspective specifically within this industry, examining how fashion brands can simultaneously manage supplier diversity, consumer expectations, and regulatory changes.

Second, by linking the insights from Study 1 (investor concerns in short-term) and Study 2 (supply chain carbon leakage in long-term), the dissertation highlights a critical theoretical gap: how firms can balance the ambition of their carbon neutrality goals with the stakeholder expectations and follow-up ethical actions. The tension between setting ambitious carbon neutrality goals and ensuring their operational feasibility can be a critical theoretical insight. For example, it would be inspiring to investigate the trade-offs between short-term financial performance and long-term ESG performance, providing insights into how firms can optimize both when setting and announcing ESG commitments. This is especially critical in the fashion industry, known for its extensive use of resources, high emissions, and globalized supply chains.

Consumer-facing firms must navigate the balance between fast fashion and sustainability. It would be worth investigating how brands manage tensions between profitability and long-term carbon neutrality goals.

Third, the integration of Studies 2 and 3 advances the conversation on responsible carbon reduction and external stakeholder complexities, extending the boundaries of carbon reduction within firm's own sustainable operations. It emphasizes that environmental performance must be evaluated across scopes (1, 2, and 3) and in the context of entire OSCM. It would be worth analyzing how specific supply chain structures could influence carbon neutrality strategies and outcomes and identify innovative ways to measure, reduce, and manage Scope 3 emissions, particularly in complex global supply chains. Research could explore how firms integrate circular economy strategies, such as recycling, reuse, and managing Scope 3 emissions, particularly in textile manufacturing and distribution.

Lastly, the integration of all three studies contributes to the development of critical thinking in sustainable OSCM. It theorizes that environmental performance is an indicator of interconnected systems involving internal operations, supply chains, and external stakeholders, with each element requiring coordinated strategies. Future studies may develop more methodologies to capture the interdependencies and interactions among these systems and their collective impact on sustainability outcomes. How firms can build resilience and adaptability into their OSCM to manage sustainability challenges in a dynamic environment may also be considered as a research potential. In the manufacturing industry, especially fashion and textile where trends evolve rapidly, firms must reimagine their production processes, supplier relationships, and consumer engagement to remain competitive while meeting sustainability objectives.

5.2 Practical implications

This dissertation offers actionable insights for firms, managers, customers, investors, and policymakers to collectively address the challenges of carbon neutrality and environmental sustainability. By balancing ambitious goal setting with operational capabilities, managing supply chain emissions, and addressing stakeholder complexities, all parties can contribute to meaningful progress toward a sustainable future.

Managers should align carbon neutrality goals with the firm's operational capabilities and supply chain realities to ensure feasibility and minimize risks to firm value. They are supposed to communicate realistic and transparent goals to stakeholders, including investors, customers, and suppliers. Overly ambitious goals without adequate capabilities or planning can lead to shareholder concerns and reduced firm value. Managers may prioritize presenting firms' operational and green capabilities to mitigate the risks associated with ambitious sustainability targets.

One key practical implication is the need for managers to extend their focus beyond internal operations to address emissions across their supply chains (Scope 3). This includes identifying potential areas of carbon leakage and collaborating with both upstream and downstream supply chain partners to implement sustainable practices. Managers are supposed to build long-term partnerships with suppliers and customers to enhance sustainability in the supply chain. For suppliers they may provide sustainability training, implement sustainability audits, and encourage green practices. For customers they may segment customers based on environmental preferences and tailor sustainability initiatives to specific customer groups. They can also leverage data and analytics to monitor emissions across scopes and identify areas for improvement.

Investors should evaluate firms' sustainability strategies from a comprehensive perspective, including the feasibility of their carbon neutrality goals, supply chain integration efforts, and ability to manage stakeholder pressures. Firms with robust operational strategies, effective supply chain management, and innovative environmental practices are more likely to deliver long-term value. Investors can also utilize their power to push firms to disclose detailed information about emissions across all scopes (1, 2, and 3) and their progress toward achieving carbon neutrality goals. By investing in firms that prioritize environmental management systems and innovation, investors can encourage the development of solutions that address carbon leakage and other environmental challenges.

Policymakers should establish clear guidelines for carbon neutrality goal setting to ensure that firms set realistic and achievable targets. Policies may incentivize firms to address Scope 3 emissions and integrate sustainability into their supply chain operations. Policymakers can also fund research and development in environmental technologies that help firms reduce emissions across operations and supply chains. They may promote cross-industry knowledge sharing to disseminate best practices for managing supply chain complexity and supply chain emissions. Additionally, governments are supposed to facilitate collaboration between firms, suppliers, and customers to drive collective progress toward sustainability goals. Subsidies or tax incentives can encourage firms to adopt supply chain sustainability practices and environmental management systems.

