

POLYTECHNIQUE MONTRÉAL

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**Assessment of Corporate Climate Mitigation Targets from a (Responsible)
Investor Perspective**

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présentée par **Anne-France BOLAY**

en vue de l'obtention du diplôme de *Philosophiæ Doctor*

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DEDICATION

To all the person with unknowns and chaos.

*"The important thing is to not stop questioning. Curiosity has its own reason for existing."
"As our circle of knowledge expands, so does the circumference of darkness surrounding it."*

Albert Einstein

"Show me a sane man and I will cure him for you."

Carl Jung

"You have to go on and be crazy. Craziness is like heaven."

Jimi Hendrix

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It is the end, one that seemed never to come, but finally has!

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RÉSUMÉ

Pour réussir la transition vers une économie à faibles émissions de carbone afin d'atténuer les risques liés aux changements climatiques, la participation d'acteurs non étatiques, tels que les investisseurs, est cruciale. Les investisseurs exigent de plus en plus des approches prospectives pour évaluer et comparer la performance des entreprises face aux risques liés à la transition climatique. Toutefois, ils ont du mal à trouver des méthodes et des indicateurs fiables et utiles à la décision.

Au-delà de l'empreinte carbone actuelles des entreprises, les investisseurs doivent évaluer les actions et la capacité des entreprises à transitionner pour anticiper leur empreinte carbone future. Une information clé reflétant comment les entreprises se projettent dans l'avenir est leurs cibles de réduction d'émissions carbone. Cependant, comparer les cibles de différentes entreprises est complexe, car les paramètres utilisés pour établir ces objectifs peuvent varier considérablement d'une entreprise à l'autre (cible en émissions absolues ou d'intensité, ambition, *scope* couvert, année de référence et année cible). Les études précédentes sur l'ambition ou la progression des cibles des entreprises montrent des lacunes similaires dans leurs méthodes, ce qui empêche une large applicabilité à dans les secteurs, une comparabilité cohérente entre les entreprises, et l'analyse d'un ensemble limitée de paramètres déterminant le progrès des cibles. Cela aboutit à une compréhension partielle des cibles de réduction des émissions carbone des entreprises. De plus, le nombre croissant d'entreprises fixant des cibles soulève des inquiétudes quant à leur fiabilité, ce qui remet en question leur crédibilité.

Ce projet de thèse vise à fournir une évaluation approfondie et exhaustive des cibles de réduction des émissions carbone des entreprises en développant des méthodologies et des indicateurs permettant de comparer de manière rigoureuse et systématique différents types de cibles de réduction des émissions carbone pour des entreprises dans différents secteurs. Ce projet de recherche comprend six objectifs spécifiques, qui ont conduit à trois articles scientifiques traitant chacun d'un sujet principal d'intérêt relié aux cibles des entreprises: (1) l'ambition, (2) la progression, et (3) la fiabilité. Ultimement, ce projet de recherche vise à améliorer la compréhension des cibles des entreprises afin de mieux informer les décisions des investisseurs.

La première contribution de ce projet de recherche est le développement d'un processus d'harmonisation qui transforme les cibles afin qu'ils aient le même *scope* d'émissions, la même période et la même métrique, fournissant une structure d'analyse cohérente et consistante pour

comparer des cibles avec différents paramètres. Deuxièmement, ce processus d'harmonisation a permis de calculer des seuils de référence sectoriels prospectifs en émissions absolues et en intensité carbone. Ceux-ci incluent environ 1 000 entreprises dont les cibles couvrant des émissions de *scope* 1 et/ou 2 dans 13 secteurs. Ce processus limite la surestimation de l'ambition des cibles en évitant l'inclusion de parties déjà atteintes en raison du choix de l'année de référence par les entreprises, et souligne les cibles déjà atteintes. La troisième contribution est le développement d'un indicateur de progression des cibles, qui atténue les limites des indicateurs existants (1) en intégrant le temps restant pour atteindre une cible, (2) en tenant en compte de la forte variabilité constatée dans les progressions, et (3) en quantifiant les résultats de la progression plutôt qu'en étiquetant simplement les objectifs comme « en bonne voie » ou « pas en bonne voie ». Quatrièmement, 19 déterminants clés expliquant la progression des entreprises vers leurs cibles ont été identifiés grâce à l'analyse de 120 déterminants pour environ 1 500 cibles couvrant les *scopes* 1 et 2 de 1 000 entreprises. Cette analyse, qui utilise l'indicateur de progression développé, a révélé des informations précieuses sur les bonnes et mauvaises pratiques des entreprises, a jeté un nouvel éclairage sur les cibles ambitieuses, et a mis en évidence des orientations de recherche futures. Enfin, l'évaluation des inconsistances dans les données carbones déclarées par les entreprises, grâce au développement d'indices d'inconsistance, a mis en évidence des problèmes importants concernant la fiabilité des émissions de l'année de référence couvertes par les cibles des entreprises. Les inconsistances identifiées dans les déclarations des entreprises faussent considérablement les analyses liées à l'ambition et aux progrès des cibles des entreprises. La crédibilité des entreprises dotées de cibles est préoccupante, car ces entreprises, y compris celles avec des cibles approuvées par le *Science Based Targets initiative* et des objectifs de neutralité carbone, étaient aussi inconsistances que les entreprises sans cibles, voire plus.

De manière plus générale, ce projet de recherche contribue à (1) améliorer la compréhension des cibles des entreprises, en identifiant les bonnes et mauvaises pratiques; (2) faciliter la comparabilité des cibles des entreprises grâce à des méthodologies et des indicateurs cohérents, largement applicables à tous les secteurs, transparents et facilement reproductibles, ce qui permet une analyse annuelle récurrente; (3) fournir des résultats pouvant servir de références pour des analyses, considérant l'émergence de la littérature sur les cibles des entreprises; et (4) mettre en évidence les problèmes de crédibilité concernant certaines entreprises ayant des objectifs, suggérant la nécessité

pour les investisseurs d'évaluer de près les mauvaises pratiques des entreprises dans leurs portefeuilles et de faire de l'engagement avec les entreprises concernées.

ABSTRACT

To mitigate climate change risks, transitioning to a low-carbon economy is necessary, requiring non-state actors, such as investors, to play a critical role. Investors increasingly demand forward-looking approaches and industry data to evaluate and compare companies' performance in addressing climate transition risks, yet they struggle to find reliable and decision-useful methods and indicators. Beyond the current carbon performance of companies, investors need to assess companies' actions and readiness to transition to foresee their future carbon performance. One key indicator reflecting how companies are projecting themselves in the future is their corporate emissions reduction targets. However, comparing targets from different companies is challenging, as parameters used to produce those targets can vary widely (absolute or intensity targets, ambition, scope covered, base year, and target year). Previous studies about the ambition or progression of companies' targets show similar gaps in their methods, preventing broad applicability across sectors, consistent comparability among companies' targets, assessing a limited set of target progress parameters, and resulting in a partial understanding of companies' targets. Moreover, the rapidly increasing number of companies setting targets raises concerns about the reliability of these targets, questioning their credibility.

This research project aims to provide an in-depth and comprehensive evaluation of corporate climate mitigation performances by developing methodologies and indicators enabling the assessment of any type of emissions reduction targets across different companies and sectors, while ensuring rigorous and coherent comparisons of these targets. This research project contains six specific objectives, which led to three scientific articles each addressing one main topic of interest: (1) target ambition, (2) target progress, and (3) reliability. Ultimately, this research seeks to enhance the understanding of companies' targets to better inform investors' decisions.

The first contribution is the development of a harmonization process that transforms targets to the same scope of emissions, timeframe, and target metric, providing a coherent and consistent analysis structure to compare targets with different parameters. Second, sector-level prospective absolute and intensity carbon benchmarks, including roughly 1,000 companies with targets covering scope 1 and/or 2 emissions across 13 sectors, were calculated by applying the harmonization process. This process limits overestimation of target ambition by avoiding the inclusion of parts already achieved due to companies' choice of base year, and underscores targets already achieved. The

third contribution is the development of a target progress indicator, which alleviates limitation of existing indicators by (1) integrating the remaining time left to achieve a target, (2) accommodating the high variability found in progression, and (3) quantifying progress results rather than simply labelling targets as ‘on track’ or ‘not on track’. Fourth, 19 key determinants explaining companies progress towards their targets were identified through an explanatory analysis of 120 determinants for around 1,500 scope 1 and 2 targets from 1,000 companies. This analysis, using the developed target progress indicator, revealed valuable insights on companies poor and best practices, shed new lights on ambitious targets, and highlighted future research directions. Finally, the evaluation of inconsistencies in self-reported carbon data, through the development of inconsistency indices, underscored substantial issues surrounding the reliability of base year emissions covered by companies’ targets. Identified inconsistencies throughout companies’ disclosures significantly bias the assessments of the ambition and progress of companies’ targets. The credibility of companies with targets is concerning, as these companies, including those with targets approved by the Science Based Targets initiative and net-zero targets, were as inconsistent as, or even more inconsistent than, companies without targets.

In a broader way, this research project contributes to (1) enhancing the understanding of companies’ targets, identifying poor and best practices; (2) facilitating the comparability of companies’ targets through consistent methodologies and indicators that are broadly applicable across sectors, transparent, and easily reproducible, permitting recurrent yearly analysis; (3) providing results that can serve as baselines for future assessments of the rapidly emerging literature assessing companies’ targets; and (4) highlighting credibility concerns surrounding some companies with targets, suggesting the need for investors to closely assess poor companies’ practices in their portfolios and engage with concerned companies.

