

**Attributing Corporate Carbon Mitigation Outcomes to Substantive
Decarbonization Actions through Change Analysis**

by

Meijie Lin

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

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Abstract

As corporations increasingly disclose their environmental performance and claim to decarbonize their operations, it becomes challenging to distinguish substantive decarbonization actions from symbolic gestures that obscure business-as-usual operations. Despite numerous studies highlighting the prevalence of symbolic corporate carbon management, a clear method for measuring and comparing substantive corporate decarbonization action is still not well established.

This study develops an outcome attribution framework using decomposition and decoupling analysis to measure substantive decarbonization actions that effectively reduce emissions. Using secondary panel data from a sample of firms listed on the Hong Kong Stock Exchange from 2018 to 2023, this study aims to: 1) analyze how changes in emissions can be broken down into changes in carbon intensity, energy intensity, and revenue; 2) evaluate the extent of effective corporate carbon mitigation outcomes that can be attributed to substantive corporate decarbonization actions; and 3) examine the correlation between substantive actions and emission reductions.

The findings reveal a generally low level of substantive actions, aligning with previous research that suggests corporate climate actions are often more symbolic than substantive. More notably, the weak correlation between substantive actions and emission reductions underscores the limitation of using mitigation outcomes as a proxy for the effectiveness or substantiveness of corporate climate actions. This result emphasizes the influence of unintended external driving factors that may obscure symbolic actions and enable business-as-usual operations to persist under seemingly positive mitigation outcomes. The outcome attribution framework developed in this study offers a novel approach for researchers and decision-makers to measure and compare substantive decarbonization actions at scale, which enhances the decision-usefulness of the commonly disclosed metrics, provides clarity on the effectiveness of corporate decarbonization initiatives, and ultimately guides resources towards meaningful climate actions and advances best practices.

Keywords: corporate decarbonization, substantive decarbonization actions, effective mitigation outcomes, symbolic legitimacy, business-as-usual, index decomposition

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1. Introduction

1.1 Background and Research Problem

Corporations are both prominent contributors to global greenhouse gas emissions and key players in driving the necessary reductions to meet the Paris Agreement targets and limit global warming to 1.5 °C. As corporations increasingly disclose their environmental performance and claim to decarbonize their operations, it becomes challenging to distinguish substantive decarbonization efforts from symbolic actions that mask business-as-usual practices. Environmental performance disclosure has been analyzed through the legitimization lens in academic research for many years (Ashforth & Gibbs, 1990; Deegan, 2002, 2019; Hrasky, 2011; Suchman, 1995). Ashforth & Gibbs (1990) observed that organizations seek legitimacy through a mix of substantive and symbolic practices. Substantive management practices involve authentic and material changes in operations, whereas symbolic management practices merely portray an appearance without fundamental changes in operations (Ashforth & Gibbs, 1990). For instance, a corporate climate policy centered on general commitments and low-impact actions is likely symbolic. In contrast, a policy that includes specific emission reduction targets, a defined timeline, high-impact actions, and clear accountability mechanisms is more likely to be substantive. In an era where increasing numbers of corporations claim to address climate impact and where substantive changes in business practices are essential, it is crucial to differentiate between those that genuinely contribute to mitigating climate change and those that do not (Deegan, 2019; Dyllick & Muff, 2016).

Prior research has investigated symbolic corporate climate actions and their potential to significantly undermine climate change mitigation efforts. Symbolic legitimization could involve retrospectively reinterpreting past activities to align with current values or adopting prominent practices to meet social expectations while keeping core operations unchanged (Ashforth & Gibbs, 1990). This concept is similarly described by Slawinski (2017) as organizational inaction on climate change. Orazalin et al. (2024) recently conducted a study based on a panel dataset from 35 countries between 2002 and 2019, supporting the symbolic legitimization view on corporate

climate initiatives with empirical evidence. Examined from both theoretical and empirical perspectives, these studies underscore the prevalence of symbolic climate actions.

Furthermore, researchers observed that even genuine actions seem to deteriorate over time as symbolic actions become ingrained in the culture, making them indistinguishable from each other (Ashforth & Gibbs, 1990; C. Wright & Nyberg, 2017). Failure to distinguish substantive from symbolic corporate actions has serious implications. As Deegan (2019) noted, symbolic actions and legitimizing disclosures perpetuate business-as-usual operations and hinder genuine efforts to implement significant and necessary change. It also makes it challenging to direct sustainable investment to the climate-transition-aligned companies and not the business-as-usual ones (Coen et al., 2022).

Only a few recent studies have explored the distinction between substantive and symbolic corporate actions concerning climate change. Johnson et al. (2023) conducted a systematic literature review on corporate climate responses, categorizing them into conventional and deep decarbonization, with the latter defined as reducing CO₂e down or close to zero emissions. The authors noted that the literature on deep decarbonization is still emerging (Johnson et al., 2023). Although these emerging studies developed novel typologies with varying conceptualizations and approaches to assessing corporate climate responses (e.g. Berger-Schmitz et al., 2023; Dupuis & Schweizer, 2019; Martin, 2023), they focus on different aspects of corporate climate actions and involve extensive qualitative assessment. The methodologies in these studies make it challenging to assess firms at scale and are more subject to the interpretation of disclosures.

Corporate carbon performance is another stream of literature that offers insights into distinguishing substantive from symbolic decarbonization. The construct of corporate carbon performance encompasses both greenhouse gas emissions outcomes and the implementation of processes and managerial activities to reduce emissions (Delmas et al., 2013; Velte et al., 2020). Current research has provided abundant evidence on various determinants of corporate carbon performance (e.g. Chen et al., 2020; Damert et al., 2017; Haque & Ntim, 2022; Luo & Tang, 2022; Moussa et al., 2020; Qian & Schaltegger, 2017). A few studies systematically compared and analyzed

multiple dimensions and measurements of carbon performance used in current research, suggesting that process-based performance measurements are more subject to symbolic legitimization than outcome-based measurements (Busch, 2010; Busch & Lewandowski, 2018; Hoffmann & Busch, 2008; Trumpp et al., 2015).

Emerging empirical research in corporate carbon performance has examined the relationship between carbon management actions and carbon emission outcomes using regression. Apart from Haque & Ntim (2022) and Issa & In'airat (2024), most studies have found that decarbonization actions are not effectively translated into emission reductions (Coen et al., 2022; Doda et al., 2016; Mahapatra et al., 2021; Orazalin et al., 2024; Talbot & Boiral, 2018; C. Wright & Nyberg, 2017). Although these studies further substantiate the prevalence of symbolic carbon management, they fall short of providing effective methods to differentiate between substantive and symbolic decarbonization.

Prior research on corporate responses to climate change and carbon performance suggests, both theoretically and empirically, that symbolic decarbonization actions often dominate corporate climate strategies. One line of inquiry differentiates substantive from symbolic actions using originally developed typologies based on prior literature, while another determines substantiveness by comparing the levels of carbon management activities with effective mitigation outcomes. Nevertheless, no previous study has investigated how carbon mitigation outcomes can be attributed to substantive versus symbolic actions. This gap in understanding is crucial, as previous researchers have highlighted a lack of focus on emission reduction outcomes in corporate decarbonization research (Doda et al., 2016; Johnson et al., 2023; Zhang & Liu, 2020). This study focuses on changes in outcomes, from which substantive actions are measured as a percentage of contribution.

1.2 Purpose Statement

This study aims to quantitatively evaluate the extent of effective corporate carbon mitigation outcomes that can be attributed to substantive corporate decarbonization actions, and to subsequently examine the correlation between substantive actions and emission reductions. Through decomposing changes in emissions and attributing these changes to underlying drivers including changes in carbon intensity, energy intensity, and revenue, this study seeks to determine whether these drivers reflect substantive

internal efforts or are influenced by unintended external factors. To achieve this, a scalable measurement model is proposed for evaluating and comparing substantive corporate decarbonization actions that lead to effective outcomes.

Using secondary panel data from a sample of firms listed on the Hong Kong Stock Exchange (HKEx), the study first aims to gain a structural understanding of the underlying factors driving changes in carbon emissions across different sectors from 2018 to 2023. It further identifies substantive and effective decarbonization efforts, for which a proxy variable is constructed. Finally, the study investigates whether firms with superior mitigation outcomes tend to have taken more substantive actions or if unintended external factors have played a greater role in influencing the outcomes.

1.3 Research Questions

For the sampled firms listed on the HKEx:

- What are the respective degrees of contribution of carbon intensity, energy intensity, and revenue to year-over-year (YoY) changes in carbon emissions between 2018 and 2023 by each sector? What are the longitudinal trends in each sector?
- To what extent can the changes in carbon emissions be attributed to substantive corporate decarbonization actions by each sector? What are the longitudinal trends from 2018 to 2023 in each sector?
- How would the extent of substantive decarbonization actions be correlated to conventional outcome-based performance measures, including changes in absolute emissions and changes in emission intensities? In other words, do firms with superior mitigation outcomes also tend to have taken more substantive decarbonization actions?

1.4 Research Design and Methods

This study employs a quantitative approach, utilizing secondary panel data sourced from Bloomberg's ESG Database. Corporate carbon-related data from 2018 to 2023 is collected for firms listed on the HKEx, with the final sample size determined by the number of complete observations available. The distribution of the sampled firms across sectors, market-cap sizes, and Bloomberg ESG scores is assessed to ensure sample reliability.

The statistical analysis unfolds in three phases. Phase one involves decomposing YoY changes in carbon emissions for individual firms into predefined driving factors including carbon intensity, energy intensity, and revenue using the logarithmic-mean Divisia index (LMDI) method (Yagi & Managi, 2018). Based on the decomposed driving factors, phase two assesses the extent of substantive decarbonization actions with effective mitigation outcomes for each driving factor following an outcome attribution framework developed from the literature review. Phase three examines the correlations between the extent of substantive decarbonization actions and the extent of emission reductions on the individual firm level.

1.5 Significance of This Study

The contributions of this research are threefold. First, it enables decision-makers to gain a quantitative understanding of the factors that drive changes in corporate carbon emissions. This includes both the relative driving forces of these factors and the extent of changes in emissions that is due to substantive decarbonization actions as opposed to unintended external influences. This understanding enables comparisons between firms and industries, as well as year-over-year comparisons within the same firm to understand emission reduction trajectories.

Second, this research builds on prior studies of substantive versus symbolic corporate responses to climate change while integrating research on corporate carbon performance and the role of corporations in bridging the emissions gap. It proposes a novel framework to conceptualize substantive corporate decarbonization actions that yield effective mitigation outcomes. Additionally, it underscores the role of unintended driving factors of emission reduction that could mask business-as-usual practices. This framework enriches the current understanding of substantive and symbolic legitimization, effective corporate decarbonization, camouflaged business-as-usual practices, and corporate accountability.

Third, from a practical standpoint, this research creates a novel empirical model to measure and compare the extent of substantive decarbonization efforts. The model is based on change analysis methods commonly used in environmental economics on national and sector levels but underutilized in corporate settings. The inputs are based on common outcome measures in corporate disclosures, which are less prone to

symbolic legitimization (Busch, 2010; Busch & Lewandowski, 2018; Hoffmann & Busch, 2008; Trumpp et al., 2015). This approach effectively addresses concerns that symbolic legitimization is exacerbated by the increasing length and sophistication of corporate narrative disclosures (Haffar & Searcy, 2018; He et al., 2022; Merkl-Davies & Brennan, 2008; Talbot & Boiral, 2018). Compared to existing studies that build typologies and rely on qualitative assessments to distinguish substantive and symbolic mitigation actions, the model proposed in this study is more scalable and less subjective to the evaluator's interpretation. By relying on outcome measures, the model is more resistant to the potential deterioration of substantive actions and symbolic legitimization that are found to be common in narrative disclosure (Ashforth & Gibbs, 1990; C. Wright & Nyberg, 2017).

1.6 The Thesis Outline

This thesis is organized into six chapters. Following this introduction, the Literature Review delves into key concepts and prior research related to corporate carbon performance, as well as the effectiveness and substantiveness of corporate decarbonization efforts, from which an outcome attribution framework is developed to guide the research design. The Research Design and Methods chapter details the three phases of the research design, along with the population and sampling. The Results chapter presents the analysis findings, which are subsequently interpreted and discussed in terms of their significance and contributions in the Discussion. Finally, the Conclusion and Limitations chapter summarizes the study's main insights, acknowledges limitations, and provides recommendations for future research.

2: Literature Review

2.1 Introduction to Literature Review

The following literature review first explores the research surrounding corporate carbon performance to provide a foundational understanding for its evaluation. Relevant studies on corporate environmental strategies and performance are considered, but the focus is directed at corporate decarbonization actions and carbon performance. To understand what makes decarbonization effective, this review then examines the efficiency versus effectiveness aspect of decarbonization outcomes and corporations' role in bridging the emissions gap to further contextualize effectiveness. Next, literature on corporate decarbonization levers is synthesized to conceptualize what makes decarbonization actions substantive and not symbolic. Finally, an outcome attribution framework for substantive decarbonization action with effective outcomes is established based on the areas of literature reviewed.

2.2 Corporate Carbon Performance

As corporations increasingly take action and report on environmental efforts, an expanding body of literature has investigated corporate environmental performance. The primary points of divergence in the literature revolve around varied measures of performance and the various factors affecting performance (Busch & Lewandowski, 2018; Cheng et al., 2023; Trumpp et al., 2015). Understanding the conceptualization of corporate carbon performance in research lays the groundwork for its evaluation.

2.2.1 Carbon Performance as a Construct

Carbon performance refers to two linked concepts. First, it encompasses managerial activities aimed at managing carbon emissions, including the measurement of greenhouse gas emissions and the implementation of strategies and processes to reduce them; second, it pertains to the outcomes of these managerial activities (Velte et al., 2020). Corporate carbon performance, as a subset of environmental performance, is not directly observable and thus qualifies as a construct. A construct is an unobservable theoretical concept that can be defined in conceptual terms and observed only through indicators (Bisbe et al., 2007). Due to its complexity and multi-dimensional nature,

corporate carbon performance assumes various meanings in research, as evidenced by the use of various indicators in relevant empirical studies to measure it (Luo & Tang, 2014; Trumpp et al., 2015). Each measurement or indicator reflects a facet of the construct, limited to observable manifestations (Bisbe et al., 2007). It is hence crucial to understand the common indicators, the facets of performance they measure, and their implications.

Various conceptualizations of carbon performance and their implications have been extensively examined in the literature (Dragomir, 2018; Trumpp et al., 2015), including environmental policy (e.g. Escrig-Olmedo et al., 2017), environmental management system (e.g. Tang & Luo, 2014), environmental impact (e.g. Tanzil & Beloff, 2006; Xie & Hayase, 2007), and environmental operational performance (e.g. Haque & Ntim, 2022; Moussa et al., 2020). Two overarching dimensions – environmental management performance and environmental operational performance – are categorized by Trumpp et al. (2015) after systematically analyzing how corporate carbon performance has been studied and measured in research. Similarly, other researchers use parallel categorization for the two dimensions of environmental performance, namely process-based and outcome-based performance (Delmas et al., 2013; Hoffmann & Busch, 2008). The process dimension represents the management processes aimed at improving environmental performance, whereas the outcome dimension reflects the actual impact of these processes (Delmas et al., 2013).