This alignment of carbon neutrality goal setting and green practice is particularly significant in fashion industry characterized by high levels of resource consumption, globalized supply chains, and fast-changing consumer preferences. Fashion brands should establish clear guidelines for carbon neutrality goal setting to ensure that firms set realistic and achievable targets. Strategies may include the adoption of circular economic strategies, such as recycling, reusing, and repairing textiles, to reduce material waste and supply chain emissions. Furthermore, managers should focus on reshaping supply chains to balance the trade-offs between cost efficiency and sustainability. They can provide more transparency in reporting their environmental progress and engage customers through sustainability-focused campaigns, such as promoting eco-friendly product lines or offering incentives for recycling old clothes. Governments and policymakers can also play a role by introducing subsidies or tax incentives that encourage adoption of renewable energy and sustainable materials by textile manufacturers. By adopting these practical strategies, the fashion and textile industry can align its operational goals with environmental sustainability, ultimately reducing its resource footprint while enhancing long-term brand equity and competitive advantage.

5.2 Limitations

First, all three studies focus on publicly listed manufacturing firms in the United States, which may limit the generalizability of the findings. This sample choice reflects a constraint in the availability of comprehensive data within the textile industry at the early stages of this research. Future studies could address this limitation by specifically investigating the impact of carbon neutrality announcements and strategies for achieving such commitments within the textile industry. Alternatively, research could be extended to other industries, such as the service or retail sectors, and to different geographic regions, particularly emerging economies. Expanding the scope would enhance the applicability of the findings, uncover unique challenges, and identify best practices across varied contexts.

Second, due to challenges in collecting primary data, the three studies rely on secondary data analysis methods, including event studies, DID, and regression analysis. Although secondary data are valuable for large-scale and longitudinal analyses, they also have limitations that cannot be ignored. These include potential misalignment with specific research objectives, outdated information, data quality issues, and limited researcher control over the data collection process. Additionally, secondary data may contain biases or incomplete records. Future research could address these limitations by incorporating a broader range of methodologies, such as qualitative research, interviews, surveys, or experimental designs, to complement and deepen insights.

Third, the studies separately examine the short-term economic performance and long-term environmental performance associated with carbon neutrality commitments. However, the interaction between economic and environmental performance is likely to be more complex, with mutual influences that evolve over time. Furthermore, there are other dimensions of performance, such as market performance and corporate reputation, warrant consideration. Future research could adopt and develop a more comprehensive design of performance indicators and explore the dynamic relationships among these multiple dimensions. Such an approach would provide a richer and more holistic perspective on the consequences of pursing sustainability.

Fourth, this dissertation primarily discusses how firms can leverage their existing capabilities, such as operational strategies and supply chain management strategies, to announce and fulfill carbon neutrality commitments. However, in an era of rapid technological advancement and increasing global complexity, firms can also enhance their capabilities through external resources. Future research could explore the role of digital technologies, such as blockchain and artificial intelligence, in fostering sustainable OSCM practices to meet ESG commitments. Additionally, studies could investigate how contextual factors, such as regulatory environments and cultural differences, influence the adoption and effectiveness of green OSCM strategies.

Finally, the studies focus on the unidirectional influence of firms on their stakeholders during the announcement and fulfillment of carbon neutrality goals. Yet, stakeholders' attitudes and actions can also shape firms' ESG strategies and green OSCM initiatives. Future research could examine how stakeholders' responses, behaviors, and expectations influence firms' sustainability attitudes and strategies. Additionally, scholars could explore the dynamic and reciprocal relationships between firms and stakeholders to better understand the co-evolution of corporate sustainability practices and stakeholder engagement.

6. Appendices

Appendix A Supporting Tables for Chapter 3

Table A.1 Details of variables

Variables	**Measurement and data source**
Goal ambitiousness	The volume of emissions to be compensated (per employee) divided by the timeframe of the goal attainment (Compustat & Factiva)
Operational efficiency	Equal to "1-technical inefficiency", based on the Stochastic Frontier Estimation (SFE) methodology. (Compustat)
Flexibility in achieving carbon neutrality	A binary variable that coded zero for firms announced "net-zero", otherwise coded one (Factiva)
Momentum to reduce emissions	Difference between the change of emission (per employee) in year t and the change of emission (per employee) in year t-1 (Eikon)
Control variables	**Measurement and data source**
Labor productivity	Earnings before interest and taxes per sales (Compustat)
Leverage	Total debt scaled by total assets. (Compustat)
Tangibility	Gross property, plant, and equipment scaled by total assets. (Compustat)
CapEX	Capital expenditure divided by total assets (Compustat)
Sales growth	Annual percentage change in sales (Compustat)
Labor intensity	The ratio of employees to total assets (Compustat)
R&D intensity	R&D expenses per sales (Compustat)
Industry dummy	Dummy variable of two-digit SIC (Compustat)
Year dummy	Dummy variable of year (Compustat)
Scope dummy	Dummy variable of scope (Factiva)
Variables in PSM and Heckman selection two-stage analysis	**Measurement and data source**
If CNGS is announced	A binary variable that equals one if the firm announces carbon-neutrality goal setting and zero otherwise (Factiva)
Industry average CNGS	The sum of announcements in firms in same industry divided by total number of firms in same industry (Factiva and Compustat)
SOP	The ratio of sales to property, plant, and equipment (Compustat)
R&D intensity	R&D expenses per sales (Compustat)
ROS	Earnings before interest and taxes divided by sales (Compustat)