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LIST OF SYMBOLS AND ABBREVIATIONS

AUM	Assets Under Management
BY	Base year
CA100+	Climate Action 100+
CDP	Carbon Disclosure Project
CERES	Coalition for Environmentally Responsible Economies
CO ₂ e	Carbon Dioxide equivalent
ESG	Environmental, Social and Governance
ETS	Emissions Trading System
ILO	International Labour Organization
IFRS	International Financial Reporting Standards
ISSB	International Sustainability Standards Boards
GFANZ	Glasgow Financial Alliance for Net Zero
GHG	Greenhouse Gas Emissions
GRI	Global Reporting Initiative
GSIA	Global Sustainable Investment Alliance
GWP	Global Warming Potential
MJ	Megajoule
MWh	Megawatt Hour
NFGS	Network of Central Banks and Supervisors for Greening the Financial System
NZAOA	Net Zero Asset Owner Alliance
PRI	United Nations Principles for Responsible Investment initiative
RI	Responsible Investment
SASB	Sustainability Accounting Standards Board

SBT	Science-Based Target
SBTi	Science-Based Target Initiative
SC1	Scope 1
SC2 LB	Scope 2 Location-Based
SC2 MB	Scope 2 Market-Based
SC3	Scope 3
SDGs	Sustainable Development Goals
SFDR	Sustainable Finance Disclosure Regulation
TCFD	Task Force on Climate-Related Financial Disclosures
TPI	Transition Pathway Initiative
TY	Target Year
UN	United Nations
UNEP FI	United Nations Environment Programme Financial Initiative
USD	United States Dollar

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CHAPTER 1 INTRODUCTION

Global warming is now an undeniable threat to a livable future for humanity, and is unequivocally caused by anthropogenic greenhouse gas emissions (Lee et al., 2023). As a response to this issue, an international treaty, known as the ‘Paris Agreement’, was adopted in 2015 to aim on efforts to limit the average global temperature increase to 1.5 °C above pre-industrial levels (Rogelj et al., 2016). The scientific community has emphasized the necessity of realizing deep and sustained reductions in GHG emissions before 2030 to achieve this goal (Lee et al., 2023). Meanwhile, the existing consuming infrastructure from the lifetime operation of power generation stations, industrial plants, transportation, and buildings, would without additional mitigation, emit about 2.5 times the remaining carbon budget available for the 1.5 °C warming limit (UNEP, 2023a).

To mitigate climate change risks, a substantial amount of financial capital is required, giving investors a critical role to play. The transition to a low-carbon economy poses financial risks to their portfolios if they do not decarbonize, particularly for investors with long-term investment horizons such as pension funds. Climate transition risks typically stem from regulations such as carbon pricing, technology obsolescence, and changes in consumer preferences among other things.

Given these challenges, investors are increasingly demanding forward-looking approaches to assess and compare corporate performance in addressing climate transition risks. However, they encounter difficulties in finding reliable and decision-useful methods and indicators. Such methods should be transparent, consistent, scientifically robust, broadly applicable across portfolios, and easily replicable for continuous monitoring.

To better forecast the future carbon performance of companies, investors must look beyond their current carbon performance. They need to assess companies’ actions and willingness to transition. Corporate emissions reduction targets can serve as a key indicator of how companies are projecting themselves into the foreseeable future. However, comparing targets from different companies is challenging due to the widely varying parameters used to set those targets, such as absolute or intensity targets, ambition, scope covered, base year, and target year.

Due to these challenges, investors generally assess whether targets disclosed by companies fulfill specific parameters, such as net-zero by 2050 with a defined scope coverage, often using a checklist

approach like that of the Climate Action 100+ Net Zero Benchmark - an international investor initiative (CA100+, 2022a). This approach limits a comprehensive understanding of targets that do not meet these specific criteria and diminish comparability across different targets. Existing methods from the scientific literature comparing the ambition and progress of corporate targets face similar limitations. These methods constrain assessments towards targets of similar parameters, restrict their applicability to a few sectors, and lack consistent comparability among companies' targets. Moreover, the rapidly increasing number of companies setting targets raises concerns about the reliability of these targets and their related reporting, casting doubt on their credibility in achieving these goals. As such, a core understanding of why some companies seemingly progress much better than others is essential, but currently remains incomplete. The scarce literature is limited to specific aspects of target progress and continue to face issues of comparability among companies' targets depending on the specific study sample and indicators used.

These persisting literature gaps underscore the need for an in-depth investigation and comprehensive analysis of companies' targets combined with the development of methods and indicators to coherently compare their ambitions and progress. Furthermore, no studies have assessed the credibility of disclosed targets by companies through the lens of the potential unreliability of self-reported carbon data disclosure. This data is essential to assess the ambitions and progress of companies towards their targets and must be consistent and accurate to enable reliable assessments required for informed investor decisions.

This research therefore aims to develop methodologies and indicators required to compare the ambition and progress of all types of corporate climate mitigation targets across sectors, regardless of the varying parameters of these targets. The methodologies and indicators will be applied to three comprehensive evaluations of targets disclosed by companies, each focusing on a main topic of interest: ambition, progress, and reliability - demonstrating their broad applicability across sectors and ease of replication, enabling recurrent yearly analysis by investors. Ultimately, this research seeks to broaden and deepen the understanding of corporate targets to better enable informed investment decisions.

CHAPTER 2 LITERATURE REVIEW

This chapter presents a thorough review of the literature on the concepts relevant to this doctoral thesis. A close reading of these sections should allow readers from a variety of backgrounds to grasp these concepts and to understand the importance of this thesis for both practitioners and academics.

2.1 Responsible Investment

Throughout this doctoral thesis, the term responsible investment is used as a broader umbrella term. Nevertheless, the term responsible investment is often referred to as ethical investment, social investment, socially responsible investment, impact investment, or sustainable investment (Hochstadter & Scheck, 2015; Sandberg et al., 2009; Viviers & Eccles, 2012), and less commonly, it has previously been referred to as moral investing, or faith-based investing (Viviers & Eccles, 2012). Although all of these terms have different meanings, there is some overlap between them (N. S. Eccles & Viviers, 2011; Sandberg et al., 2009; Sparkes, 2001; Talan & Sharma, 2019).

The evolution of responsible investment partly explains the different terminologies and definitions associated with it (N. S. Eccles & Viviers, 2011; Louche et al., 2012; Sparkes & Cowton, 2004). This progression unfolds through distinct phases (Camilleri, 2020; Dumas & Louche, 2016; Revelli, 2017; Tuncay & Dorjnarán, 2023), from Responsible Investment 1.0 to 3.0 (Busch et al., 2021; Schoenmaker & Schramade, 2018). These phases help to demystify investors' objectives, current practices, and challenges, with a particular focus on issues related to climate change.

2.1.1 Responsible Investment 1.0: From Origins to Margin

Responsible investment has roots in religious institutions (Camilleri, 2020; Louche et al., 2012; Renneboog et al., 2008; Schwartz, 2003; Tuncay & Dorjnarán, 2023). Efforts to harmonize religious beliefs and investment practices date back 3,500 years in Judaism, 2,000 years in Hinduism, and to the medieval era of Christianity and Islam, which were marked by restrictions on the interest rates on loans (Glaeser & Scheinkman, 1998; Lewison, 1999; Visser & McIntosh, 1998). The practice of usury was judged as unethical, contributing to increased inequality and exploiting the poorer (Glaeser & Scheinkman, 1998; Mews & Abraham, 2007; Renneboog et al., 2008; Visser & McIntosh, 1998).

2.1.1.1 The Rise to a Marginal Practice

In the mid-17th century, the Quakers, Religious Society of Friends, initiated the practice of excluding ‘sinful’ investments (slave trade and weapons), to avoid profiting from human suffering (Camilleri, 2020; Doumpos et al., 2023; Sparkes, 2017; Trelstad, 2016). John Wesley, founder of the Methodist Church, further emphasized these principles in the 18th century, leading to the Methodist Church in the United Kingdom avoiding investments in companies involved in alcohol, tobacco, weapons, and gambling in the 1920s (Doumpos et al., 2023; Renneboog et al., 2008; Schwartz, 2003). Notably, the world’s first ‘ethical fund’ available to general public was created in 1928 in the USA and excluded ‘sin stocks’ based on religious values (Revelli, 2016; Schwartz, 2003; Sparkes, 2017).

The approach of screening portfolios based on exclusion criteria gained traction in the late 1960s, driven by social considerations related to the individuals’ civil rights movement and the Vietnam war (Domini, 2001; Renneboog et al., 2008; Sparkes, 2001). This intensified in the 1980s with the divestment campaigns against apartheid in South Africa (Busch et al., 2021; Louche & Lydenberg, 2006; Tuncay & Dorjnarant, 2023). Environmental considerations were spurred by events such as Rachel Carson’s 1961 book 'Silent Spring' documenting the dangers of chemical pesticides, the 1970 Earth Day movement drawing attention to air and water pollution from toxic industrial releases, and the 1987 Brundtland Report introducing the concept of sustainable development (Freeman III, 2002; Louche & Lydenberg, 2006; Sparkes, 2002a). Public concerns about the social and environmental externalities of companies were amplified by catastrophic incidents like Chernobyl, Bhopal, and Exxon Valdez in 1980s and an increased media coverage (Boykoff & Roberts, 2007; Camilleri, 2020; Daley & O’Neill, 1991; Renneboog et al., 2008). These circumstances raised questions about the ethics and responsibility of investments, highlighting that investing is not a neutral activity (Camilleri, 2017; Cowton, 1999; Louche et al., 2012).

2.1.1.2 A Values-driven Objective

As responsible investment practices evolved, it meant avoiding companies with unsustainable or unethical activities, whether based on personal values (e.g., moral, social, political) or in the broader interests of society (Busch et al., 2021; Schoenmaker & Schramade, 2018; Sparkes & Cowton, 2004; Trelstad, 2016). For example, some socially responsible investments, as the practice

became known, excluded companies that manufactured pesticides or other toxic products such as ozone-depleting chemicals (Cowton, 1999; Renneboog et al., 2008; Sparkes, 2002b).

It's important to note that negative screening and divestment from portfolios remain to this day one of the cornerstones of responsible investment, as shown by the social movement against the fossil fuel industry (Ayling & Gunningham, 2017; Busch et al., 2021; Piggot, 2018; Schoenmaker & Schramade, 2018). This implies that the first responsible investment phase (RI 1.0) coexists with the others.

2.1.2 Responsible Investment 2.0: From Margin to Mainstream

RI 2.0 corresponds to what is referred to as the ESG movement and is centered on the importance of including environmental, social and governance (ESG) factors into investment decisions, primarily to manage financial risks (Amel-Zadeh & Serafeim, 2018; Busch et al., 2021; Doumpos et al., 2023; UN PRI, 2021).