Although management or process-based performance measures reflect the actions that address environmental issues, they do not show the actual environmental outcomes resulting from the actions and are hence susceptible to corporate impression management (Csutora, 2011). This is further evidenced by empirical findings that common carbon management practices and internal initiatives result little in emission reduction (Doda et al., 2016; Mahapatra et al., 2021), and that climate ‘talk’ often does not lead to substantive climate ‘walk’ (Coen et al., 2022). In addition, Moussa et al. (2020) observed that firms prioritize process-oriented decarbonization initiatives over actual mitigation outcome improvement, and this observation aligns with Haque’s (2017) empirical evidence suggesting corporate management’s focus on the procedural aspect of carbon performance without achieving carbon emission reduction. Legitimacy theory

is frequently referenced in these studies to interpret findings, suggesting that organizations seek legitimacy through a mix of substantive and symbolic management, and the distinction between the two is not straightforward (Ashforth & Gibbs, 1990; Orazalin et al., 2024). Accordingly, the disclosed management processes and initiatives might convey merely the appearance of environmental efforts to manage stakeholders' perceptions (Diouf & Boiral, 2017; C. Wright & Nyberg, 2017). Clarkson et al. (2008) termed such discretionary disclosure of management processes as “soft disclosure items”, for lacking credibility, substantiveness, and verifiability. Although process-based performance demonstrates managerial efforts, ample empirical and theoretical evidence suggests its inherent inadequacies, often characterized by symbolic statements or processes devoid of substantive changes (Hrasky, 2011). Consequently, process-based performance should not be solely relied upon to differentiate and evaluate corporate decarbonization actions and accountability.

Compared to process-based performance, operational or outcome-based performance measures provide mitigation outcome insights but do not demonstrate the management processes and actions behind the outcomes (Busch & Hoffmann, 2011). Outcome-based performance measures are widely used in empirical research to operationalize corporate carbon performance (Trumpp et al., 2015), including metrics such as carbon intensity (e.g. Chen et al., 2020) and absolute emission reduction (e.g. Coen et al., 2022). This tendency is expected because while process-based measures are more discretionary, outcome measures provide a more reliable and commensurable basis for evaluating performance. Nevertheless, solely relying on outcome-based performance is insufficient for evaluating and comparing corporate carbon performance, because outcome measures could be difficult to interpret without context and background (Kolk & Mauser, 2002). Particularly, Sullivan and Gouldson (2012) highlighted the lack of decision-usefulness of carbon-related disclosure, arguing that understanding how companies manage their emissions, the effectiveness of their actions, and comparing performance between firms hinges on broader contextual information. Therefore, while outcome-based measures offer greater reliability in measuring performance, their lack of context hinders performance comparison and

decision-making. Meanwhile, process-based measures, often symbolic and disconnected from actual outcomes, fall short of providing the necessary context.

Considering the pros and cons of relying on management processes and operational outcomes, evaluating and comparing corporate carbon performance requires understanding the relationship between decarbonization management processes and carbon mitigation outcomes.

2.2.2 The Researched Landscape of Corporate Carbon Performance

Current understanding of corporate carbon performance is concentrated on what influences it, often using correlation analysis to explore the interplay between corporate carbon performance and an array of other factors. These influencing factors are broadly categorized by Trumpp et al. (2015) into financial performance factors (e.g. Busch, Bassen, et al., 2022; Busch & Lewandowski, 2018; Delmas et al., 2015), environmental disclosure (e.g. Qian & Schaltegger, 2017; Zhang & Liu, 2020), external factors (e.g. Damert et al., 2017; Luo & Tang, 2022), and internal factors (e.g. Haque & Ntim, 2022; Luo & Tang, 2021; Moussa et al., 2020). Concerning financial performance factors, whether or not “it pays to be green” has been extensively explored with mixed findings (Misani & Pogutz, 2015), although more recent meta-analytic findings suggest a generally positive correlation between good carbon performance and superior financial performance (Busch & Lewandowski, 2018; Velte et al., 2020). Variances in findings are largely attributed to how carbon and financial performance are measured, indicator specification (Busch & Lewandowski, 2018; Misani & Pogutz, 2015), and time horizons (Delmas et al., 2015). The bidirectional relationship between carbon performance and disclosure is another common focus in research, although it is not clear if carbon performance determines carbon disclosure or is determined by it given numerous potential moderators that influence the relationship (Ali & Wilson, 2023; Clarkson et al., 2008; Velte et al., 2020). Prior studies also shed light on various governance-related and external determinants of carbon performance. Factors such as larger firm size, political connection, presence of a sustainability committee, and social culture contribute positively to emission reductions while headquarters location, state ownership, and higher pressure on energy prices contribute negatively (Xia & Cai, 2023). The mixed and nuanced results from these studies provide a comprehensive basis for

understanding what influences corporate carbon mitigation outcomes, illustrating the importance of context, conceptualization, and measurement.

Despite ample research on the factors influencing corporate carbon mitigation outcomes, studies that directly address the relationship between carbon management processes and mitigation outcomes are scarce. Haque and Ntim (2022) found a positive correlation between corporate emission reduction initiatives and reduced carbon emission intensity. This positive association is expected, as process-based and outcome-based dimensions are reasonably interrelated (Trumpp et al., 2015). Nevertheless, further insights are needed to determine to what extent mitigation outcomes can be attributed to management processes. These insights are crucial because researchers have highlighted factors influencing carbon mitigation outcomes that are not deliberate and hence exogenous to corporate decarbonization actions; these factors include efficiency improvement from economies of scale, fluctuations in business metrics, decreases in production, updates in emission factors used, and changes in measurement protocols (Busch, Johnson, et al., 2022; Erb et al., 2022; Haigh & Shapiro, 2012; Lewandowski, 2017; Slawinski et al., 2017; Sullivan & Gouldson, 2012; Talbot & Boiral, 2018). These factors complicate the attribution of mitigation outcomes, potentially confounding the evaluation and comparison of decarbonization efforts between firms and allowing false positives to go unaccountable (Coen et al., 2022). Thus, attributing mitigation outcomes to deliberate decarbonization measures requires distinguishing between deliberate actions and exogenous contributors.

In addition, the research methods commonly used in understanding corporate carbon performance are quite homogenous, as noted by Xia and Cai (2023) and Yagi and Managi (2018). They observed a heavy reliance on ad-hoc panel regression models in prior research, which provide correlational insights but offer limited understanding of the relative importance of influencing factors. Although some studies have compared various factors to identify the primary drivers of decarbonization (Leffel et al., 2024; Xia & Cai, 2023), there is still a lack of structural understanding of relevant drivers and their relative contribution to mitigation outcomes. Notably, such structural understanding is pursued in studies that decompose changes in emissions to dissect

various driving forces, and these decomposition analyses have been mostly conducted on national (e.g. Khuong et al., 2019; Rodríguez & Pena-Boquete, 2017; J. Zhang et al., 2020) and sector levels (e.g. Kim, 2017; Lin et al., 2014; Liu et al., 2022). This indicates a potential underutilization of decomposition analysis for corporate carbon emissions. One example of corporate-level decomposition is by Yagi & Managi (2018), who adapted the widely used LMDI model for corporate analysis, focusing on the structural relationship between corporate carbon emissions and financial performance. Such decomposition of changes in emissions could provide valuable insights into understanding how companies manage their emissions and the effectiveness of their corresponding actions. This need for understanding is emphasized by Sullivan and Gouldson (2012), who noted that reported changes in emissions could be attributed to actual reductions in energy use, fuel switching, or simply changes in calculation methodologies. To address the existing gap in research methods and improve the understanding of corporate emissions, this study aims to employ the LMDI decomposition model to enhance structural understanding of the key drivers behind corporate carbon performance.

2.3 Corporate Decarbonization Effectiveness

Corporate carbon performance is commonly assessed with outcome-based measures in empirical research, but different outcome measures have varying implications for decarbonization effectiveness. Understanding corporations' role in carbon mitigation is crucial for evaluating effectiveness. This section of the review aims to identify key considerations that contribute to outcome effectiveness to better evaluate corporate carbon performance.

2.3.1 Efficiency and Effectiveness

Effective decarbonization involves achieving absolute reductions in emissions. Corporate action is considered effective when 1) absolute emission reductions are successfully achieved and durable, and 2) firms have undertaken the necessary measures to realize these reductions (Slawinski et al., 2017). To assess corporate carbon performance, empirical research employs an array of outcome-based

performance measures. These include carbon intensity (e.g. Chen et al., 2020; Luo & Tang, 2022), absolute reduction (e.g. Coen et al., 2022; Haque & Ntim, 2022; Qian & Schaltegger, 2017), and absolute emissions (Busch, Bassen, et al., 2022; Dahlmann et al., 2019; Moussa et al., 2020). These measures have varying implications and are evaluated in this section with respect to the effectiveness criteria.

There has been a notable shift in the literature from using efficiency metrics to advocating for effectiveness-oriented absolute metrics. Eco-efficiency metrics measure the amount of energy or emissions per unit of output, and efficiency improvement is relative to a production or financial base (Haigh & Shapiro, 2012; Rodriguez et al., 2020). In contrast, absolute metrics measure energy or emissions independent of output, and an absolute reduction indicates effectiveness (Russo et al., 2021; Slawinski et al., 2017). Companies often prioritize efficiency as a means of environmental management, favouring the win-win aspect that enables both economic growth and environmental protection (Rodriguez et al., 2020; Young & Tilley, 2006). However, eco-efficiency improvement comes with significant limitations. The concepts of planetary boundaries and critical thresholds highlight the need for absolute reductions and eco-effectiveness (Hauschild, 2015). By prioritizing efficiency, companies overlook the planetary limits and make unrealistic assumptions that growth can continue indefinitely despite finite resources (Rodriguez et al., 2020). When growth rate outpaces the rate of productivity gains, resource consumption and environmental degradation intensify (Rodriguez et al., 2020; Russo & Pogutz, 2009), likely leading to increased emissions despite lower intensity metrics (Rodriguez et al., 2020). Therefore, improvements in efficiency metrics is not indicative of effective decarbonization, and this study does not use efficiency metrics as inputs for modelling substantive actions with effective outcomes.

Addressing climate challenges ultimately hinges on measuring absolute metrics, yet nuances arise when evaluating a company's decarbonization effectiveness based on absolute emissions. Absolute metrics may not fully capture a company's decarbonization efforts, as an increase or decrease in absolute emissions needs to be contextualized with production and sales (Schaltegger & Csutora, 2012). A reduction in absolute energy consumption or emissions might occur due to a production decrease,

which does not reflect meaningful decarbonization actions (Erb et al., 2022; Slawinski et al., 2017). In this regard, Johnson et al (2023) specified that absolute reduction involves reducing a company's overall carbon emissions regardless of any changes in production caused by disruptions or relief measures. Conversely, an increase in absolute energy consumption or emissions does not necessarily signify decarbonization laggards. Effective decarbonization efforts, such as technological advancement, could drive substantial output growth with minimal emission increases. Such efforts should be highlighted and scaled, and could contribute to sustainable development by displacing less efficient competitors and reshaping market structures (Erb et al., 2022; Schaltegger & Csutora, 2012). As such, the effectiveness of decarbonization actions depends on the extent to which growth is decoupled from emissions, a concept widely studied in the environmental economics literature through decoupling analysis (Zhang et al., 2020).

Decoupling analysis illustrates the dynamics between economic growth and environmental degradation, and the Tapio decoupling model has been widely adopted by researchers to identify multiple states of decoupling (Zhang et al., 2020). Eight decoupling states are identified through the Tapio decoupling model as illustrated below:

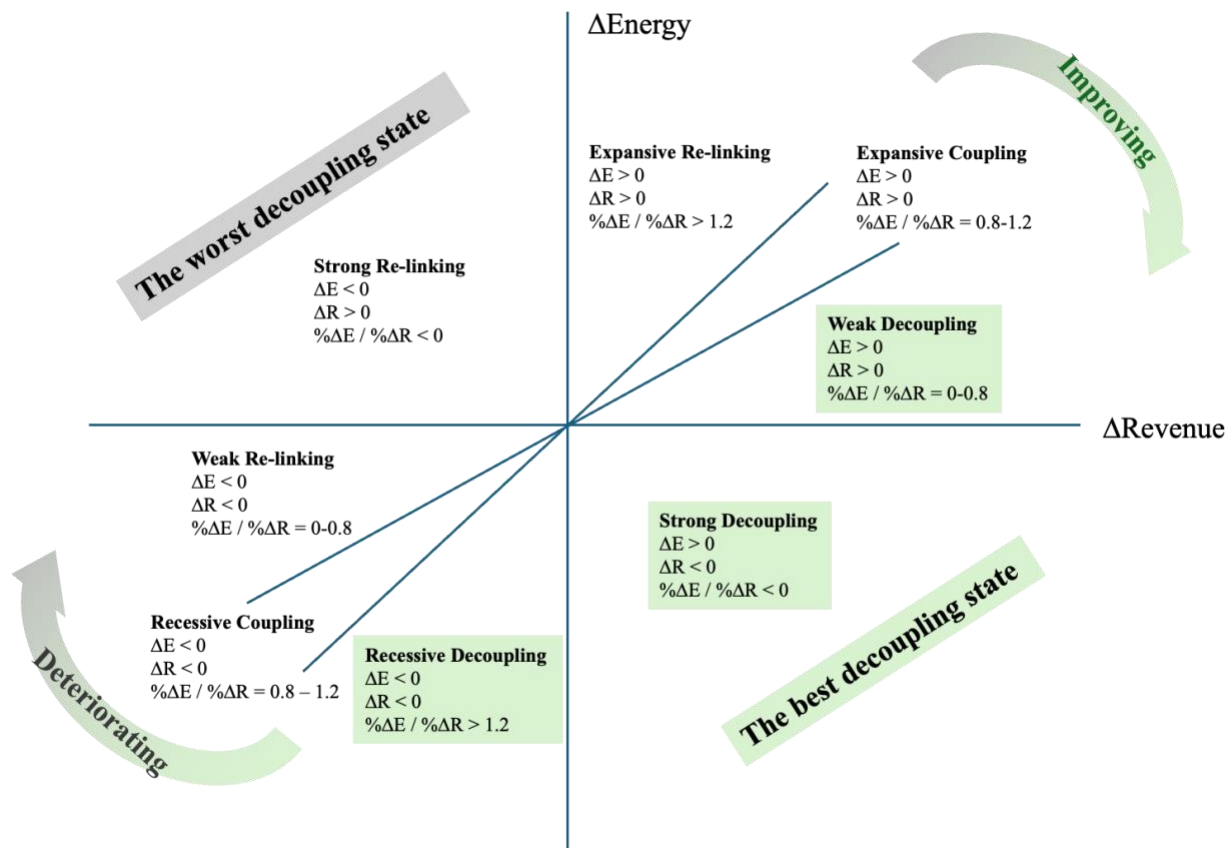


Figure 1. *Eight Decoupling States for Energy Consumption and Revenue*
(Adapted from Tapio (2005) and Wei et al. (2020))

Accordingly, this research operationalizes effective outcomes as any of the three following decoupling states that demonstrate revenue decoupled from emissions: strong decoupling, weak decoupling, and recessive decoupling. Moreover, the Tapio decoupling model considers a $\pm 20\%$ variation of decoupling values around 1 as coupling to avoid overinterpreting marginal changes as significant (Tapio, 2005), which addresses concerns raised by Lewandowski (2017) and Haigh and Shapiro (2012) around low-hanging fruit actions and marginal efficiency improvement that do not constitute substantive decarbonization with effective outcomes.