Table A.2 Descriptive Statistics and Correlations of Variables

*(Note: Industry dummy, Year dummy, and Scope dummy are not shown because they are categorical dummy variables; *** p<0.01, ** p<0.05, * p<0.1)*

	Variable	Observations	Mean	Std.	1	2	3	4	5	6	7	8	9	10
1	Goal ambitiousness	146	0.01	0.08										
2	Operational efficiency	146	1.28	7.72	-0.02									
3	Flexibility	146	0.34	0.48	0.14*	0.07								
4	Momentum	146	-0.76	5.46	0	0.02	-0.03							
5	Labor productivity	146	52.9	167.3	-0.23***	-0.03	-0.04	-0.08						
6	Leverage	146	0.31	0.18	-0.16*	-0.12	-0.26***	-0.22***	0.20**					
7	Tangibility	146	0.48	0.37	-0.02	-0.02	0.12	-0.19**	-0.12	-0.05				
8	CapEX	146	0.04	0.04	0.09	-0.04	0.09	-0.04	-0.08	-0.16*	0.46***			
9	Sales growth	146	0.11	1.04	0	-0.02	-0.06	0	-0.30***	-0.13	-0.12	-0.01		
10	Labor intensity	146	0.01	0.01	-0.04	0.09	-0.08	-0.04	-0.12	0.25***	0.01	0	-0.09	
11	R&D intensity	146	0.06	0.13	-0.02	-0.04	-0.16**	-0.25***	0.12	0.07	0.16*	-0.03	-0.01	-0.01

Table A.3 Table of variance inflation factor (VIF)

Variable	VIF	1/VIF
Goal ambitiousness	1.137	0.879
Operational efficiency	1.062	0.942
Flexibility	1.448	0.691
Momentum	1.163	0.860
IMR	1.367	0.731
Labor productivity	1.331	0.751
Leverage	1.307	0.765
Tangibility	1.507	0.664
CapEX	1.462	0.684
Sales growth	1.198	0.835
Labor intensity	1.159	0.863
R&D intensity	1.129	0.885
Scope	1.178	0.849
Mean	1.265	0.800