The term ESG first appeared in a 2004 United Nations Global Compact (UN Global Compact) report entitled “Who cares Wins – Connecting Financial Markets to a Changing World”, endorsed by 20 financial institutions (R. G. Eccles et al., 2019; Pollman, 2022; UN Global Compact, 2004). This report emphasized the importance of sound corporate governance in effectively implementing policies and measures to address environmental and social challenges that can impact a company's financial performance, making them financially material to investment value and leading to the inclusion of the letter G in the term ESG (Pollman, 2022; UN Global Compact, 2004).

It's worth noting that governance factors (e.g., executive compensation, board composition and board independence) were previously integrated by investors into their decisions (Goranova & Ryan, 2014; Marens, 2022; Mitchell, 2006). For instance, the creation of the Council of Institutional Investors in 1985 exemplifies how pension funds in the USA exercised their shareholders rights to change governance structure and policies of publicly traded companies that were poorly performing (Gillan & Starks, 2007; Smith, 1996; Sparkes & Cowton, 2004).

The 2004 UN Global Compact report was followed in 2005 by the Freshfield report on fiduciary duty (see Section 2.1.2.1), forming the foundations of the UN-backed Principles for Responsible Investment (PRI) launched in 2006 (R. G. Eccles et al., 2019; Pollman, 2022; UN PRI, 2021). The PRI, which started as an investor initiative with 45 founding members, reached nearly 4,000

signatories reporting on their responsible investment activities in 2023 (658 asset owners and 3,123 investment managers), representing roughly USD 140 trillion in total assets under management (AUM) (UN PRI, 2024a, 2024b).

Despite differing perspectives in the literature regarding the timeline for when responsible investment achieved mainstream status (ranging from 2006 to over 2014; see Arjalie (2010), Sievänen et al. (2013), and Paetzold & Busch (2014)), the number of PRI signatories can serve as a barometer to measure its adoption (R. G. Eccles et al., 2019). The substantial number of signatories in 2023 suggests that responsible investment practices are mainstream.

The rise to a mainstream adoption of responsible investment practices was enabled by elements such as a shift towards a financial justification (rationale), climate change as a main issue, the increased number of responsible investment approaches and the growing availability of ESG data, which helped overcome specific barriers (R. G. Eccles et al., 2019; Pollman, 2022; Richardson, 2009b; Townsend, 2020).

2.1.2.1 Financial Rationale: A Risk-driven Objective

Social movements, companies acting irresponsibly, and international conventions raised the attention of institutional investors (e.g., pension funds, banks, insurance companies), who were early adopters of RI 2.0 practices, especially pension funds due to their specific characteristics (legal origin, large size of AUM, and long-term investment horizon) (Hawley & Williams, 2007; Sievänen et al., 2013; UN PRI, 2024b; Wagemans et al., 2013). These circumstances suggested that ESG information was relevant not only for excluding companies based on a values-driven approach (RI 1.0), but also for enhancing long-term financial performance or for reducing financial risks (A. K. Chatterji et al., 2009; Chatzitheodorou et al., 2019; Derwall et al., 2011).

Companies acting as irresponsible citizens: A potential risk

The 1989 Exxon Valdez oil spill in Alaska was an important trigger for institutional investors (e.g., pension funds), exposing them to enormous liability and negative reputation due to environmental damages resulting from poor governance (Camilleri, 2017; Renneboog et al., 2008; Sparkes, 2002a). This led investors to demands transparent disclosure from companies regarding their sustainability impacts and related practices (see Section 2.1.2.3) (Ioannou & Serafeim, 2017; Pattberg, 2012).

Other corporate incidents further emphasized the importance of acknowledging litigation and reputational risks, such as the 2010 BP Deepwater Horizon oil spill and the 2015 Volkswagen 'Dieselgate' scandal, where ESG information could have alerted investors to potential financial risks (Glossner, 2021; Kölbel et al., 2017; Parella, 2018; Uhlmann, 2016). In both cases, corporate culture and governance issues were apparent: Volkswagen's employee remuneration system and lack of board independence were concerning, while BP's safety violations track record was particularly alarming (Cherry & Sneirson, 2011; Kabeyi, 2019; Mansouri, 2016).

Notably, in the three years preceding the incident, BP accumulated 862 safety violations across two of their USA facilities, accounting for 97% of the industry's total safety violations (Bratspies, 2011). Among these, 760 were deemed "willful and egregious" by the Occupational Health and Safety Administration (OSHA), whereas none of BP's competitors had more than eight of these violations during the same period.

Companies acting as responsible citizens: The 'doing well by doing good' debate

On the other hand, companies acting as socially responsible citizens, such as valuing the satisfaction of their employees, have been promoted as a win-win strategy by generating long-term financial value (e.g., brand reputation, attractiveness as an employer, employee retention and motivation), while reducing financial risks (Edmans, 2011; Falck & Heblich, 2007; X. Luo & Bhattacharya, 2009; von Wallis & Klein, 2015). This strategy lies at the center of the extensive academic debate on 'doing well by doing good'.

Thousands of scientific studies over several decades have measured the relationship between corporate social responsibility and financial performance, and by extension, that of responsible investment (or ethical and socially responsible investment depending of the period) (Friede et al., 2015; Herremans et al., 1993; Orlitzky et al., 2003). The large majority of these studies found a non-negative relationship, with the majority confirming a positive one (Friede et al., 2015; van Beurden & Gössling, 2008; von Wallis & Klein, 2015). The non-negative relationship suggests that there is no trade-off between responsible investment and financial performance implications, contradicting the initial assumption among investors that it leads to lower financial returns (Herremans et al., 1993; Richardson, 2009b; Townsend, 2020).

Throughout this ongoing debate, the accumulated evidence has helped to build a solid business case for sustainability (Richardson, 2009a; Townsend, 2020; Weber & Felmate, 2016). That is,

‘doing good by better managing the risks’ could yield attractive risk-adjusted returns by avoiding potential financial losses, thereby potentially increasing portfolio value (X. Luo & Bhattacharya, 2009; Revelli, 2017; Richardson, 2009a).

International conventions: A signal

International conventions (e.g., UN Framework Convention on Climate Change in 1992, Kyoto Protocol in 1997, International Labour Organisation (ILO) Declaration on Fundamental Principles and Rights at Work in 1998, Paris Agreement in 2015) and related norms (e.g., ILO standards, the Ten Principles of the UN Global Compact, OECD Guidelines) have played a pivotal role in shaping financial discourse by signaling to investors the importance of companies’ externalities (Bolton & Kacperczyk, 2023b; Depoers, 2022; Pargendler, 2020). The awareness of rising social and environmental risks has been further amplified by various international initiatives, investor networks and NGOs, such as the Coalition for Environmentally Responsible Economies (CERES, see Section 2.1.2.3), the UN-supported PRI, and the Task Force on Climate-Related Financial Disclosures (TCFD), to name just a few (R. Eccles & Strohle, 2018; Pattberg, 2012; Wagemans et al., 2013).

For example, the ratification by governments of the Kyoto Protocol in 1997 signalled to investors that carbon emissions of companies (externalities) might be regulated in the upcoming years and become priced. This occurred five years later with the EU Emissions Trading System (ETS) (Depoers, 2022). Therefore, incorporating these companies’ externalities (carbon emissions) reduced the risks that long-term investments become unprofitable (Condon, 2020; Schoenmaker & Schramade, 2018; Semieniuk et al., 2020).

Furthermore, the Paris Agreement in 2015 had a greater effect on investors; they reviewed their expectations of long-term carbon policy risks to a shorter one, resulting in a premium on the market value associated with the carbon emission intensity levels of companies (Bolton & Kacperczyk, 2023b). According to Bolton & Kacperczyk, (2023b), who analysed data from 2005 to 2018, this shift reflects a broader recognition among investors of the financial risks associated with climate change following the Paris Agreement.

However, domestic policies appear to have a stronger influence on investors than international agreements, suggesting that the latter may be perceived as empty promises without corresponding policies (Bolton & Kacperczyk, 2023b). Nonetheless, commitments made through international

agreements can serve as an indicator of forthcoming policies, such as the Kyoto Protocol leading to the EU ETS, indicating that these externalities may not be fully captured in firm-market valuations (Campiglio et al., 2023). This implies that investors should consider not only the current carbon performance of companies, but also their future trajectory, suggesting the need for forward-looking approaches in assessing future performance (Campiglio et al., 2023; Kalesnik et al., 2021; Popescu et al., 2021; TCFD, 2021c).

Over time, further climate-related risks have been recognized as financially material (see Section 2.1.2.2) and have been prominently promoted by the TCFD, among others (TCFD, 2023). It's interesting to note that the TCFD was officially announced at the 2015 UN Climate Change Conference (COP21) leading to the Paris Agreement and was established by the Financial Stability Board (FSB) under the directive of Mark Carney, former chair of the FSB and Governor of the Bank of England, with Michael R. Bloomberg serving as the TCFD's chair (Christophers, 2017; Dwyer & Unerman, 2020). Furthermore, the TCFD's final report and recommendations, released in 2017, resulted in a disclosure framework that embodies the financial rationale and risk-driven approach characteristic of the RI 2.0 phase (TCFD, 2017a).

A risk-driven objective: A necessity for institutional investors

The shift from the RI 1.0 ethical perspective to the RI 2.0 financial rationale appeared necessary for institutional investors, as indirectly demonstrated by the 2005 report produced by the international law firm Freshfields Bruckhaus Deringer, commonly referred to as the Freshfields report (Richardson, 2009a; Sandberg, 2011; Townsend, 2020). Commissioned by the United Nations Environment Programme Finance Initiative (UNEP FI) Asset Management Working Group, which included thirteen asset managers and pension funds, the Freshfields report analyzed whether integrating ESG information into the investment decision-making process was legally permissible for institutional investors (Freshfields Bruckhaus Deringer, 2005; Pollman, 2022; Sandberg, 2011).