2.3.2 Bridging the Emissions Gap

In addition to decoupling growth from emissions, the effectiveness of corporate decarbonization is shaped by the role of corporations as non-state carbon mitigation contributors that complement state-led mitigation efforts. Hale et al. (2021) highlighted

the importance of distinguishing non-state mitigation efforts to understand how these contributors achieve results and interact with state initiatives, as such insights provide a more granular understanding of national progress toward the Paris Agreement goals. Despite over 160 nations committing to the Paris Agreement goals by submitting Nationally Determined Contributions (NDCs) (UNFCCC, 2024), the Intergovernmental Panel on Climate Change (IPCC) concluded that even if the current NDCs are fully implemented, global emission levels by 2030 will exceed the 1.5°C threshold and potentially the 2°C threshold (UNEP, 2023). This gap between the pledged emission reduction by nations and the necessary reduction needed to achieve the Paris Agreement goals is known as the emissions gap. The UNEP's Emissions Gap Report 2023 emphasized the insufficient emission reductions to close the emissions gap as of 2023, despite strengthened NDCs (UNEP, 2023). Meanwhile, a prevailing consensus in research underscores the essential role and collective capacity of non-state actors in achieving global emission reduction targets (Blok et al., 2012; Coen et al., 2022; Hale et al., 2021; Kuramochi et al., 2020; Ruiz Manuel & Blok, 2023). The corporate sector, in particular, accounts for a substantial share of global emissions (Griffin, 2017; Preston & Ward, 2021), making corporate decarbonization efforts a significant aspect of non-state efforts. Therefore, the potential of corporations to bridge the emissions gap is pivotal in determining the effectiveness of corporate decarbonization actions.

Amidst the prevalent recognition of corporations' potential to bridge the emissions gap, concerns arise regarding the effectiveness of their decarbonization outcomes when they overlap with state-led initiatives. Hsu et al. (2019) and UNEP (2015) have emphasized understanding the interactions between state and non-state decarbonization efforts when evaluating their contributions. Specifically, UNEP (2015) suggested that as much as one-third of non-state climate mitigation outcomes could overlap with national policies, and Roelfsema et al. (2018) estimated a 70-80% overlap under conservative assumptions. A prominent overlap in decarbonization outcome occurs in emission reductions from the state electricity supply (Hsu et al., 2019), which is also reflected in corporations' carbon emissions calculation for grid electricity use. This represents a case where carbon emissions decline without deliberate corporate

mitigation efforts, making such a decline exogenous to corporate actions and potentially camouflaging business-as-usual operations.

In summary, effective corporate decarbonization outcomes are evaluated based on the decoupling of revenue from absolute emissions and ensuring that emission reductions are independent of electricity grid decarbonization.

2.4 Substantive Corporate Decarbonization Actions

Having conceptualized effective mitigation outcomes, evaluating corporate carbon performance also requires understanding corporations' actions to mitigate carbon emissions and whether these disclosed actions are substantive or merely symbolic.

2.4.1 Substantive vs. Symbolic Actions

There is an emerging research discourse exploring the impact of corporate climate initiatives on actual carbon performance to evaluate the substantiveness of these initiatives, including corporate sustainability initiatives (Haque & Ntim, 2022; Issa & In'airat, 2024), climate commitments (Coen et al., 2022), net zero pledges (Berger-Schmitz et al., 2023), carbon management practices (Doda et al., 2016), climate change targets (Dahlmann et al., 2019), and carbon reduction practices (Mahapatra et al., 2021). This line of inquiry is commonly explored through the lens of substantive vs. symbolic actions (Berger-Schmitz et al., 2023; Block et al., 2023). On the one hand, corporations' carbon mitigation practices might serve symbolic legitimization objectives largely due to the substantial financial investments required for substantive mitigation projects (Haque, 2017). Symbolic legitimization objectives often reflect an appearance of commitment without much outcome in actual emission reductions (Hyatt & Berente, 2017). On the other hand, corporations could undertake substantive decarbonization actions, characterized by significant managerial commitment to understanding and implementing operational changes that achieve real emission reductions (Berger-Schmitz et al., 2023).

Most studies in this discourse found little compelling empirical evidence that corporate climate initiatives are translated into reduced emissions, indicating a lack of substantiveness in decarbonization actions (Coen et al., 2022; Doda et al., 2016;

Mahapatra et al., 2021; Martin, 2023). Although Haque and Ntim's (2022) study identified a positive association between substantive climate engagement and emission reductions, it differs from others due to its less progressive conceptualization of actions and outcomes. Haque and Ntim (2022) used Refinitiv's environmental scores to proxy substantive climate engagement and emission intensities to measure carbon performance, and such less progressive conceptualization also explains similar results from Issa & In'airat (2024). In summary, while these studies focus on different aspects of climate response, symbolic actions seem to prevail in corporate responses to climate change.

In terms of methodology, these studies commonly employ various textual analyses and originally constructed scoring methodologies to investigate substantive carbon mitigation practices. For example, Coen et al. (2022) studied whether climate "talk" translates into climate "walk" by using machine-aided content analysis to build an empirical model based on frequencies of identified keywords to proxy climate "talk", which is disclosed actions. Doda et al. (2016) identified key carbon management practices and developed a scoring criterion to rate each firm's carbon management, subsequently regressing the score on emission performance to see if actions lead to effects. Berger-Schmitz et al. (2023) created an original framework to quantify the substantiveness of corporations' net zero targets by mapping interview responses to this framework. Similarly, Martin (2023) developed a corporate climate action typology to evaluate if corporate climate actions are meaningful and effective, then ranked the firms by the scores generated based on the typology. While the results generated from these methodologies offer valuable insights, the processes are often arduous and time-consuming, involving certain dictionary approaches and textual analysis (e.g. Coen et al., 2022; Mahapatra et al., 2021; Martin, 2023); or resource-intensive, leveraging proprietary techniques or databases (e.g. Doda et al., 2016). Additionally, due to the idiosyncratic nature and varied expression of decarbonization practices disclosed by firms (Mahapatra et al., 2021), standardizing or consolidating these frameworks and typologies is challenging. This highlights the lack of a scalable model to standardize and quantify substantive corporate actions, which would benefit future scholarship and

decision-makers in analyzing and comparing the substantiveness of corporate decarbonization actions.

2.4.2 Corporate Decarbonization Levers

To further conceptualize and understand substantive decarbonization actions, this study reviews the literature on corporate decarbonization levers. Johnson et al.'s (2023) systematic literature review on corporate responses to climate change categorizes decarbonization actions into four areas: 1) administrative (e.g. target setting, data collection and monitoring, management systems), 2) applicative (e.g. energy efficiency, process improvement, product innovation) 3) communicative (e.g. reporting, public relations), and 4) collaborative (e.g. supply chain coordination, carbon offsetting). The authors also distinguish deep decarbonization from conventional responses, highlighting that deep decarbonization focuses more on specific administrative and applicative actions and rarely includes comprehensive responses such as management systems (Johnson et al., 2023). The characterization of deep decarbonization in Johnson et al.'s (2023) study aligns with the concept of substantive decarbonization actions in this study, emphasizing absolute emission reduction outcomes. Therefore, while recognizing that corporate carbon management encompasses a wide range of valid activities, this study aims to evaluate the substantiveness of decarbonization actions based on emission reduction outcomes.

Further review of the corporate low-carbon transition literature uncovers decarbonization levers that are more substantive and effective, identifying fuel substitution, electrification, and energy efficiency as the broad categories of transition pathways for most industries (Erb et al., 2022; Long & Feng, 2024; Markard & Rosenbloom, 2023; Pinkse et al., 2024). Fuel substitution involves switching to electricity powered by low-carbon sources or transitioning from coal to gas or biofuels (Erb et al., 2022; Pinkse et al., 2024). Among these options, natural gas and biofuels have faced skepticism for being dead-end pathways with limitations, delays, and insufficient outcomes (Markard & Rosenbloom, 2023). From the perspective of outcome effectiveness, renewable energy adoption emerges as the most substantial fuel substitution action. Additionally, electrification is another dominant approach to decarbonizing the corporate energy mix, especially as the electricity sector transitions to

incorporate more renewable energy (Dolter, 2017; Markard & Rosenbloom, 2023). Accordingly, the degree of renewable energy adoption and electrification is used in this research to quantify substantive efforts at lowering the carbon intensity of the corporate energy mix.

Having discussed pathways for lowering the carbon intensity of the energy mix, another facet of decarbonization involves reducing the energy intensity of output. This is where numerous carbon management activities, if effective, ultimately translate into measurable reductions. Activities such as product development and design, process improvement, plant retrofits, and new technology solutions are challenging to evaluate and compare based on process-based disclosure. However, if these activities are substantive and effective, their results will ultimately manifest in decoupled growth from energy use. Therefore, the Tapio decoupling model discussed in the prior section is deemed appropriate to capture both the substantiveness of decarbonization activities and the effectiveness of mitigation outcomes.

Despite corporations' growing use of carbon offsets to cut emissions, concerns frequently arise in the corporate decarbonization literature that question whether buying offsets is a substantive mitigation effort. Commonly cited criticisms around carbon credits include additionality, permanency, and overall quality of the emission reductions (Erb et al., 2022). Increasingly, stakeholders are advocating for a hierarchical framework that prioritizes value chain emission reduction over offsets. They argue that offsets should only be used as a last resort after all other genuine emission mitigation methods have been exhausted (Berger-Schmitz et al., 2023; Christiansen et al., 2023; Erb et al., 2022; Martin, 2023). In this regard, using offsets is not categorized as substantive action in this study.

In conclusion, corporations have two primary avenues for directly reducing their carbon emissions: decreasing the carbon intensity of their energy sources and reducing the energy consumption per unit of revenue generated. Substantive actions for the former involve adopting renewable energy and electrification, while efforts towards the latter are operationalized through decoupling analyses between growth and energy use.

2.5 Key Findings from the Literature Review

This study aims to establish a scalable model to quantify a novel aspect of corporate carbon performance, specifically substantive decarbonization actions that are effective at reducing carbon emissions. The literature review first investigated various facets of the corporate carbon performance construct and the empirical understanding surrounding it. Currently, studies on corporate carbon performance predominantly rely on ad-hoc panel regressions to investigate a multitude of external factors and internal firm characteristics that influence carbon mitigation outcomes. While these studies provide abundant insights into factors that may contribute to superior performance, they fail to offer a structural understanding of the key drivers of performance or to render decision-making support for comparing individual firm performance.

There are change analysis methodologies commonly used in environmental economics research that are underutilized at the corporate level. These methodologies, including decomposition and decoupling analyses, could offer structural insights into the relative contributing forces behind changes in emissions. This presents a methodology gap in corporate decarbonization literature. Adopting change analysis in evaluating corporate carbon performance could provide crucial decision-making insights that illustrate how and how effectively each firm manages decarbonization (Schaltegger & Csutora, 2012; Sullivan & Gouldson, 2012), and could also shed light on projecting companies' emission reduction trajectories (Bolay et al., 2022).

Additionally, while some studies have examined whether corporate carbon management processes are more symbolic or substantive, the methodologies employed – commonly textual analysis and scoring with original typologies – are often time- and resource-intensive and thus not readily scalable. Given the prevalence of information overload alongside a simultaneous lack of context in corporate environmental disclosures (Sullivan & Gouldson, 2012; Velte et al., 2020), there is a clear absence of a scalable framework – based on commonly reported metrics – that can effectively contextualize changes in emissions and evaluate the substantiveness of corporate decarbonization actions. The insights generated from such a framework will facilitate differentiating decarbonization performance among firms and pierce through the veil of

impression management that often obfuscates performance comparison (Hoffmann & Busch, 2008; Velte et al., 2020).

2.6 Outcome Attribution Framework

Based on the different streams of literature reviewed, an outcome attribution framework is developed to map the current understanding of substantive corporate decarbonization actions rooted in effective outcomes. The research design that follows will be built on this framework. While this framework could inevitably simplify these complex constructs, the purpose is not to offer a fine-grained performance evaluation system. Rather, this research seeks to broadly evaluate the extent of substantive efforts reflected in effective outcomes for corporate decarbonization in a scalable manner, drawing from prior research on decarbonization levers, effectiveness, and corporations' roles in carbon mitigation to contextualize the evaluation.

Table 1: Outcome Attribution Framework – Conceptualization and operationalization of the key constructs

Constructs	Conceptualization	Operationalization			Citations
Corporate carbon performance	$\Delta GHG (Scope 1 + 2) =$ Driving Factors	$\frac{\Delta GHG (Scope 1 + 2)}{\Delta Energy}$ Factor C/E Carbon intensity of the energy mix	$\frac{\Delta Energy}{\Delta Revenue}$ Factor E/R Energy intensity of revenue	$\Delta Revenue$ Factor R	(Ang, 2005; Wei et al., 2020; Yagi & Managi, 2018; J. Zhang et al., 2020)
		LMDI Decomposition			
Effective mitigation outcomes	- Decoupling of revenue from absolute emissions; - Firms undertook the necessary measures.	Factor C/E decrease	3 Tapio decoupling states	/	(Erb et al., 2022; Haigh & Shapiro, 2012; Johnson et al., 2023; Rodriguez et al., 2020; Schaltegger & Csutora, 2012; Slawinski et al., 2017; Tapio, 2005; J. Zhang et al., 2020)
Substantive decarbonization actions	Operational changes and endogenous efforts that effectively result in carbon mitigation.	Renewable energy adoption Electrification	3 Tapio decoupling states	/	(Ashforth & Gibbs, 1990; Crossley et al., 2021; Erb et al., 2022; Long & Feng, 2024; Markard & Rosenbloom, 2023; Orazalin et al., 2024; Pinkse et al., 2024)
Business-as-usual	- Symbolic legitimacy strategies that might not improve outcomes; - Exogenous factors that improve outcomes inadvertently	Residual	Residual	Factor R	(Ashforth & Gibbs, 1990; Crossley et al., 2021; Johnson et al., 2023; Slawinski et al., 2017)

3. Research Design and Methods

3.1 Research Design

This study employs a quantitative approach, utilizing secondary panel data sourced from Bloomberg's ESG Database. Bloomberg is a trusted and renowned financial data provider and its comprehensive ESG datasets cover nearly 93% of the global equity market capitalization including the HKEx (Bloomberg, 2024). Corporate carbon-related data from 2018 to 2023 was collected for firms listed on the HKEx, and the final sample size was determined by the number of complete observations from the dataset. The distribution of the sampled firms across sectors, market-cap sizes, and sustainability performance scores is assessed to ensure sample reliability.

The statistical analysis unfolds in three phases as the following:

3.1.1 Phase One – Decomposition

Phase one involves decomposing each firm's YoY changes in carbon emissions using the LMDI method into three predefined driving factors including changes in the carbon intensity of energy (C/E), changes in energy efficiency in terms of revenue (E/R), and changes in revenue (R) (Yagi & Managi, 2018). The LMDI decomposition method has been used by a growing number of studies that set changes in carbon emissions as the governing function to dissect the driving factors (e.g. Rodríguez & Pena-Boquete, 2017; Wu et al., 2016; Yagi & Managi, 2018; Zhang et al., 2020). In this study, decomposition analysis is conducted on both individual firm and aggregate subcategory levels, for every YoY change in carbon emissions from 2018 to 2023 as well as comparing 2018 with 2023. The results provide a structural and quantitative understanding of the driving factors behind changes in emissions.