Appendix B: Supporting Figures and Tables for Chapter 3

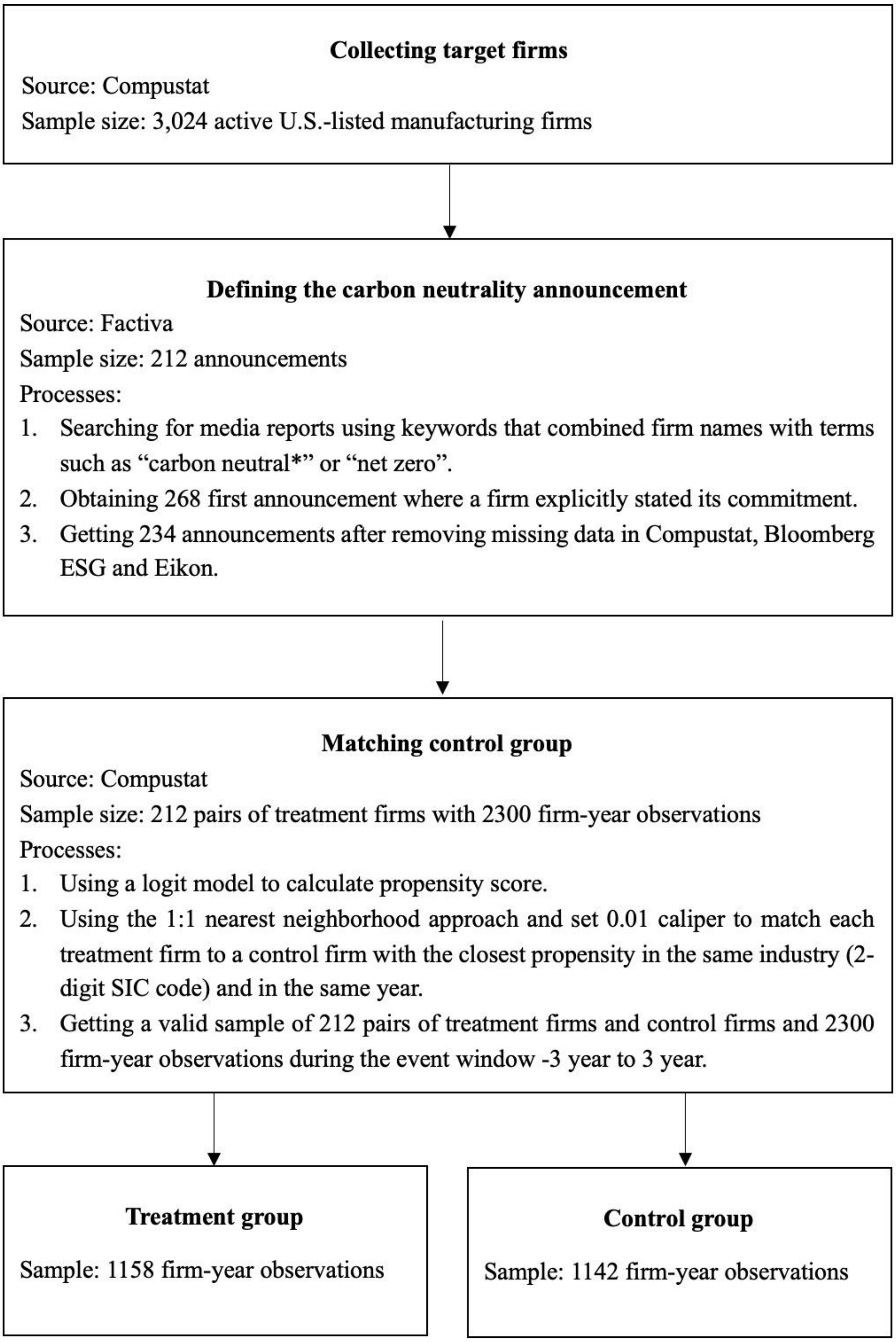

Figure B.1 Flow chart of data processing

Table B.1 Distribution of sample firms across industries

SIC Code	Industry	Frequence	Percentage
20	Food & Kindred Products	27	12.73
23	Apparel, Finished Products from Fabrics & Similar Materials	6	2.83
24	Lumber and Wood Products, Except Furniture	1	0.47
25	Furniture and Fixtures	3	1.42
26	Paper and Allied Products	6	2.83
27	Printing, Publishing and Allied Industries	2	0.94
28	Chemicals and Allied Products	43	20.28
29	Petroleum Refining & Related Industries	11	5.19
30	Rubber and Miscellaneous Plastic Products	4	1.89
32	Stone, Clay, Glass, and Concrete Products	5	2.36
33	Primary Metal Industries	9	4.25
34	Fabricated Metal Products	6	2.83
35	Industrial & Commercial Machinery & Computer Equipment	23	10.85
36	Electronic & Other Electrical Equipment & Components	25	11.79
37	Transportation Equipment	23	10.85
38	Measuring, Photographic, Medical, & Optical Goods, & Clocks	17	8.02
39	Miscellaneous Manufacturing Industries	1	0.47
All	All industries	212	100

Table B.2 Summary of variable definition and data source

Type	Variables	Definition	Data source
Dependent Variables	$Emission\ Scope123$	GHG emission in scope 123 per revenue	Bloomberg
	$Emission\ Scope12$	GHG emission in scope 12 per revenue	Bloomberg
	$Emission\ Scope3$	GHG emission in scope 3 per revenue	Bloomberg
Independent Variable	$Announcement$	1, if a firm announces carbon neutrality target;0, otherwise	Factiva
Control Variables	$Assets$	Log-transformed total assets	Compustat
	$Firm\ Size$	Log-transformed employees	Compustat
	$Leverage$	Ratio of total debt to total assets	Compustat
	SGA	Sales to property, plant and equipment	Compustat
	ROA	Return on Assets	Compustat
	$R\&D\ Intensity$	Research & development expenses per employee	Compustat
	$Inventory\ Turnover$	Ratio of cost of goods sold to inventory	Compustat
	$Tangibility$	Ratio of tangible assets to total assets	Compustat
	$Sales\ Growth$	Ratio of sales during the fiscal year to the sales during the year before	Compustat
	SGA	Log-transformed Selling, General & Administrative Expense	Compustat

