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**EXPLORING CORPORATE GOVERNANCE'S ROLE IN CLIMATE RISK USING
ARTIFICIAL INTELLIGENCE AND BIBLIOMETRIC TECHNIQUES**

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Department of Management and Business Administration

Settore Scientifico Disciplinare ECON-06/A Economia Aziendale
**Scientific Disciplinary Sector ECON-06/A Business Administration, Accounting &
Performance Measurement**

Dottorando / Doctoral Student
Damian Honey

Coordinatore / Coordinator
Prof. Federica Ceci

Supervisore / Supervisor
Prof. Stefania Migliori

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**EXPLORING CORPORATE GOVERNANCE'S ROLE IN CLIMATE RISK USING
ARTIFICIAL INTELLIGENCE AND BIBLIOMETRIC TECHNIQUES**

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DAMIAN HONEY

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Damian Honey

Exploring corporate governance's role in climate risk using artificial intelligence and bibliometric techniques

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"Give thanks to the Lord, for he is good. His love endures forever."

Psalm 136:1

This dissertation is dedicated to my beloved parents:

Anthony Dominic

(gone but forever in my heart)

and

Magdline Roshi

*for their countless sacrifices, and the values they instilled in me. Thank you for everything – I
hope this accomplishment makes you proud.*

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ABSTRACT

This thesis explores the pivotal role of corporate governance in managing climate risk while aligning with Sustainable Development Goal 13: Climate Action. Additionally, it examines the topic from the perspective of innovation. Using advanced methodologies such as text mining, natural language processing, and bibliometric techniques, the study provides novel insights into governance mechanisms. The research is structured into three chapters, applying agency theory and panel data regression analysis. Chapter 1 introduces a unique corporate climate risk disclosure (CCRD) score derived from manually collected annual reports of French SBF-120 firms (2012–2022). Leveraging an index-based corporate governance quality (CGQ) measure, it evaluates the impact of CGQ and governance committees on CCRD, with significant findings post-2017 TCFD recommendations. Chapter 2 focuses on climate risk, specifically physical and transition risks, employing ClimateBERT to analyze S&P 500 firms' 10-K filings (2017–2022). The findings indicate that audit committee (AC) characteristics—independence, gender diversity, and expertise—effectively mitigate climate risks. Chapter 3 conducts a bibliometric analysis of 119 peer-reviewed articles (2013–2022) revealing publication trends, thematic structures, and emerging research avenues in governance and innovation, such as board of directors and environmental innovation. This thesis highlights the critical role of CGQ and AC characteristics in reducing agency conflicts and enhancing climate risk management. Additionally, it underscores the untapped potential of board interlocks, ambidexterity, and sustainability in fostering innovation. By offering actionable insights for policymakers, organizations, and researchers, this study contributes to theoretical frameworks and practical applications in sustainability governance.

Keywords: *Corporate governance quality, Board of directors, Audit committee characteristics, Governance committee, Climate risk disclosure, Physical risk, Transition risk, Innovation, Bibliometric analysis, BERT*

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence	GMM	Generalised Method of Moments
AC	Audit Committee	GRI	Global Reporting Initiative
AC_EXP	Audit Committee Expertise	ISS	Institutional Shareholder Services
AC_GEN	Audit Committee Gender Diversity	LVG	Leverage
AC_IND	Audit Committee Independence	LQD	Liquidity
AC_TEN	Audit Committee Tenure	LSEG	London Stock Exchange Group
BERT	Bidirectional Encoder Representations from Transformers	OECD	Organisation for Economic Co-operation and Development
BGD	Board Gender Diversity	NLP	Natural Language Processing
IND	Board Independence	Obs.	Observations
BOD	Board of Directors	OLS	Ordinary Least Squares
BSZ	Board Size	MENA	Middle East/North Africa
CDP	Carbon Disclosure Project	ROA	Return on Assets
DUAL	CEO Duality	SEC	Securities and Exchange Commission
CEO	Chief Executive Officer	SBF	Société des Bourses Françaises
CCRD	Corporate Climate Risk Disclosure	S&P	Standard and Poor's
CG	Corporate Governance	SD	Standard Deviation
CG_COM	Corporate Governance Committee	SDG	Sustainable Development Goal
CGQ	Corporate Governance Quality	TBQ	Tobin's Q
CSR	Corporate Social Responsibility	G20	The Group of Twenty
EDGAR	Electronic Data Gathering, Analysis, and Retrieval	TCFD	Task Force on Climate-related Financial Disclosures
ESG	Environmental, Social and Governance	2SLS	Two Stage Least Squares
FSB	Financial Stability Board	UN	United Nations
FTSE	Financial Times Stock Exchange	US	United States
FG	Firm Growth	USA	United States of America
FP	Firm Performance	VIF	Variance Inflation Factor
FSZ	Firm Size	VOS	Visualization of Similarities

1. INTRODUCTION

1.1. Research Background

Corporate governance is a foundational concept that defines the systems, structures, and processes through which organizations are directed and controlled (Cadbury, 1992). Corporate governance encompasses various components, such as the roles of the board of directors, audit committees, governance committee and other governance structures (Jan and Sangmi, 2016), all of which ensure that companies meet their obligations to shareholders, stakeholders, and the wider society (Luca *et al.*, 2024). The governance quality shapes the organizational culture and values, influencing not only financial outcomes but also a company's social and environmental responsibility. As organizations face growing pressures to address climate change, the role of corporate governance has expanded beyond the traditional financial objectives to include broader environmental concerns, most notably those related to climate risk (Elkington, 2006).

Climate change represents a significant and pervasive challenge that demands urgent and coordinated global action. It affects both business operations and society, with far-reaching economic, environmental, and social implications. SDG 13, "Climate Action," calls for urgent action to combat climate change and its impacts. Governance, therefore, must not only focus on profitability but also on fostering sustainability and ensuring that firms are resilient to the risks posed by climate change (Shrivastava and Addas, 2014). This thesis explores the role of corporate governance in managing climate risks and fostering innovation, particularly in the context of AI and bibliometric techniques. It addresses how governance structures—specifically, the role of

governance quality, the board of directors and audit committees—can influence climate risk and innovation, particularly in light of growing concerns about environmental sustainability.

The relationship between corporate governance and innovation, particularly in the context of environmental innovation, has become increasingly evident. Governance mechanisms, such as board composition, the establishment of committees, and agency relationships, play critical roles in driving innovation. Agency theory, which deals with the conflicts that arise from the separation of ownership and control in a company (Jensen and Meckling, 1976; Fama, 1980), is particularly relevant in understanding the role of corporate governance in addressing these issues. According to agency theory (Fama and Jensen, 1983), governance mechanisms such as the independence of boards and committees help align the interests of managers with those of shareholders, minimizing the risks of opportunistic behavior and ensuring that long-term sustainability goals are pursued. In the context of climate risk, agency theory underscores the importance of independent and diverse boards in mitigating opportunistic behavior (Finegold, Benson and Hecht, 2007) and aligning corporate strategies with long-term sustainability goals. For example, independent directors bring diverse perspectives and reduce the influence of entrenched management, and robust climate risk management (Galbreath, 2010). By integrating agency theory, this thesis explores how governance mechanisms address the challenges of climate risk, providing a theoretical foundation for the empirical analyses.

The quality of governance within an organization is influenced by various factors, including the board structure, compensation, shareholders' rights and audit and risk oversight of the board of directors (Al-Gamrh *et al.*, 2020). Effective boards, characterized by diversity, independence, expertise and tenure, are better equipped to oversee strategic decisions related to

climate risk and innovation. The composition of the board—whether it includes a mix of independent directors, specialists, and individuals with expertise in environmental sustainability—directly impacts the company’s ability to respond to climate-related challenges (Kouloukoui *et al.*, 2020). Specific committees within the board, such as the governance committee and audit committee, play pivotal roles in overseeing these issues. These committees are responsible for ensuring transparency and accountability in reporting (Peters and Romi, 2012), particularly in the area of climate risk disclosures. The governance committee is responsible for ensuring that the organization’s governance structure is robust, providing oversight on matters such as board effectiveness, climate risk, and strategic direction. Similarly, the audit committee ensures that financial and non-financial information, including climate-related disclosures, are accurate and transparent (Pucheta-Martínez, Gallego-Álvarez and Bel-Oms, 2021). This growing emphasis on the role of committees is vital for companies seeking to enhance their ESG practices and meet global sustainability goals.

Climate risk is broadly classified into two categories: physical risks and transition risks. Physical risks arise from the physical impacts of climate change, such as extreme weather events, rising sea levels, and resource scarcity, which can disrupt business operations and supply chains (Ben-Amar, Herrera and Martinez, 2023; Du, Tsang and Wang, 2024). Transition risks, on the other hand, are associated with the shift toward a low-carbon economy, driven by regulatory changes, technological innovations, and shifts in consumer preferences (Kolber *et al.*, 2024). These include changes in market dynamics, technological advancements, and policy reforms aimed at reducing greenhouse gas emissions (Ben-Amar, Herrera and Martinez, 2023). Effective governance structures are essential for managing these risks, ensuring that organizations adopt proactive strategies for emissions reduction and climate adaptation. This thesis investigates how

governance quality influences climate risk disclosures and the extent to which audit and governance committees contribute to effective risk management.

1.2. Research Significance

The primary objective of this thesis is to explore the role of corporate governance in managing climate risks and to find a future direction in terms of innovation through AI and bibliometric techniques. Specifically, the research aims to investigate how corporate governance influences climate risk and the mechanisms driving this relationship, analyze the evolution of literature on corporate governance and innovation while identifying emerging trends, and leverage AI tools to effectively quantify and assess climate risk. This thesis contributes to the literature by providing a comprehensive analysis of how corporate governance best practices can influence corporate behavior related to climate change. By integrating bibliometric methods, the research presents an innovative approach to understanding the dynamics of the board of directors and innovation, offering valuable insights for policymakers, businesses, and researchers. Previous research has underscored the critical role of corporate governance in addressing environmental challenges, including climate risk. Studies indicate that firms with robust governance structures are more likely to engage in climate risk disclosures and adopt sustainable practices (Shrivastava and Addas, 2014). However, significant gaps remain in the literature concerning the application of advanced techniques, such as AI and bibliometric analysis, to investigate the interplay between governance, climate risk, and innovation.

Regarding corporate governance and CCRD, previous studies have explored this relationship from various perspectives. First, most research has focused on individual corporate governance attributes rather than overall governance quality (Ahmadi, Nakaa and Bouri, 2018;

Orazalin and Mahmood, 2021; Altunbas *et al.*, 2022; Shahab *et al.*, 2022). Second, CCRD has been analyzed in the context of voluntary disclosures, sustainability disclosures, CSR disclosures, and environmental disclosures. Despite these efforts, a comprehensive overview of corporate governance's influence on climate risk disclosure is still lacking (Bui, Houque and Zaman, 2020; Konadu *et al.*, 2022; Ahsan *et al.*, 2024). Similarly, ACs have been extensively studied in relation to corporate responsibility and sustainability reporting. Research has examined the impact of ACs on voluntary disclosures (Klein, 2002; Karamanou and Vafeas, 2005; Vafeas, 2005; Gan *et al.*, 2013) and the quality of financial and non-financial reporting (Pucheta-Martínez and De Fuentes, 2007; Al-Shaer, Salama and Toms, 2017; Appuhami and Tashakor, 2017; Boiral, Heras-Saizarbitoria and Brotherton, 2019; Clarkson *et al.*, 2019; Buallay and Al-Ajmi, 2020). These studies highlight the critical role of ACs in monitoring and enhancing reporting quality (Bronson *et al.*, 2009; Akhtaruddin and Haron, 2010). Furthermore, AC characteristics have been linked to sustainability reporting in the UK (Al-Shaer and Zaman, 2018) and ESG disclosures in Spain, where gender diversity within ACs has been found to positively influence ESG disclosures (Bravo and Reguera-Alvarado, 2019). While several studies have linked ACs to voluntary and non-financial disclosures related to climate risk, the specific focus on physical and transition risks is missing. Also, the board of directors play a vital role in corporate governance. However, most studies have focused on isolated aspects, such as board size, duality, or narrowly defined variables. Based on the premise that the board of directors significantly influences innovation, there is a need to explore interrelated concepts in this area.

Adding to the existing discourse, this thesis (chapter 1) introduces a novel perspective by examining climate-related risk disclosures in annual reports through the lens of corporate governance quality. In alignment with the recommendations of the TCFD, an index for measuring

CCRD is developed using text mining techniques. This approach bridges the gap in the literature by providing a more standardized and detailed assessment of climate risk disclosures. While prior studies have linked ACs to voluntary and non-financial disclosures related to climate risk, this thesis (chapter 2) specifically focuses on physical and transition risks, offering clearer and more actionable measures of climate risk. Additionally, this thesis (chapter 3) explores the evolving body of literature on the board of directors and innovation, conducting a bibliometric analysis to identify critical developments and future research directions. Through this integrated approach, the study aims to enhance the understanding of corporate governance's role in addressing climate risk and fostering innovation.

1.3. Structure of thesis

The remainder of this thesis is structured as follows. The next section presents Chapter 1, which explores the impact of governance quality on corporate climate risk disclosures, emphasizing the role of governance committees. Chapter 2 examines the influence of audit committee characteristics on climate risk, utilizing AI techniques such as ClimateBERT for data analysis. Chapter 3 conducts a bibliometric analysis of the board of directors and innovation, identifying emerging trends and future research avenues. Finally, the concluding section summarizes the findings of this thesis, followed by the references.

2. CHAPTER 1 - THE IMPACT OF GOVERNANCE QUALITY ON CORPORATE CLIMATE RISK DISCLOSURE: THE ROLE OF THE GOVERNANCE COMMITTEE

In this chapter, the impact of corporate governance quality on corporate climate risk disclosures in annual reports is examined. Additionally, the analysis is extended to explore how the presence of a governance committee influences this relationship, either enhancing or weakening it. Since the CCRD framework is based on TCFD guidelines, the sample is divided into periods before and after the release of the final TCFD recommendations. Through rigorous analysis, interesting findings emerge, offering valuable contributions to the literature.

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- 10th Anniversary Conference of the European Journal of Islamic Finance on 2-3 October 2024 in Turin, Italy.
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2.1. Introduction

Corporate environmental reporting emerged in the early 1980s, and it has since become an important research domain, with urgent calls now being made for the increased disclosure of sustainability information (Demaria and Rigot, 2021). High-profile corporate scandals such as Enron (Clarke, 2005) and various stock market downturns have resulted in an increase in societal

expectations regarding companies' ethical, social, and environmental responsibilities (Money and Schepers, 2007). In response to this, a growing global contingent of regulators is scrutinizing corporate governance frameworks to align business practices with environmental disclosures (Chan et al., 2014). Furthermore, the importance of tackling climate issues has prompted certain companies to communicate their environmental commitments independently of any formal requirement to do so (Aragón-Correa et al., 2016). If there is no compulsory obligation to release a CCRD, environmental and climate risk data may be subject to managerial window dressing in annual reports. The interplay between corporate governance and climate commitments has increased demand for the transparent and consistent disclosure of climate-related matters, driving firms to disclose climate-related information meticulously (Ahsan et al., 2024, Nadeem, 2020).

Intending to encourage the voluntary disclosure of climate change-related impacts, the Financial Stability Board (FSB) launched the Task Force on Climate-related Financial Disclosures (TCFD); it was tasked with developing consistent standards for disclosing corporate climate risks (TCFD, 2017). This was done to foster transparency and reduce the information gaps that obstruct understanding of the financial implications of climate risks (Demaria and Rigot, 2021). Established in 2015, the TCFD introduced comprehensive voluntary disclosure categories aligned with existing climate and environmental frameworks such as the Carbon Disclosure Project (CDP), Carbon Disclosure Standards Board, Global Reporting Initiative (GRI), G20/OECD Principles of Corporate Governance, and International Integrated Reporting Framework. These recommendations complement existing reporting practices, ensuring the provision of transparent climate information and improving financial transparency through market discipline mechanisms (Ding et al., 2023).

Integrated reporting has been strengthened across Europe and beyond, specifically in terms of corporate climate issues (Qureshi et al., 2020, Bin-Feng et al., 2022). French firms, in compliance with regulations such as the New Economic Regulations and Grenelle II, have been actively disclosing social, economic, and environmental data for over a decade. Directive 2014/95/EU, which was transposed into French law in 2017, mandates big companies to disclose social and environmental information in their annual reports. This national regulation is in accordance with European Union directives (Hichri, 2022) and evidences the integration of climate risk in reporting. French companies with cross-border operations are adept at following the GRI or ISO 26000 to organize their disclosures of nonfinancial information in a way that integrates corporate climate risk (Albertini, 2019). This integration provides evidence of France's efficient approach to energy transition, which is supported by stringent environmental laws. The increasing focus of recent studies on climate-related aspects signals the growing importance of these issues, among which is corporate climate risk (Nadeem, 2020, Ahsan et al., 2024, Demaria and Rigot, 2021, Elleuch Lahyani, 2022).

Regarding corporate governance and CCRD, previous studies have assessed this relationship from different perspectives. Firstly, most extant studies have examined the association using individual corporate governance attributes rather than overall governance quality (Altunbas et al., 2022, Shahab et al., 2022, Orazalin and Mahmood, 2021, Ahmadi et al., 2018). Secondly, CCRD has been studied from the perspective of voluntary disclosures, sustainability disclosures, CSR disclosures, and environmental disclosures; crucially, a comprehensive overview of corporate governance's influence on the disclosure of climate risk remains lacking (Ahsan et al., 2024, Bui et al., 2020, Konadu et al., 2022). Adding to this discourse, our study introduces a novel perspective that identifies climate-related risk disclosures in annual reports. Following the TCFD's

recommendations, we develop an index measuring CCRD using text mining. We also use an alternate measure to estimate CCRD (*CCRD_Alt*) using the term frequency-inverse document frequency following Engle et al. (2020). Our results hold when using this alternative measure, and we attribute this to the fact that our CCRD score is a precise measure due to its reliance on standardized mandatory reporting. To the best of our knowledge, this is the first study to examine corporate CCRD while employing a comprehensive index of corporate governance quality (CGQ) rather than individual governance attributes. This study aims to explore the effect of CGQ on CCRD before going on to explore the role played by the corporate governance committee (*CG_COM*) in managing corporate CCRD.

To achieve the aim of this study, we manually gather the financial reports of French SBF-120 firms over the period 2012 to 2022 and introduce a novel keyword-matching scoring approach utilizing machine learning and text-mining techniques to compute CCRD. We employ a stratified analysis based on the final TCFD report, issued in 2017, recognizing the climate-related risk information (Bingler et al., 2022). Our study adds to the CCRD and governance quality literature in manifold ways. *First*, we extend the corporate governance literature by exploring the effect of CGQ on CCRD. We observe a direct association between CGQ and CCRD, suggesting that higher governance quality increases the climate-related risk disclosures of French firms. This finding indicates that better CGQ reduces agency conflicts, aligns stakeholders' and managers' interests, and enhances the climate disclosures of French corporates. *Second*, we document that the existence of a governance committee enhances the influence of CGQ on CCRD, thereby contributing to the board committee literature. The existence of a governance committee enhances the governance quality of firms and consequently promotes CCRD. *Third*, we broaden the limited literature on CCRD, and our findings provide managers and policymakers with a more nuanced understanding

of the role of governance quality, which may enable them to manage the ever-increasing importance of CCRD. These results are robust to alternate regression techniques and different proxies of governance quality and CCRD.

The rest of the paper is organized as follows. Section 2 develops hypotheses grounded in a comprehensive review of corporate governance-related literature. Section 3 describes the data and methodologies used to measure CCRD and investigate the hypotheses. Section 4 provides the empirical results. This is followed by the conclusion, implications, and limitations in Section 5.

2.2. Literature review and hypotheses development

The impact of climate change ranks among the most serious environmental challenges faced by countries worldwide in recent decades (Albitar et al., 2023). This issue is recognized globally as an urgent concern, as reflected in the United Nations' 13th Sustainable Development Goal titled "Climate Action,"¹ which emphasizes the need for a decisive response to climate change and its consequences. According to the United Nations, rising sea levels and the increase in extreme weather events, coupled with the rise in greenhouse gas emissions, necessitate urgent action to be taken to fulfill the commitments outlined in the Paris Agreement on climate change (Schleussner et al., 2022). The TCFD, established in 2015, has played a significant role in emphasizing the importance of disclosing climate-related financial risks and opportunities (TCFD, 2017). Empirical studies also confirm that having a comprehensive understanding of exposure to corporate climate-related risks is vital. Consequently, the disclosure of climate risks via a single and coordinated corporate risk management approach implemented in every company is expected by stakeholders (Weinhofer and Busch, 2013). Moreover, acknowledging the concept of climate

¹ <https://www.globalgoals.org/goals/13-climate-action/>

change within their business operations and incorporating the TCFD into their disclosure mechanisms enables companies to conduct assessments of the risks and ramifications associated with climate change (Ding et al., 2023, TCFD, 2017). When it comes to disclosing climate risk and monitoring the company's strategy, the top management complements the critical contribution of the board of directors and management (Albitar et al., 2023, Tao and Hutchinson, 2013, Bui et al., 2020).

Previous empirical studies investigating the impact of CGQ/board characteristics on voluntary disclosures have reported mixed findings. Ho and Wong (2001) observed that the existence of an audit committee (with a percentage of family members on the board) is positively (negatively) associated with voluntary disclosure for firms listed in Hong Kong. Donnelly and Mulcahy (2008) indicated that the number of non-executive directors is positively related to corporate voluntary disclosure in the Irish market. Chan et al. (2014) found that firms with better corporate governance ratings provide more CSR information, while Gerged (2021) observed positive associations of board size, board independence, and CEO duality, and negative associations of managerial and institutional ownership, with corporate environmental disclosure in Jordan. Michelin and Parbonetti (2012) recommended focusing on the specific attributes of each director to explain the impact of board composition on sustainability disclosure, and Van der Laan Smith et al. (2005) suggested that country of origin should be considered as an important determinant of CSR disclosure.

CGQ depends upon different corporate governance mechanisms, such as board structure, executive compensation, shareholder rights, and audit quality (Al-Gamrh et al., 2020, Lei and Song, 2012, Fahlenbrach, 2009). *Board structure* is considered one of the most important determinants of corporate governance; therefore, most of the earlier empirical studies investigated

the impact of board structure on various corporate disclosures (Donnelly and Mulcahy, 2008, Gerged, 2021, Ho and Wong, 2001). Utilizing agency and resource-based theories, Moumen et al. (2016) argued that an appropriate board structure improves governance quality by reducing agency conflicts and enhancing corporate resources. While investigating the impact of board characteristics on voluntary corporate disclosure in emerging MENA countries, they suggested that the composition of the board and its size improve the informativeness of corporate risk disclosures. Using a sample of FTSE 350 firms, Jizi (2017) investigated the impact of sustainable development disclosures and indicated that board independence is associated with higher social disclosure. Husted and de Sousa-Filho (2019) investigated the impact of board structure on corporate environmental, social, and governance (ESG) disclosures in Latin America. They found positive associations of board independence and board size with ESG disclosure and negative associations of CEO diversity and gender diversity with ESG disclosure.

Executive compensation - another important attribute of corporate governance - has also been studied from various perspectives, as it is considered one of the ways of aligning shareholders' and managers' interests by addressing agency problems (Fahlenbrach, 2009). Using an international dataset, Luo et al. (2021) observed an increase in corporate carbon disclosure and transparency when CEO compensation is aligned with stakeholders' interests. Similarly, using a sample of Indian-listed firms, Kumar (2024) studied the impact of executive compensation on voluntary disclosure and found that higher executive compensation significantly improves voluntary disclosure by reducing information asymmetry.