The Freshfields report clarified that institutional investors (fiduciaries) should; 1) act in the best interests of their beneficiaries (the ultimate owners of the investments), rather than serving their own interests or personal preferences; 2) manage beneficiaries' investments diligently and prudently (Freshfields Bruckhaus Deringer, 2005). These duties generally imply the pursuit of profits in the interests of beneficiaries, with investment decisions accounting for expected returns

and risks, and considering not only individual investment characteristics but also the portfolio as a whole, in line with modern portfolio theory (Freshfields Bruckhaus Deringer, 2005; Sandberg, 2011). This contradicted the previous belief that the pursuit of profits was narrowly focused on maximizing each investment, thereby potentially limiting considerations of ESG information by institutional investors (Pollman, 2022; Sparkes, 2017). Furthermore, it demonstrated that excluding investments based solely on investors' personal preferences (RI 1.0: values-driven) to the detriment of beneficiaries' interests, such as financial losses due to inadequate portfolio diversification, breaches fiduciary duty, except when there is a clear consensus among beneficiaries about shared preferences (e.g., charities' funds) (Richardson, 2011; Sandberg, 2011).

Moreover, information reasonably expected to affect risk-adjusted returns, including ESG information, must be considered in the investment decision-making process, and failing to do so could constitute a breach of fiduciary duty (Freshfields Bruckhaus Deringer, 2005; Pollman, 2022; Sandberg, 2011). This underscores the necessity for financial discourse and a risk perspective around ESG factors (RI 2.0), emphasizing the importance of their underlying drivers, such as international conventions and domestic policies (Christophers, 2017; Gosling & Macneil, 2023; Pargendler, 2020; Richardson, 2009a). However, suggesting that failing to consider ESG information automatically constitutes a breach of fiduciary duty is not straightforward (Schanzenbach & Sitkoff, 2020).

The reasonable expectation of financial materiality can vary based on factors such as investment time horizons, geographical locations, and industries (Busco et al., 2020; R. G. Eccles et al., 2012; Edmans et al., 2023; Jebe, 2019). For instance, different investment horizons may lead to varying investment strategies and considerations of ESG factors. The weight given to ESG information compared to other financial factors in the decision-making process remains at the investor's discretion (Freshfields Bruckhaus Deringer, 2005). However, institutional investors, such as pension funds, which are expected to aim for financial portfolio performance over an extended horizon, must account for long-term ESG risks, particularly climate change, due to its anticipated financial impacts on society and, by extension, on investments (Freshfields Bruckhaus Deringer, 2005; Lee et al., 2023; NGFS, 2023b; UNEP, 2023a).

2.1.2.2 Climate-related Risks and Opportunities

Figure 2.1 presents an overview of the climate-related risks and opportunities, which is adapted from the frameworks of the TCFD (2017a) and NGFS (2023). As presented in Figure 2.1, there are two main categories of climate-related risks: the physical impacts of changes in climate patterns and the transition to a low-carbon economy. These categories lead to risks for companies, their value chain, or their sector that could become financially material under certain circumstances, which in turn translate into financial risks for financial institutions (NGFS, 2023b; TCFD, 2017a). Note that not all risks are financially material for all companies, even those in the same sector (R. G. Eccles, 2024; Edmans, 2023; TCFD, 2017a). Nevertheless, the transition can also present opportunities (TCFD, 2017a).

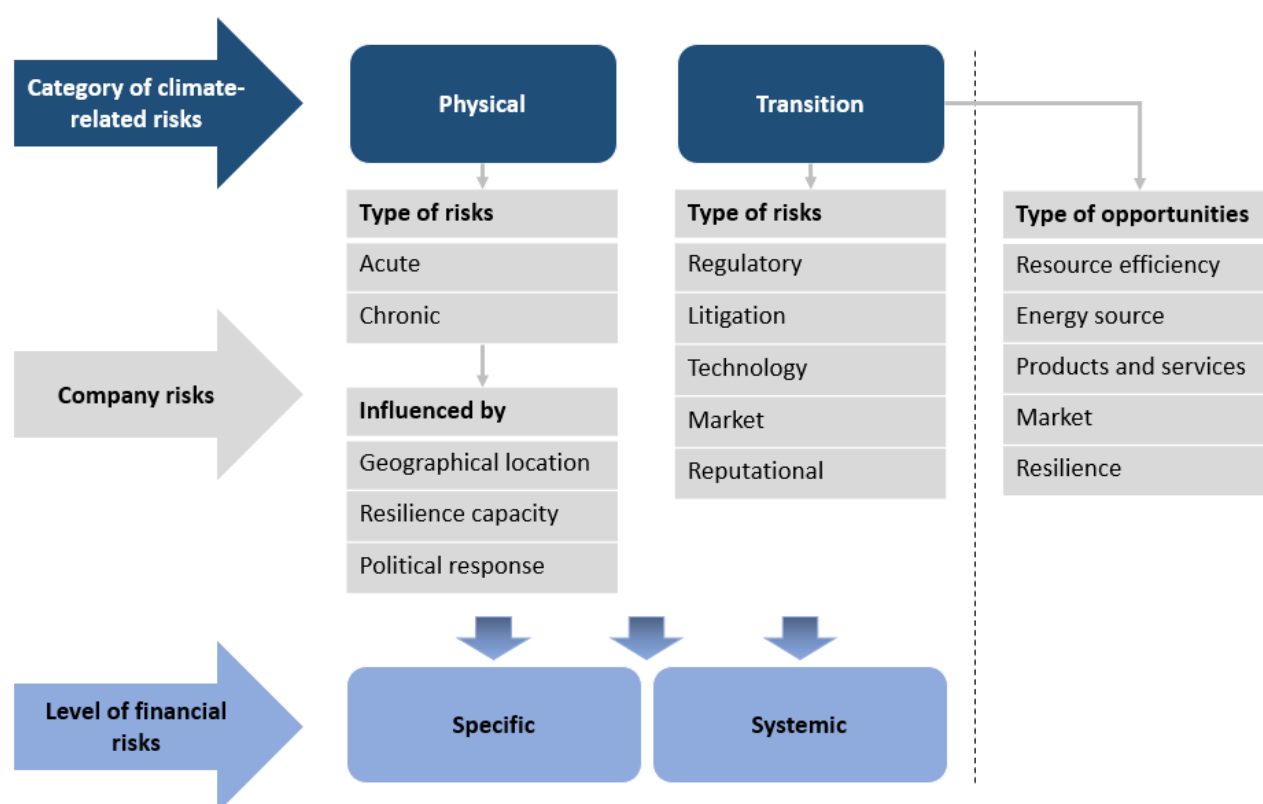


Figure 2.1: Overview of climate-related risks and opportunities for companies divided by category of climate risks and representing varying levels of financial risks for investors. Adapted from the frameworks of the TCFD (2017a) and NGFS (2023).

Physical risks

Physical risks include chronic and acute risks. Chronic risks correspond to long-term changes in climate patterns, such as increase in temperature, resulting in sea level rise from ice sheet melting and changes in precipitation patterns (Goldstein et al., 2019; Monasterolo, 2020; NGFS, 2020). These changes increase the severity and occurrence of extreme weather events, which are considered as acute risks (Baldwin et al., 2021; Domeisen, 2019; Lee et al., 2023). More specifically, acute risks encompass extreme weather events such as cyclones, hurricanes, floods, wildfires, and heatwaves.

Physical risks can directly damage exposed assets, human health, and natural capital (Battiston et al., 2021; Hunt & Watkiss, 2011; Monasterolo, 2020), while also leading to indirect effects such as supply chain disruptions, water scarcity, resource availability, reduced productivity, and increased insurance premiums (Giglio et al., 2021; Ginglinger & Moreau, 2023; Goldstein et al., 2019). For example, Pankratz et al. (2023) found that extreme temperatures (heat waves) negatively impacted company productivity, resulting in decreased revenues. Depending on geographical location, higher temperatures can lead to water stress, which could reduce electricity generation efficiency at thermal power plants (due to the need for cooling purposes), and potentially disrupt generation at hydropower plants, thereby increasing operating costs for both (Mikellidou et al., 2018).

Furthermore, the amplitude of physical climate risks will depend on the policy responses aimed at mitigation, with the physical impacts varying according to the resilience achieved through climate adaptation of cities and infrastructures (Araos et al., 2016; Forzieri et al., 2018; Lee et al., 2023; Liu & Song, 2020).

Transition risks and opportunities

Transition risks correspond to regulatory, litigation, technology, market, and reputational risks. Regulatory risks primarily includes carbon taxes and ETS, but it also covers other legislation such as support for clean technologies (e.g., the Inflation Reduction Act in the USA) or bans on polluting products like fossil fuel combustion engine cars (Bistline et al., 2023; Kleimann et al., 2023; Nascimento et al., 2024; Plötz et al., 2019). As of 2023, 23% of global GHG emissions were covered by an ETS and/or a carbon tax (World Bank, 2023). However, carbon prices generally tend to be lower than the level recommended to achieve the reductions required to respect the Paris

Agreement, with remaining rebates and free allocations to companies varying from countries to countries (World Bank, 2023). Additionally, some countries have faced setbacks in their policies, such as the UK's postponement of its ban on new fossil fuel combustion engine cars from 2030 to 2035 (Nascimento et al., 2024).

Current policies were estimated to limit global warming to only 3°C, whereas achieving all the 2030 nationally determined commitments (NDCs) would result in approximately 2.5 °C (UNEP, 2023a). This discrepancy suggests that carbon prices and other regulatory measures may increase in the coming years due to policy adjustments, thereby potentially affecting the profitability and financial returns of higher polluting firms (Bolton & Kacperczyk, 2023b; P. Hsu et al., 2023; Monasterolo & Angelis, 2020).

Excluding litigations concerning corporate incidents such as BP Deepwater Horizon oil spill (see Section 2.1.2.1), climate litigation cases have more than doubled in the last decade compared to all previously identified cases (Setzer & Higham, 2023). Of these, a rising number target companies for their: 1) historical contributions to anthropogenic cumulative emissions, therefore their responsibilities for climate damages; 2) failure to adapt, implying their prospective contributions and responsibilities for climate damages; 3) misleading claims (climate-washing), regarding the credibility of corporate emissions reduction targets, claims about sustainability attributes of products, or failures to appropriately disclose their climate risks (Benjamin et al., 2022; Setzer & Higham, 2023; UNEP, 2023b). While the fossil fuel sector has been particularly targeted, failures to adapt and misleading claims reached other sectors such as materials, power generation, mining, transportation, and agriculture and food production (Benjamin et al., 2022; Setzer & Higham, 2023; UNEP, 2023b). Additionally, litigation cases have begun targeting the responsibility and decision-making processes of financial institutions related to their financial activities with fossil fuel companies (Setzer & Higham, 2023; Solana, 2020b).