Moderator	$Vertinteg$	The variable $vertinteg$ is the degree of vertical integration for the given firm in the given year, which indicates the potential of the given firm's products to be vertically related to the other products sold by the same firm. (scaled by number of employees)	VTNIC
	$Supplier\ Selection$	1, if the company use environmental criteria (ISO 14000, energy consumption, etc.) in the selection process of its suppliers or sourcing partners; 0, otherwise	EIKON
	$Supplier\ Termination$	1, if the company report or show to be ready to end a partnership with a sourcing partner if environmental criteria are not met; 0, otherwise	EIKON
	$Supplier\ Training$	1, if the company provides training in environmental, social or governance factors for its suppliers; 0, otherwise	EIKON
	$Supplier\ Development$	1, if the company have a policy to include its supply chain in the company's efforts to lessen its overall environmental impact; 0, otherwise	EIKON

Table B.3 PSM-logit regression

VARIABLES	(1) logit
SOP	-0.378***
	(0.065)
ROA	3.954***
	(0.576)
$Sales\ Growth$	-0.0964
	(0.093)
$Tangibility$	-0.682***
	(0.242)
$Leverage$	0.3433
	(0.264)
$Inventory\ Turnover$	0.0312**
	(0.015)
$D.Emission\ Scope123$	-0.613***
	(0.172)
$D.Emission\ Scope12$	0.317**
	(0.125)
$Constant$	-4.821***
	(0.774)
Observations	12,013

Pseudo R^2	0.289
Industry FE	YES
Year FE	YES

*Note. *p<0.1, **p<0.05, ***p<0.01 using two-tailed tests. Robust standard errors clustered at the firm level are reported in parentheses. Industry FE, and Year FE are included.*

Table B.4 Balance Test

	unmatched	Mean		%reduction		t-test	V(T)/
Variable	matched	treated	control	%bias	|bias|	t	p> |t|
SOP	U	1.945	4.715	-21.5		-2.39	0.017
	M	1.945	2.003	-0.4	97.9	-0.45	0.655
ROA	U	0.062	-0.099	25.5		2.84	0.005
	M	0.062	0.053	1.4	94.6	0.92	0.358
$Sales\ Growth$	U	0.078	0.855	-4.8		-0.53	0.596
	M	0.078	0.073	0.0	99.4	0.07	0.941
$Tangibility$	U	0.559	0.485	16.1		2.25	0.025
	M	0.559	0.533	5.7	64.5	0.78	0.434
$Leverage$	U	0.296	0.251	9.4		1.07	0.284
	M	0.296	0.311	-3.0	67.8	-0.74	0.457
$Inventory\ Turnover$	U	5.767	5.347	9.2		1.32	0.186
	M	5.767	5.964	-4.3	53.0	-0.48	0.628
$D.Emission\ Scope123$	U	-0.089	-0.045	-10.5		-2.34	0.019
	M	-0.089	-0.159	16.6	57.6	1.01	0.313
$D.Emission\ Scope12$	U	0.083	-0.013	12.5		3.53	0.000
	M	0.083	0.037	6.0	52.3	0.53	0.594

*Note. *p<0.05.*

Table B.5 Summary statistics

Variables	Observations	Mean	SD	Min	Median	Max
$Emission\ Scope123$	2300	5.705	1.534	1.433	5.586	12.681
$Emission\ Scope12$	2300	4.245	1.470	0.157	3.979	9.798
$Emission\ Scope3$	2300	4.947	1.952	0.000	5.056	12.681
$Assets$	2300	8.356	2.208	1.066	8.466	13.303
SGA	2300	6.267	2.022	0.578	6.343	9.746
SOP	2300	2.126	1.914	0.000	1.713	33.362
ROA	2300	0.072	0.118	-2.267	0.074	0.940
$R\&D\ Intensity$	2300	0.107	0.201	0.000	0.027	1.000
$Sales\ Growth$	2300	0.268	1.739	-0.990	0.052	36.123
$Leverage$	2300	0.285	0.206	0.000	0.267	1.821
$Inventory\ Turnover$	2300	5.686	4.486	0.950	4.435	21.388
$Tangibility$	2300	0.547	0.380	0.006	0.454	3.451
$Vertinteg$	2300	0.024	0.045	0.000	0.006	0.702
$Supplier\ Selection$	2300	0.500	0.500	0.000	0.000	1.000
$Supplier\ Development$	2300	0.520	0.500	0.000	1.000	1.000