Moreover, shareholders have inherent entitlements, such as the right to engage with and cast votes during the company's general shareholder assemblies, as well as in the process of selecting managing directors (Armour, 2020). Empirical studies have investigated the impact of

shareholder rights through the lens of agency theory, hypothesizing that strong shareholder rights reduce agency conflicts and enhance the efficacy of corporate governance mechanisms (Jiraporn and Gleason, 2007, Jiraporn et al., 2005). For example, Jiraporn et al. (2006) observed that firms with weaker shareholder rights are more diversified, as managers of such firms exploit the situation and diversify firms carelessly, thereby increasing agency problems. Jiang and Anandarajan (2009) investigated the influence of shareholder rights on earnings quality and found that greater shareholder rights increase corporate earnings quality by enhancing corporate governance. Treepongkaruna et al. (2022) observed that shareholders' litigation rights reduce corporate ESG controversies and enhance firm value. In summary, strong shareholder rights function as a tool with which to mitigate agency conflicts and improve the effectiveness of corporate governance; they may also enhance corporate disclosure (Flammer et al., 2021, Treepongkaruna et al., 2022).

Audit quality, which is another important component of corporate governance, has been found to be positively related to corporate governance effectiveness based on the empirical findings (Beisland et al., 2015, Lin and Hwang, 2010, Jiraporn and Gleason, 2007, Jiraporn et al., 2005, Konadu et al., 2022). Empirical evidence indicates that auditors possess a comprehensive understanding of the risks associated with their client's financial and environmental activities. This understanding enables them to respond to heightened ESG-related financial reporting risk with augmented audit effort (Burke et al., 2019, Asante-Appiah and Lambert, 2023).

Summarizing the literature highlighted above, it is evident that an ideal mix of board structure, ESG-linked compensation, shareholder rights, and audit quality boosts the effectiveness of corporate governance by mitigating agency conflicts and allying shareholders' and managers' interests (Beisland et al., 2015, Lin and Hwang, 2010, Jiraporn and Gleason, 2007, Jiraporn et al., 2005, Konadu et al., 2022). In this study, we use a corporate governance index to measure CGQ

based on four comprehensive dimensions, i.e., board structure, compensation, shareholder rights, and audit quality. We propose that enhanced corporate governance can improve CCRD by addressing agency conflicts and improving understanding of the corporate climate risks faced by French firms. Accordingly, we develop our first hypothesis as follows:

H1: Higher CGQ enhances corporate CCRD.

The board of directors bears the responsibility for devising and executing corporate strategy; they do this with the help of board committees, which serve as essential guardians of sound corporate governance mechanisms, as highlighted by Giannarakis et al. (2020). Given the importance of social and environmental concerns, it is important to establish dedicated board committees for this reason (Gerged et al., 2022, Gull et al., 2023). Regarding CCRD, such committees play an important role in systematically planning, implementing, and assessing sustainability policies and initiatives (Liao et al., 2015). They function as a vital conduit between the board and stakeholders, addressing environmental issues and overseeing the company's commitment to climate responsibility. There is scarce literature on corporate governance committees, with a particular lack in the areas of sustainability performance and disclosures.

Despite the relative lack of research in this area, some recent studies have shared vital insights regarding the impact of board committees. For example, Gerged et al. (2022) showed that the presence of environmental committees bolsters the impact of gender-diverse boards on corporate environmental disclosure in sub-Saharan countries. Using data from 41 countries, Gull et al. (2023) investigated the impact of CSR committees on CSR decoupling and observed that the presence of a CSR committee decreases corporate CSR decoupling. Muhammad and Migliori (2023) found that the presence of a sustainability committee increases the environmental

performance of Italian firms. Conversely, Giannarakis et al. (2020) could not identify the significant impact of the sustainability committee on the environmental disclosures of S&P 500 listed firms. Berrone and Gomez-Mejia (2009) also found no significant impact of environmental committees on the environmental performance of U.S. firms. We argue that the existence of a governance committee may enhance the effectiveness of CGQ in relation to CCRD and develop the following hypothesis:

H2: The presence of a corporate governance committee enhances the impact of CGQ on CCRD.

2.3. Data, variables, and methodology

2.3.1. Data

This study focuses on firms listed in the SBF-120 French index from 2012 to 2022. The strong focus of the French government on climate-related matters, supported by rigorous environmental laws such as the NER Act (2001), the Grenelle II Bill (2010), and the Energy Transition and Green Growth Act (2015), renders France an excellent environment in which to examine the proposed hypotheses (Demaria and Rigot, 2021). The selected time frame aligns with our expectation that SBF-120 firms, being substantial entities, would adopt the climate risk and opportunities guidelines set forth by the TCFD after its final report in June 2017. These guidelines underline the importance of making climate-related financial disclosures in annual reports (TCFD, 2017).

To measure CCRD, text mining techniques are employed on annual reports sourced from company websites, consistent with previous French studies (Demaria and Rigot, 2021, Hichri, 2022). The governance quality data is acquired from the ESG group of the Institutional

Shareholder Services (ISS) group of companies.² We also include firm-level control variables in our regression models, following similar empirical studies (Ahsan et al., 2024, Bin-Feng et al., 2022, Gull et al., 2023). Data for the firm-level control variables is acquired from Refinitiv Eikon. Financial firms and entities without climate change information are excluded from the initial sample, in line with established practices (Hichri, 2022, Albertini, 2019). Finally, data from the three different sources is merged, resulting in a final dataset of 113 firms comprising 1,206 firm-year observations from 2012 to 2022. To ensure accuracy, the continuous variables are winsorized at the 1% and 99% percentiles to manage outliers.

2.3.2. Main variables

Corporate climate risk disclosure

Identical to earlier studies (Demaria and Rigot, 2021, Ding et al., 2023), our approach involves the use of firms' annual reports to assess climate change information; we use these because they are a reliable source and are important for stakeholders. In contrast to Engle et al. (2020), we opt not to include the climate change news index to align our study more closely with the TCFD's recommendations regarding the required disclosures in the annual reports. Engle et al. (2020) used fixed climate change vocabulary developed using authoritative texts published by various governmental and research organizations for textual analysis. However, we argue that the climate risk evidence presented in annual reports indicates the climate risk disclosed by the company following the TCFD's recommendations. Therefore, using annual reports for textual analysis to extract climate risk disclosure is more appropriate (Ding et al., 2023). We also followed Ding et al. (2023) to extract the climate-related information vocabulary as they built their vocabulary in

² <https://www.issgovernance.com>

alignment with the TCFD's recommendations. The CCRD estimation process involves several steps. First, we downloaded the sample annual reports from 2012 to 2022. Second, we manually extracted climate-related information and build a repository of climate-related information disclosed by the firms. Then, we transform this repository into a raw text corpus using Jupiter Notebook for preprocessing. Third, we preprocess the corpus to ensure better organization; this encompasses removing punctuation, stop words, and white spaces and converting text to lowercase before stemming. Fourth, the stemmed corpus is tokenized, generating a list of unigram, bigram, and trigram keywords. Finally, these keywords are enriched with the keywords provided by Ding et al. (2023) to form CCRD vocabulary summarized in Appendix 1. Similarly, each firm-year annual report is preprocessed to compare with CCRD vocabulary, thereby facilitating the computation of CCRD scores for each firm-year. A higher CCRD score represents a higher CCRD.

We use an alternate measure to estimate CCRD (*CCRD_Alt*) to repeat our analyses as a robustness check, using a similar approach to Engle et al. (2020). We used the climate change vocabulary provided by Engle et al. (2020). *CCRD_Alt* is estimated for each firm-year using cosine similarity between the term frequency–inverse document frequency scores of the cleaned climate-related text of each annual report and the climate change vocabulary. A greater *CCRD_Alt* value indicates a higher level of CCRD.

CGQ and governance committee (CG_COM)

CGQ is the key explanatory variable. An index-based measure of CGQ developed by the ESG group of ISS³ is used in this study. The index provided by the ISS-ESG group is grounded on four comprehensive dimensions: 1) board structure, 2) compensation, 3) shareholder rights, and 4) audit

³ <https://www.issgovernance.com/esg/>

and risk oversight. ISS-ESG calculates raw points for each of the four dimensions and then sums these raw points for each firm in each year to get a total score (Al-Gamrh et al., 2024). We classify this score into two quantiles and assign a value of 1 for a high median value of the corporate governance score and 0 otherwise (*CGQ*). We also use the total raw score (*CGQ_SC*) as an alternate proxy for governance quality in our robustness analysis. A higher raw score also represents higher governance quality.

The ISS-ESG group's index was devised to assess CGQ based on four dimensions which encompass a range of best practices in corporate governance. *Board structure* assesses elements such as the composition and commitment of the board, the composition of key committees, board policies, related-party transactions, diversity and inclusion, and any structural controversies. The *compensation* dimension evaluates executive pay structures, focusing on pay-for-performance alignment, nonperformance-based pay, equity compensation, risk mitigation related to equity, compensation of non-executive directors, transparency in communication and disclosures, and termination arrangements. *Shareholder rights* examines the alignment of voting rights with ownership stakes, defenses against takeovers, litigation rights, issues related to meetings and voting, and other shareholder rights. Lastly, the *audit and risk oversight* dimension reviews the independence and quality of external auditors, any controversies related to audits and accounting, the company's policies and practices regarding information security risk and oversight, and additional issues related to the audit process and overall risk oversight. Together, these dimensions provide a holistic assessment of a company's governance practices and promote transparency, accountability, and the protection of shareholder interests.

Corporate governance committee (*CG_COM*) is our categorical variable, taking a value of 1 when a committee is present and 0 otherwise. We introduce it into our analysis to accommodate

the diverse interrelation between CGQ and CRD , contingent on the existence or nonexistence of CG_COM .

2.3.3. Methodology

To investigate the relationship between CGQ and $CCRD$, we develop our baseline regression equation as under:

$$CCRD_{it} = \beta_0 + \beta_1 CGQ_{it} + \beta_2 Cont_{it} + yr_t + ind_i + \varepsilon_{it} \dots\dots\dots (1)$$

where $CCRD_{it}$ is the CCRD of firm i at time t . CGQ_{it} is the governance quality of firm i at time t . $Cont_{it}$ represents nine control variables at the firm level, i.e., firm size (FSZ), leverage (LVG), liquidity (LQD), profitability (ROA), performance (TBQ), board size (BSZ), board independence (IND), board diversity (BGD), and CEO duality ($DUAL$). Yr_t represents time fixed effects, ind_i represents industry fixed effects, and ε_{it} represents standard errors. Table 1 provides details of all the variables.

[Insert Table 1 here]

2.4. Empirical analysis

2.4.1. Descriptive statistics and correlation analysis

The descriptive statistics reflecting the dependent variable, independent variables, and control variables across the complete sample are presented in Table 2. The mean value of 0.552 (0.168) for $CCRD$ ($CCRD_Alt$), with a minimum value of 0.021 (0.034) and a maximum value of 0.750 (0.375), indicates variations in the disclosure of climate risk by the sample French firms listed on the SBF-120 index. The mean value of 5.084 for CGQ , with a standard deviation of 2.617,

indicates variations in the governance quality of the sample French firms. The mean value of 0.462 for *CG_COM* demonstrates that 46.2% of the sample firms have a governance committee.

[Insert Table 2 here]

The correlations between the dependent, independent, and control variables are presented in Table 3. We observe highly significant positive (0.235***) correlations of *CGQ* with *CCRD* as well as with *CCRD_Alt* (0.543***), favoring hypothesis 1. We also observe a highly significant positive (0.283***) correlation between *CG_COM* and *CCRD*, favoring hypothesis 2. Further, the variance inflation factor (VIF) in the last row of Table 3 indicates that our models do not have multicollinearity issues (Baltagi, 2008, Bin-Feng et al., 2022).

[Insert Table 3 here]

2.4.2. Baseline regression results

Table 4 presents the results of the primary regression analysis examining how governance quality (*CGQ*) affects the *CCRD* of the sampled firms (H1). A strongly significant positive (0.041***) relationship is noted between *CGQ* and *CCRD* (Column 1). We rerun the regression analyses for H1 by including the firm-level control variables first (Column 2) and then the firm-level and governance variables (Column 3); we do so to ensure the association between *CGQ* and *CCRD* remains consistent even after including these variables. We observe consistent results in Columns 2 (0.021***) and 3 (0.023***), indicating that better governance quality improves the *CCRD* of the sample French firms, favoring hypothesis 1. Further, given that *CCRD* is constructed using TCFD guidelines and the TCFD provided their final report in 2017, providing detailed guidelines about *CCRD*, we therefore split our sample into two periods, i.e., 2012 to 2017 (before the TCFD guidelines) and 2018 to 2022 (after the TCFD guidelines). The results are presented in Columns 4

and 5, respectively. We observe a weakly significant positive association (0.013*) between *CGQ* and *CCRD* during the pre-guidelines period (2012–2017) which turns highly significantly positive (0.030***) during the post-guidelines period (2018–2022).

These results are congruent with the fact that before the issuance of the final report of the TCFD in 2017, *CCRD* was still in place (TCFD, 2017). However, climate risks were not disclosed in a meticulous fashion due to the absence of clear guidelines. The highly significant positive association during the post-guidelines period confirms the comprehensiveness of the TCFD report, a document that helped French firms disclose climate risk appropriately. This is an interesting finding, as it confirms the importance of the TCFD guidelines published in the task force’s final report in 2017. This finding suggests that French firms seek to legitimize themselves by disclosing climate-related information in line with the TCFD guidelines, thus maintaining their social acceptance; and better governance mechanisms help these firms enhance their *CCRD*. Moreover, the computed results show that lower *CGQ* may decrease *CCRD* due to the governance conflicts that arise as a result of the diverging interests of the principals and agents of the business, in accordance with agency theory (Moumen et al., 2016, Fahlenbrach, 2009).

[Insert Table 4 here]

2.4.3. The role of the governance committee

The results of regression analysis examining hypothesis 2 are presented in Table 5; this analysis investigates the role of the governance committee (*CG_COM*) regarding the impact of *CGQ* on *CCRD*. To test H2, we first apply regression analysis on the complete sample period (2012–2022). We observe a highly significant positive (0.018***) relationship between *CGQ* and *CCRD* for the firms with a governance committee (Column 1) and a moderately significant (0.017**) relationship for the firms without a governance committee (Column 2). These results partially

support H2 and suggest that the presence of a governance committee helps French firms enhance their CCRD. We repeat our analysis for the TCFD pre-guidelines (2012–2017) and post-guidelines (2018–2022) periods. The results for the TCFD pre-guidelines period are presented in Columns 3 and 4 (Table 5). An insignificant positive (0.016) relationship is observed between *CGQ* and *CCRD* in the presence of a governance committee; this turns negative and insignificant (-0.001) in the absence of a governance committee. For the post-guidelines period (2018–2022), we observe moderately significant positive relationships between *CGQ* and *CRD* in the presence (0.023**) and absence (0.028**) of a governance committee.

These results partially support H2 of the study. They suggest that the presence of a governance committee leads to an improvement in the overall governance quality of French firms and consequently a better CCRD. These results support earlier studies that demonstrate board committees' direct impact on enhancing CGQ (Gerged et al., 2022, Gull et al., 2023, Muhammad and Migliori, 2023). However, these results contradict other studies whose findings indicate that board committees play a purely symbolic role (Giannarakis et al., 2020, Berrone and Gomez-Mejia, 2009).

[Insert Table 5 here]

2.4.4. Robustness and endogeneity

To confirm that the results are not sensitive to the measurement proxy of *CRD*, we compute CCRD using an alternate technique (*CCRD_Alt*), i.e., CRD calculated following Engle et al. (2020). This proxy differs from our main variable of interest (*CCRD*), as it is calculated using vocabulary based on the climate change news index. The results are presented in Table 6. We observe a highly significant positive (0.009***) association between *CGQ* and *CCRD_Alt* for the complete sample period, i.e., 2012 to 2022 (Column 1). Furthermore, we observe an insignificant association (-

0.001) between *CGQ* and *CCRD* during the pre-guidelines period (Column 2) which turns into a highly significant positive (0.018***) during the post-guidelines period (Column 3).

We also use an alternate proxy of governance quality (*CGQ_SC*, i.e., the raw score of *CGQ*, suggesting higher quality at higher values and vice versa). The results are presented in Columns 4 to 6 of Table 6. Here, we observe a highly significant positive (0.001***) association between *CGQ_SC* and *CCRD_Alt* from 2012 to 2022 (Column 4), a positive but insignificant (0.000) association from 2012 to 2017 (Column 5), and a highly significant positive (0.002***) from 2018 to 2022 (Column 6), congruent with the main results of the study.

[Insert Table 6 here]

We apply different regression techniques to our baseline equation to reduce the potential endogeneity issues. First, we apply one-year lagged OLS (Column 1 – Table 7) to control for endogeneity due to reverse causality (Siddik et al., 2019) and observe a significant positive (0.003***) association between *L.CGQ_SC* and *CCRD*, in line with the main results of the study (Table 4). Second, we apply 2SLS to further ensure that the results do not suffer from endogeneity due to simultaneity. We use lagged and industry median values of the governance quality score (*CGQ_SC*) as instrumental variables. The results of the second-stage regression in Column 2 (Table 7) indicate a significant positive (0.003***) impact of *CGQ_SC* on *CCRD* (Ahsan et al., 2024, Gull et al., 2023). Finally, we apply GMM system (two-step) regression to further resolve the endogeneity issues (Roodman, 2009) and observe a significant positive (0.002***) association between *CGQ_SC* and *CCRD*, consistent with the main results of the study (Table 4).

[Insert Table 7 here]

2.4.5. Additional analysis

It may be possible that certain industries are more sensitive to climate-related risk; therefore, we divide our sample data into sensitive and nonsensitive industries, as the firms operating in sensitive industries face higher pressure regarding their sustainability performance (Garcia et al., 2017, Ahsan et al., 2022). The results are presented in Table 8. We observe significant positive associations between *CGQ_SC* and *CCRD* for sensitive (0.014**, Column 1) and other industries (0.036***, Column 2). These findings indicate that better CGQ improves CCRD for all firms operating in sensitive as well as other industries. Further, we observe a significant positive (0.042***) association between *CG_COM* and *CCRD* for sensitive industries (Column 1) and a significant negative (-0.052***) association (Column 2) for other industries. This indicates that the presence of a governance committee enhances CCRD for firms operating in sensitive industries, while for firms operating in other industries, the presence of a governance committee negatively impacts CCRD, thus indicating that their presence is symbolic (Berrone and Gomez-Mejia, 2009).

[Insert Table 8 here]

2.5. Conclusion and implications

Corporate climate disclosure has passed the tipping point⁴ and climate-related disclosure requirements are changing rapidly. In 2017, the TCFD set out its series of recommendations to establish a framework for businesses to manage climate risks, and 89 countries globally—including France—support the TCFD. This study explores the impact of CGQ on CCRD and then goes on to explore the role played by the corporate governance committee (*CG_COM*) in managing the CCRD of French SBF-120 listed firms from 2012 to 2022. Emphasizing the urgent

⁴ <https://www.wri.org/insights/tipping-point-for-corporate-climate-disclosure>

action required in response to the 13th Sustainable Development Goal, and given CGQ's critical role in compliance, this study addresses the pressing need for firms to disclose climate change-related events (Demaria and Rigot, 2021). The extant literature has examined the role of CCRD from the perspective of the environment, sustainability, CSR, ESG, and climate change. Furthermore, it has focused on individual corporate governance attributes rather than overall governance quality (Altunbas et al., 2022, Orazalin and Mahmood, 2021, Shahab et al., 2022), giving limited consideration to a comprehensive overview of corporate governance's influence on CCRD. We fill this gap by introducing a novel perspective that examines climate-related disclosures in annual reports using text mining.

Our findings provide strong evidence that CGQ is associated with higher CCRD in French firms. In addition, we document that the presence of a governance committee enhances the impact of CGQ on CCRD. This observation is consistent with earlier research indicating a positive impact of corporate governance attributes on voluntary corporate disclosures (Ho and Wong, 2001, Donnelly and Mulcahy, 2008, Michelon and Parbonetti, 2012). Moreover, our findings align with the prevailing perspective that board committees enhance corporate performance by improving CGQ (Gerged et al., 2022, Gull et al., 2023, Muhammad and Migliori, 2023). These findings align with agency theory by indicating that better CGQ reduces agency conflicts and improves the ability of French corporates to tackle CCRD efficiently.

We contribute to the literature in various ways. First, by following the TCFD's recommendations (TCFD, 2017), we develop an index measuring CCRD using text mining. Second, we use an overall governance quality index based on four comprehensive dimensions, namely 1) board structure, 2) compensation, 3) shareholder rights, and 4) audit and risk oversight. Third, aside from the empirical contributions, we also suggest significant policy implications. That

is, we expand the limited body of research on CCRD, and our results provide managers and policymakers with a nuanced understanding of the role governance quality plays in addressing the growing importance of CCRD.

Our study also has some limitations. For one, our sample is based on companies from the top index on Euronext Paris. This index is mostly comprised of larger firms that generally have more resources to invest in climate projects. Thus, caution is advised when generalizing our findings to smaller companies or those from different countries (Van der Laan Smith et al., 2005). However, this limitation suggests a direction for future research, which could include smaller firms and extend the investigation to different regions.

Tables:

Table 1: Variable definitions

Variable Level	Variable Name	Model Name	Proxy	Source
Dependent	Climate Risk Disclosure	<i>CCRD</i>	Corporate climate risk disclosure, computed using text mining techniques, as explained in Section 3.2.	Self-computed
		<i>CCRD_Alt</i>	An alternate measure of corporate climate risk disclosure, computed using text mining techniques and explained in Section 3.2.	Self-computed
Explanatory	Corporate Governance Quality	<i>CGQ</i>	Dummy equal to 1 for a high median value of the corporate governance score and 0 otherwise. ISS-ESG calculates the score based on four key dimensions, i.e., shareholder rights, compensation, audit and risk oversights, and board structure.	ISS-ESG
	Corporate Governance Quality Score	<i>CGQ_SC</i>	The corporate governance quality score provided by ISS-ESG; a higher score indicates higher governance quality and vice versa.	ISS-ESG
	Corporate Governance Committee	<i>CG_COM</i>	An indicator variable equal to 1 if a board-level corporate governance committee exists and 0 otherwise	Refinitiv Eikon
	Firm Size	<i>FSZ</i>	Firm size is measured by the natural log of total assets	Refinitiv Eikon
Control	Leverage	<i>LVG</i>	Leverage is measured by the total liabilities to total assets ratio	Refinitiv Eikon
	Liquidity	<i>LQD</i>	Ratio of current assets over current liabilities	Refinitiv Eikon
	Return on Assets	<i>ROA</i>	Return on assets is measured by net income to total assets	Refinitiv Eikon
	Tobin's Q	<i>TBQ</i>	Tobin's Q is measured by company market capitalization and total liabilities to total assets	Refinitiv Eikon
	Board Size	<i>BSZ</i>	Total number of directors on the board of directors	Refinitiv Eikon
	Independent Directors	<i>IND</i>	Ratio of independent directors	Refinitiv Eikon
	Board Gender Diversity	<i>BGD</i>	Board gender diversity is measured by the ratio of women on the board	Refinitiv Eikon
	Duality	<i>DUAL</i>	An indicator variable equal to 1 if CEO-chairman duality exists and 0 otherwise	Refinitiv Eikon

Table 2: Descriptive statistics

	Mean	Std. Dev.	Median	Min.	Max.
<i>CCRD</i>	0.552	0.101	0.560	0.021	0.750
<i>CCRD_Alt</i>	0.168	0.057	0.164	0.034	0.375
<i>CGQ</i>	5.084	2.617	5	1	10
<i>CGQ_SC</i>	-6.454	6.086	-5.846	-21.913	6.391
<i>CG_COM</i>	0.462	0.499	0.000	0.000	1.000
<i>FSZ</i>	23.250	1.778	23.197	18.994	28.412
<i>LVG</i>	0.624	0.171	0.611	0.252	1.084
<i>LQD</i>	1.367	0.611	1.259	0.325	3.703
<i>ROA</i>	0.035	0.054	0.034	-0.178	0.248
<i>TBQ</i>	2.328	3.219	1.333	0.629	22.619
<i>BSZ</i>	10.815	5.824	12.000	0.000	26.000
<i>IND</i>	0.443	0.257	0.471	0.000	1.000
<i>BGD</i>	0.306	0.177	0.364	0.000	0.643
<i>DUAL</i>	0.548	0.498	1.000	0.000	1.000

Notes: This table presents the descriptive statistics of the dependent and explanatory variables used in this study. CCRD and CCRD_Alt are the scores of corporate climate risk disclosure; CGQ_SC is the corporate governance quality score based on board structure, compensation, shareholder rights, and audit and risk oversight; CG_COM is the dummy variable representing the presence of a governance committee; FSZ is the natural log of total assets; LVG is the ratio of total liabilities to total assets; LQD is the ratio of current assets over current liabilities; ROA is the ratio of net income to total assets; TBQ is the ratio of company market capitalization and total liabilities to total assets; BSZ is the total number of directors on the board; IND is the ratio of independent directors on the board; BGD is the ratio of women directors on the board; DUAL is a dummy variable equal to 1 if there is CEO–chairman duality and 0 otherwise.