As of 2023, there are 59 active cases on the retrospective responsibility of primarily fossil fuels and cement companies, with 20 of these brought by governmental entities (cities and regions) seeking reparations for past damages or future adaptation costs (Setzer & Higham, 2023). For instance, Grasso & Heede (2023) estimated that ExxonMobil, based on its cumulative emissions from 1988 to 2022, should pay \$478 billion USD for damages expected under a 3°C scenario (current policies pathway). This type of estimation aligns with a similar study from Heede (2014)

that has been referenced in court (Benjamin, 2020). However, litigation risks might not only entail direct trial and penalty costs, but could also affect firm valuations (Kolaric, 2023; Sato et al., 2023), spill over to the responsibilities of financial institutions (Solana, 2020b) and impact the reputations of both companies and financial institutions, as previously discussed in Section 2.1.2.1 (Solana, 2020a).

Furthermore, reputational risks could extend to other companies in the sector, potentially leading to the stigmatization of the sector, as with fossil fuels companies (Bergman, 2018; Solana, 2020a). These risks could lead to reduced revenues due to increased operation costs, such as attracting and retaining employees, higher financing costs, and shifts in customer demand for products or services (Solana, 2020a; TCFD, 2017a). Market risks include shifts in customer preferences, along with increased costs of materials, water, or energy due to other climate risks (TCFD, 2017a).

Technological risks may arise from, among other factors: 1) low-carbon technologies becoming more affordable, potentially due to climate-related policies; 2) energy-saving technologies that reduce carbon emissions by decreasing the amount of energy required for operations, in addition to lowering energy costs for the users (NGFS, 2020; Semieniuk et al., 2020).

As shown in Figure 2.1, the transition to a low carbon economy presents opportunities in resource efficiency, energy source, products and services, market, and resilience (TCFD, 2017a). For the most part, these opportunities are simply the inverse of the transition risks. For example, enhancing resource efficiency in company operations not only reduces market risks associated with rising costs but also directly lowers operation costs (TCFD, 2017a).

Level of financial risks

Financial risks for investors can be either specific (idiosyncratic) or systemic. Specific risks pertain to a company and its value chain, or with an entire sector, influenced by factors like geographical location, as well as company adaptation and mitigation efforts, as discussed throughout this section (NGFS, 2023b; SASB, 2016; TCFD, 2017a). Stranded assets are an example of specific risks, arising from investments in long-lifespan infrastructures that failed to adapt to changing conditions like carbon policies (regulatory risks) or shift in consumer preferences (market risks) (Bos & Gupta, 2019; Kemfert et al., 2022; van der Ploeg & Rezai, 2020). These assets, which have investments expected to provide financial returns, become financially unviable before the end of their expected lifespan, thus resulting in financial losses (Caldecott, 2017). The level of portfolio

exposure to stranded assets can lead to important financial losses, as these assets could potentially lose their financial value (Battiston et al., 2017; Semieniuk et al., 2023).

Systemic risks can arise from a combination of: 1) abrupt policy responses, 2) interdependencies between sectors and within their value chain, 3) common exposures across financial institutions (portfolio overlaps), leading to feedback effects and propagation, and 4) the interconnectedness of financial institutions, which amplifies these risks (Battiston et al., 2021; Campiglio et al., 2023; FSB & NGFS, 2022; Semieniuk et al., 2020). Given that climate-related risks affect nearly all sectors (SASB, 2016; TCFD, 2017a), the varied levels of direct and indirect exposures across investors' portfolios, in conjunction with the enumerated factors, especially policy responses (regulatory risks), could potentially trigger a systemic risk and thereby, lead to financial instability (Battiston et al., 2017; Campiglio et al., 2023; NGFS, 2023b).

Climate-related risks: Inherent forward-looking nature

The complexity of assessing climate-related risks lies in their uncertainty, including which climate scenarios will unfold, their timelines, and extents, as well as their inherently forward-looking nature (Monasterolo, 2020; NGFS, 2023a; Weber, 2024). Unlike traditional risk management approaches that often rely on historical data and assume normally distributed shocks with short-term horizons, climate-related risks are characterized by emerging impacts without historical precedents, potential fat-tail distributions, and long-term horizons (Bolton et al., 2020; Calel et al., 2015; Dépoues et al., 2019; Weitzman, 2011). Consequently, traditional risk management approaches are less suitable, necessitating forward-looking methods to adequately assess not only systemic risks and portfolio exposure but also companies' actions and readiness to transition, to better understand their future carbon performance (Battiston, 2019; Bolton et al., 2020; Campiglio et al., 2023; NGFS, 2022; TCFD, 2021c).

2.1.2.3 ESG Data and Measurement: Remaining Challenges

In response to the growing demand from investors, three main sources of data have emerged: third-party providers, voluntary corporate disclosure, and mandatory disclosure (Busch, Johnson, et al., 2022; In & Schumacher, 2021; Ioannou & Serafeim, 2017; Papadopoulos, 2022). Despite the increased availability of ESG data and scores, persistent challenges remain in the data and methods used to evaluate the performance of companies (Cunha et al., 2021; Eurosif, 2023; OECD, 2022; Widyawati, 2019). A recurrent concern is the lack of standardized, comparable, transparent,

and reliable data, with similar issues affecting the measurement methods (Berg et al., 2022; Boiral et al., 2022; A. Chatterji et al., 2016; Schoenmaker & Schramade, 2019). These challenges undermine the credibility and usefulness of the results, contributing to the criticisms facing the ESG movement (Edmans, 2023; Pollman, 2022; Popescu et al., 2021). Additionally, the metrics provided by these methods do not necessarily meet investor needs, particularly in terms of climate transition metrics (Kalesnik et al., 2021; NGFS, 2022; OECD, 2022; Popescu et al., 2021).

Third-party ESG data providers: Diverging results

Third-party ESG data providers appeared in the 1980s with early players such as EIRIS, KLD and Innovest, expanding to over a hundred of providers in the following decades (R. G. Eccles et al., 2019). The past fifteen years, however, have seen a consolidation phase, characterized by mergers and acquisitions resulting in large data vendors (Avetisyan & Hockerts, 2017; R. Eccles & Strohle, 2018; Escrig-Olmedo et al., 2019). Notable examples include Morningstar acquiring Sustainalytics, MSCI ESG acquisition of several providers such as Risk Metrics (which included KLD and Innovest), and S&P Global's purchase of Trucost (Avetisyan & Hockerts, 2017; R. Eccles & Strohle, 2018; RepRisk, 2020). This consolidation phase indicates a maturation of the ESG data market (R. Eccles & Strohle, 2018).

These providers offer services ranging from ESG ratings, often referred to as scores, based on proprietary models, to detailed company reports and aggregated data like corporate carbon footprints (R. Eccles & Strohle, 2018; Eurosif, 2023; NGFS, 2022). This data is either collected from various sources, including company documents (such as sustainability reports and financial filings), government databases, and direct inputs from surveys and interviews conducted with companies, or it is estimated using proprietary models (Busch, Johnson, et al., 2022; Christensen et al., 2022; R. Eccles & Strohle, 2018; Papadopoulos, 2022).

Despite the market's apparent maturation and the high costs of accessing these services, unresolved issues persist, such as methodological opacity and divergence in company performances among providers, which weaken the credibility of their outputs (Berg et al., 2022; Busch, Johnson, et al., 2022; A. Chatterji et al., 2016; Christensen et al., 2022; Papadopoulos, 2022). Berg et al. (2022) found that divergence in company ratings was driven by differences in measurement methods for underlying ESG factors, partly influenced by subjective assessments by raters, followed by differences in the ESG factors considered and their weighting in the total ESG score. Christensen

et al. (2022) found that increased company disclosure can exacerbate divergence in ratings across providers. This emphasizes the lack of standardisation and comparability among the ESG factors used by different providers.

From voluntary to mandatory reporting: Diverging standards

The standardisation and availability of sustainability information reported voluntarily by companies, particularly climate-related information, have greatly evolved over the past thirty years, helped by various investors initiatives. Notable developments in this evolution include the launch of the Global Reporting Initiative (GRI) standards in 1997, co-founded by CERES; the arrival of the Carbon Disclosure Project (CDP) in 2000, which collects standardized climate-related information through questionnaires sent on behalf of investors; the establishment of the Sustainability Accounting Standards Board (SASB) in 2011, focusing on industry-specific materiality issues; and the formation of the TCFD in 2015, which emphasizes on the disclosure of climate-related risks (see also Section 2.1.2.1) (Depoers, 2022; Ioannou & Serafeim, 2017; Pattberg, 2012; Pollman, 2022).

It's noteworthy that the creation of CERES in 1989, an initiative of institutional investors partnering with environmental organizations, was a direct consequence of the Exxon Valdez oil spill in Alaska (Barnard, 1990; Sparkes, 2002a). Since its inception, CERES has advocated for corporate sustainability disclosure and corporate accountability, co-founding international initiatives such as the GRI and, more recently, the Climate Action 100+ (CA100+) in 2017 (Ioannou & Serafeim, 2017; Pattberg, 2012).

As with third-party data providers, sustainability disclosure standards are showing signs of consolidation with the arrival of the International Sustainability Standards Board (ISSB). Since its creation in 2021, the ISSB has officially incorporated the SASB, TCFD, Climate Disclosure Standards Board, the International Integrated Reporting Council (IFRS, 2024a; Stolyow & Paugam, 2023), making an important step towards uniformization. The ISSB operates under the International Financial Reporting Standards (IFRS), which sets accounting standards mandatory in the vast majority of countries (IFRS, 2024b). However, ISSB standards, released in 2023, are not yet mandatory, which may be due to their recency.