The LMDI decomposition model is based on the Kaya identity, which measures how carbon emissions and their underlying drivers change (Kaya, 1989). It has been adapted by Yagi and Managi (2018) for corporate analysis. The CO₂ emissions in year t (C^t) can be represented as the following in multiplicative form:

$$C^t = \frac{C^t}{E^t} \times \frac{E^t}{R^t} \times R^t$$

According to the LMDI model, the change in CO₂ emissions between the base year 0 and the target year t $\Delta C (\Delta C = C^t - C^0)$ can be decomposed into the following factors in additive form:

$$\Delta C^t = \Delta C_{ce}^t + \Delta C_{er}^t + \Delta C_r^t$$

Terms	Explanations
C^t, C^0	The total CO ₂ emissions (Scope 1 and Scope 2) in the target year t, year 0
E^t, E^0	The total energy consumption in year t, year 0
R^t, R^0	The total sales revenue in year t, year 0
ΔC^t	Changes in CO ₂ emissions between base year and target year t
ΔC_{ce}^t	The carbon intensity effect in changes in CO ₂ emissions
ΔC_{er}^t	The energy intensity effect in changes in CO ₂ emissions
ΔC_r^t	The revenue effect in changes in CO ₂ emissions
$\frac{C^t}{E^t}$ $\frac{C^0}{E^0}$	The carbon intensity of the energy mix in year t The carbon intensity of the energy mix in year 0
$\frac{E^t}{R^t}$ $\frac{E^0}{R^0}$	The energy intensity of sales revenue in year t The energy intensity of sales revenue in year 0

Among them,

$$\Delta C_{ce}^t = \frac{\ln\left(\frac{C^t}{E^t}\right) - \ln\left(\frac{C^0}{E^0}\right)}{\ln(C^t) - \ln(C^0)} \times (C^t - C^0)$$

$$\Delta C_{er}^t = \frac{\ln\left(\frac{E^t}{R^t}\right) - \ln\left(\frac{E^0}{R^0}\right)}{\ln(C^t) - \ln(C^0)} \times (C^t - C^0)$$

$$\Delta C_r^t = \frac{\ln(R^t) - \ln(R^0)}{\ln(C^t) - \ln(C^0)} \times (C^t - C^0)$$

3.1.2 Phase Two – Substantiveness Measurement

Phase two of the research design involves determining substantive decarbonization efforts with effective mitigation outcomes based on the factors decomposed from phase one. As detailed in the literature review, for factor C/E, substantive effort is indicated by fuel substitution or electrification (Erb et al., 2022; Markard & Rosenbloom, 2023; Pinkse et al., 2024). For factor E/R, substantive and effective decarbonization is operationalized using the Tapio decoupling model to determine the decoupling elasticity of energy consumption from revenue sales (Tapio, 2005; Wei et al., 2020; J. Zhang et al., 2020). This is where numerous carbon management activities, if effective, ultimately translate into measurable decoupling. The Tapio decoupling model minimizes the risks of overinterpreting minor changes as significant by treating variations within 0.2 of 1 as coupling (Tapio, 2005). This threshold enables a more reliable capture of substantive actions beyond marginal fluctuations. Lastly, factor R represents fluctuations in revenue and is considered external to decarbonization efforts. The results would be a percentage score that indicates the percentage of carbon mitigation that is attributable to substantive efforts. The operationalization of evaluating substantive actions is detailed in Table 2.

Table 2: Empirical Model – Operationalization of substantive actions and effective outcomes

Operationalization of substantive actions and effective outcomes between year t and year 0			
LMDI Decomposition	Factor C/E: the carbon intensity of energy	Factor E/R: the energy intensity of sales	Factor R: sales revenue
Effective mitigation outcomes:	Decrease in carbon intensity (negative Factor C/E)	Using Tapio Decoupling analysis	Exogenous factor
Substantive decarbonization efforts:	Renewable energy adoption: Increase in the % of total energy consumption (E) that is RE $\frac{RE(t)}{E(t)} \% - \frac{RE(0)}{E(0)} \%$ Electrification: - If Scope 1 decreases and Scope 2 increases - Then electrification is operationalized as decrease in the % of Scope 1 emissions $\frac{Scope\ 1(t)}{Scope1(t) + Scope2(t)} \% - \frac{Scope\ 1(0)}{Scope1(0) + Scope2(0)} \%$	- Effort score 100% for “Strong decoupling” or “Recessive decoupling” - Effort score (1-% decoupled) for “Weak decoupling”	
Exogenous factors	Residual	Residual	

Notably, since all calculations in the framework above rely on change analyses rather than direct comparisons of raw data between firms, variation in units across firms will not distort comparisons as long as each firm consistently uses the same unit over time. This is another advantage of applying change analysis for evaluating corporate carbon performance.

3.1.3 Phase Three – Correlation Analyses

Phase three entails conducting correlation analyses between the extent of substantive decarbonization actions and the degree of absolute and relative carbon emission reductions, both averaged annually to minimize the effect of a particularly strong or weak period. The explanatory variable – the extent of substantive decarbonization actions – is constructed from phases one and two. The independent variable – corporate carbon mitigation outcome – is measured both as changes in absolute emissions and as changes in emission intensities relative to sales.

A strong correlation suggests that the extent of emission reduction reflects the level of substantive decarbonization actions. Conversely, a weak correlation implies that comparing firms' mitigation outcomes offers little insight into their level of substantive efforts. This discrepancy underscores the importance of looking beyond mitigation outcomes, acknowledging unintended external influences on corporate carbon mitigation, and identifying potential decarbonization leaders in their growth stage.

3.2 Population and Sample

The population of this research is all firms listed on the HKEx, and the variables collected include Scope 1 and Scope 2 emissions, energy composition and consumption, renewable energy use, and revenue for each sampled firm and each year from 2018 to 2023.

Since the study uses secondary data from Bloomberg's ESG Database, data availability is partially constrained by Bloomberg's data scraping algorithm. While there are over 2,000 companies listed on the HKEx, the sample size is restricted by the number of complete observations available from Bloomberg's ESG Database. Data from 2018, the first year the disclosure rule was implemented, and 2023, the most recent year at the time of data collection, are included if available, but their absence

does not disqualify a firm from the sample. The primary criterion for inclusion is the availability of complete data from 2019 to 2022. A firm is excluded from the sample if the queried results lack data on carbon emissions, energy consumption, or sales revenue for any year from 2019 to 2022. Additionally, 14 observations were dropped after tracing back to original reports, due to unexplained, drastic fluctuations in the reported data. For example, one observation showed a tenfold decrease in carbon emissions with only a marginal decrease in energy consumption, which seems unreasonable without explanations.

Restricted data availability and the exclusion criteria have led to a significant dropout of firms, resulting in a final sample size of 339 firms, as detailed in Table 3. This dropout is partly due to Bloomberg's algorithm failing to capture some data points and partly due to missing data or inconsistencies in the original corporate reports, which may also contribute to the former. Missing data and inconsistencies have been widely observed by numerous researchers, as noted by Talbot & Boiral (2018), potentially due to the lack of external verification. This represents a limitation of the study, and relevant mitigation measures are discussed in the "validity and reliability" section.

The number of observations for each year-over-year comparison period is detailed below.

Table 3: Sample Breakdown by Year and Sector

Sectors	2018 to 2019	2019 to 2020	2020 to 2021	2021 to 2022	2022 to 2023	2018 vs. 2023
Industrials	46	50	50	50	50	46
Energy	9	10	10	10	9	8
Utilities	15	16	16	16	16	15
Materials	14	20	20	20	20	14
Consumer Staples	10	15	15	15	14	10
Consumer Discretionary	43	49	49	49	49	43
Communication Services	16	17	17	17	16	15
Information Technology	20	23	23	23	22	19
Health Care	19	26	26	26	26	19
Real Estate	47	59	59	59	55	44
Financials	48	54	54	54	54	48
Total	287	339	339	339	331	281
Total firm-year observations: 1,635						

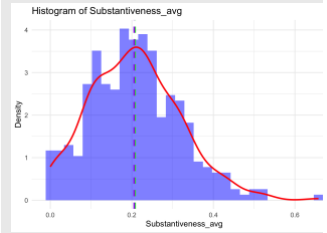
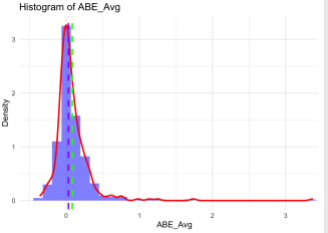
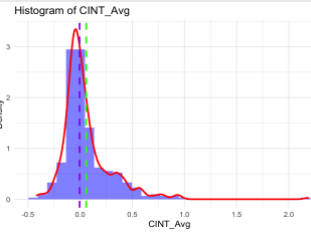
3.3 Statistics

This research uses Microsoft Excel for data cleansing and model development, and RStudio for statistics, analytics, and visualization.

3.3.1 Correlation Statistics

To determine the appropriate correlational statistics to use, the distribution of the relevant variables is examined as follows:

Table 4: Distribution of Variables

	Substantive Action Scores	Absolute emission reductions	Carbon intensity reductions
Skewness	0.462	5.95	2.88
Kurtosis	3.4	61.3	20.1
Mean	0.208	0.0828	0.0583
Median	0.205	0.0303	-0.00517
Kolmogorov–Smirnov test	p-value = 0.6844	p-value = 4.513e-09	p-value = 1.539e-09
Kolmogorov–Smirnov test conclusion	Normally distributed	Not normally distributed	Not normally distributed
Histograms			

Substantive action scores, absolute emission reductions, and carbon intensity reductions are calculated for each year-over-year period and averaged across 2018 to 2023 for 339 samples. Skewness, kurtosis, mean, and median are calculated for these variables, and the Kolmogorov-Smirnov test is conducted to assess if the data is normally distributed (Mishra et al., 2019). The results indicate that substantive action scores are approximately normally distributed, but both absolute emission reductions and carbon intensity reductions are characterized by high kurtosis in their respective distributions.

Although Pearson's correlation coefficient is most commonly used in research to investigate linear associations between two variables, it is only valid under bivariate normality and is highly sensitive to outliers (Bishara & Hittner, 2012; Croux & Dehon, 2010; Ventura-León et al., 2023). Additionally, the distributions of absolute emissions and emission intensity reductions are both characterized by high kurtosis, and nonnormality with high kurtosis can produce a distorted and inflated Pearson correlation coefficient (Bishara & Hittner, 2012, 2015). Consequently, alternative correlation coefficients are assessed for the non-normal bivariate distributions in this study.

It is important to highlight that the primary focus of this correlation analysis is to understand if firms that achieve greater carbon mitigation outcomes also engage in more substantive efforts, rather than predicting or regressing one variable on the other. In this regard, Spearman's rank correlation is well-suited for this analysis as it assesses the strength and direction of a monotonic relationship while accommodating the non-normality and outliers present in the data (de Winter et al., 2016; Gibbons, 1993, p. 30; Sedgwick, 2014; Wilcox, 2001, p. 190). Specifically, Spearman's rank correlation converts observations to ranks, and then Pearson's correlation is computed from the ranks to calculate the rank-based correlation coefficient known as Spearman's rho (Bishara & Hittner, 2015; Wilcox, 2001, p. 191).

3.3.2 Comparative Statistics

To compare the extent of substantive actions across subcategories, independent sample t-tests are employed to statistically test the differences in means between a specific subcategory and the rest of the sample. Given that the sample sizes and variances between one subcategory and the rest of the sample are often unequal, Welch's t-test is more appropriate and robust than the commonly used Student's t-test. It is therefore used to determine if the extent of substantive actions in any subcategory is statistically significantly different.

To compare correlation coefficients across subcategories and determine if one subcategory differs significantly from the rest, Fisher's Z transformation is performed on the correlation coefficients (Myers & Sirois, 2014; Puth et al., 2015; Soper, 1913). Fisher's z-transformation converts the correlation coefficients into z-scores, which can be compared for statistical significance (Myers & Sirois, 2014; Puth et al., 2015).

3.4 Validity and reliability

To ensure the quality of the research design and execution, potential threats to internal validity, external validity, and reliability relevant to this study are carefully reviewed and mitigated. The most pertinent threat to internal validity stems from instrumentation issues, which occur when the measurement instrument fails to produce valid and consistent scores, potentially due to inadequate criterion, content, and construct validity (Ihantola & Kihn, 2011). Instrumentation issues could compromise the ability to derive reliable inferences from the scores produced (Creswell & Creswell, 2023, p. 198). In this study, construct validity and potential instrumentation issues are mitigated through: 1) conducting a thorough literature review on various facets of the corporate carbon performance construct before selecting appropriate measures to address the research questions, and 2) developing an outcome attribution framework to define the measurement of substantive corporate decarbonization actions and to ensure consistent application of this framework across all observations.

Threats to external validity arise from a small or biased sample that may not accurately represent the full population, particularly when sampling is non-random, as in this study (Creswell & Creswell, 2023, p. 215). To mitigate such threats, the number and characteristics of the sample are assessed. The final sample size of 339 firms exceeds the minimum required sample size of 335 based on power analysis, ensuring a 95% confidence level for a population of 2,609 firms (Serdar et al., 2021). The distributions of the sampled firms by sector, market-capitalization size, and sustainability performance ratings are evaluated to assess the sample's balance and representativeness. Sectors are classified according to the Global Industry Classification Codes and the data is retrieved from Refinitiv; firm sizes are categorized by market capitalization data retrieved from Bloomberg and averaged across the sample period; sustainability performance is represented by Bloomberg's ESG scores, also averaged across the sample period. The final sample reflects a sector distribution representative of the population, a balanced distribution by firm size, and a normal distribution in ESG performance, as illustrated below. Analyzing the sample distribution ensures that the sample is not skewed toward particular sectors, market capitalization size, or sustainability over- or under-performers.

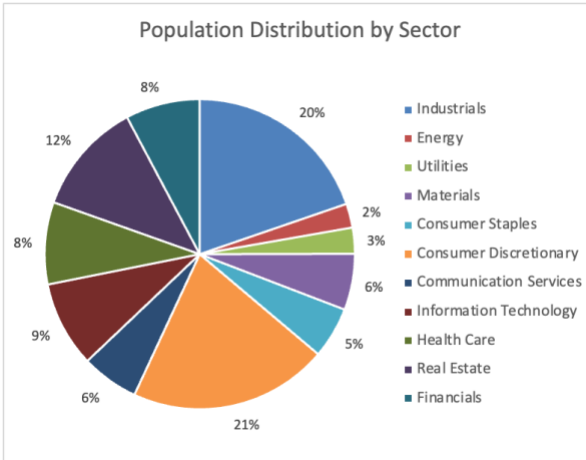


Figure 2. Population Distribution by Sector

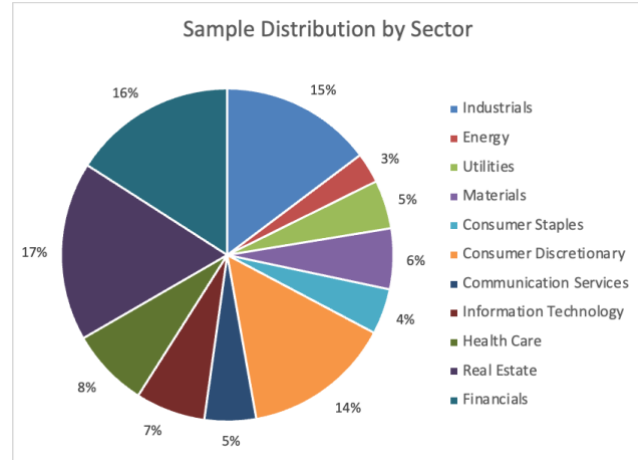


Figure 3. Sample Distribution by Sector

Table 5: Sample Distribution by Market-cap Size

Size by Market Capitalization (Ross, 2024)	Number
Large-Cap (> \$10 billion)	102
Mid-Cap (\$2-10 billion)	130
Small-Cap (< \$ 2 billion)	107
Total	339

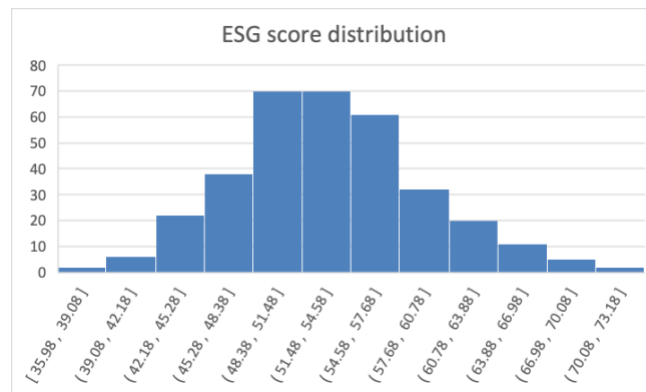


Figure 4. ESG Score Distribution

Reliability, in the quantitative research context, refers to the consistency and repeatability of a measurement instrument, and a lack of reliability leads to random or chance error (Creswell & Creswell, 2023, p. 243; Ithantola & Kihn, 2011). To enhance

reliability, the collected data is reviewed for anomalies including drastic increases or decreases and repetitive values for different years. These anomalies are traced back to the original sustainability report to either 1) confirm the data if reasonable explanations are provided, 2) update the data if it is not captured by Bloomberg or reported with a different unit, or 3) drop the sample if no reasonable explanations are found for significant inconsistencies over the years. 14 observations are excluded after review.