Table 3: Pairwise correlations

Variables	<i>CCRD</i>	<i>CCRD_Alt</i>	<i>CGQ</i>	<i>CGQ_SC</i>	<i>CG_COM</i>	<i>FSZ</i>	<i>LVG</i>	<i>LQD</i>	<i>ROA</i>	<i>TBQ</i>	<i>BSZ</i>	<i>IND</i>	<i>BGD</i>	<i>DUAL</i>
<i>CCRD</i>	1.000													
<i>CCRD_Alt</i>	0.543*** (0.000)	1.000												
<i>CGQ</i>	0.235*** (0.000)	0.157*** (0.000)	1.000											
<i>CGQ_SC</i>	0.305*** (0.000)	0.202*** (0.000)	0.794*** (0.000)	1.000										
<i>CG_COM</i>	0.283*** (0.000)	0.038 (0.188)	0.188*** (0.000)	0.243*** (0.000)	1.000									
<i>FSZ</i>	0.432*** (0.000)	0.142*** (0.000)	0.265*** (0.000)	0.329*** (0.000)	0.493*** (0.000)	1.000								
<i>LVG</i>	0.155*** (0.000)	0.104*** (0.000)	0.178*** (0.000)	0.162*** (0.000)	0.070** (0.016)	0.391*** (0.000)	1.000							
<i>LQD</i>	-0.153*** (0.000)	-0.109*** (0.000)	-0.121*** (0.000)	-0.157*** (0.000)	0.040 (0.176)	-0.344*** (0.000)	-0.516*** (0.000)	1.000						
<i>ROA</i>	-0.121*** (0.000)	-0.089*** (0.002)	-0.135*** (0.000)	-0.103*** (0.000)	-0.065** (0.024)	-0.200*** (0.000)	-0.413*** (0.000)	0.249*** (0.000)	1.000					
<i>TBQ</i>	-0.186*** (0.000)	-0.209*** (0.000)	-0.191*** (0.000)	-0.186*** (0.000)	-0.077*** (0.008)	-0.327*** (0.000)	-0.308*** (0.000)	0.257*** (0.000)	0.456*** (0.000)	1.000				
<i>BSZ</i>	0.410*** (0.000)	0.243*** (0.000)	0.118*** (0.000)	0.191*** (0.000)	0.471*** (0.000)	0.650*** (0.000)	0.168*** (0.000)	-0.083*** (0.005)	-0.114*** (0.000)	-0.240*** (0.000)	1.000			
<i>IND</i>	0.373*** (0.000)	0.133*** (0.000)	0.310*** (0.000)	0.412*** (0.000)	0.411*** (0.000)	0.509*** (0.000)	0.088*** (0.002)	-0.021 (0.486)	-0.089*** (0.002)	-0.222*** (0.000)	0.609*** (0.000)	1.000		
<i>BGD</i>	0.454*** (0.000)	0.300*** (0.000)	0.154*** (0.000)	0.247*** (0.000)	0.335*** (0.000)	0.407*** (0.000)	0.041 (0.158)	-0.002 (0.951)	-0.011 (0.698)	-0.209*** (0.000)	0.659*** (0.000)	0.611*** (0.000)	1.000	
<i>DUAL</i>	0.186*** (0.000)	0.061** (0.035)	-0.015 (0.603)	0.019 (0.507)	0.236*** (0.000)	0.239*** (0.000)	-0.013 (0.655)	-0.021 (0.489)	0.045 (0.120)	-0.114*** (0.000)	0.486*** (0.000)	0.344*** (0.000)	0.403*** (0.000)	1.000
VIF			1.17	1.17	1.41	2.37	1.54	1.56	1.43	1.43	3.07	2.07	2.05	1.41

Notes: This table presents pairwise correlations. *** p<0.01, ** p<0.05, * p<0.10. VIF is the variance inflation factor.

Table 4: The impact of governance quality on corporate climate risk disclosure

	(1)	(2)	(3)	(4)	(5)
	2012–2022	2012–2022	2012–2022	2012–2017	2018–2022
	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>
<i>CGQ</i>	0.041*** (0.005)	0.021*** (0.005)	0.023*** (0.005)	0.013* (0.007)	0.030*** (0.007)
<i>FSZ</i>		0.029*** (0.002)	0.021*** (0.002)	0.020*** (0.003)	0.024*** (0.003)
<i>LVG</i>		0.002 (0.018)	-0.002 (0.018)	-0.070*** (0.025)	0.059** (0.027)
<i>LQD</i>		0.003 (0.005)	-0.002 (0.005)	-0.013** (0.007)	0.012 (0.007)
<i>ROA</i>		-0.112** (0.051)	-0.107** (0.051)	-0.100 (0.072)	-0.096 (0.075)
<i>TBQ</i>		0.002*** (0.001)	0.003*** (0.001)	0.001 (0.001)	0.002 (0.002)
<i>BSZ</i>			0.003*** (0.001)	0.002** (0.001)	0.004*** (0.001)
<i>IND</i>			-0.000 (0.013)	0.004 (0.018)	0.014 (0.020)
<i>BGD</i>			0.023 (0.025)	-0.001 (0.036)	0.079** (0.036)
<i>DUAL</i>			-0.003 (0.006)	0.006 (0.009)	-0.008 (0.007)
Constant	0.487*** (0.027)	-0.147*** (0.048)	0.019 (0.058)	0.151* (0.082)	-0.116 (0.083)
Observations	1,206	1,128	1,128	609	519
Adj. R ²	0.284	0.449	0.462	0.367	0.439
Year	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes

Notes: This table presents the regression analysis results investigating the impact of corporate governance quality on corporate climate risk disclosure. All variables are defined in Table 1. Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 5: The impact of the governance committee on corporate climate risk disclosure

	(1)	(2)	(3)	(4)	(5)	(6)
	2012–2022		2012–2017		2018–2022	
	<i>CG_COM</i> ==1	<i>CG_COM</i> ==0	<i>CG_COM</i> ==1	<i>CG_COM</i> ==0	<i>CG_COM</i> ==1	<i>CG_COM</i> ==0
	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>
<i>CGQ</i>	0.018*** (0.007)	0.017** (0.007)	0.016 (0.010)	-0.001 (0.010)	0.023** (0.009)	0.028** (0.011)
<i>FSZ</i>	0.015*** (0.003)	0.024*** (0.004)	0.007 (0.005)	0.025*** (0.005)	0.018*** (0.004)	0.024*** (0.007)
<i>LVG</i>	-0.014 (0.025)	-0.048* (0.027)	-0.069* (0.036)	-0.120*** (0.036)	0.019 (0.037)	0.046 (0.042)
<i>LQD</i>	0.006 (0.006)	-0.025*** (0.007)	-0.012 (0.009)	-0.036*** (0.010)	0.013 (0.009)	-0.003 (0.012)
<i>ROA</i>	-0.046 (0.065)	-0.003 (0.073)	0.124 (0.110)	-0.065 (0.105)	-0.116 (0.093)	0.137 (0.124)
<i>TBQ</i>	0.002* (0.001)	0.003** (0.001)	0.000 (0.001)	0.003** (0.001)	0.004** (0.002)	-0.005 (0.003)
<i>BSZ</i>	0.005*** (0.001)	0.002 (0.001)	0.005*** (0.002)	0.002 (0.002)	0.004** (0.002)	0.003 (0.002)
<i>IND</i>	0.048** (0.021)	0.009 (0.024)	0.051* (0.031)	0.006 (0.033)	0.046 (0.030)	0.032 (0.036)
<i>BGD</i>	0.084** (0.038)	-0.010 (0.036)	-0.001 (0.054)	-0.048 (0.049)	0.168*** (0.057)	0.014 (0.055)
<i>DUAL</i>	0.011 (0.007)	-0.001 (0.009)	0.022* (0.012)	-0.006 (0.014)	0.004 (0.010)	0.006 (0.013)
Constant	-0.048 (0.081)	0.018 (0.092)	0.230* (0.130)	0.064 (0.119)	-0.141 (0.110)	-0.069 (0.155)
Observations	501	627	253	356	248	271
Adj. R ²	0.536	0.429	0.471	0.347	0.450	0.418
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents regression analysis results investigating the impact of corporate governance quality on corporate climate risk disclosure in the presence of a governance committee. All variables are defined in Table 1.

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 6: The impact of governance quality on corporate climate risk disclosure: Alternate proxies

	(1)	(2)	(3)	(4)	(5)	(6)
	2012–2022	2012–2017	2018–2022	2012–2022	2012–2017	2018–2022
	<i>CCRD_Alt</i>	<i>CCRD_Alt</i>	<i>CCRD_Alt</i>	<i>CCRD_Alt</i>	<i>CCRD_Alt</i>	<i>CCRD_Alt</i>
<i>CGQ</i>	0.009***	-0.001	0.018***			
	(0.003)	(0.004)	(0.005)			
<i>CGQ_SC</i>				0.001***	0.000	0.002***
				(0.000)	(0.000)	(0.000)
<i>FSZ</i>	-0.003*	-0.003	-0.002	-0.003**	-0.003*	-0.003
	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)
<i>LVG</i>	-0.006	-0.007	0.001	-0.006	-0.007	0.006
	(0.012)	(0.014)	(0.019)	(0.011)	(0.014)	(0.018)
<i>LQD</i>	-0.008***	-0.008**	-0.004	-0.007**	-0.008**	-0.003
	(0.003)	(0.004)	(0.005)	(0.003)	(0.004)	(0.005)
<i>ROA</i>	-0.026	-0.071*	0.061	-0.029	-0.073*	0.066
	(0.032)	(0.041)	(0.052)	(0.032)	(0.041)	(0.052)
<i>TBQ</i>	-0.002***	-0.002***	-0.004***	-0.002***	-0.001**	-0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
<i>BSZ</i>	0.003***	0.002***	0.004***	0.003***	0.002***	0.004***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)
<i>IND</i>	-0.022***	-0.001	-0.036**	-0.029***	-0.005	-0.047***
	(0.008)	(0.010)	(0.014)	(0.009)	(0.011)	(0.015)
<i>BGD</i>	-0.023	-0.056***	0.012	-0.023	-0.056***	0.015
	(0.016)	(0.020)	(0.025)	(0.016)	(0.020)	(0.025)
<i>DUAL</i>	-0.004	0.007	-0.009*	-0.004	0.006	-0.009*
	(0.004)	(0.005)	(0.005)	(0.004)	(0.005)	(0.005)
Constant	0.272***	0.297***	0.215***	0.295***	0.306***	0.264***
	(0.036)	(0.047)	(0.058)	(0.037)	(0.047)	(0.059)
Observations	1,117	603	514	1117	603	514
Adj. R ²	0.353	0.232	0.344	0.360	0.233	0.356
Year	Yes	Yes	Yes	Yes	Yes	Yes
Industry	Yes	Yes	Yes	Yes	Yes	Yes

Notes: This table presents regression analysis results investigating the impact of corporate governance quality on corporate climate risk disclosure using alternate proxies. All variables are defined in Table 1.

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 7: The impact of governance quality on corporate climate risk disclosure: Alternate regression techniques

	(1)	(2)	(3)
	Lagged OLS	2SLS	GMM
	<i>CCRD</i>	<i>CCRD</i>	<i>CCRD</i>
<i>L.CCRD</i>			0.514*** (0.013)
<i>L.CGQ_SC</i>	0.003*** (0.000)		
<i>CGQ_SC</i>		0.003*** (0.000)	0.002*** (0.000)
<i>FSZ</i>	0.020*** (0.002)	0.021*** (0.003)	0.008*** (0.002)
<i>LVG</i>	0.017 (0.019)	0.015 (0.018)	0.021* (0.012)
<i>LQD</i>	0.002 (0.005)	0.003 (0.005)	0.003 (0.002)
<i>ROA</i>	-0.097* (0.053)	-0.085 (0.060)	0.005 (0.031)
<i>TBQ</i>	0.003*** (0.001)	0.003*** (0.001)	0.001 (0.001)
<i>BSZ</i>	0.003*** (0.001)	0.003*** (0.001)	0.002*** (0.001)
<i>IND</i>	-0.018 (0.014)	-0.021* (0.012)	-0.004 (0.010)
<i>BGD</i>	0.026 (0.026)	0.017 (0.029)	-0.003 (0.013)
<i>DUAL</i>	-0.004 (0.006)	-0.005 (0.005)	-0.006 (0.004)
Constant	0.064 (0.061)	0.051 (0.059)	0.049 (0.137)
Observations	1,128	1,128	1,128
Hansen		7.484	57.446
Hansen_P		0.023	0.314
AR1			-4.524
AR1_P			0.000
AR2			0.183
AR2_P			0.855
Year	Yes	Yes	Yes
Industry	Yes	Yes	Yes

Notes: This table presents regression analysis results investigating the impact of corporate governance quality on corporate climate risk disclosure using alternate regression techniques. All variables are explained in Table 1.

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

Table 8: The impact of governance quality and governance committees on corporate climate risk disclosure: The role of industry sensitivity

	(1)	(2)
	Sensitive Industries	Other Industries
	<i>CCRD</i>	<i>CCRD</i>
<i>CGQ_SC</i>	0.014** (0.006)	0.036*** (0.012)
<i>CG_COM</i>	0.042*** (0.006)	-0.052*** (0.015)
<i>FSZ</i>	0.017*** (0.003)	0.029*** (0.006)
<i>LVG</i>	-0.014 (0.020)	0.133*** (0.050)
<i>LQD</i>	-0.012** (0.005)	0.037*** (0.014)
<i>ROA</i>	-0.061 (0.054)	-0.041 (0.130)
<i>TBQ</i>	0.001 (0.001)	0.012*** (0.002)
<i>BSZ</i>	0.002** (0.001)	0.004** (0.002)
<i>IND</i>	-0.005 (0.014)	0.010 (0.036)
<i>BGD</i>	0.008 (0.027)	-0.004 (0.069)
<i>DUAL</i>	0.005 (0.006)	-0.007 (0.012)
Constant	0.151** (0.066)	-0.333** (0.147)
Observations	853	275
Adj. R ²	0.483	0.519
Year	Yes	Yes
Industry	Yes	Yes

Notes: This table presents regression analysis results investigating the impact of corporate governance quality and governance on corporate climate risk disclosure for firms operating in sensitive and other industries. All variables are defined in Table 1.

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.10.

3. CHAPTER 2 - HARNESSING CLIMATEBERT TO EXAMINE THE IMPACT OF AUDIT COMMITTEE CHARACTERISTICS ON CLIMATE RISK

In this chapter, a deeper exploration is conducted into the primary research focus—corporate governance and climate risk—by specifically examining a crucial component of corporate governance: the audit committee. The analysis investigates the characteristics of the AC and their impact on climate risk, with particular emphasis on the distinction between physical and transition risks. The findings reveal significant insights with valuable contributions and implications.

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3.1. Introduction

Climate risk disclosures are vital in climate finance and accounting, influencing business practices and raising public awareness in recent years (Bakaki and Bernauer, 2017). This awareness drives firms to communicate their climate-related commitments, even if they are not actively reducing their impact (Aragón-Correa, Marcus and Hurtado-Torres, 2016). Climate risk mainly comprises physical and transition risks: physical risks stem from extreme weather events (Ben-Amar, Herrera and Martinez, 2023; Du, Tsang and Wang, 2024), while transition risks arise from regulatory reforms aimed at creating a low-carbon economy and combating global warming (Kolber *et al.*, 2024). The real challenge lies in two aspects: first, the pricing

of these risks, which are primarily qualitative in nature, and second, the adequate disclosure of these firm-specific risks (Kolber *et al.*, 2024).

Since 2010, the US Securities and Exchange Commission (SEC) has mandated publicly listed firms disclose material climate risk in their annual 10-K filings (*US Security and Exchange Commission*, 2010). However, this requirement falls short of addressing the problem effectively. The SEC's principles-based approach permits firms to self-identify climate-related risks relevant to their business, granting managers significant leeway in deciding what to disclose. As a result, many disclosures in 10-K filings are viewed by investors and capital market participants as vague and unhelpful (Ilhan *et al.*, 2023). Additionally, the lack of consistent materiality in climate risk disclosures and the absence of strict SEC requirements exacerbate the issue. This inconsistency leads to confusion about whether disclosing climate-related risks is truly mandatory or merely voluntary (Matsumura, Prakash and Vera-Muñoz, 2022).

Despite these challenges, annual reports are indispensable for investors to comprehend how managers tackle climate risks (Bingler *et al.*, 2022). Due to the lack of mandatory climate change regulations, ethical business practices and corporate governance are gaining significance for management, especially regarding non-financial disclosure (Chithambo *et al.*, 2021). Stakeholders such as investors, governments, and communities are highly concerned about non-financial disclosures related to physical and transition risks. Audit committees (ACs) are a key component of a robust corporate governance framework, enhancing financial and non-financial reporting quality by boosting a firm's internal control mechanisms. Agency theory contends that these internal controls align shareholder and manager interests (Fama and Jensen, 1983), reducing agency problems and helping firms achieve their monitoring goals through ACs (Safari, 2017).

One of the main functions of ACs is to ensure rigorous oversight that safeguards the interests of investors and other stakeholders (DeZoort *et al.*, 2002). In response to the growing concern over misleading stakeholders, ACs in modern firms are increasingly enhancing their oversight of sustainability disclosures (Al-Shaer and Zaman, 2018; Dwekat *et al.*, 2022; Pozzoli, Pagani and Paolone, 2022). ACs are now expected to thoroughly scrutinize both financial and non-financial information to accurately assess the firm's performance. Specifically, regarding non-financial matters, ACs play a complementary role, extending their monitoring beyond sustainability disclosures to include oversight of climate change risks. The effectiveness of an AC hinges on distinct individual attributes and skills.

Previous research has examined the impact of AC on voluntary disclosure (Klein, 2002; Karamanou and Vafeas, 2005; Vafeas, 2005; Gan *et al.*, 2013) and the quality of financial and non-financial reporting (Pucheta-Martínez and De Fuentes, 2007; Al-Shaer, Salama and Toms, 2017; Appuhami and Tashakor, 2017; Boiral, Heras-Saizarbitoria and Brotherton, 2019; Clarkson *et al.*, 2019; Buallay and Al-Ajmi, 2020). These studies emphasize the AC's critical role in monitoring tasks (Bronson *et al.*, 2009; Akhtaruddin and Haron, 2010). AC characteristics have also been studied in the context of sustainability reporting in the UK (Al-Shaer and Zaman, 2018) and ESG disclosures in Spain, where gender diversity within ACs positively influences ESG disclosures (Bravo and Reguera-Alvarado, 2019). While several studies have linked ACs to voluntary and non-financial disclosures related to climate risk, this study specifically focuses on physical and transition risks, providing clearer measures of climate risk.

Previous research has shown the beneficial impact of ACs on climate-related disclosures through robust corporate governance. This study fills a gap in the literature by empirically examining the influence of AC characteristics on climate risk, specifically distinguishing between AC independence, gender diversity, expertise, and tenure. Based on

agency theory, which helps reduce conflicts of interest and agency problems (Jensen and Meckling, 1976), we predict that these AC characteristics mitigate climate risk by improving environmental reporting (Fama, 1980; Fama and Jensen, 1983) and thereby reducing information asymmetry when communicating climate-related information to shareholders (Ilhan *et al.*, 2023). We focused on these AC attributes for several reasons. For instance, independent directors on ACs are effective monitors within firms (Wang and Sun, 2022). Board gender diversity enhances the flow of quality information among directors (Miller and Del Carmen Triana, 2009; Nielsen and Huse, 2010). AC members with expert knowledge can detect errors in financial statements and management operations (Pozzoli, Pagani and Paolone, 2022), and senior members within the ACs decrease unethical accounting practices (Persons, 2009). These attributes collectively improve the firm's effectiveness in addressing climate risk.

This research examines a sample of S&P 500 non-financial firms from 2017 to 2022, focusing on large US firms due to their significant greenhouse gas emissions and leadership in product innovations and carbon management goals. These firms also face stricter regulations and have diverse shareholders with vested interests. We calculate climate risk using physical and transition risk assessments, employing a powerful natural language processing (*NLP*) technique called *BERT* (Bidirectional Encoder Representations from Transformers). Utilizing *ClimateBERT*, a fine-tuned model by Deng *et al.* (2023), this approach enhances the existing literature on climate risk identification from annual reports and advocates for using *NLP* methods to extract qualitative climate-related information. *BERT*, developed by researchers at Google (Devlin *et al.*, 2019), surpasses other *NLP* methods in identifying climate-related content. Our climate risk score is, therefore, more accurate, leveraging standardized mandatory reporting and the advanced capabilities of the *BERT* algorithm.

Our paper stands out from previous studies in several ways. First, it examines the distinct effects of physical and transition risks as measures of climate risk. Second, it directly

captures this risk from Section 1.A of 10-k filings, a mandatory and critical document of US firms. Third, we use *BERT*, an advanced NLP algorithm that interprets words in context (Deng *et al.*, 2023; Kolber *et al.*, 2024), to calculate physical and transition risks, offering a more accurate measure over other keyword-based methods (Grüning, 2011; Engle *et al.*, 2020; Sautner *et al.*, 2023; Berkman, Jona and Soderstrom, 2024). This measure effectively reflects the extent of climate risk presented in the 10-K report. Additionally, our paper differentiates between physical and transition risks to assess their association with individual AC characteristics.

Our findings align with our conjectures, suggesting that AC independence, gender diversity, and expertise reduce physical and transition risk. This supports agency theory, which posits that ACs mitigate agency problems by providing an effective monitoring mechanism. In contrast, AC tenure is positively related to physical and transition risk. In additional analyses, we tested using an alternative measure of climate risk by replacing physical and transition risk with carbon emissions, which denotes regulatory climate risk. The results remained consistent, indicating that AC characteristics reduce climate risk across different measures, including physical risk, transition risk, and carbon emissions. We also addressed potential endogeneity concerns using alternative econometric model specifications. Our results remained robust, strengthening the validity of our conclusions and indicating that the observed relationships are not biased by causality or omitted variables. Overall, our results suggest that when AC members possess the right mix of independence, diversity, and expertise, they are better equipped to identify and manage risks associated with climate change. These findings are significant as they offer a concrete framework for enhancing AC effectiveness in addressing climate-related challenges.