Moreover, ISSB standards differ in focus from the Corporate Sustainability Reporting Directive (CSRD), which is mandatory in the European Union and emphasizes double materiality – meaning

companies must account for both the financial impacts of sustainability issues on their business (financial materiality) and sustainability-related impacts of their activities on society (Laine, 2024; Stolowy & Paugam, 2023). This raises questions about the extent to which these standards will ultimately converge, or whether it will simply add another compliance layer for companies operating globally. (Stolowy & Paugam, 2023). For example, jurisdictions with carbon regulations often mandate specific reporting at the facility level rather than for the company as a whole (Busch, Johnson, et al., 2022; Stanny, 2018; The World Bank, 2022).

Both voluntary and mandatory reporting enhance data transparency, in contrast to third-party providers who often lack transparency in the data and methods they use (Berg et al., 2022; Eurosif, 2023; Popescu et al., 2021). However, the reliability of voluntarily reported corporate data frequently faces skepticism, while mandatory reporting face challenges with data comparability issues due to different national regulations (Busch, Johnson, et al., 2022; In & Schumacher, 2021; Matisoff et al., 2013). Nevertheless, data reported directly by companies are considered valuable by investors (Eurosif, 2023). Additionally, investors are increasingly demanding forward-looking information to mitigate climate-related risks in their portfolios, yet they struggle to find reliable forward-looking indicators (Bolton et al., 2022; Eurosif, 2023; In & Schumacher, 2021; TCFD, 2021c).

ESG and climate-related measurements: Missing the forward-looking perspective

To assess companies' climate-related risks, ESG ratings and climate-related tools are widely used, although their reliability is questioned by investors (Brock et al., 2023; Gyönyörová et al., 2023; Krueger et al., 2020; NGFS, 2022). This mistrust is corroborated by industry surveys showing that many investors believed these ratings and metrics do not adequately reflect either the true ESG performance of companies or the forward-looking carbon performance of companies (Brock et al., 2023; Eurosif, 2023). Furthermore, this mistrust underscores the need for enhanced methodologies that can provide more valuable insights into the future carbon performance of companies.

For instance, Dremptic et al. (2020) demonstrated that larger firms often received higher ratings than smaller firms due to their greater capacity to meet providers' information demands. This suggests that ESG ratings may reflect the level of disclosure more than actual company performance. In addition, the aggregation of numerous factors within the Environmental (E) pillar

score can mask specific deficiencies or strengths, thereby obscuring true company performance (NGFS, 2022; Schoenmaker & Schramade, 2019).

Furthermore, OECD's research indicates that the E pillar score primarily reflects disclosure practices rather than forthcoming changes in companies, casting doubt on its usefulness as a forward-looking climate metric (OECD, 2022). For instance, providers measure whether companies have an emissions reduction target (true or false), but they do not assess the quality of these targets, nor the companies' progress towards achieving them (Eurosif, 2023; Kalesnik et al., 2021; NGFS, 2022; OECD, 2022).

Forward-looking climate-related metrics include climate scores, climate stress testing like Value-at Risk (VAR) measures, and temperature alignment tools such as implied temperature rise (ITR) metrics (A. J. Bingler & Senni, 2022; Eurosif, 2023; Kalesnik et al., 2021; NGFS, 2022). These tools are designed to help investors assess potential climate risks and align their portfolios. However, they are also subject to a range of limitations that may affect their reliability and decision-usefulness for investors (Battiston et al., 2017; A. J. Bingler & Senni, 2022; Kalesnik et al., 2021; Raynaud et al., 2020; Weber, 2024).

Kalesnik et al. (2021) examined the predictive power of forward-looking climate scores developed by third-party providers and found no evidence that these metrics carried useful forecasting information about the future carbon performance of companies. Climate stress testing methodologies, which assess potential financial losses under global warming scenarios, are highly sensitive to the discount rates applied and rely on climate scenarios with uncertain underlying assumptions that could vary drastically, even for the same global warming temperature (e.g. carbon capture and storage technologies) (Battiston et al., 2017; Campiglio et al., 2023; Weber, 2024). Despite their complexity, such tools, especially those developed within academic settings, are gaining importance for central banks to assess the financial industry's exposure climate-related risks, although they often overlook potential financial opportunities (NGFS, 2023b; Weber, 2024).

Implied temperature rise methods are not universally recognized as indicators of climate risks and remain subject to debate (J. A. Bingler et al., 2022; Raynaud et al., 2020). However, this methodology consisting of applying project companies' future carbon performance against Paris Agreement-aligned scenarios may not genuinely be forward-looking (Raynaud et al., 2020; TCFD, 2021c). For example, such projections may rely on historical GHG emissions trends, representing

a backward-looking approach that fails to capture companies' current efforts and pressures to transition (Raynaud et al., 2020; TCFD, 2021c). However, these projections may also rely on a forward-looking approach based on production plans (e.g., investment plans), typically limiting the projection to about five years, and emissions reduction targets, often questioned for their credibility (A. J. Bingler & Senni, 2022; Eurosif, 2023; Popescu et al., 2021; TCFD, 2021c). The complexity of methodological assumptions, such as the climate scenarios, projection methods, allocation methods of companies' share of global carbon budget, and temperature alignment calculations, contribute to discrepancies in the results – leading to important differences in assigned temperature ratings at the firm-level, such as 1.5°C versus 3.6°C depending on the provider (Chmel et al., 2023; Institut Louis Bachelier, 2020; Raynaud et al., 2020). The uncertainty and the opacity surrounding these methods compromise their comparability and perceived reliability (Chmel et al., 2023; Eurosif, 2023; Raynaud et al., 2020).

To be decision-useful, investors place the highest importance on the transparency and understandability of the underlying calculation methods, research processes, assumptions, and data sources, along with broad applicability across portfolios (Eurosif, 2023; TCFD, 2021c). Bingler & Senni (2022) assessed sixteen forward-looking climate tools and noted that their effectiveness was compromised by opaque methodologies and unclear assumptions, which obscure the interpretability of the results and limit their usefulness to investors. Investors seemed less concerned with the use of approximations per se, but were troubled by the lack of scientific reliability, transparency, and understandability of some tools' assumptions and calculations (Eurosif, 2023). This undermines the trustworthiness of their results, making it difficult for investors to make informed decisions based on these tools (Brock et al., 2023; Eurosif, 2023; TCFD, 2021c). Moreover, it underscores the necessity for the scientific community to aid in the development of more trustworthy and adequate forward-looking information and indicators.

However, investors tend to view companies' emissions reduction targets approved by the Science Based Target initiative (SBTi) as a reliable metric of companies' efforts to transition (Eurosif, 2023). This may be attributed to their scientific basis and standardized sectoral approach, which can enhance their credibility and be viewed as facilitating comparability between companies, unlike other types of targets (see Section 2.2). However, the sectoral approach of SBTi does not cover every sector, limiting its broad applicability (Bjorn et al., 2021; Eurosif, 2023; SBTi, 2022a).

Nevertheless, other types of corporate emissions reduction targets, applicable across any sector, can enhance the understanding of a company's actions and preparedness to transition, with timeframes potentially extending beyond the typical five-year of companies' investment plans (Day et al., 2022; GFANZ, 2023; NGFS, 2022; Popescu et al., 2021; TCFD, 2021c). This aspect is particularly relevant for long-term investors, such as pension funds. However, these targets have their limitations, including issues with comparability between companies, credibility concerns and uncertain achievement, which are further detailed in Section 2.2.

2.1.2.4 Mainstream Practice: Under a Flexible 'Big Tent'

The shift towards a financial rationale was accompanied by an increased number of responsible investments approaches (Busch et al., 2021; Richardson, 2009b; Townsend, 2020). One of the initial barriers was that responsible investment reduced portfolio diversification (RI 1.0; employing only a negative screening approach), which in turn could diminish risk-adjusted returns, and neglect potential investment growth opportunities (Bello, 2005; Richardson, 2009b; Sparkes & Cowton, 2004; von Wallis & Klein, 2015). Furthermore, adequate portfolio diversification may be required (modern portfolio theory), depending on the jurisdiction of institutional investors, to fulfill their fiduciary duty (Freshfields Bruckhaus Deringer, 2005). The current mainstream practice of responsible investment includes the approaches of screening (i.e., negative, positive, best-in-class, norms-based), ESG integration, thematic investing, stewardship and impact investing (CFA Institute et al., 2023). Often, investors combine more than one approach throughout their portfolios (Amel-Zadeh & Serafeim, 2018; GSIA, 2023; Krueger et al., 2020).

Table 2.1 presents the standardized definitions and clarifications of the responsible investment approaches, established in late 2023 through a joint partnership between the CFA Institute, the Global Sustainable Investment Alliance (GSIA), and the PRI (CFA Institute et al., 2023). This joint partnership followed a recommendation from the International Organization of Securities Commissions, aiming to address the lack of agreed-upon definitions amidst the mainstreaming adoption of responsible investment approaches (CFA Institute et al., 2023; IOSCO, 2021). This lack of clarity regarding the responsible investment approaches and the terminology (e.g., impact funds, sustainable funds, Paris-aligned funds) could lead to confusion about the sustainability attributes of financial products, and the potential for misunderstanding ('impact washing') (Busch et al., 2021; IOSCO, 2021; Kim & Yoon, 2023; Kölbel et al., 2020).

Table 2.1: Responsible investment approaches as defined and clarified by the CFA Institute, the GSIA and the PRI. Adapted from CFA Institute et al. (2023).