In addition to data review, resistance methods are employed to minimize the effects of extreme or unusual data (Schinka et al., 2003, p. 55). Substantive corporate decarbonization action is assessed with a score generated from the model developed in this research. The score is averaged across 5 year-over-year periods for each firm to mitigate the impact of particularly strong or weak years. Similarly, emission reductions are averaged across these 5 periods, with any year-over-year changes exceeding 200% being reviewed and traced back to the original sustainability report to ensure that 1) the data is correctly captured and converted, and 2) the change is not due to expansion of the reporting scope. In cases where drastic carbon emission increases result from an expanded data collection scope to include more subsidiaries, sites, or offices, such increases are excluded from the calculation of average changes in carbon emissions.

To further improve resistance to extreme or usual values, rank-based measures are used for correlation analysis (de Winter et al., 2016; Schinka et al., 2003, p. 55; Sedgwick, 2014). Comparisons across firms, sectors, and other dimensions are based on rankings of scores and reduced carbon emissions, and Spearman's rank correlation is used to understand the relationship between the extent of substantive decarbonization actions and the extent of carbon reductions. These measures enhance the reliability of data analysis and results by minimizing the effects of extreme or unusual data.

4. Results

This chapter is organized into four sections, each presenting specific results. Section 4.1 covers the descriptive results and comparative findings from the decomposition analyses. Section 4.2 focuses on the extent of substantive decarbonization actions, offering descriptive, correlational, and comparative findings. Section 4.3 explores longitudinal and comparative findings and section 4.4 presents the results from robustness checks.

4.1 Structural Understanding of the Driving Factors

The LMDI analysis compares 2018 and 2023 with 281 firms that have complete observations for both years. Changes in absolute carbon emissions from 2018 to 2023 are decomposed into 3 driving factors, namely changes in the carbon intensity of energy (C/E), changes in energy efficiency in terms of revenue (E/R), and changes in revenue (R). The relative contribution ratios of the 3 driving factors are calculated and visualized as stacked bars.

Relative contribution ratios represent how one factor (each of C/E, E/R, and R) changes relative to the others. However, since these ratios do not capture the direction of changes for each driving factor, diverging bar plots are used to complement the stacked bars to provide directional insights.

4.1.1 Comparing Absolute Emission Reducers and Increasers

Among the 281 firms that compared carbon performance between 2018 and 2023, 148 increased their absolute carbon emissions (the “Increasers”), while 133 managed to decrease theirs (the “Reducers”).

For the Reducers, changes in C/E contribute more to lowering emissions compared with changes in R. Conversely, for the Increasers, changes in R have a much larger impact on emission growth than changes in C/E (Figure 5).

Ideally, absolute emission reductions should be driven by decreases in carbon and energy intensities and not by revenue decline. Thus, the favourable scenario involves decreases in C/E and E/R that outweigh any increases in R. Whereas 60% of the Reducers manage to grow revenue while reducing absolute emissions, the remaining 40% cut emissions partially or fully due to revenue declines. This implies that

the carbon performance of such firms is not necessarily better than the Increasers. Meanwhile, although a sizeable portion of the Increasers also reduced C/E and E/R, the overall effect is overshadowed by a predominant increase in R (Figure 6).

Notably, changes in E/R stand out as a key differentiating driver of absolute emission changes. Not only is it the largest driving factor for the Reducers (Figure 5), but it also exhibits the most significant directional difference between the Reducers and the Increasers (Figure 6).

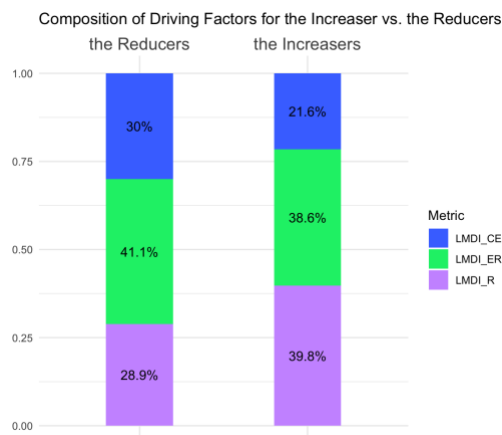


Figure 5. Composition of Driving Factors for the Increasers vs. the Reducers

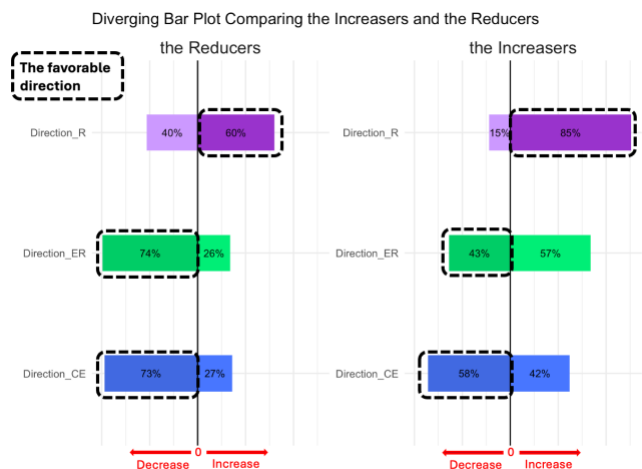


Figure 6. Diverging Bar Plot Comparing the Increasers and the Reducers

4.1.2 Comparing Across Sectors

The three driving factors are also compared across sectors structurally in stacked bars (Figure 7) and directionally in diverging bars (Figure 8).

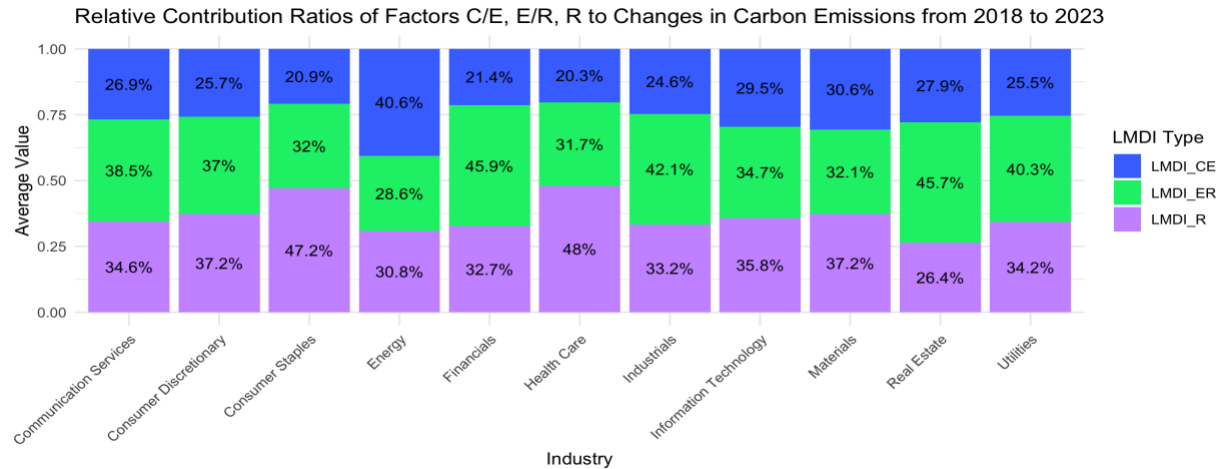


Figure 7. Relative Contribution Ratios of Factors C/E, E/R, R to Changes in Carbon Emissions from 2018 to 2023

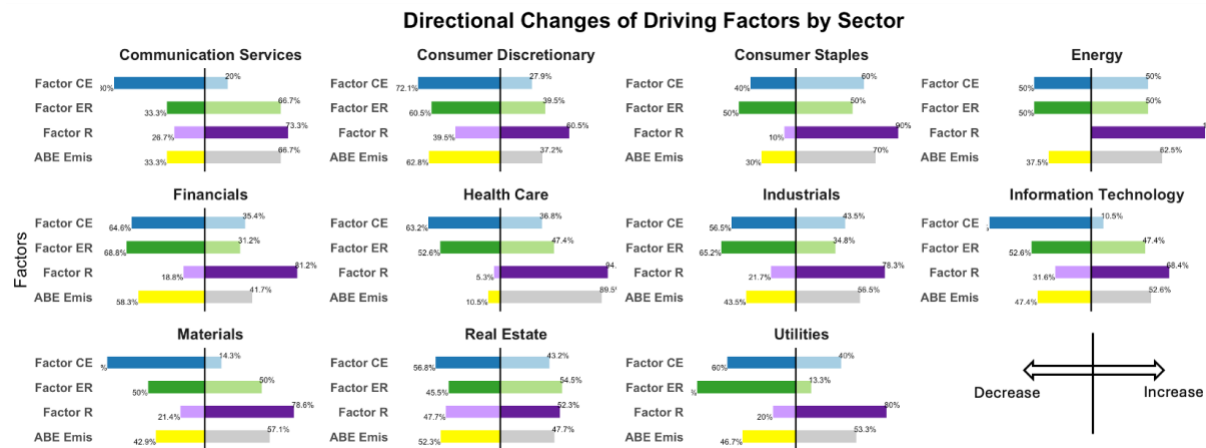


Figure 8. Directional Changes of the Driving Factors by Sector
(Note: the darker shade on each bar represents the favourable direction for the respective factor)

Aside from the energy sector, changes in C/E have the smallest impact on emissions across all sectors. Changes in E/R drive nearly half the changes in carbon emissions in the financial, real estate, industrials, and utilities sectors. Among these, the financial, industrials, and utilities sectors exhibit significantly more decreases than increases in E/R. Changes in R drive almost half of the changes in emissions for the

consumer staples and healthcare sectors, and a vast majority of the sampled firms in these two sectors experience growth in both sales and carbon emissions from 2018 to 2023.

4.2 Substantive Decarbonization Action Scores

The extent of substantive decarbonization actions is calculated based on specific criteria applied to the decomposed driving factors for each firm. It is expressed as a percentage score that reflects the extent of decarbonization through deliberate actions to reduce the carbon intensity of the energy mix and decouple revenue from energy consumption over a given period. The substantive action scores used for analysis are all averaged across 5 year-over-year periods for each firm to reflect an averaged level of effort throughout the sample period.

4.2.1 Descriptive Statistics

Comparing the substantive action scores across sectors reveals that consumer staples and financials are leaders in substantive decarbonization actions, while information technology lags behind (Figure 9).

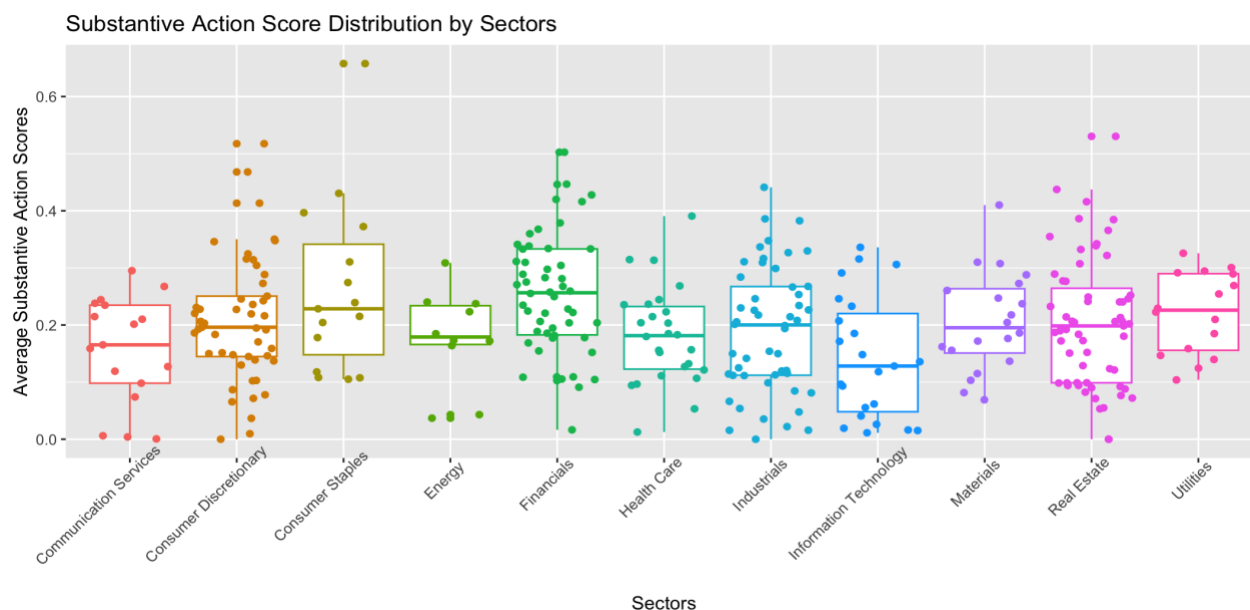


Figure 9. Substantive Action Score Distribution by Sector

Two-sample t-tests are conducted to compare the substantive action scores of various sub-categories with the rest of the sample. Statistically significant differences in

substantive efforts are only observed in three sectors. The financial sector demonstrates a statistically significantly higher level of substantive efforts, whereas communication services and information technology exhibit lower efforts.