The contribution of this research is substantial in several ways. First, to the best of our knowledge, we are the first to establish a relationship between AC characteristics and climate

risk, providing a new perspective on how effective governance mechanisms can directly influence climate risk management. Second, the paper is relevant to governance advocates and academics, promoting AC characteristics such as independence, gender diversity, and expertise to ensure well-rounded and balanced decision-making for effective corporate governance. For instance, independence in AC members ensures unbiased oversight (Wang and Sun, 2022), reducing the risk of conflicts of interest (Fama, 1980; Fama and Jensen, 1983b) and enhancing the credibility of climate-related decisions (Mangena and Pike, 2005; Pucheta-Martínez and De Fuentes, 2007). Gender diversity brings a variety of perspectives (Miller and Del Carmen Triana, 2009; Nielsen and Huse, 2010) and problem-solving approaches (Miglaní and Ahmed, 2019), promoting more innovative and comprehensive risk management strategies (Miller and Del Carmen Triana, 2009; Nielsen and Huse, 2010). Expertise, particularly in areas relevant to climate science and environmental policy, equips AC members with the knowledge necessary to understand and address complex climate issues (Helfaya and Moussa, 2017; Al-Shaer and Zaman, 2018). By advocating for these traits, the paper addresses the growing need for diverse and skilled oversight bodies that can navigate the complexities of climate governance.

Third, this paper contributes to SDG 13 by bridging the gap between firms and markets regarding sustainability reporting. Effective sustainability reporting improves transparency and accountability and enables better decision-making by stakeholders who rely on accurate and comprehensive information about a firm's environmental impact. By linking AC characteristics to improved sustainability reporting, we emphasize the importance of strong governance in achieving broader environmental goals.

Finally, our paper adds to the literature on efficient *NLP* techniques to account for climate risk based on 10-K filings. The innovative use of *NLP* methods provides a sophisticated approach to accurately quantifying climate risk, offering valuable insights for firms to better understand and mitigate their environmental impact. Traditional methods of assessing climate

risk data can be time-consuming and prone to human error and complexities (Bingler *et al.*, 2022). By employing *NLP* techniques, our research demonstrates how automated analysis of textual data can enhance the precision and efficiency of climate risk assessment. This advancement benefits individual firms and contributes to developing more reliable and scalable tools for industry-wide climate risk management.

The remainder of this paper is structured as follows: Section 2 presents a literature review and the development of hypotheses related to AC characteristics and climate risk. Section 3 outlines the research methodology, detailing the variables selected and the sample used for empirical analysis. Section 4 shows the results and discussions. Finally, Section 5 provides the conclusion, implications, limitations, and future research directions.

3.2. Literature Review and Hypotheses Development

The committees in the board of directors play a crucial role in managing and advising a firm (Klein, 2002; Ramos *et al.*, 2023), enabling the board to fulfill its responsibilities effectively by delegating tasks across various committees (Koh, Laplante and Tong, 2007). Among these, the audit committee is particularly noteworthy for its growing significance, as emphasized by the Cadbury Report, the Smith Report, and the Sarbanes Oxley Act (Al-Shaer and Zaman, 2018). This study, therefore, seeks to explore the domain of climate risk, with a focus on physical and transition risk, as well as carbon emission, as indicators of climate risk. The scope, intensity, and trends of climate risk disclosures are dissected through the lens of agency theory, especially within the context of voluntary reporting. Agency theory, positing the AC as a vital governance mechanism, provides a framework for understanding the AC's influence on varying levels of climate risk disclosure. Agency theory is pertinent to this study as it elucidates how addressing climate risks can ameliorate conflicts of interest, furnishing shareholders with comprehensive corporate information that spans mandatory and voluntary disclosures related

to climate change. Such efforts are instrumental in bolstering the accountability and transparency of top management. A critical perspective, however, questions whether the current emphasis on voluntary disclosures, including those related to climate risk, suffices in the face of escalating environmental challenges. While the AC is instrumental in enhancing disclosure, a compelling need exists for standardized reporting frameworks to ensure consistency and comparability across organizations. This approach addresses shareholder concerns and aligns with broader societal expectations for sustainable corporate practices. Therefore, enhancing the AC's focus on climate risk could significantly contribute to more informed decision-making by stakeholders and reflect a more profound commitment to environmental stewardship at the corporate level.

Hence, specific characteristics of AC are essential for effectively executing monitoring tasks (Akhtaruddin and Haron, 2010). Research indicates that certain AC characteristics positively impact climate change disclosures. For instance, Al-Shaer and Zaman, (2018) found that the independence of ACs and the frequency of their meetings positively impact the credibility of sustainability reports in the UK. Similarly, Bravo and Reguera-Alvarado, (2019) discovered that gender diversity within ACs positively influences ESG disclosures in Spain. Moreover, independence emerges as a key feature of AC that enhances its ability to supervise and monitor (Bronson *et al.*, 2009). Therefore, AC independence is vital for enhancing financial and non-financial disclosures (Pucheta-Martínez and De Fuentes, 2007; Appuhami and Tashakor, 2017; Boiral, Heras-Saizarbitoria and Brotherton, 2019; Clarkson *et al.*, 2019; Buallay and Al-Ajmi, 2020). Despite the breadth of research focusing on AC characteristics and environmental performance, there is a notable gap in the literature concerning the relationship between ACs and climate change risk. To our knowledge, no study has yet explored this specific area, which we aim to address in our research. In this study, we include several AC characteristics, such as AC independence, AC gender diversity, AC expertise, and

AC tenure, and examine their impact on climate risk. This study aims to explore how these characteristics influence physical, transition, and carbon emission risk, offering a comprehensive and systematic analysis of the effects of AC characteristics on climate risk.

3.2.1. Audit Committee Independence and Climate Risk

The Sarbanes-Oxley Act mandates that all listed companies have fully independent AC members (Dwekat *et al.*, 2022). AC independence is commonly defined by the percentage of outside directors on the AC (Beasley, 1996; Klein, 2002), as independent directors are considered effective monitors within the firms (Wang and Sun, 2022). Consequently, independent AC members can mitigate conflicts of interest, reduce agency problems, and improve CSR reporting (Fama, 1980; Fama and Jensen, 1983). Moreover, AC independence boosts auditors' confidence in issuing going-concern reports to financially distressed companies (Carcello and Neal, 2000). ACs with more independent directors have been shown to enhance the efficiency of both financial and non-financial disclosures (Mangena and Pike, 2005; Pucheta-Martínez and De Fuentes, 2007), thereby increasing the firm's credibility (Al-Shaer and Zaman, 2018). Empirical studies have shown a significant relationship between AC independence and environmental-related risks and reporting. For instance, Prado-Lorenzo and Garcia-Sanchez (2010) found that companies with audit committees that include outside directors with expertise in environmental issues are likelier to adopt advanced environmental risk management practices. Raimo *et al.* (2021) observed that AC independence improves the quality of integrated reports. Al-Shaer and Zaman (2018) found that firms with independent ACs are more likely to engage with the use of Big 4 audit firms for sustainability assurance. Recently, Buallay and Al-Ajmi (2020) showed a positive impact of AC independence on ESG disclosures.

Conversely, some studies have shown an adverse influence of AC independence on CSR disclosure (Haniffa and Cooke, 2005; Al-Shaer and Zaman, 2018; Pucheta-Martínez,

Gallego-Álvarez and Bel-Oms, 2021). This could be possible due to a perceived lack of genuine independence, resulting from an excessive workload and limited industry experience (Abdul Rahman and Haneem Mohamed Ali, 2006). Ali, Frynas and Mahmood (2017) argue that this adverse effect on CSR disclosures could stem from a lack of comprehensive understanding of CSR issues. Moreover, other studies found no significant association between board independence and environmental disclosures, including investigations into Indonesian mining firms (Tireksani and Djajadikerta, 2016), Iranian firms (Salehi, Tarighi and Rezanezhad, 2017), and Saudi Arabian firms (Habbash, 2016). Amran, Lee and Devi (2014) reported that board independence does not significantly affect sustainability reporting quality among Asian Pacific firms. Moreover, (Wang and Sun, 2022), along with Li, Mangena and Pike (2012), and Katmon *et al.* (2019), found no significant association between AC independence and the quality of CSR disclosure or non-financial disclosure.

While some studies highlight that AC independence may enhance environmental performance and reduce climate risk, others report a negative or insignificant relationship. This discrepancy indicates a mixed body of literature concerning the impact of AC independence on environmental performance and disclosures. Overall, outside directors on audit committees represent a significant factor in effectively managing climate risks. Their independence, expertise, and external perspectives enhance the audit committee's function, providing a critical oversight mechanism that can navigate the complex issues surrounding climate risk. As environmental concerns continue to rise on the corporate agenda, the strategic composition of audit committees, inclusive of knowledgeable outside directors, will be imperative for companies aiming to achieve sustainable growth and resilience against climate-related challenges. Given that, we expect AC independence to reduce climate risk. Hence, we propose the following hypothesis to explore the relationship between AC independence and climate risk.

***H (1):** There is a negative and significant relationship between audit committee independence and climate risk.*

3.2.2. Audit Committee Gender Diversity and Climate Risk

Gender diversity at the board level significantly enriches the quality of information exchange among directors (Miller and Del Carmen Triana, 2009), owing to individual members' varied knowledge, skills, perspectives, and abilities (Miller and Del Carmen Triana, 2009; Nielsen and Huse, 2010). From the agency theory perspective, ACs are pivotal as control systems that monitor and protect shareholders' interests (Fama and Jensen, 1983). Hence, including female members in the AC can substantially enhance the committee's effectiveness (Miglani and Ahmed, 2019). Existing literature supports the notion that female directors are more inclined towards sustainability issues than their male counterparts, a difference often attributed to inherent personality traits (Kahre, Mirmehdi and Eram, 2013; Liao, Luo and Tang, 2015; Nadeem, Zaman and Saleem, 2017; Cabral and Sasidharan, 2021; Oradi and E-Vahdati, 2021). Specifically, female directors are more likely to prioritize environmental responsibility, whereas males tend to concentrate on financial performance (Ibrahim and Angelidis, 1994; Liao, Luo and Tang, 2015).

Research shows that female directors are more proactive towards social and environmental disclosures. This proactive approach is attributed to their increased sensitivity and inclination towards participative decision-making, directly aligning with stakeholders' information needs (Rao and Tilt, 2016). Moreover, female directors are notably more vigilant in overseeing ESG disclosures. Their keen focus on social and environmental issues during AC meetings can be linked to their unique beliefs and values, thus enhancing the quality of discussions and oversight (Galbreath, 2018; Husted and Sousa-Filho, 2019). Female directors also promote participative communication within the board, fostering more thorough discussions and monitoring of ESG issues (Bear, Rahman and Post, 2010). Literature on ACs

underscores the efficacy of gender-diverse committees. Such diversity not only enhances AC effectiveness (Aldamen, Hollindale and Ziegelmayr, 2018; Miglani and Ahmed, 2019) but also significantly improves the transparency of non-financial information (Appuhami and Tashakor, 2017; Rezaei Pitenoei, Safari Gerayli and Khozein, 2022).

Empirical evidence supports the positive relationship between gender diversity within ACs and the quality of ESG disclosures. The increased gender diversity mitigates agency conflicts (Galbreath, 2018; Bravo and Reguera-Alvarado, 2019; Husted and Sousa-Filho, 2019) and correlates with a decline in material weaknesses within the internal controls (Parker *et al.*, 2017). Moreover, gender diversity in ACs is directly linked to improved sustainable performance (Appuhami and Tashakor, 2017; Rezaei Pitenoei, Safari Gerayli and Khozein, 2022) and enhanced quality of ESG reporting (Bravo and Reguera-Alvarado, 2019). The importance of gender diversity extends to specialized environmental disclosure. For instance, studies have shown its importance in climate change disclosure among Canadian firms (Ben-Amar, Chang and McIlkenny, 2017), in the reporting of greenhouse gas emissions by Australian firms (Hollindale *et al.*, 2019), and in environmental disclosures among Spanish firms (Fuente, García-Sánchez and Lozano, 2017). Furthermore, it has improved the carbon disclosure scores of firms in developing countries (Hossain *et al.*, 2017).

In contrast, other studies suggest that gender diversity may not impact environmental disclosures. For instance, Amran, Lee and Devi (2014) examined Asian Pacific firms, showing that gender diversity does not significantly improve sustainability reporting quality. Likewise, studies in Jordan (Ghabayen, Mohamad and Ahmad, 2016), Malaysia (Alazzani, Hassanein and Aljanadi, 2017), and Pakistan (Naseem *et al.*, 2017) reported no significant relationship between female directors and environmental disclosures. Additionally, an inverse relationship between female directors and sustainability reporting was identified in firms based in Sri Lanka (M. Shamil *et al.*, 2014).

Overall, most of the available literature strongly supports the beneficial impact of female representation on ACs in promoting ESG disclosures and addressing agency problems. These studies suggest the necessity for broader gender diversity in corporate governance, not merely as a token gesture towards equality but as a strategic imperative for enhancing corporate transparency, accountability, and sustainability. Given that, we conjecture that female representation on ACs leads to a reduction in climate risk through facilitating environmental disclosure and improving sustainable performance. Hence, we propose the following hypothesis:

***H (2):** There is a negative association between audit committee gender diversity and climate risk.*

3.2.3. Audit Committee Expertise and Climate Risk

Based on agency theory, the expertise of AC members is crucial for effective corporate governance (Fama and Jensen, 1983). ACs with greater expertise significantly bolster investor protection by implementing robust internal control systems, risk management frameworks, and ensuring an efficient flow of information to internal and external stakeholders (Sultana, Singh and Van der Zahn, 2015). AC members with specialized knowledge, gained through extensive experience, can smoothly detect errors in financial statements and management operations (Pozzoli, Pagani and Paolone, 2022). Therefore, a profound understanding of financial matters and the individual competencies of AC members are instrumental in enhancing the committee's efficiency and overall monitoring capabilities (Velte, 2018).

Extant literature shows a positive relationship between AC financial expertise and the reliability of voluntary disclosures (Be'dard, Chtourou and Courteau, 2004; Karamanou and Vafeas, 2005). This is because the financial experience of AC members serves as a magnet for pertinent human resources, fostering enhanced sustainable reporting. (Helfaya and Moussa, 2017; Al-Shaer and Zaman, 2018) also discovered a positive linkage between AC financial

expertise and the credibility of sustainability assurance. In a similar vein, Zaman *et al.* (2021) provided empirical evidence that industry-specific expertise among AC members significantly elevates the quality and credibility of CSR assurance.

On the other hand, Appuhami and Tashakor (2017) found a negative relationship between AC expertise and sustainability disclosures. Li, Mangena and Pike (2012) reported a similar negative association concerning the quality of non-financial disclosures. Buallay and Al-Ajmi (2020) offered a theoretical perspective on this paradox, suggesting that effective monitoring hinges more on the discretionary power of top management rather than the financial expertise of the AC.

Since the empirical evidence is inconsistent, it invites further scrutiny of the relationship between AC expertise and corporate transparency. We aim to explore this further based on the following hypothesis:

***H (3):** There is a negative association between audit committee expertise and climate risk.*

3.2.4. Audit Committee Tenure and Climate Risk

Following the Enron scandal, research into board tenure and the quality of financial reporting has gained significant attention (Pozzoli, Pagani and Paolone, 2022). Agency theory contends that this interest stems from the notion that long board tenure can reduce information asymmetry by enhancing the frequency and quality of interaction between the board and managers (Pozzoli, Pagani and Paolone, 2022). Moreover, AC characteristics are crucial in fostering sustainable behavior among managers, thereby limiting opportunistic behaviors regarding ESG decisions (Arif *et al.*, 2020). The presence of seasoned members within the AC is particularly effective in curbing unethical accounting practices, as these members are presumably less influenced by top management's group pressure (Persons, 2009). Hence, the

extended tenure of AC members is crucial in boosting their monitoring capabilities over time (Bedard, Chtourou and Courteau, 2004).

While the literature on AC characteristics is wide, few studies investigate AC tenure and non-financial performance (Paolone *et al.*, 2023). Scholars such as Bravo and Reguera-Alvarado (2019) and Othman *et al.* (2014) uncovered a significant positive relationship between AC tenure and the depth and relevance of ESG disclosures, as well as voluntary ethics disclosure, respectively. The impact of AC tenure on firm performance, however, has yielded inconsistent results across various studies (Buntara and Adhariani, 2019; Polychronidou, Drogalas and Tampakoudis, 2020; Jادیappa *et al.*, 2021; Dordzhieva, 2022). Sharma and Iselin (2012) studied the impact of AC tenure on financial misstatements and found a positive relationship, suggesting a potential decline in independent judgment from directors with extended tenure. Conversely, Beasley (1996) posited that longer AC tenure could reduce fraud risk in financial statements, supported by subsequent findings on its positive impact on monitoring efficacy (Persons, 2009) and audit quality due to increased familiarity with the client's system (Carey and Simnett, 2006).

On the other hand, other studies argue against the beneficial aspects of longer tenure for monitoring effectiveness. For instance, Cucari, Esposito De Falco and Orlando (2018), as well as Setiany *et al.* (2017), observed that extended board tenure may not necessarily enhance ESG performance or the quality of financial reporting. These studies suggest that increased familiarity may undermine the board's control functions (Pozzoli, Pagani and Paolone, 2022). Moreover, Owens-Jackson, Robinson and Waller Shelton (2009) found no significant association between committee tenure and fraudulent financial reporting. Despite the limited research on AC tenure, Bravo and Reguera-Alvarado (2019) provide evidence that longer AC tenure could improve climate performance through ESG disclosures. Based on these

arguments, it's plausible to argue that extended AC tenure may serve as a mitigating factor against climate risk. Thus, we hypothesize:

H (4): There is a negative association between audit committee tenure and climate risk.

3.2.5. Audit Committee and Climate Risk

The audit committee's primary function is safeguarding shareholder interests by overseeing financial and non-financial reporting processes (Turley and Zaman, 2004). This oversight is crucial for preventing corporate failures (Alhababsah and Yekini, 2021) and mitigating the risk of misstatements or fraud (Sattar, Javeed and Latief, 2020). Moreover, the role of AC now encompasses the broader task of mitigating any risks that could lead firms to mislead stakeholders (Trotman and Trotman, 2015; Pozzoli, Pagani and Paolone, 2022), establishing it as a vital internal governance mechanism. By reducing agency conflicts and enhancing the decision-making process, the audit committee contributes significantly to internal governance (Pozzoli, Pagani, and Paolone, 2022). Agency theory contends that managers, acting on behalf of shareholders, leverage the audit committee as a monitoring tool to mitigate opportunistic behavior by agents and to align diverging interests (An, Davey and Eggleton, 2011; Pozzoli, Pagani and Paolone, 2022). When the interests of principals (shareholders) and agents (managers) align, the likelihood of conflicts of interest diminishes significantly (Cerbioni and Parbonetti, 2007; Angela Liu, Hsu and Li, 2015; Suttipun, 2021). Thus, the AC plays a critical role in establishing sound corporate governance practices by providing thorough monitoring and oversight (Cohen, Krishnamoorthy and Wright, 2004; Buallay and Al-Ajmi, 2020; Dwekat *et al.*, 2020; Mohammadi, Saeidi and Naghshbandi, 2021). Its effectiveness not only enhances transparency and accountability but also fosters a culture of integrity that permeates the entire organization, thereby protecting the interests of all stakeholders and supporting the firm's sustainable success.

The AC is essential in enhancing voluntary disclosure (Klein, 2002) due to its influence on strategic-level management decisions (Suttipun, 2021). Previous studies consistently show the effectiveness of AC in boosting voluntary disclosures (Klein, 2002; Vafeas, 2005; Gan *et al.*, 2013). Additionally, studies by Gan *et al.*, (2013) and Karamanou and Vafeas, (2005) highlight the AC's critical contribution to improving the quality and breadth of mandatory and voluntary disclosures. However, extant literature predominantly examines the AC's impact on the quality of financial and non-financial reporting (Al-Shaer, Salama and Toms, 2017), specifically emphasizing voluntary disclosures over climate risk reporting. Hence, we propose the following hypothesis to explore the relationship between AC and climate risk.

H (5): There is a negative association between the audit committees and climate risk.

3.3. Research Methods

3.3.1. Data Collection

We sampled U.S. S&P 500 firms from 2017 to 2022, covering all industries. After excluding firms with missing data, our final sample includes 2,862 firm-year observations. This period was chosen due to the increased public awareness regarding the impact of climate change on businesses (Nguyen, Trinh and Chen, 2024). The given timeframe allows us to capture the evolving corporate strategies in response to climate change concerns, reflecting how firms adapt to external pressures over time. We selected U.S. S&P 500 firms because these large firms are more likely to integrate climate-related initiatives than smaller firms (Giannarakis *et al.*, 2017). Large firms often have more resources and visibility, which can drive them to adopt sustainable practices and set industry standards. Additionally, these large firms have contributed substantially to reducing climate change's effects. Their significant market presence and influence mean that their actions can have a widespread impact, potentially encouraging other firms to follow suit. To measure our dependent variable, climate risk, we

applied the *BERT* technique to 10-K filings from the *EDGAR* database. This advanced text analysis method allows for a comprehensive understanding of how firms communicate their climate risks, capturing the subtle details in their disclosures. Data on AC characteristics and control variables were obtained from *LSEG Eikon*, ensuring a robust dataset for our analysis. Continuous variables are winsorized at the 1% and 99% percentiles to manage outliers, which helps maintain the integrity of our empirical findings by reducing the influence of extreme values.

3.3.2. Variables Measurements

3.3.2.1. Dependent Variable

In this study, physical and transition risks are the main proxies for our dependent variable, climate risk. To quantify climate risk, we employ a powerful natural language processing (*NLP*) technique called *BERT* (Bidirectional Encoder Representations from Transformers), an AI-based algorithm for language understanding developed by researchers at Google (Devlin *et al.*, 2019). We utilize *ClimateBERT* by Deng *et al.* (2023) to classify sentences into physical and transition risks and then calculate a document-level climate-risk score for each firm-year related to each class.

Estimating climate risk scores involves several steps, each critical to ensuring the accuracy and reliability of our results. First, we collected 10-K reports of S&P 500 firms from the *EDGAR* database on the SEC website, covering the period from 2017 to 2022. This step ensured we had a robust and extensive dataset, capturing a wide range of corporate disclosures over several years. Sentences related to physical and transition risks were then extracted from section 1.A of these 10-K reports and preprocessed. Preprocessing involved cleaning the text data to remove any special characters and sentences with less than 10 words, ensuring that the sentences fed into the model were as accurate as possible. We used *ClimateBERT*, a model fine-tuned by Deng *et al.* (2023) using 3,732 custom-annotated sentences, to classify the

extracted sentences into physical and transition risk categories. The choice of *ClimateBERT* was based on its exceptional performance, achieving F1 scores of 0.95, matching the results of (Kolber *et al.*, 2024), and it perfectly aligns with our requirements. Once the sentences were classified, the model assigned probability scores to each sentence, indicating the likelihood of each sentence pertaining to physical or transition risks. To derive the final climate risk score, we summed the probability scores of all the sentences in section 1.A and normalized them by dividing by the total number of sentences in that section. This normalization ensured that the final score accurately reflected the proportion of climate risk-related content in the reports.

We selected this method because it is a more advanced *NLP* technique that provides superior results (Kolber *et al.*, 2024) compared to other keyword-based approaches (Grüning, 2011; Engle *et al.*, 2020; Sautner *et al.*, 2023; Berkman, Jona and Soderstrom, 2024). Research shows that keyword-based methods often fail to capture the full context of the text, leading to less accurate outcomes. By contrast, more advanced *NLP* techniques, such as *BERT*, are designed to understand the deeper meanings and relationships within the text, resulting in better performance. In particular, a simple *BERT* model outperforms keyword-based approaches (Varini *et al.*, 2020). Moreover, our climate risk score is forward-looking, as it is based on risks disclosed in SEC filings. These filings are a crucial source of information because they are legally required for all U.S. firms, ensuring a comprehensive and standardized data set. This legal requirement means that our method is grounded in advanced *NLP* techniques and relies on robust and legally mandated data sources, providing a strong foundation for accurate and reliable climate risk assessment (Kolber *et al.*, 2024).