	Definitions	Clarifications
Screening	“...based on defined criteria that determine whether an investment is permissible.”	Includes four sub-approaches: negative, positive, best-in-class and norms-based. Could be qualitative (condition) or quantitative (threshold) criteria such as geographical location (e.g., flood plain) or ESG factors (e.g., ESG score, carbon score, human rights score). Best-in-class approach: at minima better than the median or average performance relative to an appropriate peer group.
ESG integration	“Ongoing consideration of ESG factors within an investment analysis and decision-making process with the aim to improve risk-adjusted returns.”	Does not imply that ESG factors are more, less, or equal in weight (consideration) to other ESG factors, nor that multiple ESG factors or each category are considered. Therefore, does not imply any distinct characteristics (e.g., low carbon portfolio). Hypothesis for ESG factors integrated: potentially financially material (risks or returns) and not entirely captured in companies’ valuations.
Thematic investing	“Selecting assets to access specified trends.”	Top-down process to construct portfolio with assets expected to achieve higher returns based on an ESG trend (e.g., sustainable agriculture, aging population). Should be related to key medium or long-term drivers (i.e., economic, technological, demographic, cultural, political, environmental, social, regulatory).
Stewardship	“...use of investor rights and influence to protect and enhance overall long-term value... including the common economic, social, and environmental assets on which their interests depend”	Includes activities such as board participation, engaging discussion with companies, proxy and voting at shareholder meetings, litigation, contributing to industry research, third-party, or collective initiatives. Includes common assets such as a stable climate (environmental asset) or population’s health (social asset).
Impact investing	“...intention to generate a positive, measurable social and/or environmental impact alongside a financial return.”	Implies measuring the positive impact generated (environmental and/or social), e.g., MWh of renewable energy capacity added, number of additional affordable housing units. Differs from philanthropy activities, as pursuing a financial return.

Given the heterogeneity of approaches, responsible investment could be likened to a 'big tent', mirroring the PRI's self-identification as a 'big tent' organization (see, e.g., PRI, 2021), accepting signatories of varying AUM sizes, geographical locations, and sustainability performance levels (leaders and laggards) (Gibson Brandon et al., 2023; Kim & Yoon, 2023; Liang et al., 2022; Pollman, 2022). That is, responsible investment in practice could involve: 1) considering financially material ESG information to improve risk management relative to potential financial returns, where higher levels of risks could be acceptable with higher potential returns (ESG integration approach); and 2) selecting companies with forward-looking carbon performance above the median of their peers to mitigate climate-related risks (best-in-class screening approach), as presented in Table 2.1.

On the other hand, the stewardship approach could correspond to actively investing in underperforming companies on climate-related factors to potentially drive change, aiming to protect common environmental assets such as a stable climate. Furthermore, the impact investing approach, which appeared later in the literature (Dordi et al., 2024; Schlütter et al., 2023), implies a clear intent to contribute to real-world changes, with measurable positive environmental or social outcomes (Busch et al., 2021; Hochstadter & Scheck, 2015; Kölbel et al., 2020; Schoenmaker & Schramade, 2018).

The ambiguity surrounding the meaning of responsible investment (ESG) appears to stem from the lack of distinction between the usefulness of ESG information in evaluating a company's process versus the expected sustainable outcomes yielded by those practices and by extension, the impact of investors. This confusion among different investors' objectives under various flexible approaches ('big tent') has contributed to the numerous criticisms facing the ESG movement, including its politicization by anti-ESG proponents (Edmans, 2023; Pollman, 2022; Starks, 2023). Consequently, Edmans (2023) has suggested "the end of ESG", whereas other authors, Busch et al. (2021), have proposed "a call for (re)-orientation" to differentiate approaches (see Section 2.1.3.2), ultimately leading to the emergence of RI 3.0.

The suggestion of Edmans (2023) is that ESG factors considered financially material to long-term investment decisions, such as employee satisfaction (his field of research) or climate change, should not be segregated into special terms like ESG investing or responsible investing; rather, it's simply investing. This implies that investors who consider ESG factors primarily to align with their

values (RI 1.0) should be distinguished from those who prioritize (financial) value (RI 2.0). However, the flexibility of the ‘big tent’ approach has allowed to garner interest from various investors and stakeholders, facilitating ESG inclusion within companies and as suggested by Serafeim (2021), remaining potentially necessary for fostering accountability and progress.

2.1.3 Responsible Investment 3.0: From Mainstream to Real-World Changes

Given the confusion under RI 2.0, RI 3.0 is characterized by a shift towards impacts, with investors aiming to positively contribute to real-world changes, addressing societal challenges such as the those outlined by the UN Sustainable Development Goals (SDGs) or the Paris Agreement (Busch et al., 2021; Schoenmaker & Schramade, 2018). Similarly to the ESG movement (RI 2.0) detaching itself from ethical investing (RI 1.0), nascent literature argues that impact investing should be differentiated and better defined, rather than remaining a blurry sub-field of responsible investment (or approach as of now, see Table 2.1) (Busch et al., 2021; Dordi et al., 2024; Kölbel et al., 2020; Schoenmaker & Schramade, 2018).

2.1.3.1 A Combination with An Impact-oriented Objective

While the concept originated earlier, the term 'impact investing' first appeared in 2007 when the Rockefeller Foundation sought discussions with leaders in finance, philanthropy, and development through a meeting in Italy (Agrawal & Hockerts, 2021; Dordi et al., 2024; Hochstadter & Scheck, 2015). This new term explicitly implied the non-divisible components of addressing societal challenges while pursuing financial returns (Bugg-levine & Emerson, 2011; Hochstadter & Scheck, 2015). That is, the positive social or environmental impacts cannot be substituted by financial aspects, nor should in theory the opposite, suggesting an optimization of both. This contrasts with RI 2.0, which primarily focus on managing financial risks, allowing for potential substitutions between levels of ESG (or climate) risks and financial returns. Furthermore, impact-oriented investments focus on a positive screening approach (inclusion list, see Schoenmaker & Schramade, 2018); rather than avoiding companies based solely on ethical perspective and personal values (RI 1.0) (Bugg-levine & Emerson, 2011; Busch et al., 2021).

2.1.3.2 Beyond the Current Defined Approach of Impact Investing

As discussed by Busch et al. (2021), an investor’s positive impact may go above and outside the current industry definition of impact investing (See Table 2.1; for further details, see CFA Institute

et al., 2023). To better define impact-oriented investment, Busch et al. (2021) proposed to divide them into two categories; impact-generating investments and impact-aligned investments.

Impact-generating investments

This category of investments induces a change by allocating capital to assets generating positive impacts (e.g., companies financing renewable energy projects through green bonds, see Tolliver et al., 2019) or expected to generate impacts (e.g., companies transitioning; committing to science-based emissions reduction targets, see Section 2.2.2) (Busch et al., 2021). This is consistent with the definition of impact investing as intended by the joint partnership between the CFA Institute, GSIA and PRI, as long as investors can credibly demonstrate their contributions (CFA Institute et al., 2023). However, stewardship approach can induce change by applying: 1) active ownership (see Section 2.1.2.4), or 2) participating to international initiatives and coalitions (Busch et al., 2021).

As discussed throughout Section 2.1.2, a number of international investor initiatives such as the GRI, PRI, or TCFD have facilitated the inclusion of ESG and climate considerations within companies (Campiglio et al., 2023; Ioannou & Serafeim, 2017; Serafeim, 2021). Lately, a growing number of investors are joining coalitions such as the Net Zero Asset Owner Alliance (NZAOA), pledging to invest in line with net-zero emissions by 2050, or are supporting networks like Climate Action 100+, which monitors companies' commitments to net zero and facilitates investor engagement activities (Climate Action 100+, 2023; Gosling & Macneil, 2023; In & Schumacher, 2021). Nevertheless, demonstrating their contribution by measuring their positive impacts may be challenging for investors (see Section 2.1.2.3)

Impact-aligned investments

In this category of investments, companies' impacts are already aligned with relevant environmental or social thresholds (e.g., 1.5 °C warming scenario), suggesting that they have already changed (no further changes) and made a positive contribution to real-world outcomes.

Leaving behind the concept of additionality

The broader inclusion for impact-oriented investments proposed by Busch et al. (2021) partly relates to the concept of additionality, which is inherent in the traditional definition but has been voluntarily set aside. This concept implies that impact investments - or the actions of investors -

should enhance the quality or quantity of positive impacts beyond what would have occurred in their absence (Brest & Born, 2013; Hockerts et al., 2022).

Demonstrating additionality is feasible under certain conditions, such as when investors are willing to: 1) accept below financial market returns (see Barber et al., 2021), based on the assumption that other (mainstream) investors prioritize profit maximisation; or 2) pursue opportunities that may outperform the market and that other investors might not consider due to increased transaction costs (such as expenses related to research and small deal sizes) or higher risks (such as limited exit strategies, investments in early-stage companies, or governance issues) (Brest & Born, 2013; Busch et al., 2021; Hockerts et al., 2022). As suggested by Hockerts et al. (2022), once these opportunities become known and reach market conditions, other investors will also provide capital. This means that in an open market with impact investments at market conditions, demonstrating the additionality of impact investors would be very challenging, if not unprovable, as the positive impacts would occur regardless in the absence of impact investors (Brest & Born, 2013; Busch et al., 2021; Hockerts et al., 2022). Furthermore, growth in the number of impact investors could further diminish the distinctiveness of investors' additionality (Hockerts et al., 2022).

If the primary goal of impact investing is to channel capital towards addressing social and environmental challenges while pursuing financial returns (as discussed in Section 2.1.3.1), then, the emphasis on investors' additionality should be reevaluated. In fact, if the emphasis on additionality persists, the expansion of impact investing could paradoxically lead to its conceptual obsolescence, as achieving additionality becomes unattainable (Hockerts et al., 2022). Consequently, the two categories of impact-oriented investments proposed by Busch et al. (2021) hold relevance, even if one category includes companies that are not expected to generate further changes (impact-aligned).

2.1.3.3 Positive Impact Measurement: Intentionality is Insufficient

To distinguish it from previous forms of responsible investment (RI 1.0 and RI 2.0), the concept of intentionality – investors' objectives towards impacts – and measurement were established at the inception of the term impact investing during the Rockefeller meeting (Bugg-levine & Emerson, 2011). Measuring the positive impact is fundamental to enhance the credibility of impact-oriented investments and limit the risks of 'impact washing'. (Findlay & Moran, 2019; Roor & Maas, 2024; Schlütter et al., 2023). A mere statement of investor' intentionality is insufficient

without effective measurement of impact to ensure a positive contribution to real-world social or environmental challenges (Cremasco & Boni, 2022; Roor & Maas, 2024; Scheitza & Busch, 2024). However, the investors' objectives toward impact should be transparent and documented, as mandated in European regulations (Sustainable Finance Regulations Disclosure, SFDR; see, e.g., Badenhop et al., 2023).