Table B.6 Summary statistics of control group

Variables	Observations	Mean	SD	Min	Median	Max
$Emission\ Scope123$	1142	5.335	1.251	2.964	5.168	9.649
$Emission\ Scope12$	1142	4.353	1.120	1.001	4.121	9.646
$Emission\ Scope3$	1142	4.370	1.701	0.000	4.178	9.495
$Firm\ Size$	1142	1.039	1.933	-4.017	1.221	5.540
SGA	1142	5.212	1.814	0.578	5.375	9.746
SOP	1142	2.134	1.939	0.000	1.746	33.362
ROA	1142	0.072	0.118	-0.871	0.077	0.738
$R\&D\ Intensity$	1142	0.108	0.198	0.000	0.027	1.000
$Sales\ Growth$	1142	0.333	1.931	-0.990	0.057	34.234
$Leverage$	1142	0.291	0.238	0.000	0.271	1.821
$Inventory\ Turnover$	1142	5.515	4.705	0.950	3.971	21.388
$Tangibility$	1142	0.558	0.382	0.006	0.467	3.451
$Vertinteg$	1142	0.025	0.053	0.000	0.006	0.702
$Supplier\ Selection$	1142	0.338	0.473	0.000	0.000	1.000
$Supplier\ Development$	1142	0.367	0.482	0.000	0.000	1.000

Table B.7 Summary statistics of treatment group

Variables	Observations	Mean	SD	Min	Median	Max
$Emission\ Scope123$	1158	6.070	1.693	1.433	6.263	12.681
$Emission\ Scope12$	1158	4.138	1.741	0.157	3.792	9.798
$Emission\ Scope3$	1158	5.516	2.017	0.029	5.817	12.681
$Firm\ Size$	1158	3.101	1.619	-3.297	3.217	6.701
SGA	1158	7.308	1.642	0.786	7.370	9.746
SOP	1158	2.117	1.891	0.038	1.664	31.915
ROA	1158	0.072	0.118	-2.267	0.072	0.940
$R\&D\ Intensity$	1158	0.106	0.205	0.000	0.023	1.000
$Sales\ Growth$	1158	0.204	1.524	-0.750	0.048	36.123
$Leverage$	1158	0.278	0.167	0.000	0.265	1.796
$Inventory\ Turnover$	1158	5.855	4.254	0.950	4.849	21.388
$Tangibility$	1158	0.536	0.378	0.061	0.446	2.582
$Vertinteg$	1158	0.022	0.035	0.000	0.006	0.472
$Supplier\ Selection$	1158	0.659	0.474	0.000	1.000	1.000
$Supplier\ Development$	1158	0.672	0.470	0.000	1.000	1.000

Table B.8 Correlation Table

Variables	1	2	3	4	5	6	7	
Emission Scope12	1							
Emission Scope3	0.301*	1						
Announcement	-0.120*	0.229*	1					
Firm Size	-0.01	0.413*	0.317*	1				
SGA	-0.240*	0.301*	0.308*	0.904*	1			
SOP	-0.434*	-0.220*	-0.024	-0.120*	-0.015	1		
ROA	-0.097*	0.013	-0.004	0.205*	0.201*	0.180*	1	
R&D Intensity	0.081*	0.082*	-0.033	0.016	0.002	-0.003	0.001	
Sales Growth	-0.033	-0.060*	0.004	-0.091*	-0.080*	0.171*	0.049*	
Leverage	0.059*	0.006	0.011	0.057*	0.062*	0.006	-0.021	
Inventory Turnover	0.134*	0.136*	-0.021	0.029	-0.066*	0.044*	-0.037	
Tangibility	0.599*	0.262*	-0.039	-0.017	-0.155*	-0.470*	-0.043*	
Vertinteg	0.109*	-0.035	-0.009	-0.239*	-0.236*	-0.080*	-0.196*	
Supplier Selection	-0.007	0.310*	0.239*	0.523*	0.504*	-0.115*	0.111*	
Supplier Development	-0.029	0.320*	0.245*	0.509*	0.495*	-0.128*	0.125*	
	8	9	10	11	12	13	14	15
R&D Intensity	1							
Sales Growth	0.031	1						
Leverage	-0.026	-0.051*	1					
Inventory Turnover	0.119*	-0.017	0.122*	1				
Tangibility	0.150*	-0.076*	-0.071*	0.231*	1			
Vertinteg	-0.022	0.051*	-0.152*	-0.088*	0.095*	1		
Supplier Selection	-0.015	-0.079*	0.001	0.005	0.03	-0.077*	1	
Supplier Development	-0.005	-0.074*	0.009	-0.016	0.027	-0.113*	0.900*	1

Note. ∗p<0.05; coefficients with absolute value > 0.043 are significant at 0.05 level.