3.3.2.2. Independent Variables

Consistent with the literature, we use the following AC characteristics as our independent variables that potentially affect climate risk. AC independence (AC_IND) is measured as the proportion of independent board members on the AC (Buallay and AlDhaen, 2018; Zaman *et*

al., 2021; Dwekat *et al.*, 2022; Pozzoli, Pagani and Paolone, 2022; Wang and Sun, 2022; Paolone *et al.*, 2023). AC gender diversity (AC_GEN) is determined by the proportion of female directors on the AC (Appuhami and Tashakor, 2017; Wang and Sun, 2022). AC Expertise (AC_EXP) is a binary variable that equals 1 if the firm has an AC with at least three members, including at least one "financial expert" as defined by the Sarbanes Oxley Act, and 0 otherwise (Pozzoli, Pagani and Paolone, 2022). AC Tenure (AC_TEN) represents the average number of years that the current audit committee members have been serving (Pozzoli, Pagani and Paolone, 2022; Paolone *et al.*, 2023). Finally, we also include an AC dummy variable (AC_DUM), a binary variable equal to 1 if a board-level audit committee exists and 0 otherwise (Al-Shammari and Al-Sultan, 2010).

3.3.2.3. Control Variables

We incorporate corporate governance-related and firm-level control variables. ESG scores (ESG) measure a firm's relative environmental performance, commitment, and effectiveness based on publicly reported data (Paolone *et al.*, 2023; Yorke, Donkor and Appiagyei, 2023). Board size (BS) refers to the total number of directors on corporate boards (Zaman *et al.*, 2021; Dwekat *et al.*, 2022; Pozzoli, Pagani and Paolone, 2022; Wang and Sun, 2022; Paolone *et al.*, 2023). Board independence (BI) is the percentage of independent directors on corporate boards (Appuhami and Tashakor, 2017; Zaman *et al.*, 2021; Wang and Sun, 2022). Chairman-CEO duality (DUAL) is an indicator variable that equals 1 if CEO-Chairman duality exists and 0 otherwise (Al-Shammari and Al-Sultan, 2010; Dwekat *et al.*, 2022). CSR sustainability committee (CSR_COM) is a dummy variable equal to 1 if the company has a CSR committee and 0 otherwise (Dwekat *et al.*, 2022).

Our firm-level control variables include firm size (FS), which is measured as the natural log of total assets (Arif *et al.*, 2020; Zaman *et al.*, 2021; Dwekat *et al.*, 2022; Pozzoli, Pagani and Paolone, 2022; Wang and Sun, 2022; Paolone *et al.*, 2023). Firm leverage (FL) is the total

liabilities to total assets ratio (Appuhami and Tashakor, 2017; Arif *et al.*, 2020; Dwekat *et al.*, 2022; Pozzoli, Pagani and Paolone, 2022; Wang and Sun, 2022). Firm growth (FG) is measured by the market-to-book ratio, calculated as $(\text{Total Assets} - \text{Common Equity} + \text{Price Close} * \text{Common Shares Outstanding}) / \text{Total Assets}$ (Zaman *et al.*, 2021). Firm performance (FP) is gauged by return on assets (ROA), defined as net income to total assets (Appuhami and Tashakor, 2017; Zaman *et al.*, 2021; Wang and Sun, 2022).

3.3.3. Models Specifications

To examine the relationship between AC characteristics and climate risk, we employ ordinary least squares (OLS) regression.

To test Hypothesis H (1), we investigate the relationship between AC independence and climate risk, considering both physical and transition risks separately. This hypothesis aims to determine if independent AC members can mitigate these risks effectively. Hypothesis H (2) examines the impact of AC gender diversity on physical and transition risk. Similarly, Hypothesis H (3) explores the effect of AC expertise, and Hypothesis H (4) investigates the influence of AC tenure. Hypothesis H (5) assesses the effect of a dummy variable for AC on physical and climate risk. The models are specified as follows:

$$\begin{aligned} \text{Climate Risk}_{it} = & \beta_0 + \beta_1 \text{AC_IND}_{it} + \beta_2 \text{ESG}_{it} + \beta_3 \text{BS}_{it} + \beta_4 \text{BI}_{it} + \beta_5 \text{DUAL}_{it} + \\ & \beta_6 \text{CSR_COM}_{it} + \beta_7 \text{FS}_{it} + \beta_8 \text{FL}_{it} + \beta_9 \text{FG}_{it} + \beta_{10} \text{FP}_{it} + \text{yr}_t + \mu_i + \varepsilon_{it} \dots\dots\dots (1) \end{aligned}$$

$$\begin{aligned} \text{Climate Risk}_{it} = & \beta_0 + \beta_1 \text{AC_GEN}_{it} + \beta_2 \text{ESG}_{it} + \beta_3 \text{BS}_{it} + \beta_4 \text{BI}_{it} + \beta_5 \text{DUAL}_{it} + \\ & \beta_6 \text{CSR_COM}_{it} + \beta_7 \text{FS}_{it} + \beta_8 \text{FL}_{it} + \beta_9 \text{FG}_{it} + \beta_{10} \text{FP}_{it} + \text{yr}_t + \mu_i + \varepsilon_{it} \dots\dots\dots (2) \end{aligned}$$

$$\begin{aligned} \text{Climate Risk}_{it} = & \beta_0 + \beta_1 \text{AC_EXP}_{it} + \beta_2 \text{ESG}_{it} + \beta_3 \text{BS}_{it} + \beta_4 \text{BI}_{it} + \beta_5 \text{DUAL}_{it} + \\ & \beta_6 \text{CSR_COM}_{it} + \beta_7 \text{FS}_{it} + \beta_8 \text{FL}_{it} + \beta_9 \text{FG}_{it} + \beta_{10} \text{FP}_{it} + \text{yr}_t + \mu_i + \varepsilon_{it} \dots\dots\dots (3) \end{aligned}$$

$$Climate Risk_{it} = \beta_0 + \beta_1 AC_TEN_{it} + \beta_2 ESG_{it} + \beta_3 BS_{it} + \beta_4 BI_{it} + \beta_5 DUAL_{it} + \beta_6 CSR_COM_{it} + \beta_7 FS_{it} + \beta_8 FL_{it} + \beta_9 FG_{it} + \beta_{10} FP_{it} + yr_t + \mu_i + \epsilon_{it} \dots \dots \dots (4)$$

$$Climate Risk_{it} = \beta_0 + \beta_1 AC_DUM_{it} + \beta_2 ESG_{it} + \beta_3 BS_{it} + \beta_4 BI_{it} + \beta_5 DUAL_{it} + \beta_6 CSR_COM_{it} + \beta_7 FS_{it} + \beta_8 FL_{it} + \beta_9 FG_{it} + \beta_{10} FP_{it} + yr_t + \mu_i + \epsilon_{it} \dots \dots \dots (5)$$

$$Climate Risk_{it} = \beta_0 + \beta_1 AC_IND_{it} + \beta_2 AC_GEN_{it} + \beta_3 AC_EXP_{it} + \beta_4 AC_TEN_{it} + \beta_5 AC_DUM_{it} + \beta_6 Cont_{it} + yr_t + \mu_i + \epsilon_{it} \dots \dots \dots (6)$$

where $Risk_{it}$ is the physical risk and transition risk of firm i at time t . AC_IND_{it} is audit committee independence of firm i at time t . AC_GEN_{it} is audit committee gender of firm i at time t . AC_EXP_{it} is audit committee expertise of firm i at time t . AC_TEN_{it} is audit committee tenure of firm i at time t . AC_DUM_{it} is audit committee dummy variable of firm i at time t . $Cont_{it}$ represents 9 control variables at the corporate governance and firm-level i.e., ESG pillar score (ESG), board size (BS), board independence (BI), Chairman-CEO Duality (DUAL), CSR sustainability committee (CSR_COM), firm size (FS), firm leverage (FL), firm growth (FG), firm performance (FP). Yr_t represents time fixed-effects, μ_i represents firm fixed-effects, and ϵ_{it} represents standard errors.

[Insert Table 1 Here]

3.4. Empirical Results and Discussions

3.4.1. Descriptive statistics and correlation analysis

Table 2 shows the correlation analysis and descriptive statistics of the variables used in this study. In terms of climate risk, the average values for physical risk and transition risk are 0.19

and 0.041, indicating a moderate level of exposure to climate-related risks, which is significant as firms increasingly face scrutiny and pressure to mitigate such risks. Regarding the audit committee's (AC) characteristics, the mean AC independence score is 51.57, with an average AC gender diversity of 26%. This proportion aligns with previous studies and is attributed to the absence of mandatory female quotas on US boards (Yorke, Donkor and Appiagyei, 2023). Independent members of the AC are essential for unbiased oversight and decision-making, enhancing the integrity of financial reporting and corporate governance. Moreover, gender diversity is linked to a broader range of perspectives and more comprehensive problem-solving abilities. The average AC expertise score is 0.96, indicating that most AC members are experts. This AC expertise ensures the committee can effectively oversee complex financial and operational matters, contributing to more robust risk management and strategic guidance. The average tenure of the AC is 18 years, suggesting stability and experience within the committee, which can lead to more effective governance practices. The mean ESG score of 61% reflects the firm's commitment to ESG factors, which are increasingly important to investors and stakeholders.

For corporate governance-related control variables; the average board size is 10.87, with 83% being independent. A larger board size can provide a wider range of skills and experiences, while a high level of independence is crucial for objective oversight and accountability. The mean for CEO duality is 0.658, showing that in 65.8% of our sample, the roles of chairman and CEO are held by the same individual, leading to potential conflicts of interest but also streamlined decision-making. Additionally, the average firm size is 23.9, indicating substantial resources and market influence. The leverage ratio of 67% indicates a significant reliance on debt financing, which can amplify returns but also increase financial risk. The market-to-book ratio of 3.565 suggests that investors value these firms highly relative

to their book value, reflecting strong growth prospects. The returns on assets average of 7.9 percent show the efficient use of assets to generate earnings.

Furthermore, Table 2 shows all correlation coefficients below 0.80, suggesting no significant correlation issues (Pozzoli, Pagani and Paolone, 2022). AC independence and expertise correlate significantly and negatively with climate risk, as measured by physical and transition risk, providing preliminary evidence that firms with more independent directors and experts on the AC are better at reducing physical and transition risk. Similarly, gender diversity within the AC reduces physical risk. Conversely, Table 2 shows that a longer tenure of the AC leads to increased physical risk. Additionally, the presence of a CSR committee shows strong evidence of reducing both physical and transition risk. Moreover, all variables have a variance inflation factor (*VIF*) value of less than 10, indicating the absence of multicollinearity issues (Gujarati, 1995; Kennedy, 1998; James *et al.*, 2013). This ensures that the regression results are reliable and that the independent variables do not exhibit a problematic level of interdependence.

[Insert Table 2 Here]

3.4.2. Baseline Regressions

Tables 3 and 4 present the baseline regression findings on the impact of AC characteristics on climate risk, proxied by physical and transition risk. We conducted panel data regression analysis using ordinary least squares (*OLS*) to estimate the model parameters, incorporating both firm and industry fixed effects.

The results in Tables 3 and 4 show that AC characteristics significantly influence physical and transition risk. Specifically, in columns (1) of Tables 3 and 4, audit committee independence (AC_IND) has a significant negative impact on physical risk at the 1% level (coefficient = -0.085) and on transition risk at the 5% level (coefficient = -0.044), suggesting that a higher number of independent members within the AC reduces physical and transition

risk among US-listed firms. Hence, our hypothesis H (1) is supported. The findings imply that a higher proportion of independent directors within the AC is associated with strong adherence to climate risk protocols and reduced conflicts of interest that cause agency problems (Fama, 1980; Fama and Jensen, 1983). The findings suggest that independent directors are crucial in promoting practices that mitigate climate risks. As discussed earlier, independent directors are likely to provide unbiased oversight and encourage transparency, which can lead to better risk management and adherence to environmental regulations. Our results also align with prior literature indicating improvement in ESG performance, which includes environmental aspects related to climate risk (Appuhami and Tashakor, 2017; Al-Shaer and Zaman, 2018; Buallay and Al-Ajmi, 2020). Furthermore, high environmental disclosure scores (Arif *et al.*, 2020) have been linked to AC independence, suggesting that independent AC is more diligent in reporting and addressing environmental issues.

Additionally, we observed a negative impact of AC gender diversity on climate risk, with coefficients of -0.035 ($p < 0.05$) for physical risk and -0.073 ($p < 0.05$) for transition risk. These findings indicate that gender diversity within the AC mitigates climate risk, supporting our hypothesis 2. This can be attributed to the different perspectives and approaches that female members bring to the committee, which may enhance the committee's ability to address non-financial risks effectively (Wang and Sun, 2022). Female members often focus on long-term sustainability and ethical considerations, which can lead to better monitoring and control systems that protect shareholders' interests (Fama and Jensen, 1983). Our results also align with previous studies suggesting that gender-diverse ACs are more likely to promote transparency and accountability, leading to improved climate-related disclosures (Appuhami and Tashakor, 2017; Bravo and Reguera-Alvarado, 2019).

Our Hypothesis 3 investigated the impact of AC Expertise on climate risk, as measured by physical and transition risk. The findings presented in column (3) of Tables 3 and 4 show

that the coefficients associated with AC Expertise are both negative and statistically significant for physical risk (-0.135, $p < 0.05$) and transition risk (-0.094, $p < 0.01$). These results demonstrate that having an AC comprised of at least three members, including one “financial expert,” reduces climate risk, thus supporting our third hypothesis. Experts on the AC bring specialized knowledge and skills crucial for understanding and managing complex risk factors, including climate change-related ones. This corresponds to studies that suggest an enhancement in ESG scores based on AC expertise (Pozzoli, Pagani and Paolone, 2022). Having experts on the AC can improve risk assessment processes and ensure that the firm adopts best practices in sustainability reporting and environmental management.

Contrary to our conjecture, we report a significant positive impact of AC Tenure on physical risk at a 5% level (coefficient 0.065) and transition risk at a 1% level (coefficient 0.004). These results indicate that longer AC tenure leads to increased familiarity among members, which can undermine the effectiveness of control activities (Pozzoli, Pagani and Paolone, 2022). Over time, long-tenured members may become less vigilant and more resistant to new ideas and approaches, which can elevate climate risk. The results are also consistent with prior research, indicating that long tenure negatively impacts audit quality (Setiany *et al.*, 2017) and auditor independence (Carey and Simnett, 2006). However, the findings contradict a study highlighting a positive improvement in environmental pillar score attributed to AC tenure in a European context (Paolone *et al.*, 2023), suggesting that the impact of AC tenure on climate risk may vary depending on the regulatory and cultural environment.

Furthermore, in column 5 of Tables 3 and 4, we reveal a negative impact of the AC dummy variable on physical risk (-0.185, $p < 0.05$) and transition risk (-0.094, $p < 0.01$), indicating that the presence of an audit committee results in a substantial reduction in climate risk. These results align with the research conducted by Pozzoli, Pagani and Paolone (2022), which highlights an improvement in ESG performance attributable to the existence of the AC.

Hence, the presence of an audit committee signifies a commitment to strong governance practices and rigorous oversight, which are essential for managing climate risks effectively.

We also accounted for governance and firm-specific related control variables that may impact climate risk. For instance, we show that ESG scores are negatively and significantly associated with physical and climate risk, supporting the argument that higher ESG Scores correspond to a decrease in climate risk. Moreover, we found that board size is positively and significantly related to physical and transition risk, indicating that larger boards may face challenges in communication and coordination, making them less effective in addressing climate-related issues (Wang and Hussainey, 2013). On the contrary, board independence negatively affects physical and transition risk, suggesting that having independent members on the board and committees is important for reducing climate risk. Additionally, the existence of a CSR committee is vital in climate risk. Our results also show that firm leverage is positively and significantly related to physical and transition risk. In contrast, firm growth and performance negatively correlate with physical and transition risk, indicating that better growth and performance can help reduce these risks.

Finally, we collectively examined our model by considering all the AC characteristics related to physical and transition risk. The results in column 6 of Tables 3 and 4 align with the earlier findings obtained from examining individual AC variables. In summary, the main results regarding the impact of AC characteristics on physical and transition risk support H (1), H (2), H (3), and H (5). The findings also corroborate agency theory, which suggests that AC lowers agency problems by providing an efficient monitoring mechanism (Fama, 1980; Fama and Jensen, 1983). This theory argues that the AC's oversight function can align management's actions with shareholders' interests, thus reducing risks associated with climate change. However, our results do not support H4 due to the positive impact of AC tenure climate risk, indicating that longer tenures might lead to complacency or entrenchment, reducing the AC's

effectiveness in addressing dynamic and evolving climate risks. Overall, our main results consistently support H (1), H (2), H (3), and H (5), highlighting the importance of various AC characteristics in mitigating climate-related risks.

[Insert Tables 3 and 4 Here]

3.4.3. Sub-sample Analysis

We divided our sample into high and low carbon intensive sectors to further analyze the relationship between AC characteristics and climate risk. The results are reported in Table 5. The findings indicate that AC characteristics impact on climate risk is much stronger in high carbon-intensive sectors compared to low carbon-intensive sectors.

Our results in Panel A show that AC characteristics such as independence, gender diversity, expertise, tenure, and the very existence of AC all evidence a strong negative impact, suggesting that they decrease both physical and transition risks. For instance, increasing AC independence reduces physical risk by 1.587 units and transition risk by 2.011 units. Gender diversity and expertise have the most substantial effects, reducing risks by around 2.3 to 2.6 units. The baseline risk in these industries is also relatively high, as seen in the constant values (2.332 for physical risk and 2.548 for transition risk). This suggests that firms in high carbon-intensive industries face significant climate-related vulnerabilities .

In contrast, Panel B shows the results of low carbon-intensive industries, which demonstrate much weaker relationships between AC characteristics and climate risks. Most of the AC variables have minimal to no impact, with many coefficients being small and statistically insignificant. For example, AC independence has almost no effect on physical (-0.027) or transition risk (-0.151), while gender diversity and expertise yield only minor reductions in risk. The baseline risk in these industries is also lower (1.770 for physical risk and 1.683 for transition risk), indicating that these firms are inherently less exposed to climate-related risks.

The key differences between high and low carbon-intensive industries illustrate why AC characteristics significantly impact specific sectors. High carbon-intensive firms operate in an environment characterized by high regulatory scrutiny, elevated investor expectations, and substantial transition risks. This makes robust AC oversight crucial for addressing sustainability challenges. Conversely, low carbon-intensive firms do not encounter the same degree of climate-related financial risks, which accounts for the diminished influence of AC characteristics.

[Insert Tables 5 Here]

3.4.4. Robustness Checks

We conducted additional tests to assess the robustness of our baseline regressions. First, we used an alternative measure of climate risk to validate the consistency of our main findings. Specifically, we replaced the variables for physical and transition risks with carbon emissions. To this end, we modified our main as follows:

$$CO2_{it} = \beta_0 + \beta_1 AC_IND_{it} + \beta_2 AC_GEN_{it} + \beta_3 AC_EXP_{it} + \beta_4 AC_TEN_{it} + \beta_5 AC_DUM_{it} + \beta_6 Cont_{it} + yr_t + \mu_i + \varepsilon_{it} \dots\dots\dots (3)$$

where $CO2_{it}$ is carbon emission measured by CO2 equivalent emissions. The remaining variables are identical, as indicated in Equation 6. Table 1 provides details of all the variables.

The results, reported in Table 6, show that the coefficients of AC characteristics are significant both individually (columns 1 to 5) and collectively (column 6). The impact of AC independence is negative and significant (-0.091, $p < 0.05$), indicating that independent audit committees effectively reduce carbon emissions. Similarly, AC gender diversity exhibits a negative and significant relationship with carbon emissions (-0.075, $p < 0.05$), suggesting that gender-diverse committees better manage environmental impact. AC Expertise also shows a negative and significant association with carbon emissions (-0.176, $p < 0.01$), highlighting the importance of having knowledgeable members who can effectively address climate-related

issues. Interestingly, AC tenure has a negative and significant relationship with carbon emissions (-0.006 , $p < 0.05$), even though it was previously found to have a positive relation with physical and transition risks (Tables 3 and 4), suggesting that while longer tenures may lead to complacency in some areas, they can also provide stability and a deeper understanding of environmental issues, leading to better management of carbon emissions. Finally, the AC dummy variable negatively and significantly impacts carbon emissions (-0.112 , $p < 0.05$), further confirming the effectiveness of having a dedicated audit committee.

Our findings are also consistent with recent research indicating that non-accounting female experts improve carbon disclosures (Abbasi *et al.*, 2024). This consistency implies that AC characteristics reduce climate risk through multiple measures, including physical risk, transition risk, and carbon emission. The stronger intensity observed for carbon emissions, with AC tenure showing a negative association, suggests that the impact of AC characteristics is robust across different dimensions of climate risk.

[Insert Table 6 Here]

Second, our baseline results suggest that AC characteristics can lead to lower climate risk. However, we are concerned about the potential endogenous determination of the association between AC characteristics and climate risk, which can affect causality. A negative association shows that AC characteristics such as independence, gender diversity, expertise, or tenure may reduce physical and transition risk. However, causality might run in the opposite direction, with firms facing high climate risks possibly enhancing their corporate governance, including AC characteristics, to manage these risks better.

To address these endogeneity concerns, we used alternative econometric model specifications, such as system *GMM*, propensity score matching (*PSM*), and entropy balancing estimations. We first employ *GMM* regression. This method is particularly useful as it allows us to control potential endogeneity issues using internal instruments to account for unobserved

heterogeneity, omitted variable bias, and measurement errors (Alam, Uddin and Yazdifar, 2019; Alam *et al.*, 2020), which may arise from reverse causality. We ran the “*xtabond2*” command in STATA 17 (Roodman, 2009) and employed the “*robust*” command to detect heteroscedasticity. Post-estimation tests, including the Wald Chi-Square, Arellano-Bond, Sargan, and Hansen tests, were performed to identify autocorrelation and over-identification issues, ensuring the robustness of our results. In addition, the $(t - 1)$ lag of the dependent variable was used to capture its persistence over time, addressing dynamic aspects of the model. System *GMM* estimation helps mitigate omitted variable bias and reverse causality. Reverse causality is a significant concern as it implies that while AC characteristics can impact climate risk (Appuhami and Tashakor, 2017; Bravo and Reguera-Alvarado, 2019; Arif *et al.*, 2020; Pozzoli, Pagani and Paolone, 2022), climate risk can also influence the development and enhancement of AC characteristics. For example, firms with higher climate risks might strengthen their AC by including more independent members or experts to oversee and manage these risks. This is similar to how higher climate risk prompts auditors to charge higher fees (Hartlieb and Eierle, 2022). Such dynamics can make it challenging to interpret the results from *OLS* regressions as they may not adequately account for this bidirectional relationship (Frijns, Gilbert and Tourani-Rad, 2014).

To validate the System *GMM* estimations, we conducted several diagnostic tests: Wald Chi-Square, Arellano-Bond, Sargan, and Hansen. The Wald Chi-Square test shows a good model fit by rejecting the null hypothesis at the 1% level. The Arellano-Bond test confirms expected first-order autocorrelation (AR(1)) and no second-order autocorrelation (AR(2)), verifying the model's dynamic lag structure. The Sargan and Hansen tests confirm the validity of the instruments with no over-identification issues.