Table 6: Welch's T-Test of Substantive Action Scores for Sub-categories

Category	Sub-category	N	M	SD	t	p	Sig
Market_cap_Size	Large-Cap	102	22.1%	0.125	1.631	0.105	ns
	Mid-Cap	130	20.1%	0.102	-0.5	0.62	ns
	Small-Cap	107	19.4%	0.106	-1.26	0.21	ns
Sector	Industrials	50	19.0%	0.111	-1.04	0.302	ns
	Real_Estate	59	20.2%	0.114	-0.22	0.828	ns
	Utilities	16	22.2%	0.071	0.91	0.374	ns
	Consumer_Staples	15	26.3%	0.152	1.522	0.149	ns
	Materials	20	20.6%	0.087	0.024	0.981	ns
	Health_Care	26	18.1%	0.085	-1.44	0.16	ns
	Energy	10	17.8%	0.085	-1	0.339	ns
	Financials	54	25.8%	0.111	3.837	0	***
	Consumer_Discretionary	49	20.7%	0.109	0.154	0.878	ns
	Communication_Services	17	0.156	0.095	-2.16	0.044	*
	Information_Technology	23	0.142	0.107	-2.96	0.007	**

4.2.2 Correlation Analysis

To address the research question of whether firms with superior mitigation outcomes tend to have taken more substantive actions, this section presents the results of correlation analyses between each firm's substantive action score and the extent of both absolute emission reduction and emission intensity reduction. Although a greater extent of substantive decarbonization actions is correlated with greater decreases in both absolute emissions and carbon intensity, the correlation is low for both absolute reduction (Spearman's rho = -0.35) and for intensity reduction (Spearman's rho = -0.37).

4.2.2.1 Substantive action and absolute carbon emission reduction

Correlations between substantive actions and absolute carbon emission reductions are weak in most sectors and across different firm sizes, except for the large-cap firms and the industrials sector showing moderate correlations.

To compare if the correlation of any subcategory differs significantly from the rest of the sample, Fisher's Z test is performed to compare the correlation coefficients

(Myers & Sirois, 2014; Puth et al., 2015). As a result, only the large-cap firms differ significantly with a moderate correlation.

Notably, in the energy sector, and contrast to the rest of the sample, an inverse relationship between substantive actions and carbon reduction is observed. Although the correlation coefficient is statistically significant compared to the rest of the sample, the energy sector's small sample size of only 10 creates a significant disparity when compared with the rest of the sectors. This imbalance could result in a loss of statistical power of the result (May & Looney, 2022).

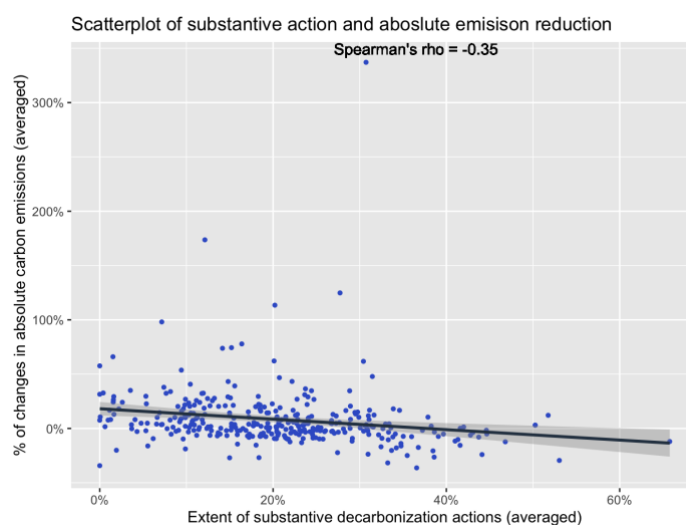


Figure 10. Scatterplot of Substantive Action and Absolute Emission Reduction

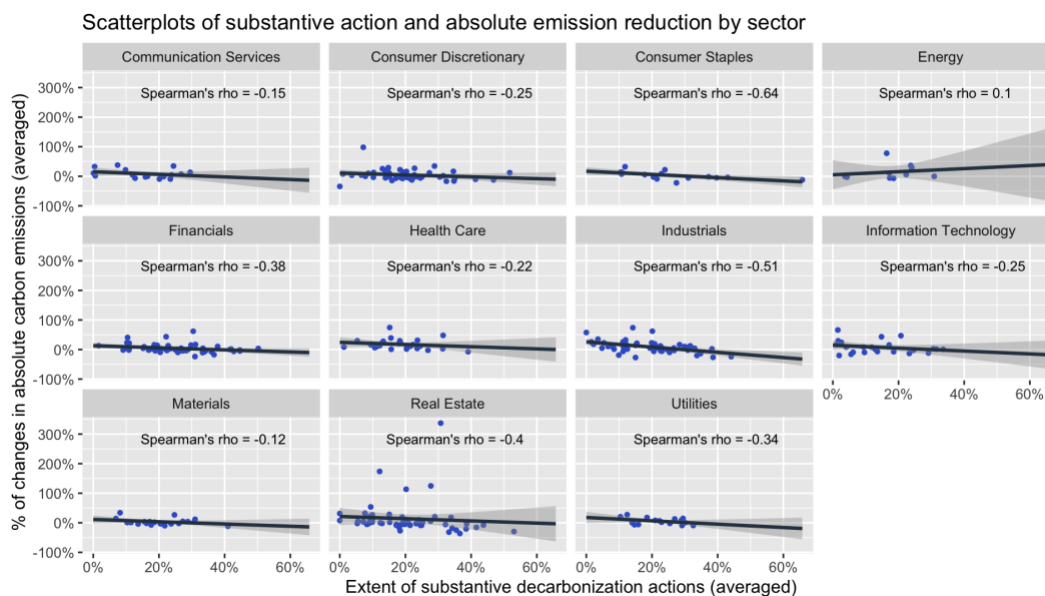


*Figure 11. Scatterplots of Substantive Action and Absolute Emission Reduction
by Sector*

Table 7: Results of Fisher's Z Test to compare correlations between substantive actions and absolute carbon emission reductions among different sub-categories

Category	Subcategory	Correlation	N	Correlation_ Coefficient	Strength_of_ Correlation	Fisher_Z_ value	p	Sig
Mcap_Size	Large-Cap		102	-0.517	Moderate	-2.35	0.019	*
	Mid-Cap		130	-0.334	Weak	0.365	0.715	ns
	Small-Cap		107	-0.23	Weak	1.714	0.087	ns
Industry	Industrials		50	-0.507	Moderate	-1.388	0.165	ns
	Real_Estate		59	-0.399	Weak	-0.442	0.658	ns
	Utilities		16	-0.338	Weak	0.075	0.94	ns
	Consumer_Staples		15	-0.643	Strong	-1.415	0.157	ns
	Materials		20	-0.122	Very_weak	1.018	0.309	ns
	Health_Care		26	-0.216	Weak	0.654	0.513	ns
	Energy		10	0.103	Very_weak	1.289	0.197	ns
	Financials		54	-0.383	Weak	-0.35	0.726	ns
	Consumer_Discretionary		49	-0.246	Weak	0.885	0.376	ns
	Communication_Services		17	-0.152	Very_weak	0.809	0.419	ns
	Information_Technology		23	-0.248	Weak	0.586	0.558	ns

4.2.2.2 Substantive action and carbon intensity reduction

Although the correlation between substantive actions and carbon intensity decline is slightly higher than that with absolute emission reduction, it still remains weak. Fisher's Z test indicates no statistically significant difference in the correlations across the subcategories. Similar to the correlational analysis in the previous section with absolute emission reduction, the energy sector shows a very weak but inverse correlation compared to the rest. However, the unequal sample sizes limit the statistical power of this comparison.

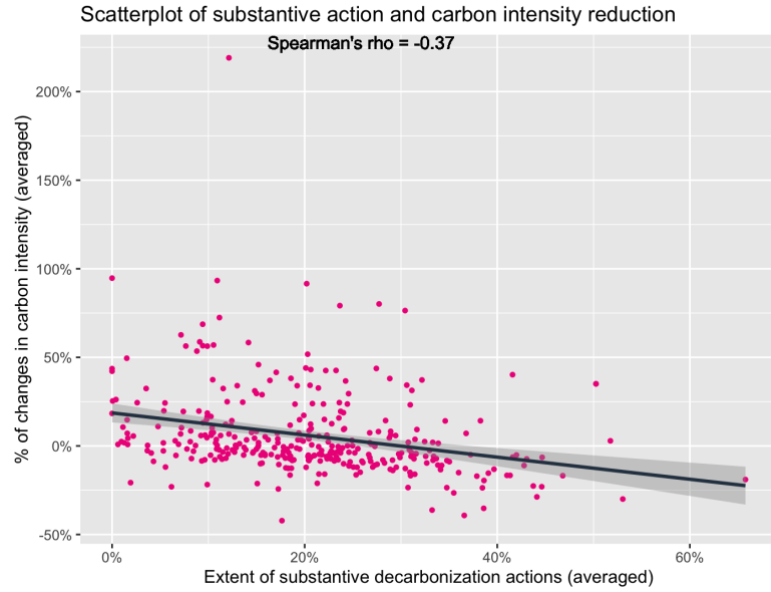


Figure 12. Scatterplot of Substantive Action and Carbon Intensity Reduction

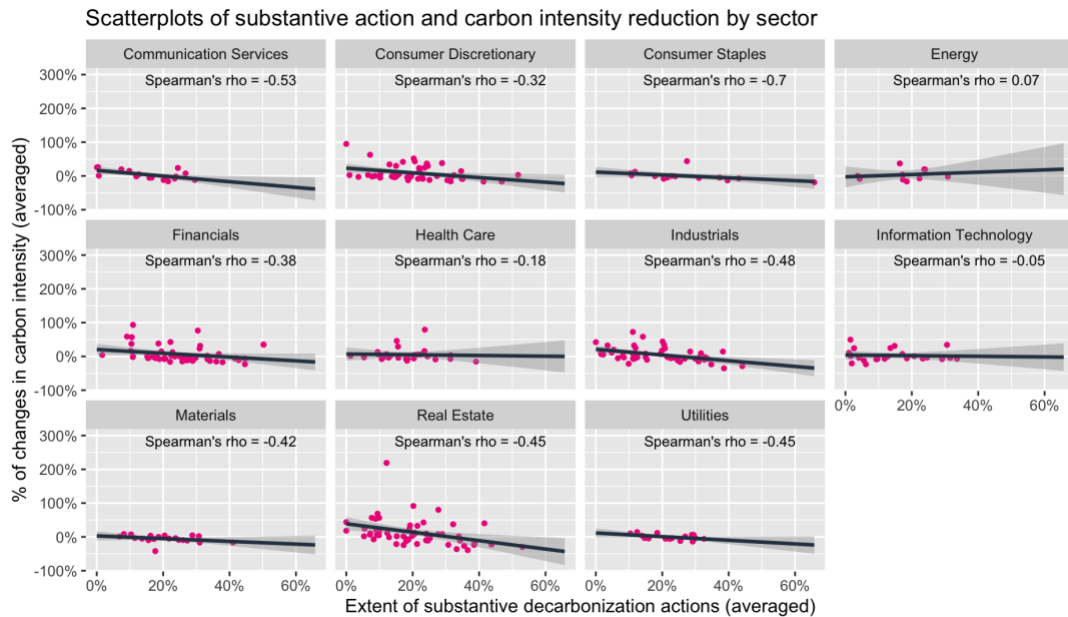


Figure 13. Scatterplots of Substantive Action and Carbon Intensity Reduction by Sector

Table 8. Results of Fisher's Z Test to compare correlations between substantive actions and carbon intensity reductions among different sub-categories

Category	Subcategory	Correlation	N	Correlation_ Strength_of_ Fisher_Z_			
				Coefficient	Correlation	value	p Sig
Mcap_Size	Large-Cap		102	-0.408	Moderate	-0.551	0.582 ns
	Mid-Cap		130	-0.429	Moderate	-0.897	0.37 ns
	Small-Cap		107	-0.261	Weak	1.564	0.118 ns
Industry	Industrials		50	-0.476	Moderate	-0.927	0.354 ns
	Real_Estate		59	-0.446	Moderate	-0.753	0.451 ns
	Utilities		16	-0.453	Moderate	-0.351	0.726 ns
	Consumer_Staples		15	-0.696	Strong	-1.631	0.103 ns
	Materials		20	-0.421	Moderate	-0.233	0.816 ns
	Health_Care		26	-0.179	Very_weak	1.051	0.293 ns
	Energy		10	0.067	Very_weak	1.255	0.209 ns
	Financials		54	-0.382	Weak	-0.145	0.885 ns
	Consumer_Discretionary		49	-0.316	Weak	0.468	0.64 ns
	Communication_Services		17	-0.527	Moderate	-0.728	0.467 ns
	Information_Technology		23	-0.045	Very_weak	1.672	0.095 ns

4.2.3 Comparing Substantive Actions Between the Reducers and the Increasers

While the previous section identified weak correlations between substantive actions and mitigation outcomes including both absolute emissions and intensity reductions, this section adopts a dichotomous approach to compare substantive actions between the Reducers and Increasers.

4.2.3.1 Substantive action scores

To understand if there is a significant difference in substantive action between the Reducers and the Increasers, Welch's T test is used to compare the statistical significance of the differences between these two independent pairs (Derrick et al., 2017). As a result, the extent of substantive action is statistically significantly higher for the Reducers in both absolute emissions and carbon intensity compared to the Increasers.

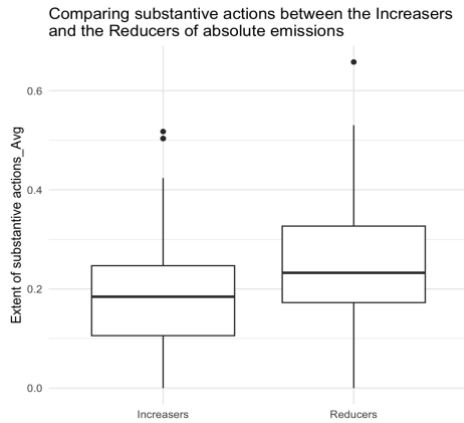


Figure 14. Comparing Substantive Actions between the Increasers and the Reducers of Absolute Emissions

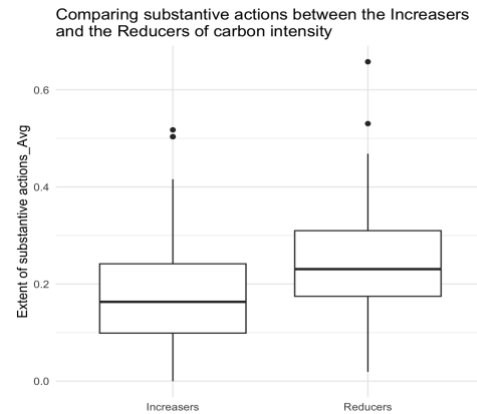


Figure 15. Comparing Substantive Actions between the Increasers and the Reducers of Carbon Intensity

Table 9. Comparing Substantive Actions between the Increasers and the Reducers in Absolute Emissions and Carbon Intensity

Welch's T	Absolute emissions	Carbon intensity
M (Reducers)	0.244	0.239
M (Increasers)	0.18	0.169
T	5.267	6.099
df	260.3	335.9
p	<0.001	<0.001
Sig	***	***
95% CI Lower	0.04	0.047
95% CI Upper	0.088	0.092

4.2.3.2 Correlations between substantive actions and carbon performance

When comparing the Increasers and the Reducers regarding correlations, only the correlations related to carbon intensity exhibit a statistically significant difference. While carbon intensity Reducers show a moderate correlation between substantive actions and carbon intensity reduction, Increasers show no correlation.