Table B.9 The results of VIF test

Variables	VIF
Announcement	1.130
Firm Size	3.570
SGA	3.590
SOP	1.440
ROA	1.110
R&D Intensity	1.040
Sales Growth	1.050
Leverage	1.040
Inventory Turnover	1.150
Tangibility	1.530
Mean VIF	1.665

Appendix C: Supporting Tables for Chapter 4

Table C1 Distribution of the sample

2-digit SIC	Frequency	Percentage
20	21	8.90%
21	2	0.85%
22	1	0.42%
23	7	2.97%
24	3	1.27%
25	2	0.85%
26	11	4.66%
27	3	1.27%
28	36	15.25%
29	10	4.24%
30	4	1.69%
31	1	0.42%
32	3	1.27%
33	13	5.51%
34	6	2.54%
35	31	13.14%
36	32	13.56%
37	24	10.17%
38	21	8.90%
39	5	2.12%
Total number of firms	236	100.00%

Year	Frequency	Percentage
2011	34	3.62%
2012	95	10.11%
2013	97	10.32%
2014	114	12.13%
2015	136	14.47%
2016	154	16.38%
2017	168	17.87%
2018	142	15.11%
Total number of firm-year observations	940	100.00%

Table C2 Variable measurements

Variable	Measurement	Database
Energy use	The total of direct or indirect energy consumption (in gigajoules) divided by net sales (in millions of U.S. dollars) of focal firm	Thomson Reuters ESG and KLD
Emission	The ratio of total carbon dioxide and carbon dioxide equivalent emissions (in kilograms) divided by net sales (in millions of U.S. dollars) of focal firm	Thomson Reuters ESG and KLD
Horizontal customer base complexity	The natural logarithm of the number of Tier-1 customers of the focal firm	Bloomberg
Vertical customer base complexity	The natural logarithm of the number of Tier-2 customers per Tier-1 customer	Bloomberg
Spatial customer base complexity	The natural logarithm of the standard deviation of the EPI of each firm's Tier-1 customers' countries	Yale
Environmental innovation	The environmental innovation score from the Thomson Reuters ESG database. Environmental Innovation Score is a Category Score* and to calculate it, we use the percentile rank scoring methodology. Score=(a+b/2)/c a=no. of companies with a worse value b=no. of companies with the same value c=no. of companies with a value *Category scores indicate the company's performance in the respective categories. To calculate the environmental category scores, the TRBC industry group is used as the benchmark, as these topics are more relevant and material to companies within the same industries.	Thomson Reuters ESG and KLD
Environmental management systems	The number of years (naturally logarithm transformed) that ISO 14001 has been implemented in a firm	KLD
ROA	Return-on-assets	Compustat
Firm size	The natural logarithm of the number of employees	Compustat
Horizontal supply base complexity	The natural logarithm of the number of Tier-1 suppliers of the focal firm	Bloomberg

Vertical supply base complexity	The natural logarithm of the number of Tier-2 suppliers per Tier-1 customer	Bloomberg
Customer concentration	Transaction value between the firm and its top 4 customers, scaled by firm sales (cost of goods sold)	Bloomberg
Supplier concentration	Transaction value between the firm and its top 4 suppliers, scaled by firm sales (cost of goods sold)	Bloomberg
Leverage	Debt/Equity	Compustat
R&D intensity	Research & development expenses per employee	Compustat
Environmental partnership	The environmental partnership score from the Thomson Reuters ESG database (similar to environmental innovation score)	Thomson Reuters ESG and KLD
Environmental management team	The environmental management team score from the Thomson Reuters ESG database (similar to environmental innovation score)	Thomson Reuters ESG and KLD
Environmental supply chain policy	The environmental supply chain policy score from the Thomson Reuters ESG database (similar to environmental innovation score)	Thomson Reuters ESG and KLD
Average customer energy use	Average of the total of direct or indirect energy consumption (in gigajoules) divided by revenues (in millions of U.S. dollars) of customers	Thomson Reuters ESG and KLD
Average customer CO2 emission	Average of the ratio of total carbon dioxide and carbon dioxide equivalent emissions (in kilograms) divided by revenues (in millions of U.S. dollars) of customers	Thomson Reuters ESG and KLD
Average customer environmental management team	Average level of customer environmental management team	Thomson Reuters ESG and KLD