[Insert Tables 7 and 8 Here]

To further address endogeneity concerns arising from potential model misspecification, reduce selection biases and achieve a more balanced comparison between the sample, we employed the propensity score matching (*PSM*) and entropy balancing estimation (*EBE*) approach (Albitar, Al-Shaer and Liu, 2023). The need to run *EBE* is to match the treated and control groups without discarding data (Hainmueller, 2012; Hainmueller and Xu, 2013), may overcome one of the limitations of *PSM*. Table 9 presents these results, with *PSM* in Panel A and *EBE* in Panel B. This approach was particularly pertinent, as noted in Table 5, where differing results are observed for high carbon-intensive and low carbon-intensive sectors (Tavakolifar *et al.*, 2021). The results in Table 9 are consistent with our baseline results, though entropy balancing yields stronger, more statistically significant effects. Entropy balancing produces higher intercept values than *PSM*, suggesting that when differences are better controlled, the baseline climate risk level appears greater. This implies that *PSM* may underestimate initial climate risk.

In particular, the results show that independent audit committees reduce climate risk, with entropy balancing amplifying the effect, particularly in transition risk mitigation, indicating that *PSM* may have slightly underestimated their influence. Audit committee gender diversity consistently shows a negative relationship with climate risk, with stronger effects under entropy balancing, confirming our baseline findings. Audit committee expertise remains a key factor in mitigating climate risk, with entropy balancing highlighting a stronger impact than *PSM*. Longer tenure is more influential in reducing transition risk, with entropy balancing showing a greater effect than *PSM*, suggesting *PSM* may undervalue this role. Overall, these robustness tests confirm our main *OLS* findings, emphasizing that independent, diverse, and experienced audit committees help mitigate climate risk.

[Insert Table 9 Here]

3.5. Conclusion

In this study, we examine the impact of AC characteristics on climate risk. The AC has become essential in corporate governance, providing oversight of sustainable activities and ensuring the credibility of financial and non-financial reporting processes (Yorke, Donkor and Appiagyei, 2023). We use a panel dataset of S&P 500 firms operating in the US, controlling for year and industry-fixed effects. Climate risk is proxied by physical and transition risks, whereas AC characteristics include independence, gender diversity, expertise, and tenure. We calculate climate risk using *BERT* and collect other data from Refinitiv Eikon for 2017–2022. Traditionally, AC characteristics have been found beneficial for environmental disclosures (Klein, 2002; Be'dard, Chtourou and Courteau, 2004). Therefore, we propose that AC characteristics will help address climate risk. However, limited empirical studies have analyzed the relationship between AC characteristics and climate change, with most focusing on enhancing climate-related disclosures (Al-Shaer and Zaman, 2018; Bravo and Reguera-Alvarado, 2019). Our study aims to fill this gap by examining how AC characteristics affect firms' climate risk. Our findings provide evidence that AC independence, gender diversity, and expertise are negatively related to physical and transition risk, suggesting these AC characteristics effectively reduce climate risk. According to agency theory (Jensen and Meckling, 1976), AC reduces climate risk by decreasing information asymmetry and protecting stakeholders' interests in climate change. Additionally, our results confirm the monitoring role of the AC, which is consistent with previous studies (Turley and Zaman, 2004; An, Davey and Eggleton, 2011; Trotman and Trotman, 2015; Pozzoli, Pagani and Paolone, 2022). The presence of more independent and female members on AC ensures better monitoring (Wang and Sun, 2022) and enhances AC effectiveness (Miglani and Ahmed, 2019), suggesting that having an accounting expert on the AC contributes to reducing climate risk through improved overall monitoring capabilities (Velte, 2018). By providing oversight and ensuring accurate

disclosures, ACs can play a crucial role in mitigating the risks associated with climate change, thereby enhancing the firm's long-term sustainability and resilience.

3.5.1. Practical and Theoretical Implications

Our study has practical and theoretical implications. It encourages governance advocates and academics to establish policies and rules that promote beneficial AC characteristics such as independence, gender diversity, and expertise. These characteristics are crucial as they contribute to a well-rounded and balanced decision-making process for effective governance. Independence ensures that members can make unbiased decisions without external pressures. Gender diversity brings different perspectives and approaches, leading to more innovative solutions. Expertise ensures members know how to make informed decisions, particularly in complex areas, such as climate risk and sustainability.

Our findings show that AC member characteristics are associated with lower climate risk, a strategy many US firms adopt. Our results suggest that when AC members possess the right mix of independence, diversity, and expertise, they are better equipped to identify and manage risks associated with climate change. This approach not only protects the business from potential financial losses but also enhances its reputation among environmentally conscious stakeholders.

Our results also suggest that AC characteristics contribute to SDG13 by bridging the gap between the firms and the markets regarding sustainability reporting. This association with global sustainability goals is vital as it shows a commitment to addressing climate change, which can attract investment from socially responsible investors. It also meets the growing demand from consumers and regulators for greater transparency and accountability in environmental practices.

We recommend creating efficient monitoring bodies. Increasing stakeholder participation shows a firm's clear intent to meet stakeholder needs, especially related to climate

actions, and enhances transparency. By involving stakeholders in the decision-making process, firms can ensure that their strategies align with the expectations and concerns of those affected by their operations, promoting trust and cooperation, which are essential for long-term success. AC characteristics serve as examples of these effective monitoring bodies, ensuring that the environmental concerns of all stakeholders are addressed and indicating greater compliance with global standards. This compliance helps firms avoid legal penalties and positions them as leaders in sustainability, giving them a competitive advantage in the market. Policymakers might consider developing recommendations to encourage the appointment of AC members with financial expertise to enhance non-financial performance. Financial expertise is crucial as it enables AC members to better understand and evaluate the financial implications of sustainability initiatives, leading to more effective implementation and monitoring.

Moreover, although US firms may not require female representation on ACs (Yorke, Donkor and Appiagyei, 2023), it is practical to appoint more female directors, given the current business environment. Research has shown that gender-diverse boards are more likely to focus on sustainability and corporate social responsibility, which are increasingly important in today's business landscape. Regulators could consider mandatory quotas for female representation on boards. Such quotas could help accelerate progress toward gender equality and ensure that the benefits of diverse leadership are realized more broadly across industries.

3.5.2. Limitations and Future Research Directions

Despite the contributions of this study, several limitations remain, which can serve as an avenue for future research. First, the paper examines data from a limited timeframe, specifically from 2017 to 2022. While this provides a snapshot of recent trends, it may not capture longer-term patterns and changes. Expanding the timeframe could offer a more comprehensive understanding of the dynamics at play. Second, the research design has methodological limitations since the dataset is restricted to US firms, limiting the generalizability of the

findings. Including a broader range of firms, such as those from S&P 1500 or other countries, could make the results more applicable to different contexts. Adopting this broader approach would help determine if the findings are specific to the US context or if they hold true across various regulatory and cultural environments. Third, comparative cross-country and cross-industry analyses could be a further avenue of research. Such analyses would allow for examining how different regulatory frameworks, industry practices, and cultural contexts influence the relationship between AC characteristics and climate risk. In summary, future research should consider expanding the dataset to include more years and a more diverse set of firms and countries. Additionally, employing a variety of estimation methods and conducting comparative analyses across different contexts would provide deeper insights and help to confirm the validity of the results.

Table 1. Variables Explanation

Variable Level	Variable Name	Model Name	Proxy	Source
Dependent	Physical Risk	P_Risk	Physical risk is computed using BERT technique	Self-computed
	Transition Risk	T_Risk	Transition risk is computed using BERT technique	Self-computed
	Carbon Emission	CO2	CO2 equivalent emissions	Refinitiv Eikon
Explanatory	Audit Committee Independence	AC_IND	Proportion of independent board members on the AC	Refinitiv Eikon
	Audit Committee Gender Diversity	AC_GEN	Proportion of female directors on the AC	Refinitiv Eikon
	Audit Committee Expertise	AC_EXP	The variable takes 1 and is 0 otherwise if the company have an AC with at least three members and at least one "financial expert" within the meaning of the Sarbanes Oxley Act	Refinitiv Eikon
	Audit Committee Tenure	AC_TEN	Average number of years that the current audit committee has been serving	Refinitiv Eikon
	Audit Committee	AC_DUM	A binary variable that is 1 if a board-level audit committee exists and 0 otherwise	Refinitiv Eikon
Control	ESG Score	ESG	It measures a company's relative Environmental performance, commitment and effectiveness based on publicly reported data	Refinitiv Eikon
	Board Size	BS	Total number of directors on the Board of Directors	Refinitiv Eikon
	Board Independence	BI	Percentage of independent directors	Refinitiv Eikon
	Chairman-CEO Duality	DUAL	An indicator variable that equals 1 if CEO-Chairman duality exists and 0 otherwise	Refinitiv Eikon
	CSR Sustainability Committee	CSR_COM	Dummy variable equal to 1 if the company have a CSR committee, and 0 otherwise	Refinitiv Eikon
	Firm Size	FS	Natural log of total assets	Refinitiv Eikon
	Firm Leverage	FL	Leverage = Total liabilities to total assets ratio	Refinitiv Eikon
	Firm Growth	FG	The market-to-book ratio = (Total Assets – Common Equity + Price Close * Common Shares Outstanding)/Total Assets	Refinitiv Eikon
	Firm Performance	FP	ROA = Net income to total assets	Refinitiv Eikon

Table 2. Correlation Matrix and Descriptive Statistics

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 P_Risk	1															
2 T_Risk	0.489**	1														
3 AC_IND	-0.078**	-0.069**	1													
4 AC_GEN	-0.037*	-0.016	0.097**	1												
5 AC_EXP	-0.061**	-0.061**	0.305*	0.212**	1											
6 AC_TEN	0.048**	0.022	0.082**	0.162*	0.153**	1										
7 AC_DUM	-0.073**	-0.058**	0.42***	0.254**	0.740**	0.219**	1									
8 ESG	-0.045*	0.035	0.222**	0.416**	0.281**	0.226**	0.338*	1								
9 BS	0.082***	0.046*	0.199**	0.201**	0.337***	0.202***	0.434**	0.338*	1							
10 BI	-0.081**	-0.106***	0.380*	0.330***	0.487**	0.227**	0.637**	0.490**	0.373***	1						
11 DUAL	0.011	-0.030	0.059**	0.017	0.119*	0.114*	0.138**	0.035	0.161**	0.035	1					
12 CSR_COM	-0.092***	-0.134**	0.096*	0.314**	0.131***	0.160**	0.152*	0.602**	0.275**	0.252*	0.0128	1				
13 FS	0.012	0.043*	0.035	0.182***	0.042*	0.164***	0.026	0.373**	0.450*	0.124**	0.101**	0.325*	1			
14 FL	0.012	-0.072**	-0.009	0.114***	0.044*	0.055**	0.045*	0.109*	0.163**	0.129**	0.035	0.073**	0.156***	1		
15 FG	-0.067**	-0.152**	-0.025	0.038*	0.029	0.019	0.035	-0.07**	-0.15**	-0.009	-0.022	-0.092**	-0.36**	0.186**	1	
16 FP	-0.055**	-0.135**	0.06**	0.034	0.07***	0.083**	0.098**	0.020	-0.13**	0.051**	0.002	-0.050**	-0.38**	-0.021	0.53*	1
VIF	-	-	1.77	1.78	1.93	1.73	1.69	1.68	1.88	1.87	1.29	1.91	1.89	1.37	1.51	1.71
Mean	0.019	0.041	51.57	26.04	0.961	18.01	0.962	61.47	10.87	83.36	0.658	0.730	23.90	0.667	3.565	0.079
SD	0.023	0.069	13.80	10.18	0.541	8.24	0.334	24.65	3.567	33.50	0.474	0.444	3.386	0.373	4.079	0.070
Obs.	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862	2,862

Note: This table presents Pearson's correlation matrix and descriptive statistics of the variables used in this study. SD denotes standard deviation. VIF denotes the variance inflation factor. All variables are defined in Table 1. Sig. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3. The impact of AC characteristics on climate risk

Dependent Variables →	Climate risk proxied by physical risk					
Explanatory Variables↓	(1)	(2)	(3)	(4)	(5)	(6)
Cons.	0.072*** (0.003)	0.032*** (0.002)	0.092*** (0.013)	0.022*** (0.003)	0.071*** (0.002)	0.102*** (0.033)
AC_IND	- 0.085*** (0.022)					-0.125** (0.052)
AC_GEN		-0.035** (0.017)				-0.075** (0.037)
AC_EXP			-0.135** (0.062)			-0.165** (0.082)
AC_TEN				0.065** (0.028)		0.095** (0.048)
AC_DUM					-0.185** (0.082)	-0.225** (0.112)
ESG	-0.112** (0.055)	-0.042*** (0.015)	-0.162* (0.091)	-0.092* (0.051)	-0.112** (0.055)	-0.172** (0.085)
BS	0.521*** (0.146)	0.451*** (0.076)	0.571*** (0.196)	0.501*** (0.126)	0.521** (0.246)	0.571*** (0.176)
BI	-0.073** (0.029)	-0.052** (0.021)	-0.123*** (0.044)	-0.053** (0.026)	-0.071** (0.029)	-0.119** (0.059)
DUAL	0.095 (0.071)	0.055 (0.070)	0.245 (0.221)	0.175 (0.151)	0.195 (0.171)	0.125 (0.101)
CSR_COM	- 0.227*** (0.071)	-0.157** (0.071)	-0.277** (0.121)	-0.207*** (0.051)	-0.227** (0.111)	-0.277*** (0.101)
FS	0.294*** (0.092)	0.224*** (0.022)	0.344** (0.142)	-0.274*** (0.072)	-0.494** (0.212)	-0.354** (0.142)
FL	0.201** (0.094)	0.131** (0.064)	0.251* (0.144)	0.181** (0.074)	0.301*** (0.094)	0.231* (0.124)
FG	- 0.526*** (0.202)	-0.456*** (0.132)	-0.576** (0.252)	-0.506*** (0.182)	-0.226** (0.092)	-0.556** (0.232)
FP	-0.743** (0.356)	-0.673* (0.356)	-0.793* (0.406)	-0.723** (0.336)	-1.443* (0.830)	-0.773** (0.386)
<i>Year Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
<i>Industry Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
Mean (VIF)	1.79	1.81	1.83	1.67	1.73	1.97
R^2	0.174	0.177	0.162	0.171	0.169	0.192
<i>F-Value</i>	22.27***	23.21***	21.37***	22.09***	23.11***	26.66***
Obs.	2,862	2,862	2,862	2,862	2,862	2,862

Note. This table reports the regression results on the impact of AC characteristics on climate risk, which is proxied by physical risk. All variables are defined in Table 1. Standard errors are in parentheses below the coefficients. Sig. *** p<0.01, ** p<0.05, * p<0.1.

Table 4. The impact of AC characteristics on climate risk

Dependent Variables →	Climate risk proxied by transition risk					
Explanatory Variables↓	(1)	(2)	(3)	(4)	(5)	(6)
Cons.	0.097*** (0.026)	0.099*** (0.021)	0.096*** (0.023)	0.093*** (0.020)	0.101*** (0.026)	0.172*** (0.033)
AC_IND	-0.044** (0.022)					-0.114** (0.052)
AC_GEN		-0.073** (0.033)				-0.143** (0.063)
AC_EXP			-0.094*** (0.034)			-0.164*** (0.062)
AC_TEN				0.004** (0.002)		0.074* (0.042)
AC_DUM					-0.094*** (0.032)	-0.164** (0.072)
ESG	-0.073** (0.034)	-0.103* (0.054)	-0.123** (0.062)	-0.033* (0.018)	-0.123** (0.061)	-0.143** (0.067)
BS	0.422*** (0.047)	0.452* (0.077)	0.472*** (0.097)	0.082** (0.037)	0.472*** (0.097)	0.492*** (0.117)
BI	-0.066* (0.037)	-0.096* (0.055)	-0.112** (0.053)	-0.072*** (0.017)	-0.116* (0.067)	-0.136 (0.107)
DUAL	0.034* (0.018)	0.071* (0.041)	0.084* (0.047)	0.060* (0.033)	0.084* (0.048)	0.104 (0.088)
CSR_COM	- 0.128*** (0.028)	-0.158*** (0.058)	-0.178** (0.078)	-0.088** (0.042)	-0.178** (0.078)	-0.198** (0.098)
FS	0.195*** (0.037)	0.225*** (0.067)	0.245*** (0.087)	0.155*** (0.043)	0.245*** (0.087)	0.265** (0.107)
FL	0.102* (0.055)	0.132* (0.077)	0.152** (0.075)	0.062* (0.035)	0.152* (0.090)	0.172 (0.125)
FG	- 0.427*** (0.103)	-0.457*** (0.133)	-0.477*** (0.153)	-0.387** (0.163)	-0.477* (0.253)	-0.497*** (0.173)
FP	-0.644** (0.257)	-0.674** (0.287)	-0.694** (0.307)	-0.604*** (0.217)	-0.694** (0.307)	-0.714** (0.327)
<i>Year Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
<i>Industry Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
Mean (VIF)	1.73	1.71	1.74	1.77	1.73	1.91
R ²	0.198	0.192	0.189	0.194	0.196	0.199
F-Value	23.12***	23.15***	23.32***	23.47***	23.14***	25.33***
Obs.	2,862	2,862	2,862	2,862	2,862	2,862

Note. This table reports the regression results on the impact of AC characteristics on climate risk, which is proxied by transition risk. All variables are defined in Table 1. Standard errors are in parentheses below the coefficients. Sig. *** p<0.01, ** p<0.05, * p<0.1.

Table 5. Additional Analysis – High Carbon Intensive vs. Low Carbon Intensive Sectors

<i>Dependent Variables →</i>	<i>Physical Risk</i>	<i>Transition Risk</i>
<i>Explanatory Variables ↓</i>	<i>(1)</i>	<i>(3)</i>
<i>Panel A. High Carbon Intensive Sectors</i>		
<i>Cons.</i>	2.332*** (0.215)	2.548*** (0.301)
<i>AC_IND</i>	-1.587** (0.696)	-2.011** (0.983)
<i>AC_BGD</i>	-2.375** (0.964)	-2.509*** (0.913)
<i>AC_EXP</i>	-2.336** (0.937)	-2.661*** (0.873)
<i>AC_TEN</i>	-0.975* (0.564)	-1.054** (0.513)
<i>AC_DUM</i>	-1.096** (0.546)	-2.266** (0.976)
<i>Panel B. Low Carbon Intensive Sectors</i>		
<i>Cons.</i>	1.770*** (0.537)	1.683*** (0.525)
<i>AC_IND</i>	-0.027 (0.056)	-0.151 (0.096)
<i>AC_BGD</i>	-0.095* (0.053)	-0.147* (0.083)
<i>AC_EXP</i>	-0.076* (0.044)	-0.106* (0.061)
<i>AC_TEN</i>	-0.015 (0.094)	-0.085 (0.053)
<i>AC_DUM</i>	-0.176 (0.107)	-0.146 (0.096)

Note. This table shows the regression results on high carbon vs. low carbon intensive sectors. Year and Firm fixed effects as well as control variables are included to both models. All variables are defined in Table 1. Standard errors are in parentheses. Sig. *** p<0.01, ** p<0.05, * p<0.1

Table 6. Alternative Measure of Climate Risk

Dependent Variables → Climate risk proxied by carbon emission						
Explanatory Variables↓	(1)	(2)	(3)	(4)	(5)	(6)
Cons.	0.599*** (0.055)	0.560*** (0.044)	0.720*** (0.073)	0.507*** (0.049)	0.573*** (0.071)	0.408*** (0.065)
AC_IND	-0.091** (0.037)					-0.101** (0.042)
AC_GEN		-0.075** (0.032)				-0.095** (0.041)
AC_EXP			-0.176*** (0.064)			-0.214*** (0.082)
AC_TEN				-0.006** (0.003)		-0.005* (0.003)
AC_DUM					-0.112** (0.054)	-0.376*** (0.051)
ESG	-0.004** (0.002)	-0.005*** (0.002)	-0.004** (0.002)	-0.004** (0.002)	-0.004** (0.002)	-0.005*** (0.002)
BS	0.006 (0.010)	0.004 (0.010)	0.007 (0.011)	0.006 (0.010)	0.006 (0.011)	0.004 (0.010)
BI	-0.007** (0.003)	-0.008*** (0.003)	-0.006** (0.003)	-0.007*** (0.003)	-0.006** (0.003)	-0.009*** (0.003)
DUAL	0.051 (0.042)	0.049 (0.041)	0.052 (0.042)	0.058 (0.042)	0.050 (0.042)	0.057 (0.041)
CSR_COM	- 0.266*** (0.061)	-0.282*** (0.061)	-0.267*** (0.061)	-0.270*** (0.061)	-0.266*** (0.061)	-0.286*** (0.061)
FS	0.174*** (0.019)	0.180*** (0.019)	0.174*** (0.019)	0.179*** (0.019)	0.174*** (0.019)	0.184*** (0.019)
FL	-0.049 (0.090)	-0.020 (0.089)	-0.050 (0.090)	-0.046 (0.090)	-0.048 (0.090)	-0.018 (0.089)
FG	- 0.056*** (0.006)	-0.051*** (0.006)	-0.055*** (0.006)	-0.055*** (0.006)	-0.055*** (0.006)	-0.051*** (0.006)
FP	-0.165 (0.368)	-0.244 (0.364)	-0.188 (0.368)	-0.102 (0.368)	-0.175 (0.368)	-0.172 (0.366)
<i>Year Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
<i>Industry Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
R^2	0.184	0.201	0.187	0.185	0.186	0.203
<i>F-Value</i>	41.24***	47.36***	44.35***	41.85***	43.21***	51.43***
<i>Obs.</i>	2,392	2,392	2,392	2,392	2,392	2,392

Note. This table reports the regression results of an alternative measure of climate risk, which is proxied by carbon emission. All variables are defined in Table 1. Standard errors are in parentheses below the coefficients. Sig. *** p<0.01, ** p<0.05, * p<0.1.

Table 7: GMM Robust Regression on Physical Risk

Dependent Variables →	Climate risk proxied by physical risk					
Explanatory Variables ↓	(1)	(2)	(3)	(4)	(5)	(6)
P_Risk _(t-1)	0.038*** (0.002)	0.037*** (0.001)	0.048*** (0.007)	0.012*** (0.002)	0.406*** (0.017)	0.054*** (0.017)
AC_IND	-0.045** (0.022)					-0.066** (0.027)
AC_GEN		-0.018** (0.009)				-0.039** (0.019)
AC_EXP			-0.071** (0.033)			-0.087** (0.043)
AC_TEN				-0.044* (0.025)		-0.046* (0.025)
AC_DUM					-0.097** (0.043)	-0.118** (0.059)
ESG	-0.059** (0.029)	-0.022*** (0.008)	-0.085* (0.048)	-0.048* (0.027)	-0.059** (0.029)	-0.091** (0.045)
BS	0.274** (0.137)	0.217** (0.090)	0.301** (0.133)	0.234** (0.096)	0.174 (0.129)	0.201** (0.093)
BI	0.038 (0.035)	0.057 (0.041)	0.065* (0.033)	0.018 (0.014)	0.037** (0.015)	0.063** (0.031)
DUAL	0.050 (0.037)	0.029 (0.037)	0.129 (0.116)	0.092 (0.079)	0.103 (0.090)	0.066 (0.053)
CSR_COM	-0.119* (0.067)	-0.083** (0.037)	-0.146** (0.064)	-0.109** (0.047)	-0.119** (0.058)	-0.106** (0.053)
FS	0.145* (0.078)	0.118* (0.062)	0.181** (0.075)	0.104** (0.048)	0.260** (0.112)	0.186** (0.075)
FL	0.106** (0.049)	0.079* (0.044)	0.132* (0.076)	0.095** (0.039)	0.108* (0.059)	0.122* (0.065)
FG	-0.277* (0.156)	-0.220** (0.089)	-0.303** (0.133)	-0.166* (0.096)	-0.119** (0.048)	-0.293** (0.122)
FP	-0.391** (0.187)	-0.354* (0.187)	-0.417* (0.214)	-0.381** (0.177)	-0.759* (0.437)	-0.407** (0.203)
<i>Year Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
<i>Industry Effects</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>	<i>Yes</i>
<i>Wald Chi²</i>	332.87***	331.08***	333.21***	332.07***	334.75***	344.98***
AR (1) (<i>p-value</i>)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.007)
AR (2) (<i>p-value</i>)	(0.177)	(0.171)	(0.176)	(0.179)	(0.176)	(0.179)
Sargan test (<i>p-value</i>)	(0.107)	(0.101)	(0.103)	(0.116)	(0.113)	(0.146)
Hansen test (<i>p-value</i>)	(0.233)	(0.219)	(0.211)	(0.217)	(0.211)	(0.217)
Obs.	2,382	2,382	2,382	2,382	2,382	2,382

Note. This table reports the system GMM regression results on the impact of AC characteristics on climate risk, which is proxied by physical risk. All variables are defined in Table 1. Robust standard errors are in parentheses below the coefficients. Sig. *** p<0.01, ** p<0.05, * p<0.1.