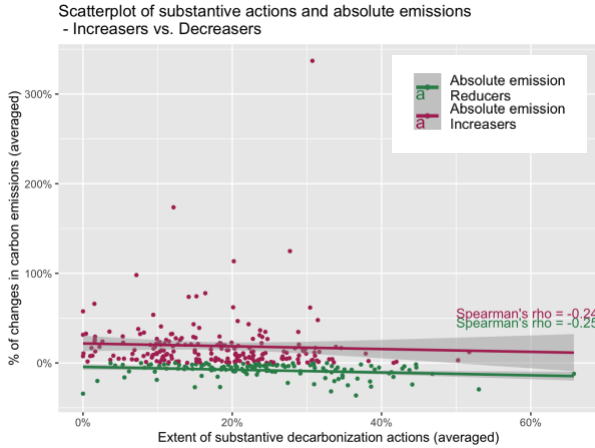


Figure 16. Scatterplot of Substantive Actions and Absolute Emission Reduction – Increasers vs. Reducers

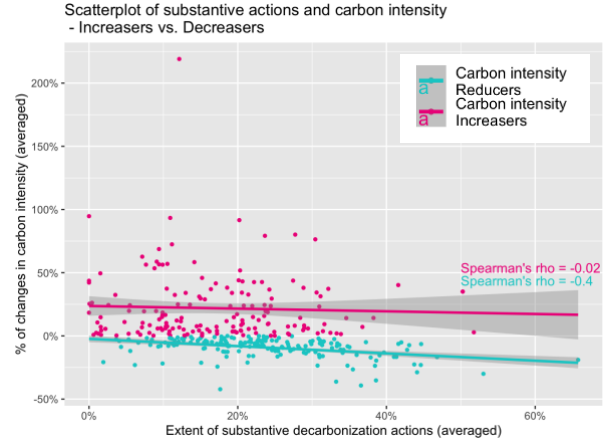


Figure 17. Scatterplot of substantive Actions and Carbon Intensity Reduction – Increasers vs. Reducers

Table 10: Comparing the action-outcome correlations between the Increasers and the Reducers in absolute emissions and carbon intensity

Group		Correlation	Fisher's_Z	p_value	Sig
Absolute emissions	Reducers	-0.25	-0.139	0.89	ns
	Increasers	-0.24			
Carbon intensity	Reducers	-0.4	-3.704	0.0002	***
	Increasers	-0.02			

4.3 Longitudinal Trends

From 2018 to 2023, the relative contribution ratios of the three driving factors among all sampled firms have remained relatively stable. Changes in energy efficiency have consistently been the largest driver, while changes in carbon intensity have been the smallest. Additionally, the extent of substantive decarbonization actions across the entire sample has remained similar during this period. There is a slight downward trend observed from 2020 to 2023.

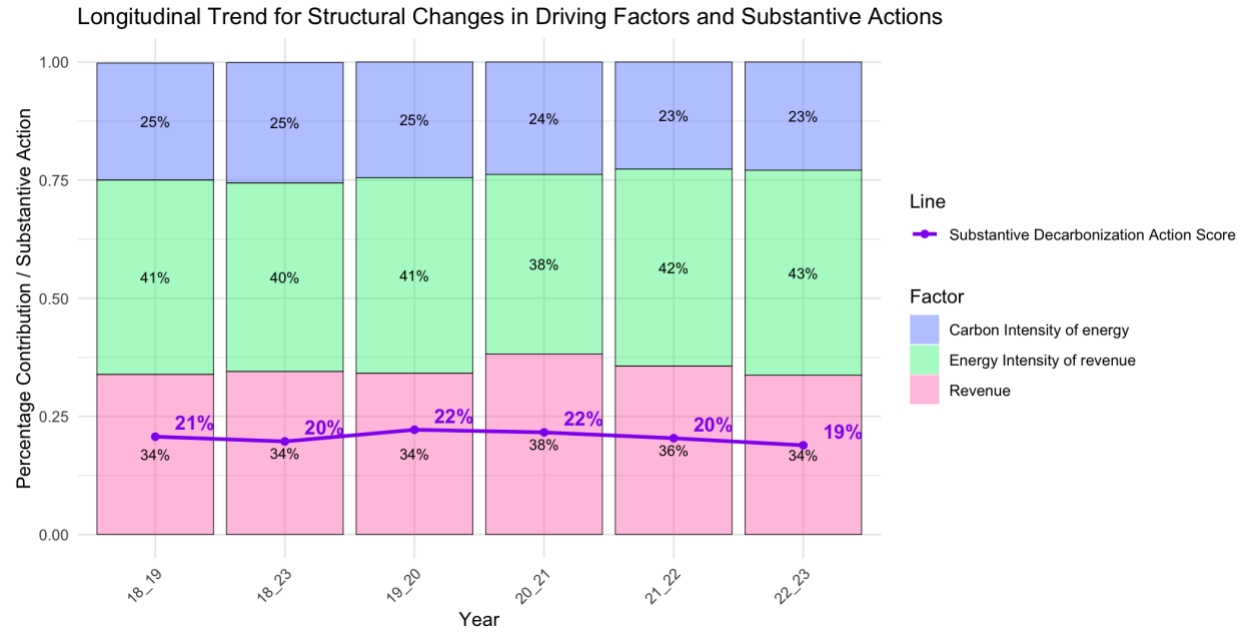


Figure 18. Longitudinal Trend for Structural Changes in Driving Factors and Substantive Actions

Longitudinal trends vary across sectors. Notably, the communication services and consumer discretionary sectors show an upward trend in the extent of substantive efforts. The energy and materials sectors improved their efforts only until 2021.

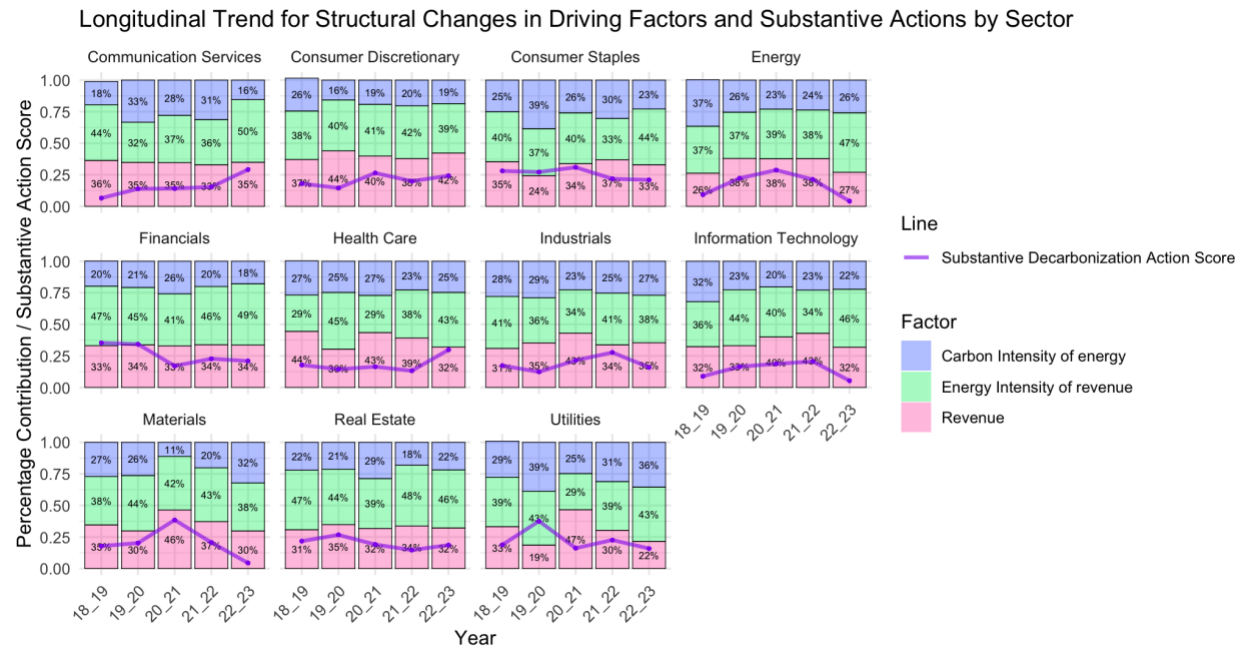


Figure 19. Longitudinal Trend for Structural Changes in Driving Factors and Substantive Actions by Sector

4.4 Robustness Checks

Although Spearman's rank correlation is less sensitive to outliers than Pearson's correlation, given the generally weak correlations observed in this study and the presence of outliers in the sample, it is necessary to ensure that the resulting low correlations are not heavily influenced by outliers.

Influence diagnostics is commonly used by researchers to understand if a small number of unrepresentative data points could disproportionately distort the outcomes (Wright et al., 2019). Among them, Cook's distance is widely used in generalized linear models to identify outliers in both predictor and outcome variables (Su & Tsai, 2011). To account for the non-linearity of the underlying data, this study uses generalized Cook's distance to identify outliers, which is found to be most robust by Wright et al. (2019).

A cut-off of 0.012 ($4/(n-p)$) is used in this study to identify outliers (Sulthan & Jayakumar, 2014). As a result, 9 outliers are removed from the absolute emissions correlations and 14 from carbon intensity correlations to create a new sample for the correlation analyses. Although correlations expectantly strengthened to some extent after winsorisation, they remain no stronger than moderate and are largely consistent with the original findings.

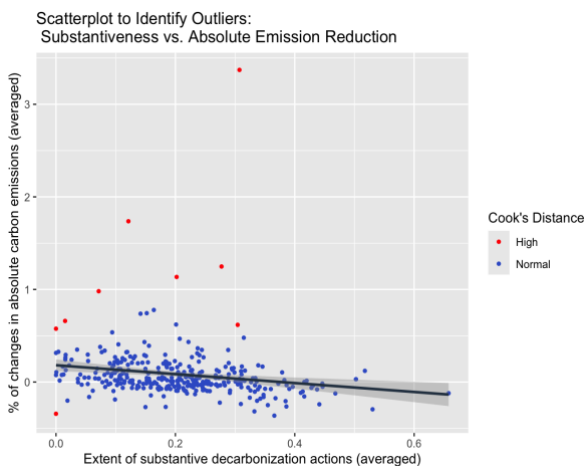


Figure 20. Scatterplot to Identify Outliers: Substantiveness vs. Absolute Emission Reduction

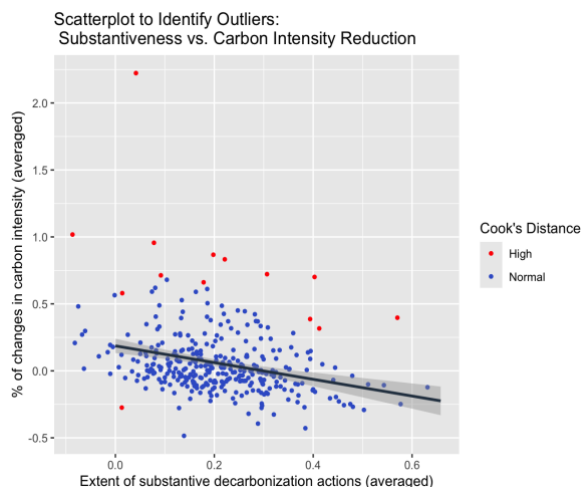


Figure 21. Scatterplot to Identify Outliers: Substantiveness vs. Carbon Intensity Reduction

Table 11: Outliers Removed - Results of Fisher's Z Test to compare correlations between substantive actions and absolute emission reductions among sub-categories

Category	Subcategory	Correlation	N	Correlation_ Strength_of_ Fisher_Z_		p	Sig	outliers removed
				Coefficient	Correlation value			
Mcap_Size	Large-Cap	99	-0.548	Moderate	-2.59	0.01	*	-3
	Mid-Cap	128	-0.34	Weak	0.555	0.579	ns	-2
	Small-Cap	103	-0.239	Weak	1.795	0.073	ns	-4
Industry	Industrials	49	-0.48	Moderate	-0.973	0.331	ns	-1
	Real_Estate	55	-0.496	Moderate	-1.191	0.234	ns	-4
	Utilities	16	-0.338	Weak	0.153	0.878	ns	0
	Consumer_Staples	15	-0.643	Strong	-1.345	0.179	ns	0
	Materials	20	-0.122	Very_weak	1.107	0.268	ns	0
	Health_Care	26	-0.216	Weak	0.749	0.454	ns	0
	Energy	10	0.103	Very_weak	1.348	0.178	ns	0
	Financials	53	-0.415	Moderate	-0.492	0.623	ns	-1
	Consumer_Discretionary	47	-0.288	Weak	0.684	0.494	ns	-2
	Communication_Services	17	-0.152	Very_weak	0.885	0.376	ns	0
	Information_Technology	22	-0.146	Very_weak	1.142	0.253	ns	-1

Table 12. Outliers Removed - Results of Fisher's Z Test to compare correlations between substantive actions and carbon intensity reductions among sub-categories

Category	Subcategory	Correlation	N	Correlation_ Strength_of_ Fisher_Z_		p	Sig	outliers removed
				Coefficient	Correlation value			
Mcap_Size	Large-Cap	98	-0.492	Moderate	-1.201	0.23	ns	-4
	Mid-Cap	125	-0.437	Moderate	-0.366	0.714	ns	-5
	Small-Cap	102	-0.293	Weak	1.68	0.093	ns	-5
Industry	Industrials	49	-0.465	Moderate	-0.465	0.642	ns	-1
	Real_Estate	54	-0.538	Moderate	-1.266	0.206	ns	-5
	Utilities	16	-0.453	Moderate	-0.171	0.864	ns	0
	Consumer_Staples	15	-0.696	Strong	-1.46	0.144	ns	0
	Materials	20	-0.421	Moderate	-0.027	0.978	ns	0
	Health_Care	25	-0.256	Weak	0.875	0.382	ns	-1
	Energy	10	0.067	Very_weak	1.392	0.164	ns	0
	Financials	50	-0.522	Moderate	-1.107	0.268	ns	-4
	Consumer_Discretionary	47	-0.233	Weak	1.462	0.144	ns	-2
	Communication_Services	17	-0.527	Moderate	-0.548	0.584	ns	0
	Information_Technology	22	-0.129	Very_weak	1.443	0.149	ns	-1

5. Discussion

This chapter discusses the key findings from the decomposition of emission changes, the assessment of substantive actions, and the correlations between mitigation efforts and outcomes. It also expands on the contributions of this study to both practice and academic research.

5.1 Discussion on the Decomposition of Emission Changes

Changes in absolute emissions from 2018 to 2023 are decomposed through the LMDI method into three drivers: changes in the carbon intensity of energy, energy intensity of revenue, and revenue. Emission increases are predominantly driven by revenue growth, which overshadowed improvements in carbon and energy intensity, a pattern particularly evident in growth sectors such as consumer staples and healthcare. Both sectors saw significant revenue growth during the sample period from 2018 to 2023 (S&P China, 2024a, 2024b), and while a notable proportion of firms in these sectors reduced their carbon and energy intensities, a vast majority of them still increased absolute emissions over time. This observation reflects a common sustainability challenge where environmental degradation worsens despite decarbonization efforts if growth rates outpace efficiency improvement (Rodriguez et al., 2020; Russo & Pogutz, 2009). It underscores the need to go beyond efficiency improvement, especially in the face of business growth (Dahlmann et al., 2019; Rodríguez & Pena-Boquete, 2017; Russo et al., 2021).

The most significant driver differentiating the emission Reducers from the Increasers appears to be energy intensity. This suggests that firms that successfully reduce emissions over time tend to rely most on improving energy efficiency per unit of sales. Additionally, a decline in revenue emerges as another key driver for the Reducers, aligning with observations by Erb et al. (2022), who noted that absolute emissions can decrease even in the absence of actions aimed at improving emissions performance.