Table C3 Descriptive statistics and correlations

	Variables	Observations	Mean	1	2	3	4	5	6	7
1	Energy use	940	3330							
2	Emission	940	2.407	0.607***						
3	Horizontal customer base complexity	940	3.576	-0.168***	-0.172***					
4	Vertical customer base complexity	940	2.319	0.048	0.101***	0.159***				
5	Spatial customer base complexity	940	4.529	-0.086***	-0.068**	0.435***	0.031			
6	Environmental innovation	940	45.53	-0.071**	-0.107***	0.313***	0.026	0.173***		
7	Environmental management system	940	0.784	-0.042	-0.091***	0.241***	0.019	0.156***	0.250***	
8	IMR	940	0.98	0.221***	0.192***	-0.374***	-0.038	-0.307***	-0.155***	-0.271***
9	ROA	940	0.144	-0.070**	-0.032	-0.067**	-0.012	-0.068**	-0.121***	-0.054*
10	Firm size	940	3.515	-0.206***	-0.294***	0.512***	-0.213***	0.336***	0.376***	0.364***
11	Leverage	940	4.399	-0.015	-0.009	0.025	0	0.033	-0.016	-0.042
12	R&D intensity	940	39.05	-0.004	-0.008	-0.127***	-0.062*	-0.084**	-0.215***	-0.132***
13	Environmental partnership	940	55.35	-0.013	-0.096***	0.152***	-0.228***	0.116***	0.285***	0.253***
14	Environmental management team	940	57.77	-0.025	-0.061*	0.199***	-0.123***	0.076**	0.202***	0.134***
15	Environmental supply chain policy	940	60.44	-0.083**	-0.170***	0.154***	-0.124***	0.118***	0.159***	0.195***
16	Horizontal supply base complexity	940	3.585	-0.155***	-0.259***	0.564***	-0.151***	0.363***	0.380***	0.326***
17	Vertical supply base complexity	940	2.438	0.048	0.058*	0.008	0.177***	0.014	-0.012	0.083**
18	Supplier concentration	940	2.671	-0.048	-0.065**	0.295***	0.136***	0.105***	0.131***	0.156***
19	Average customer energy use	940	195	0.201***	0.447***	-0.05	0.080**	0.005	-0.001	-0.011
20	Average customer CO2 emission	940	126.1	0.180***	0.255***	-0.119***	0.182***	0.006	-0.039	-0.009
21	Average customer environmental management team	940	8.530	0.118***	0.159***	-0.193***	0.333***	-0.115***	-0.150***	-0.143***
22	Customer concentration	940	5.016	-0.088***	0.060*	0.111***	0.151***	-0.029	-0.189***	-0.121***

	Variables	Observations	8	9	10	11	12	13	14
9	ROA	940	-0.055*						

10	Firm size	940	-0.416***	-0.147***					
11	Leverage	940	-0.026	0.029	0.043				
12	R&D intensity	940	0.176***	0.140***	-0.177***	-0.025			
13	Environmental partnership	940	-0.169***	0.016	0.401***	0.027	-0.014		
14	Environmental management team	940	-0.241***	0.058*	0.282***	-0.004	-0.008	0.307***	
15	Environmental supply chain policy	940	-0.258***	-0.018	0.351***	0.013	0.037	0.349***	0.260***
16	Horizontal supply base complexity	940	-0.372***	-0.161***	0.778***	0.047	0.012	0.425***	0.293***
17	Vertical supply base complexity	940	-0.048	-0.062*	0.039	0.014	0.023	0.012	-0.089***
18	Supplier concentration	940	-0.078**	0.015	0.128***	0.01	0.154***	0.119***	0.048
19	Average customer energy use	940	0.054*	0.025	-0.099***	-0.006	-0.034	-0.037	-0.053
20	Average customer CO2 emission	940	0.033	0.083**	-0.193***	-0.018	-0.088***	-0.187***	-0.110***
21	Average customer environmental management team	940	0.065**	0.057*	-0.321***	-0.019	0.072**	-0.248***	-0.190***
22	Customer concentration	940	-0.098***	0.169***	-0.132***	0.074**	0.241***	-0.108***	-0.079**

	Variables	Observations	15	16	17	18	19	20	21
16	Horizontal supply base complexity	940	0.343***						
17	Vertical supply base complexity	940	0.013	0.094***					
18	Supplier concentration	940	0.046	0.357***	0.073**				
19	Average customer energy use	940	-0.052	-0.081**	0.019	-0.025			
20	Average customer CO2 emission	940	-0.125***	-0.229***	0.007	-0.089***	0.346***		
21	Average customer environmental management team	940	-0.140***	-0.361***	0.124***	-0.079**	0.192***	0.387***	
22	Customer concentration	940	-0.036	-0.028	0.011	0.086***	0.015	-0.022	0.084***

p-value in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table C4 The results of VIF test

Variables	VIF	1/VIF
Horizontal customer base complexity	2.02	0.5
Vertical customer base complexity	1.43	0.7
Spatial customer base complexity	1.33	0.75
Environmental innovation	1.36	0.74
Environmental management system	1.27	0.79
IMR	1.48	0.68
ROA	1.13	0.88
Firm size	3.36	0.3
Leverage	1.02	0.98
R&D intensity	1.33	0.75
Environmental partnership	1.47	0.68
Environmental management team	1.24	0.81
Environmental supply chain policy	1.28	0.78
Horizontal supply base complexity	3.93	0.25
Vertical supply base complexity	1.1	0.91
Supplier concentration	1.33	0.75
Average customer energy use	1.15	0.87
Average customer CO2 emission	1.37	0.73
Average customer environmental management team	1.48	0.68
Customer concentration	1.25	0.8
Mean	1.57	0.64