Table 8: GMM Robust Regression on Transition Risk

Dependent Variables →	Climate risk proxied by transition risk					
Explanatory Variables ↓	(1)	(2)	(3)	(4)	(5)	(6)
T_Risk _(t-1)	0.051*** (0.014)	0.052*** (0.011)	0.050*** (0.012)	0.049*** (0.011)	0.059*** (0.015)	0.101*** (0.019)
AC_IND	-0.023** (0.012)					-0.067** (0.031)
AC_GEN		-0.038** (0.017)				-0.084** (0.037)
AC_EXP			-0.059** (0.028)			-0.096** (0.046)
AC_TEN				0.025* (0.013)		0.044* (0.025)
AC_DUM					-0.055** (0.023)	-0.096** (0.042)
ESG	-0.038** (0.018)	-0.054* (0.028)	-0.065** (0.033)	-0.017* (0.009)	-0.072** (0.036)	-0.084** (0.039)
BS	0.222* (0.125)	0.325** (0.131)	0.248* (0.131)	0.043** (0.019)	0.278** (0.114)	0.289** (0.117)
BI	-0.035* (0.019)	-0.051* (0.029)	-0.059** (0.028)	-0.038** (0.019)	-0.068* (0.039)	-0.080 (0.063)
DUAL	0.018* (0.009)	0.037* (0.022)	0.044* (0.025)	0.032* (0.017)	0.049* (0.028)	0.061 (0.052)
CSR_COM	-0.067* (0.035)	-0.083** (0.041)	-0.094** (0.041)	-0.046** (0.022)	-0.105** (0.046)	-0.116** (0.058)
FS	0.103** (0.049)	0.118* (0.065)	0.129* (0.076)	0.082* (0.043)	0.144** (0.061)	0.156** (0.063)
FL	0.054* (0.029)	0.069* (0.041)	0.080** (0.039)	0.033* (0.018)	0.089* (0.053)	0.101 (0.074)
FG	0.225** (0.104)	0.241** (0.107)	0.251** (0.101)	0.204** (0.086)	0.281* (0.149)	0.292* (0.152)
FP	-0.329** (0.135)	-0.355** (0.151)	-0.365** (0.162)	-0.318** (0.134)	-0.408** (0.181)	-0.420** (0.192)
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
Industry Effects	Yes	Yes	Yes	Yes	Yes	Yes
Wald Chi ²	246.12***	242.10***	242.88***	248.19***	242.88***	258.19***
AR (1) (p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.006)
AR (2) (p-value)	(0.111)	(0.119)	(0.123)	(0.117)	(0.123)	(0.117)
Sargan test (p-value)	(0.216)	(0.201)	(0.212)	(0.208)	(0.212)	(0.218)
Hansen test (p-value)	(0.313)	(0.317)	(0.317)	(0.309)	(0.317)	(0.409)
Obs.	2,382	2,382	2,382	2,382	2,382	2,382

Note. This table reports the system GMM regression results on the impact of AC characteristics on climate risk, which is proxied by transition risk. All variables are defined in Table 1. Robust standard errors are in parentheses below the coefficients. Sig. *** p<0.01, ** p<0.05, * p<0.1.

Table 9. Propensity Score Matching & Entropy Balancing Estimations

<i>Dependent Variables →</i>	<i>Physical Risk</i>	<i>Transition Risk</i>
<i>Explanatory Variables ↓</i>	<i>(1)</i>	<i>(3)</i>
<i>Panel A – Propensity Score Matching</i>		
<i>Cons.</i>	0.742*** (0.050)	0.872*** (0.023)
<i>AC_IND</i>	-0.097* (0.051)	-0.127* (0.069)
<i>AC_BGD</i>	-0.101* (0.052)	-0.131** (0.058)
<i>AC_EXP</i>	-0.091** (0.043)	-0.121** (0.057)
<i>AC_TEN</i>	-0.085 (0.074)	-0.088* (0.051)
<i>AC_DUM</i>	-0.078* (0.046)	-0.108* (0.064)
<i>Panel B – Entropy Balancing Approach</i>		
<i>Cons.</i>	1.173*** (0.087)	0.981*** (0.089)
<i>AC_IND</i>	-0.128** (0.061)	-0.237*** (0.041)
<i>AC_BGD</i>	-0.131** (0.058)	-0.239*** (0.052)
<i>AC_EXP</i>	-0.147** (0.067)	-0.231** (0.053)
<i>AC_TEN</i>	-0.099* (0.056)	-0.197** (0.079)
<i>AC_DUM</i>	-0.108* (0.064)	-0.122** (0.061)

Note. This table reports the regression results from propensity score matching and entropy balancing methods. Control variables, firm, and year fixed effects are included to both models. All variables are defined in Table 1. Standard errors are in parentheses. Sig. *** p<0.01, ** p<0.05, * p<0.1

4. CHAPTER 3 - A BIBLIOMETRIC-BASED ANALYSIS OF BOARD OF DIRECTORS AND INNOVATION

In this chapter, I expanded my primary research focus of corporate governance and climate risk by exploring its connection with innovation. The reason is that corporate governance, when combined with environmental initiatives, enhances innovative performance (Zhang *et al.*, 2020). Furthermore, integrating corporate governance with climate change issues can drive eco-innovation (Minhas *et al.*, 2024).

Therefore, to gain valuable insights for future research on the interplay between corporate governance, climate risk, and innovation, a bibliometric analysis is conducted on the board of directors and innovation. This analysis serves as a foundational step in identifying key research trends and potential gaps. It also provides a basis for further exploration of these interconnected topics, contributing to both theoretical advancements and practical implications.

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4.1. Introduction

The board of directors (BOD) contributes to the organization not only as a monitoring mechanism but also as a source of support and assistance in decision-making (Adams and Ferreira, 2007). Therefore, the board of directors receives significant attention in improving performance and mitigating agency conflicts. Numerous board attributes and process variables

can result in the implementation of an idea, service, process, structure, system or product that is new to the predominant organizational practice – referred to as the board of directors and innovation model (Jaskyte, 2012).

Initially, the research between board and innovation accounted for the inside and outside directors (Hill and Snell, 1988; Baysinger, Kosnik and Turk, 1991). However, with time, other board characteristics such as size, independent directors, duality, gender, knowledge and professional diversity or interconnections outside firms are also studied (Mukarram, Ajmal and Saeed, 2018; Hernández-Lara and Gonzales-Bustos, 2019). Apart from these, various board characteristics are emerging with the advancement in the field of research. For instance, board interlocks and ambidexterity are emerging topics that can act as a catalyst for innovation in an organization.

As far as previous studies are concerned, it is hard to generalize the results based on the varying sample and the context it has been studied. Likewise, the board of directors is a wide concept and most of the studies focus on a single aspect such as board size or duality, or the target variables are defined differently. Based on the premise that the board of directors indeed causes innovation, whether the interrelated concepts related to this concentrated topic are further researchable or not. Therefore, this study aims to assess the expanding body of knowledge related to the board of directors and innovation. This aim is supplemented by conducting a bibliometric analysis in terms of important studies and highlighting the current state of development in this area and the possible research path for further execution.

The analysis highlights that limited studies exist that identify innovation in the business based on the capabilities of the board of directors. Such as board characteristics and CEO characteristics. Moreover, there is a dearth of literature that examines the impact of the minority group on the board in terms of innovation. According to the critical mass theory when a

minority group on board reaches a certain critical mass, there is an innovation due to the qualitative change in the group's interaction (Torchia, Calabrò and Huse, 2011). Lastly, environmental innovation can also be explored in terms of innovation as an avenue for further research.

The paper is structured in the following way: the next section highlights the literature review. Section 3 is about the research methodology. Section 4 presents descriptive results using bibliometric analysis. Section 5 explores the main topics emerging from the dataset. Lastly, section 6 is about results, conclusion, limitations and avenues for future research.

4.2. Literature review

Various board characteristics are evaluated in terms of innovation. Such as, board diversity was found to enrich the decision-making related to innovation (Wang, 2011). Also, board size is one of the widely used determinants of firm innovation, explaining positive and negative relationships (Sierra-Morán *et al.*, 2021). On one hand, a larger board can have a positive impact on innovation, as it can accommodate more agents for innovation, such as key scientists (Lacetera, 2001; Shapiro *et al.*, 2015).

While on the other hand, empirical evidence suggests that board size does not have a significant impact on innovation (Bianchi Martini, Corvino and Rigolini, 2012; Valencia, 2018). According to Hill and Snell (1988), firms with inside directors tend to innovate more, in contrast to outside directors who diversify their strategies. This is following other empirical studies claiming that the effect of inside directors is positive for innovation (Chouaibi and Jarboui, 2012). However, Lacetera (2001) did not find the presence of internal directors influencing innovation. Hoskisson, Hitt, Johnson, and Grossman (2002) find evidence that the percentage of inside directors is important for internal innovations, while the percentage of outside directors is important for external innovation. Director independence is found to be

positively linked with innovation in various previous studies (Sena *et al.*, 2018; Sharma, Jhunjhunwala and Sharda, 2018), suggesting that boards be more assertive with the presence of independent directors (Ashwin, Krishnan and George, 2016). Conversely, it was argued that due to the lack of knowledge related to a firm's specific needs of independent directors, innovation could be hindered (Blibech and Berraies, 2018). According to Hoskisson *et al.*, (2002), stock options for board members were found to have a positive impact on internal innovation in the form of product generation.

Another important concept related to BOD is duality, which means that when a single person holds more than one significant position in a company, such as chairman and CEO. Similar instances could limit long-term risky strategies such as innovation (Kor, 2006). This is the reason the agency principle deters such behavior in the organization. Moreover, having separate individuals for the key positions such as CEO and Chairman turns out to be positive for investments in risky strategies driving innovation (Hill and Snell, 1988). Other studies indicate the adverse impact on investments in innovation when there is duality on the board (Blibech and Berraies, 2018). Conversely, some studies also show that the separation of such roles turns out to be negative for innovation (Sharma, Jhunjhunwala and Sharda, 2018; Valencia, 2018). Lipton and Lorsch (1992) proposed that more board meetings indicate more important investment opportunities taken up such as innovation. The reason is that board meeting allows sharing of not only technical, but also personal information. However, more board meetings may also cause difficulty in reaching an agreement on strategic decisions related to innovation and also results in higher costs such as directors' travel expense, meeting fees and even managerial time (Vafeas, 1999).

Miller and Triana (2009) found a positive relationship between gender diversity on board and expenditure on innovation. On the flip side, Galia and Zenou (2012) found a positive relationship between board gender diversity and marketing innovation, but a negative

relationship between gender diversity and product innovation. Empirical evidence also suggests that directors' links with other organizations result in knowledge and experience sharing and could have a positive impact on joint innovation (Wincent, Anokhin and Örtqvist, 2012). Directors' tenure could also harm innovation. The reason is that directors lose independence when they spend a long time in the organization and so they are lesser effective in overseeing and promoting innovation strategies. Moreover, long tenure may be associated with adherence to established norms and therefore the directors may be more reluctant to change (Bravo and Reguera-Alvarado, 2017).

4.3. Research Methods

This study adopts a bibliometric approach to study the literature surrounding board and innovation. The bibliometric analysis uses a quantitative approach to describe, evaluate and monitor the published research to highlight meaningful results for the intended user. It guides the researcher about the most influential work and also maps the research fields avoiding subjective bias (Zupic and Cater, 2015). Moreover, this technique is useful because it allows an unbiased and transparent review of the literature.

Co-Occurrence Network Analysis, Co-Citation Network Analysis and Thematic Map are used to analyze the current body of research by identifying the key clusters and important interconnections. The co-occurrences of two words in the same article are an indicator of how these two concepts are related to each other. Also, two keywords co-occurring within the same paper show the interlink among topics to which they refer. Hence, the presence of various co-occurrences among the pair of words indicates a strategic alliance towards the specific research theme (Cambrosio *et al.*, 1993) and they can be used to understand the conceptual structure of the research field (Lamboglia *et al.*, 2020).

Citation analysis uses quantitative measures of the number of publications and number of citations and co-citations as proxies of the influence of various sources in a research discourse (Culnan, 1986). Whereas co-citation is an analysis of scientific literature based on the citations constrained in the scientific papers (Cambrosio *et al.*, 1993) and it is the best-known method for grasping cognitive and social structures (Callon *et al.*, 1983). These techniques produce maps showing linkages between researchers who cite each other's work, or, to be more precise, who are cited together in the same paper (Cambrosio *et al.*, 1993). It also identifies papers considered highly relevant for discourse in the literature (Scornavacca *et al.*, 2020). Hence, co-citation analyses are dynamic due to the updates in the research area and changes in the co-citation frequencies in a certain field. The database used to conduct this study is Scopus and the objective is achieved through descriptive and social network analysis. The bibliometric analysis is carried out using R and bibliometric package and VOS Viewer. These social network analysis tools are used to obtain citation and keywords-based measures of literature sources.

Literature selection is very important for bibliometric studies. The reason is that it ensures validity and consistency. Therefore, to select the literature and analyze the results following four steps were performed.

1. Identification of relevant articles in the Scopus.
2. Incorporating restrictions on the first result derived.
3. The refining phase is by reading the title, keywords and abstract.
4. Cleaning and standardizing the keywords.

4.3.1 Data collection and refinement of results:

The first step involved the identification of relevant articles in the Scopus. Scopus was chosen as it is a well-known database in terms of extensive papers from peer-reviewed journals. Also,

it offers high-impact papers and is considered a reliable source in academia. The process related to the selection of research query started from the literature and intending to select all possible papers by defining a broad research query. So, the research query “Board” AND “Innovation” was devised to perform a search in titles, abstracts and keywords generating a total of 5,404 results. The second step involved incorporating relevant restrictions considering quality control. The search was limited to the last ten years, subject area of business and management, document type: article and language in English. As a result, the sample consisted of 379 articles. We selected articles as a document type omitting books, chapters and non-refereed publications because it is considered validated knowledge with significant impact in the field (Keupp, Palmié and Gassmann, 2012). The subsequent step was refining the sample by reading the title, keywords and abstract. Keywords were manually inserted into the papers without it. So, at the end of the removal of false positives, the data sample was composed of 119 relevant articles.

The last step before proceeding to the data analysis was cleaning and standardizing the keywords. This process consisted of homogenizing the keywords that indicated the same topic, but with different names. Table 1 shows the consolidation of the most recurring keywords.

[Insert Tables 1 Here]

4.4. Data Analysis

The data analysis involved two steps:

1. The analysis of descriptive performance indicators using publication trend, most productive journal, citation trend, most productive author and most productive countries.

2. The analysis of the conceptual structure of the dataset, exploring the main theme discussed in the corpus, through Author Keywords Co-Occurrence Network Analysis, Co-Citation Network Analysis and Thematic Map.

4.4.1. Descriptive Bibliometric Analysis

The descriptive analysis is presented in five ways: the publication trend, most productive journal, citation trend, most productive author and most productive countries.

4.4.1.1. Publication Trend

According to Figure 2, the last ten years starting from 2013 experienced an increase in publications from almost 6 to 15 per year. The largest increase in publications is from 2016 to 2018 from 5 to 15 publications per year and from 2019 to 2021 from 10 to 30 publications per year. Whereas the greatest decrease was from 2018 to 2019. The period between 2019 and 2021 appears to be the most productive experiencing the largest increase in publications.

[Insert Figure 1 Here]

4.4.1.2. Most Productive Journal

Studies related to BOD and innovation are published in various journals. Figure 3 shows the ranking of the twenty most productive journals by analyzing the number of publications in a specific journal, one can identify the most productive journal and its influence in terms of specific discipline. Figure 3 presents the most productive journal which is the international journal of innovation management publishing six documents. The second highest is the European Journal of innovation management with five documents.

[Insert Figure 2 Here]

4.4.1.3. Citations Trend

The citation trend shows how many documents are published in a specific discipline in a year. Also, shows the popularity and influence of the subject matter in the scientific community. Figure 4 shows the highest citations which is almost 6 in 2019. While the lowest citations are in 2020 which is three. The citation trend shows the increasing popularity of the topic for a decade.

[Insert Figure 3 Here]

4.4.1.4. Most Productive Author

Figure 5 illustrates the authors' production over time-related to the board and innovation. The size of the dot and number illustrates the number of published articles. Jaskyte K. is the most productive author with four documents published in this discipline from 2013 to 2022. On the second rank, four authors are publishing three articles each.

[Insert Figure 4 Here]

4.4.1.5. Most Productive Country

We computed the research output from different countries in our dataset. Figure 6 shows the impact and influence of the country in the scientific community related to our topic. The country that ranks first in terms of contribution in the field of board and innovation is China with almost 65 articles per year. The USA ranks second with almost 50. Italy and Spain are in the third-ranking with almost 30 articles.

[Insert Figure 5 Here]

4.4.2. Bibliometric Analysis

The analysis of the topic is based on the Author's Keywords Co-Occurrence Network Analysis, Co-Citation Network Analysis and Thematic Map.

4.4.2.1. Author Keywords Co-Occurrence Network Analysis

Author keywords co-occurrence network analysis can provide further evidence regarding our discourse. This network analysis shows the connection between two concepts with the help of a tie between the nodes. Keeping the minimum number of occurrences at 3, the occurrence network of 34 keywords was created as illustrated in Figure 7. The link between the two keywords shows their existence in the same publication (co-occurrence). The thickness of the node reflects the number of contributions in which the pair appears.

The red cluster shows the connection of BOD with innovation and various concepts of corporate governance, such as female directors, independent boards, gender diversity, exploitative innovation and explorative innovation. Moreover, the blue cluster shows the primary connection between corporate governance and innovation. And a secondary connection with family firms, product innovation and dynamic capabilities. The green cluster focuses on Board diversity and Innovation, while also including important concepts of board interlocks, CEO characteristics, innovation performance, the board size, board independence and board characteristics.

The analysis suggests that the board of directors, corporate governance and innovation are concentrated areas of research with various studies highlighting their inter-relationship. However, there are limited studies in terms of board characteristics, board independence, board interlocks and board size in terms of innovation.

[Insert Figure 6 Here]

4.4.2.2. Co-citation Network Analysis

To identify high-impact studies co-citation analysis is performed. Co-citation analysis allows us to understand the emergence of knowledge in the context of authors. This analysis technique uses a quantitative measure of the number of citations. The thickness of the node represents a

reference cited by a paper in the dataset. The larger the node the more important is the reference concerning the subject. As it appears in Figure 8, the thicker node represents co-citation pairs that are more frequent than others. The most apparent co-citation pair links the paper of Balsmeier, B. (2017), Zona, F. (2013) and Zuraik, A. (2019).

[Insert Figure 7 Here]

4.4.2.3. Thematic Map

To gain further insight into the topic, we perform a thematic analysis. The thematic map shows clusters of keywords and their interconnections. The co-occurrence of the keywords in the dataset allows the algorithm to identify the clusters (Scornavacca *et al.*, 2020). In the Thematic map, topics are plotted in four quadrants in terms of two parameters: density and centrality.

The thematic analysis performed on the current dataset shows clusters mainly in the first and second quadrants. According to Figure 9, CEO characteristics, innovation performance, board interlocks, family firms and agency theory are central and developed areas as they appear in the upper-right quadrant and are named motor-themes. Themes in the lower-right quadrant are relevant but still are in the process of development. Although these concepts are well-established but are pertinent to the theoretical framework of the research field. Such as, innovation, board of directors and corporate governance.

[Insert Figure 8 Here]

4.5. Conclusion

This bibliometric analysis-based study is motivated by the fact that the board of directors plays an important role in innovation in the organization. Also, the board of directors is one of the important components driving innovation and improving monitoring mechanisms in an organization. However, the board of directors is a combination of concepts that individually

drive the board to perform effectively toward the goals of the organization. Many of these components have already been discussed by scholars in different dimensions and contexts. However, considering the evolving nature of this important topic, it was important to find the state of development surrounding the topic of the board of directors and innovation.

So, the relevant articles from Scopus are analyzed to examine the existing studies and the emerging topics related to this body of knowledge. This study adds to the literature concerning board of directors and innovation aiming to highlight the concentrated areas and those areas which have limited studies. The results show that the dataset is based on three main areas board of directors, innovation and corporate governance. Growing academic interest in these topics can be inferred based on publication and citation trends.

Furthermore, our results have some practical implications, such as, buttresses that the board of directors supports innovation and firms need to be aware that environmental innovation is what will be more important in the future with a global drive towards sustainability. Secondly, apart from the concentrated variables such as independent directors, board size, and CEO characteristics. Ambidexterity is an important skill needed in strategic management to expand the board's vision and generate new ideas for the development of new products and patents keeping in view the market demand. Moreover, board interlocks promote dialogue and information exchange resulting in the promotion of investment innovation. Overall, innovation can be achieved with the right balance of board with diverse capabilities and skills which is more detrimental in this era.

There is also a limitation of the current study that it only uses the Scopus database to analyze papers that belong to the discipline of business, management and accounting. So, it could be extended to journals indexed in the Web of science. Moreover, this study also highlights important areas towards which this study could be extended such as board

characteristics, board interlocks, ambidexterity, exploitative innovation, and environmental innovation. Hence, proposing an avenue for further research.