As mentioned in the literature review, LMDI decomposition is underutilized at the corporate level. This research demonstrates how LMDI decomposition can offer valuable insights into firms' carbon emissions performance. By breaking down emission

changes into carbon intensity, energy intensity, and revenue, this approach addresses the research gap identified by Lewandowski (2017) regarding the causes of fluctuations in a firm's carbon intensity, and provides the contextual insights into the drivers of emission reductions called for by Sullivan and Gouldson (2012). LMDI results in decomposition without residuals and offers the advantages of adaptability, ease of use, and consistency in aggregation (Ang, 2004; J. Zhang et al., 2020). It could easily be integrated into decision-making tools for more granular comparisons of emissions drivers over time and between firms.

5.2 Discussion on Substantive Decarbonization Actions

The extent of substantive decarbonization actions is expressed as the percentage of emissions changes attributable to these actions, with the sampled firms averaging around 20%. In this study, substantive decarbonization actions refer to operational changes and deliberate efforts that effectively result in carbon mitigation. The remaining percentage reflects revenue fluctuations, unfavourable changes in energy and carbon intensities, and other external factors that unintentionally improve emission outcomes. The overall results indicate that only about 20% of changes in emission outcomes can be attributed to substantive decarbonization actions, and the rest are fluctuations under business-as-usual operations.

The finding of a generally low level of substantive decarbonization actions aligns with multiple empirical studies that support the view of corporate climate response as symbolic legitimization (Coen et al., 2022; Delmas et al., 2013; Doda et al., 2016; Mahapatra et al., 2021; Orazalin et al., 2024; Slawinski et al., 2017). While previous studies commonly construct explanatory variables using process-based disclosures evaluated against specific typologies, this study distinguishes itself by creating the explanatory variable with a novel approach. This involves 1) relying exclusively on quantifiable outcome measures disclosed, and 2) deriving the substantiveness score from changes in emission outcomes expressed as a percentage to which outcomes are attributed.

This novel approach to measuring substantive decarbonization actions helps address the challenges involved in piercing through the veil of impression management and identifying substantive actions in discretionary narrative disclosures (Borghei, 2021;

Merkel-Davies & Brennan, 2008), as it only relies on quantified outcomes from carbon emissions, energy mix composition and consumption, and revenue, hence bypassing potential linguistic strategies (Brunelli et al., 2021). Additionally, this novel approach responds to the call for shifting focus from the mere presence of corporate decarbonization initiatives to their actual impact on the emissions that they aim to reduce (Delmas et al., 2013; Doda et al., 2016).

Comparisons of substantive decarbonization actions across sectors show that the financial sector exhibits statistically significantly higher scores. However, this result should be interpreted with caution due to the sector's unique characteristics (Luo & Tang, 2021; Orazalin et al., 2024). The financial sector's emissions profile is dominated by Scope 3 emissions – indirect emissions arising from the entire value chain (Doda et al., 2016; Dragomir, 2018; Persefoni, 2024). The exclusion of Scope 3 in this study inevitably contributes to the financial sector outperforming in carbon mitigation.

Notably, the average extent of substantiveness in decarbonization actions across the entire sample has remained around 20% from 2018 to 2023, with a slight, steady decline beginning in 2021. While acknowledging that the 5-year time horizon offers limited longitudinal insights and coincides with the COVID-19 pandemic period, this trend aligns with prior findings that suggest a deterioration of genuine actions over time (Ashforth & Gibbs, 1990; C. Wright & Nyberg, 2017).

5.3 Discussion on Correlations

While a greater extent of substantive efforts correlates with more favourable emission reduction outcomes – both in absolute and intensity terms – the overall correlations are weak and at best moderate within certain subcategories. This suggests that carbon mitigation outcomes and substantive decarbonization efforts are generally not well-aligned. In other words, firms achieving greater emission reductions are not necessarily those engaging in more substantive decarbonization efforts, and vice versa.

Since this study conceptualizes substantive decarbonization action as internal mitigation efforts with effective outcomes, the observed weak correlations are likely attributed to the stronger influence of drivers external to corporate decarbonization efforts. While it is understandable that a higher extent of substantive actions may not result in lowering emissions – especially for firms or industries experiencing growth that

outpaces even significant improvements in energy efficiency – what is more concerning is the scenario where firms with limited substantive actions achieve greater emission reductions. This phenomenon is troubling because it allows and even encourages business-as-usual operations to persist, obscured by seemingly positive emission outcomes. As emphasized by Deegan (2019), meaningful social advancement could be impeded if business-as-usual practices are effectively legitimized through disclosures.

Underlying these positive emission outcomes achieved by business-as-usual actors are unintentional reductions in emissions. Such reductions may occur simply due to decreased production, as highlighted by Erb et al. (2022) and Slawinski et al. (2017). When not accompanied by a much greater extent of decline in energy consumption, these emission reductions are not attributable to deliberate mitigation efforts. A less obvious case of unintentional emission reductions arises when the carbon intensity of energy decreases without active adoption of renewable energy or evidence of electrification. In some cases, simply updating the emission factors used can lead to lower reported emissions (Haigh & Shapiro, 2012). This is especially relevant when reporting emissions from purchased electricity. When the carbon intensity of the state electricity supply decreases – as is the case in mainland China and Hong Kong, where most of the sampled firms are located – firms' emissions from purchased electricity will decline accordingly as the grid's emission factors are updated (Our World in Data, 2023).

Another plausible explanation for the weak correlation between substantive actions and emission reductions is missing or inaccurate data in corporate disclosure, which is commonly highlighted in the literature (Sullivan & Gouldson, 2012; Talbot & Boiral, 2018). For example, some firms reported adopting or increasing their reliance on renewable energy in their sustainability reports but failed to provide the relevant data. While they may have achieved emission reductions accordingly, their actions cannot be quantified and fed into the model due to the lack of adequate disclosure on their energy mix. Inadequate or inaccurate disclosure is a limitation of this study, which relies entirely on corporate disclosure and is subject to self-reporting bias. This will be discussed further in the limitations section.

The practical implication of the weak correlations suggests that comparing firms' mitigation outcomes offers little insight into the substantive nature of their decarbonization efforts and does little to support accountability. While it is well-established in the literature that process-based and narrative disclosures are more prone to symbolic legitimization and thus less reflective of substantive actions (Csutora, 2011; Doda et al., 2016; Haque, 2017; Merkl-Davies & Brennan, 2008; Moussa et al., 2020), outcome-based disclosures are rarely scrutinized and frequently used for performance comparisons. This result highlights the caveat of comparing emission reduction outcomes and underscores the importance of dissecting changes in outcomes to distinguish between substantive actions and unintended obscuring factors, thereby enabling better identification of meaningful climate actions and actors.

5.4 Contributions

5.4.1 Contributions to Decision-Making

This study develops an empirical model that enables decision-makers to quantitatively understand how emissions changes are driven by changes in carbon intensity, energy intensity, and revenue, as well as the extent of substantive decarbonization efforts contributing to these changes. Through this model, transformed data will yield more decision-useful insights, which not only help contextualize corporate carbon performance disclosures but also enable effective comparisons across firms and sectors regarding the drivers of emissions changes and mitigation actions. Researchers frequently highlight the lack of contextual, comparable, and decision-useful information in corporate sustainability disclosures (Borghei, 2021; Busch, Johnson, et al., 2022; Delmas et al., 2013; Kolk et al., 2008; Merkl-Davies & Brennan, 2008; Sullivan & Gouldson, 2012; Talbot & Boiral, 2018). The empirical model developed in this study offers a way to overcome these limitations without requiring changes to how firms currently disclose.

The model can be easily integrated into existing evaluation tools, as it draws on commonly disclosed metrics and does not require textual analysis or interpretation. Since the model is based on change analysis, variations in measurement units across firms do not hinder comparisons provided that each firm consistently uses the same

units over time, and the results can be aggregated. This ensures ease of use, scalability for firm evaluations, consistent aggregation, and comparability across firms or groups.

Incorporating the extent of substantive decarbonization actions into corporate carbon performance evaluation would eventually help direct resources to support meaningful climate actions and advance best practices. Coen et al. (2022) emphasized the importance of developing new metrics for climate-competitiveness and identifying climate-transition-aligned firms to ensure they receive appropriate sustainable investment. Meanwhile, Merkl-Davies & Brennan (2008) and Sullivan & Gouldson (2012) highlighted investors' need for incremental information to support informed decision-making.

5.4.2 Contributions to Research

As corporations face growing scrutiny over their contributions to climate change, research interest in corporate climate mitigation strategies and carbon performance has surged. Researchers have raised concerns about the substantiveness and effectiveness of corporate response to climate change, especially given the significant rises in both the amount and length of corporate disclosures (Kolk et al., 2008; Merkl-Davies & Brennan, 2008). This study adds to the emerging discourse around substantive versus symbolic corporate response by focusing on attributing changes in emission outcomes to substantive decarbonization actions. Incorporating various discussions on the conceptualizations of corporate carbon performance, mitigation outcome effectiveness, and the corporate role in bridging the emissions gap, this study constructs an outcome attribution framework to measure substantive mitigation actions.

This approach addresses gaps highlighted by Johnson et al. (2023) in their systematic review of corporate response to climate change, which notes a lack of scholarly focus on deep decarbonization responses geared towards absolute reduction. Additionally, this approach tackles another underexplored area concerning the outcomes of corporate climate actions (Cadez et al., 2019; Zhang & Liu, 2020). Through the outcome attribution framework, this study measures a novel aspect of corporate carbon performance rooted in substantive decarbonization actions that effectively reduce emissions, while also drawing attention to unintended drivers of emission

reductions that can obscure symbolic actions and perpetuate business-as-usual practices.

Another contribution to research is the adoption of change analysis methods, such as the LMDI decomposition and Tapio decoupling, within the context of corporate studies. Although these methods are commonly applied in environmental economics at national and sectoral levels, they are rarely utilized in corporate environmental research, with only Yagi & Managi (2018) being an exception.

6. Conclusion and Limitations

This chapter presents the conclusions from this study and offers recommendations for practice. It also examines the study's limitations and proposes potential directions for future research.

6.1 Conclusion and Recommendations

This study set out to understand and evaluate how changes in emissions are driven by changes in carbon intensity, energy intensity, and revenue, and to what extent these changes can be attributed to substantive decarbonization actions as opposed to unintended external influences such as revenue fluctuations and updating the emission factors used. Using decomposition and decoupling analysis on secondary panel data from a sample of firms listed on the HKEx from 2018 to 2023, the study found that reductions in energy intensity were the largest contributor to emission reductions, and revenue growth was the most significant driver of emission increases, often overshadowing improvement in carbon and energy intensities. Overall, only about 20% of emission changes could be attributed to substantive decarbonization actions. Since emission changes were largely driven by revenue fluctuations and other unintended factors external to corporate mitigation efforts, it is unsurprising that firms achieving greater emission reductions are not necessarily those engaging in more substantive decarbonization efforts.

The generally low level of substantive actions observed in this study is consistent with various empirical studies suggesting that corporate climate actions tend to be more symbolic than substantive. More notable is the weak correlation between substantive actions and mitigation outcomes, which highlights the caveat of using mitigation outcomes as a proxy for the effectiveness or substantiveness of corporate climate actions. This finding highlights the importance of recognizing the unintended driving factors external to decarbonization efforts, as they could obscure symbolic actions and enable business-as-usual operations to persist under seemingly positive mitigation outcomes.

The outcome attribution framework developed in this study offers a novel approach for future researchers and decision-makers to measure substantive

decarbonization actions and distinguish them from symbolic legitimization. By leveraging commonly disclosed metrics without requiring textual analysis or interpretation, this approach is easy to integrate into existing decision-making frameworks. It is consistent in aggregation, scalable, and comparable across firms or sectors, thereby enhancing the decision-usefulness of current metrics without requiring changes to how firms currently disclose. Through engaging change analysis underutilized in corporate assessment and synthesizing various research on corporate carbon mitigation, this study establishes a foundation for future researchers and decision-makers to enhance the evaluation of corporate climate mitigation efforts. The framework can be further refined and tailored to specific industries or firm characteristics as more data points become available. Measuring and comparing substantive corporate decarbonization actions will provide clarity on the effectiveness of corporate initiatives, ultimately guiding resources toward meaningful climate actions and advancing best practices.

6.2 Limitations and Future Research

It is important to acknowledge the limitations of this study and explore potential directions for future research. First, the reliability of the secondary data used in this study depends on the accuracy of corporate reporting and Bloomberg's data-scraping algorithm. While Bloomberg is a trusted and reputable data provider, and steps were taken to review and address extreme values for confirmation, update, or elimination, time and resource constraints prevented the verification of all data points. Additionally, the accuracy of the data is affected by corporate self-reporting biases, a well-known challenge in firm-level environmental data (Coen et al., 2022; Marquis et al., 2016; Talbot & Boiral, 2018). While some firms in the sample acquired external assurance for their reports, such assurance is not yet mandatory for HKEx-listed firms.

The second limitation is the exclusion of Scope 3 emissions, which in some sectors, such as finance, could constitute a significant portion of total emissions. This exclusion was necessary due to the limited data availability, as Scope 3 emissions are not a mandatory reporting metric (HKEX, 2018). Although the sum of Scope 1 and Scope 2 emissions is widely used in studies to evaluate corporate carbon performance (e.g. Busch & Hoffmann, 2011; Lewandowski, 2017; Misani & Pogutz, 2015; Trumpp &

Guenther, 2017) and is considered sufficient, as it encompasses the key corporate operational changes needed for decarbonization (Misani & Pogutz, 2015).

Third, this study has a temporal limitation. The study period was chosen based on the timing of HKEx's reporting mandate, with a majority of report issuers beginning to disclose environmental indicators from March 2018 onward (HKEX, 2018; Yip & Yu, 2023). The sample period was selected from 2018 to 2023 for maximized data availability, although much of this timeframe also coincides with the COVID-19 pandemic. While the shutdown of economic activities due to the pandemic led to temporary declines in global carbon emissions, recent research shows that firms' environmental performance was adversely impacted by economic disruptions and tighter financial constraints (Guérin & Suntheim, 2021), with many firms prioritizing economic and social concerns over environmental ones during this time (Lozano & Barreiro-Gen, 2021). Future studies could explore whether and how the pandemic influenced the drivers of emission reductions and the levels of substantive efforts with additional years of data as they become available.

An interesting area for future research would be to compare the drivers and substantive efforts between mandatory and voluntary reporting schemes, given that this study's population of interest (HKEx-listed firms) is under a mandatory reporting scheme. Some scholars have argued that mandatory reporting schemes tend to foster symbolic responses and superficial actions, as corporations may lack genuine motivations (Hyatt & Berente, 2017; Talbot & Boiral, 2018). Conversely, others have suggested that mandatory reporting reduces opportunities for impression management and is less prone to selective disclosure (Bauckloh et al., 2023; Marquis et al., 2016). Investigating the drivers and extent of substantive efforts across these two reporting schemes could provide new insights into this ongoing debate.

Moreover, the decomposition model and outcome attribution framework proposed in this research could be refined as more data becomes available. For example, incorporating additional data points such as Scope 3 emissions and a detailed breakdown of renewable energy could provide further insights. As Ruiz Manuel & Blok (2023) have suggested, how renewable energy is sourced may influence the effectiveness and substantiveness of mitigation efforts. The model could also be fine-

tuned and tailored to individual sectors, as several studies have underscored the importance of sector-specific characteristics when devising carbon mitigation strategies (Berger-Schmitz et al., 2023; Pinkse et al., 2024; Simon & Guilding, 2017). For example, carbon removals could be considered substantive actions for hard-to-abate sectors (Pinkse et al., 2024), while including Scope 3 emissions for the financial sector would help avoid overstating the extent of substantive actions.

7. References

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