Tables and Figures:

Table 1: Keywords

Original Keywords	Revised Keywords
Board	Board of directors
board composition	
board members	
board of directors	
boards	
boards of directors	
board attributes	Board characteristics
board behavior	
board capabilities	
board characteristics	
board cultural diversity	Board diversity
board diversity	
board female participation	
board gender diversity	
boardroom gender diversity	
ceo	CEO characteristics
ceo duality	
ceo expertise	
ceo hometown identity	
ceo origin	
ceo overconfidence	
ceo successors	
ceo-duality	

Annual Scientific Production

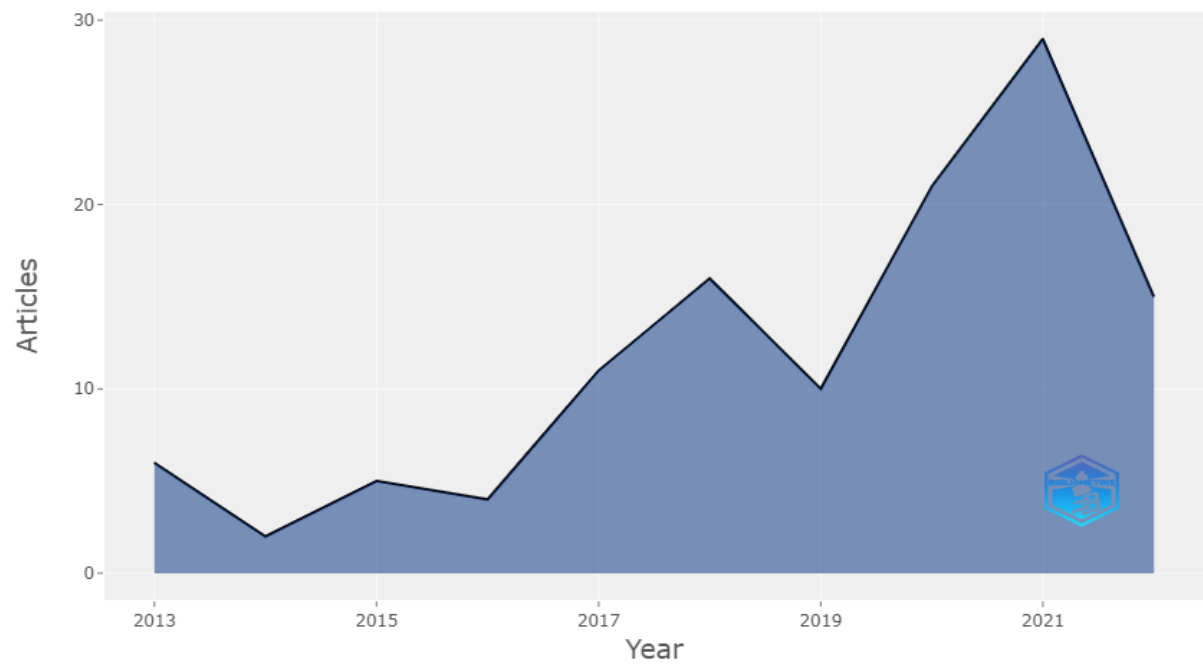


Figure 1: Annual Scientific Production

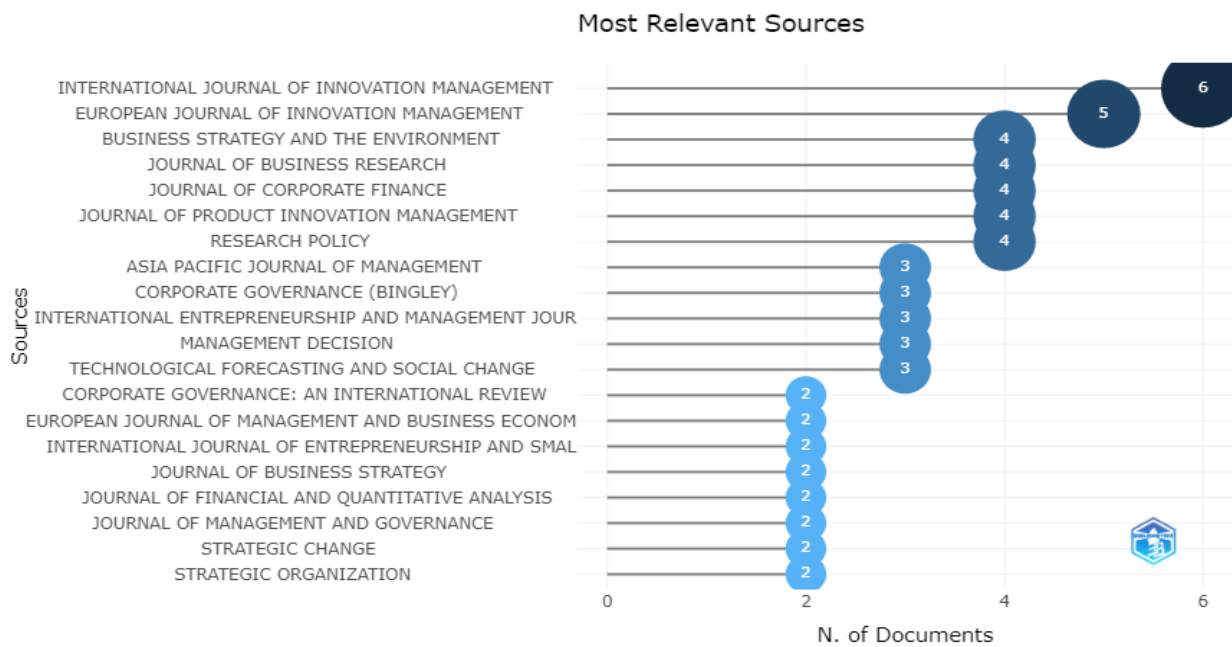


Figure 2: Most Relevant Sources

Average Article Citations per Year

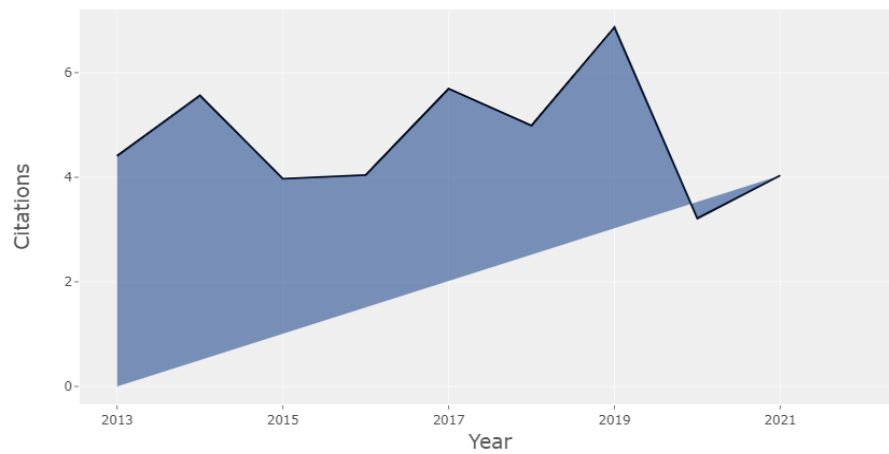


Figure 3: Average article citations per year

Most Relevant Authors

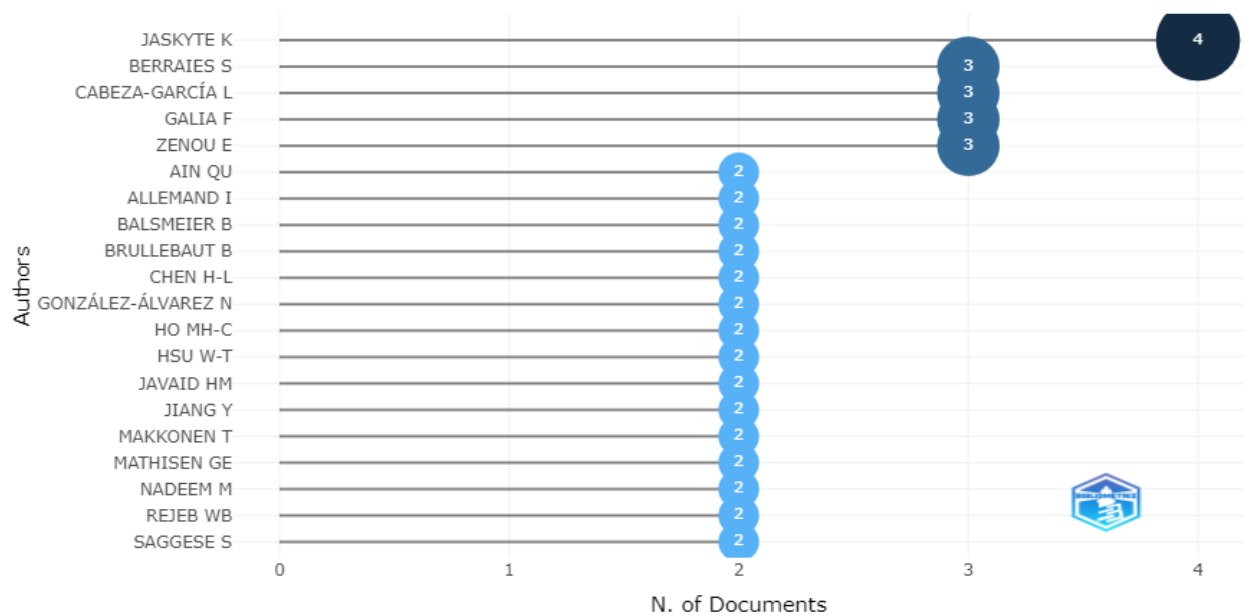


Figure 4: Most relevant authors

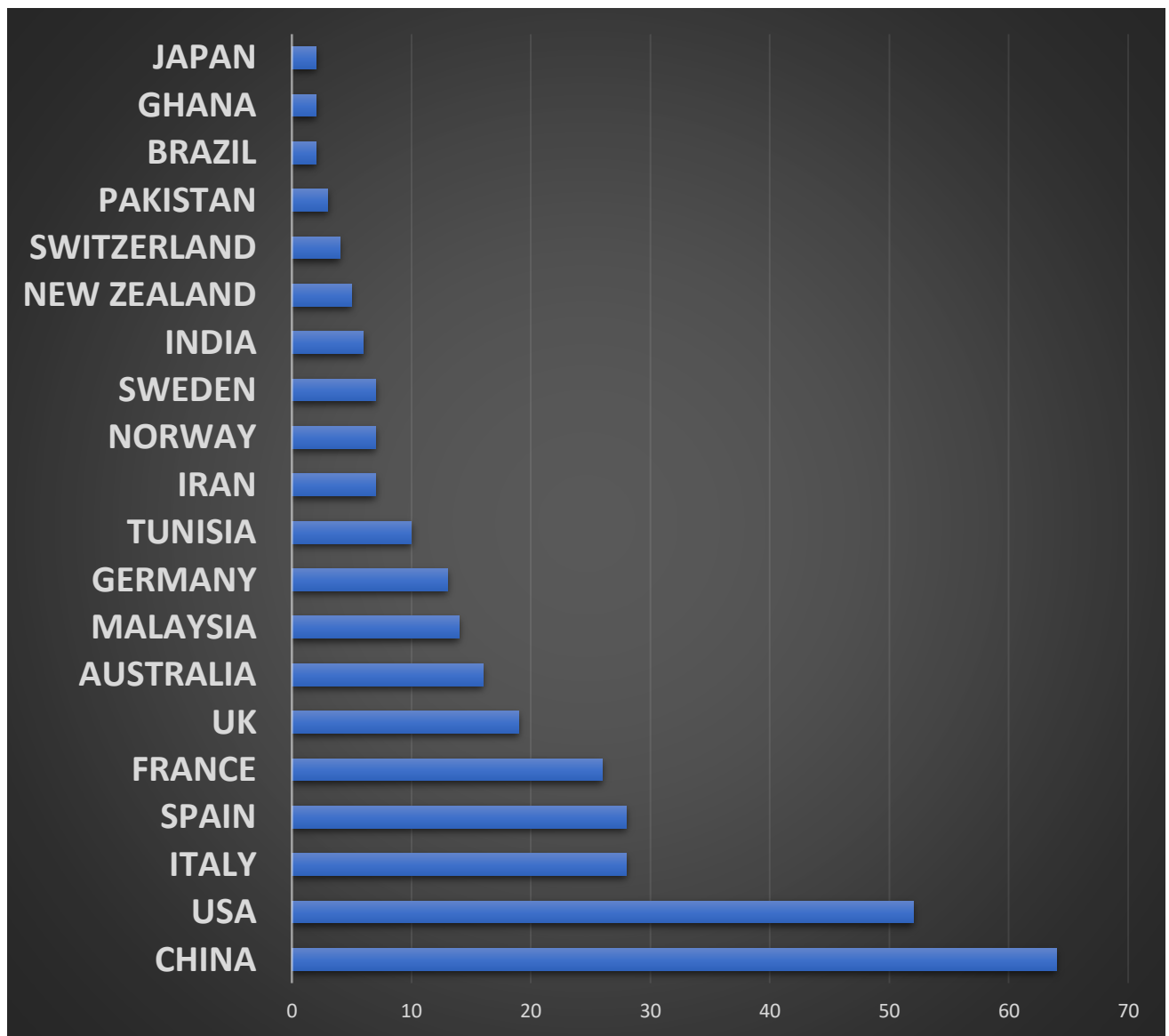


Figure 5: Most productive country

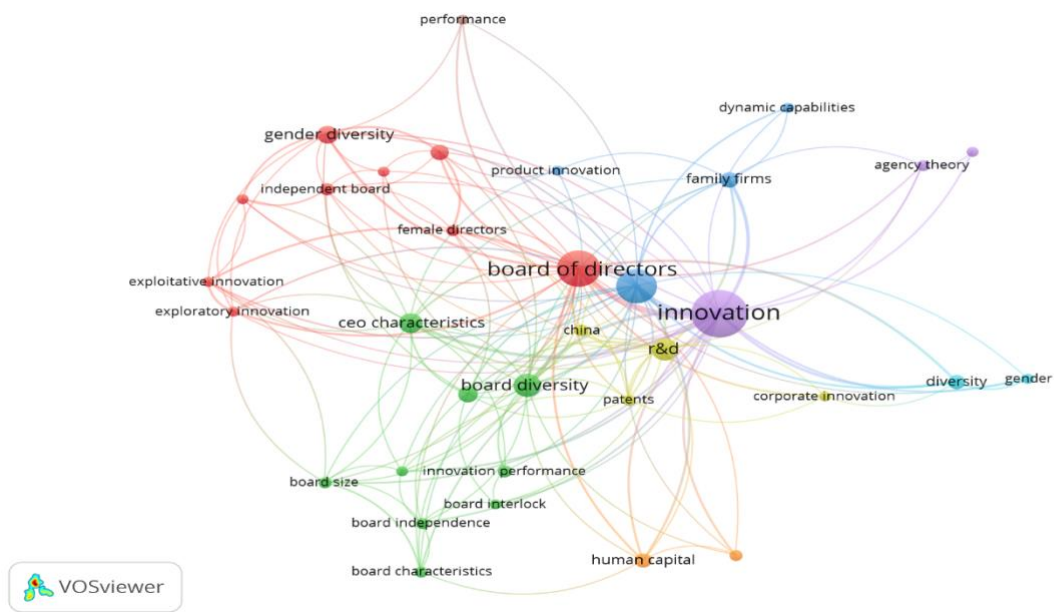


Figure 6: Keywords co-occurrence network

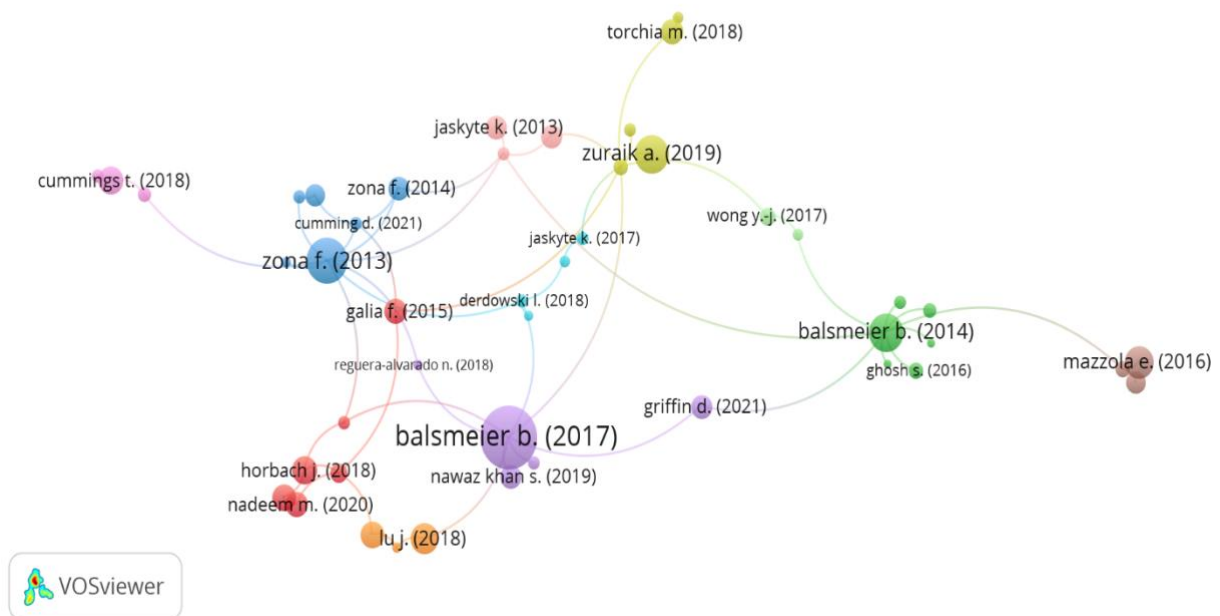


Figure 7: Co-citation network

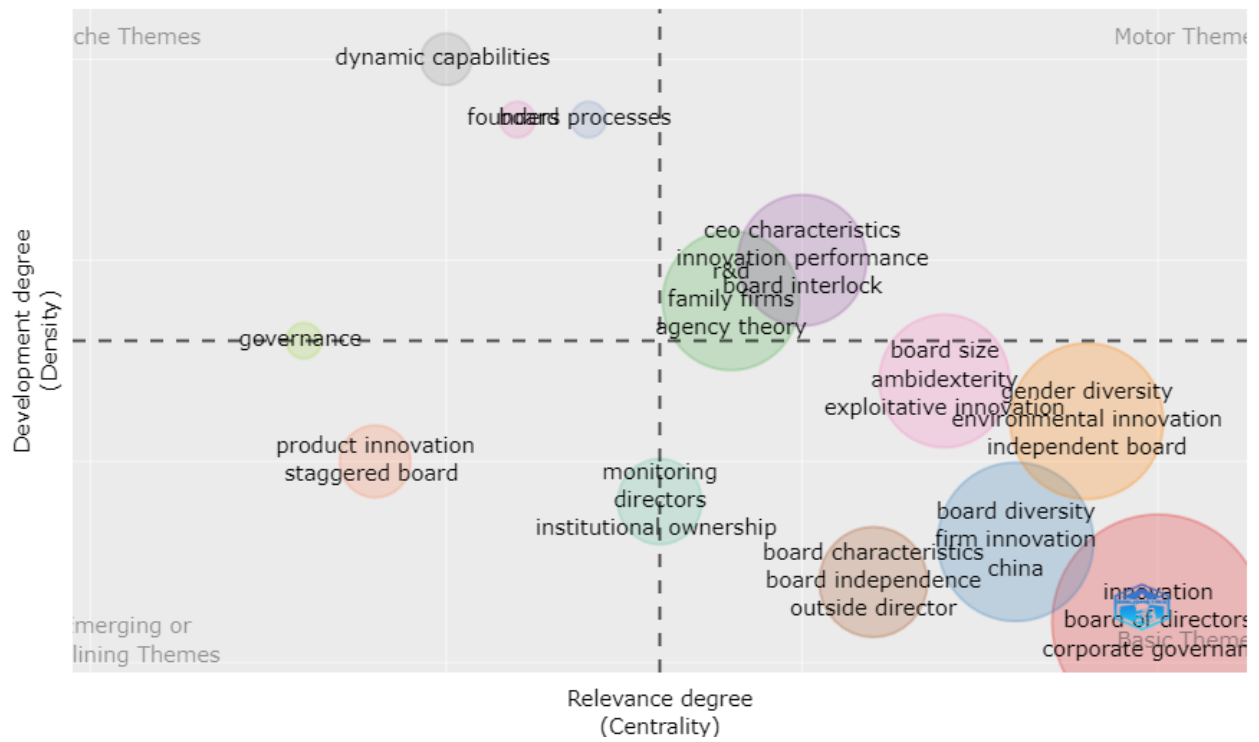


Figure 8: Thematic Map

5. CONCLUSION

5.1. Findings

This thesis provides an in-depth exploration of the intersections between corporate governance, climate risk, and innovation, making a valuable contribution to global sustainability challenges. Grounded in corporate governance principles and agency theory, the research investigates governance mechanisms—such as governance quality, governance committees, audit committee characteristics, and the board of directors—and their relationship with climate change risk, disclosure, and innovation.

Employing advanced quantitative methods, including regression analysis, AI, and bibliometric techniques, the study aligns with SDG 13: Climate Action. It utilizes datasets from French SBF-120 firms (2012–2022) and U.S. S&P 500 firms (2017–2022). For French firms, CCRD are analyzed using text mining of annual reports, with governance quality data sourced from ESG group of ISS database. U.S. firms' climate risks are assessed using BERT applied to 10-K filings from the EDGAR database. Audit committee characteristics and control variables are drawn from Refinitiv Eikon, with outliers handled through winsorization. Bibliometric analyses, including Co-Occurrence Network Analysis, Co-Citation Network Analysis, and Thematic Mapping, identify critical research trends and connections. Using Scopus as the primary database and tools like R, the bibliometric package, and VOS Viewer, the study reveals valuable insights into the literature's structure and dynamics.

Key findings highlight that CGQ significantly enhances CCRD, with governance committees reducing agency conflicts and improving transparency. AC characteristics, such as independence, gender diversity, and expertise, are found to mitigate physical and transition

risks. However, a positive association between AC tenure and climate risk underscores the complexities within governance structures. These findings offer actionable strategies for enhancing AC effectiveness, strengthening governance frameworks, and supporting robust climate governance practices. The bibliometric analysis highlights the untapped potential of board characteristic including interlocks, ambidexterity in fostering innovation. In particular, the study underscores the importance of environmental innovation as firms navigate the global shift toward sustainability.

5.2. Contribution and Implications

This thesis makes several contributions to the literature. First, following the recommendations of the TCFD (TCFD, 2017), an index measuring CCRD using text mining is developed. Second, the research employs a comprehensive governance quality index based on four dimensions to evaluate the impact of governance quality on CCRD. Third, the analysis of AC characteristics and their relationship with climate risk provides a new perspective on how effective governance mechanisms directly influence climate risk management.

In addition, this thesis advocates for AC characteristics such as independence, gender diversity, and expertise to ensure well-rounded and balanced decision-making for effective corporate governance. By promoting these traits, the research addresses the growing need for diverse and skilled oversight bodies capable of navigating the complexities of climate governance. Furthermore, the thesis contributes to SDG 13 by bridging the gap between firms and markets in sustainability reporting. Effective sustainability reporting enhances transparency and accountability, enabling better decision-making by stakeholders relying on comprehensive environmental impact information. The research also advances the use of efficient NLP techniques to account for climate risk based on 10-K filings. Moreover, it

underscores the role of the board of directors in driving innovation, emphasizing the increasing importance of environmental innovation as the global push toward sustainability intensifies.

The implications of this research are far-reaching. For businesses, the findings underscore the importance of adopting robust governance mechanisms to enhance climate risk management and drive innovation. Policymakers can leverage these insights to design frameworks that encourage transparency, accountability, and diversity within governance structures. For researchers, the study opens new avenues for exploring the interplay between governance, climate risk, and innovation, highlighting the potential of AI and bibliometric techniques in advancing this field.

5.3. Limitations and future research

Despite its contributions, this thesis has certain limitations. The sample focuses on large firms in the Euronext Paris SBF 120 and U.S. S&P 500 indexes, which predominantly include organizations with significant resources to invest in climate projects. This focus limits the generalizability of the findings to smaller firms. Additionally, the analysis is based on a limited timeframe, offering a snapshot of recent trends but potentially overlooking long-term patterns.. Another limitation is the exclusive reliance on the Scopus database to analyze papers in the business, management, and accounting disciplines. Expanding the analysis to journals indexed in the Web of Science could provide a more comprehensive view. Future research could address these limitations by including a broader range of firms, extending the timeframe, and incorporating additional data sources.

In conclusion, this thesis advances the understanding of corporate governance as a critical enabler of sustainability and innovation. By addressing key gaps in the literature and employing innovative methodologies, it provides a foundation for future research and practical

applications in the quest for a sustainable and resilient global economy. The findings reiterate the urgency of aligning corporate governance practices with climate action goals, ensuring that organizations are well-equipped to address the challenges of a rapidly changing world.

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