Complexity: The burden of the proof

The burden of measuring and (im)proving their positive impacts falls on investors, a task that can be complex (Geobey & Brierley, 2023; Roor & Maas, 2024; Schlütter et al., 2023). For instance, literature suggests change occurs in companies' behaviors due to engagement and shareholder voting activities of investors (Dyck et al., 2019; Kölbel et al., 2020), which are found to be more effective than divestment (negative screening; avoiding) (Berk & Van Binsbergen, 2022; Edmans et al., 2022; Starks, 2023). However, measuring the contribution of a single investor can be challenging, owing to the involvement of numerous actors and the varying influence of investors' actions - some may carry more weight than others (Kölbel et al., 2020; Popescu et al., 2021; Schlütter et al., 2023). Nevertheless, combining stewardship activities into the investment process of other impact-oriented approaches could further enhance positive changes (Kölbel et al., 2020) and shift the measurement burden to these approaches, alleviating the need to prove investors' positive contribution solely through stewardship.

Companies' assessments: Beyond ESG

Measuring companies' impacts requires assessments that go beyond ESG risks to include both negative and positive externalities, a principle referred to as double materiality (Busch et al., 2021; Popescu et al., 2021). Furthermore, measurement of impact-oriented investments should be context-based to better understand their contribution (Vorosmarty et al., 2018). That is, financing a renewable energy project (solar farm of 10 MW) in a region with cleaner energy production (such as in the Province in Québec) does not have the same impact than in a region using mainly coal power generation (such as a region in India). The latter implies a greater difference in GHG emissions between the current reference (reduced emissions) and a solar farm compared to one in Québec, leading to more improvement in ambient air pollution and human health.

The positive contribution of an investor could be measured in terms of reduced emissions per dollar invested, proportional to their share of the total project cost (Kölbel et al., 2020; Tolliver et al.,

2019). This also implies that the choice of an appropriate reference (e.g., regional, country) matters, as it would affect the results reported by an investor. The same problematic applies to impact-aligned investments with the choice of thresholds to determine their inclusion or the choice of benchmarks to determine the impacts of an investor strategy (Busch et al., 2021; Popescu et al., 2021).

Credibility of measurement methods

To enhance the credibility of sustainability measurement for impact-oriented investments, the methods used should meet additional prerequisites. Popescu et al. (2021) developed a criteria matrix to evaluate these methods, which includes double materiality and investor's additionality among seven key criteria:: 1) comprehensiveness of impact categories, assessing beyond GHG emissions to include social categories and trade-offs; 2) compatibility with science-based targets for sustainable development, like the Paris Agreement, SDGs, and planetary boundaries (see Steffen et al. (2015) for details on the latter); 3) prospectiveness, measuring progress towards a goal and accounts for companies' targets or investment plans; 4) life cycle consideration, covering impacts across the entire value chain, both downstream and upstream; 5) reliability, ensuring the completeness and consistency of data, comparability of results, and methodologies that are transparent, reproducible and quantitative rather than qualitative.

Of the thirteen measurement tools assessed, Popescu et al. (2021) found that none fully addressed investors' additionality measurement (see Section 2.1.3.2), with only one tool meeting the prospectiveness criteria (incorporating a forward-looking perspective), and two including the life cycle consideration criteria. The tool meeting the prospectiveness criteria was the Paris Agreement Capital Transition Assessment (PACTA), which measures portfolio alignment with low-carbon pathways. However, this tool provides only a limited forward-looking period of five years, constrained by companies' production plans, covers just eight sectors, such as power generation, and relies on a proprietary asset-level database with data uncertainty (PACTA, 2022; Popescu et al., 2021). Nonetheless, the methodology and assumptions behind the PACTA tool remain transparent (Popescu et al., 2021), in contrast to ESG and carbon scores from third-party providers, which lack transparency and credibility, as previously discussed in Section 2.1.2.3.

The development of methodology and indicators relies on the accessibility of standardized, comparable, reliable and transparent data (Oudenhoven et al., 2018; TCFD, 2021d); otherwise, the

outputs may be compromised by untrustworthiness (Berg et al., 2022; Busch et al., 2016; Popescu et al., 2021). This might explain why only two tools included life cycle consideration criteria (Popescu et al., 2021); both self-reported company data and third-party providers often fall short in carbon data outside direct company activities. Although such data can represent most of companies' total impacts within their value chain, these data are often incomplete or inaccurate when self-reported (C. Blanco et al., 2016; Huang et al., 2009; Klaaßen & Stoll, 2021). Furthermore, third-party providers data typically lack transparency in estimation methods, resulting in low comparability and inconsistencies across providers' results (Busch, Johnson, et al., 2022; Papadopoulos, 2022).

Nonetheless, as Oudenhoven et al. (2018) emphasize, one of the critical criteria to consider in developing methodologies to inform decision-making is their flexibility to adapt over time by incorporating new challenges and information. This flexibility would enable the integration of a life cycle perspective when it is missing, as recommended by Popescu et al. (2021).

2.1.4 Limitations Identified in Responsible Investment

Regardless of the investors' objectives, whether risk-driven (RI 2.0) or impact-oriented (RI 3.0), incorporating a forward-looking perspective that leads to a better understanding of the future carbon performance of companies is relevant in both cases. To forecast future carbon performance, investors must look beyond current metrics and assess companies' actions and willingness to transition. However, they face challenges in finding reliable and decision-useful methods and indicators.

Current methods have the following limitations: they either rely on a backward-looking approach, provide a limited forward-looking period, or have constrained usefulness for investors' decisions. Decision-usefulness for investors refers to methods that are simple to use, trustworthy, reproducible, and broadly applicable (Eurosif, 2023; Oudenhoven et al., 2018; Popescu et al., 2021; TCFD, 2021c). These qualities align with the TCFD's criteria, including ease of understanding, transparency, and the capability to cover different types of assets in portfolios while providing reliable and comparable outputs across companies (TCFD, 2021c).

Corporate climate mitigation targets can serve as a key indicator of how companies project their future performance (Campbell, 2021; Eurosif, 2023; GFANZ, 2023; NGFS, 2022; TCFD, 2021c). However, implied temperature rise methods from providers, which might include corporate

projections based on their climate mitigation targets, are encapsulated in complex methodological assumptions surrounded by opacity, which compromise their perceived reliability and usefulness (Chmel et al., 2023; Eurosif, 2023; Raynaud et al., 2020). Other providers methods often remains limited to whether companies disclosed an emissions reduction target; they lack a comprehensive evaluation of the quality of these targets and the companies' progress toward achieving them (Eurosif, 2023; Kalesnik et al., 2021; NGFS, 2022; OECD, 2022).

Based on the broad expectation that companies with targets will demonstrate better future carbon performance, investors value companies with climate mitigation targets, especially ambition ones such as those approved by the SBTi, due to their transparency and scientific basis (Bendig et al., 2022; Campbell, 2021; Cheng et al., 2023; Eurosif, 2023; Khandelwal et al., 2022). However, the rapidly increasing number of companies setting targets raises concerns about the reliability of these targets in general, as some appear to be merely a disclosure exercise, casting doubt on their credibility in achieving these goals (Bolton et al., 2022; Dragomir, 2023; Hale et al., 2022; SBTi, 2023). This emphasizes the importance of assessing not just whether companies have disclosed a target, but also gaining a more comprehensive understanding of their reliability. However, as detailed in the following chapter, comparing the ambition and progress of targets from different companies and sectors, including those approved by the SBTi, faces many challenges, which currently limit broad applicability across industries.

Consequently, the following needs were identified:

- Improve understanding of companies' future carbon performance based on reliable information (completeness and consistency) from corporate climate mitigation targets to inform investors' decisions.
- Develop transparent methodologies and indicators to enhance comparability across companies, ensure applicability across industries and ease of reproduction for continuous monitoring.

To address the limitations and needs identified, this doctoral dissertation is dedicated to assessing corporate climate mitigation targets. The subsequent section reviews the related scientific literature, leading to the formulation of the research problem and general objective presented in Chapter 3.

2.2 Corporate Climate Mitigation Target

Throughout this doctoral dissertation, the terms corporate climate mitigation target, corporate emissions reduction target, and corporate target are used interchangeably. Additionally, the terms carbon emissions (or simply emissions to streamline the text) and carbon performance includes greenhouse gas (GHG) emissions, not just carbon dioxide (CO₂) emissions, and is therefore expressed in the unit of CO₂ equivalent (CO₂e). This aligns with the common understanding from practitioners that a corporate carbon footprint includes GHG emissions, not just CO₂ emissions (Goldhammer et al., 2017; Popescu et al., 2021; TCFD, 2017b; Thoma et al., 2018).

2.2.1 General Definition and Characteristics

Corporate climate mitigation targets are typically expressed as a percentage of reduction for a defined emission scope between a base year and a target year (Callery & Kim, 2021; Campbell, 2021; Dahlmann, 2023). The percentage of reduction is commonly referred to as the target ambition and vary from 0% to 100% (detailed in the following section).

Type of targets

They can be reported as either absolute or intensity targets (relative to activity or economic value measures) (Dahlmann et al., 2019; Herzog et al., 2006; Kolk & Pinkse, 2004). The activity measures correspond to physical metrics, such as ton of steel, indirectly implying that these types of intensity targets can only be applied to homogeneous sectors (Koellner et al., 2005).

An intensity target can result in an increase in absolute emissions. For instance, if the percentage increase in steel production exceeds the percentage reduction in the intensity target during the same period, absolute emissions will rise despite achieving the intensity target.

Target timeframe

The timeframe is the period between the base year and target year, spanning a number of years. Literature may refer to short-term, medium-term and long-term targets, often corresponding to a target year exceeding a specific date. For example, in the CA100+ Net-Zero Company Benchmark, a long-term target correspond to a target year exceeding 2035, while the Transition Pathway Initiative had previously defined long-term target as a period over 5 years (CA100+, 2022a; Dietz, Bienkowska, et al., 2021).

Emission scope covered by targets

Following to the GHG Protocol corporate accounting and reporting standard, the corporate carbon footprint is divided into three scopes (WRI & WBCSD, 2004). Scope 1 correspond to the direct emissions of a company, while scope 2 includes indirect emissions from the consumption of the purchased of electricity, and scope 3 covers all other indirect emissions within the company's value chain (Harangozo & Szigeti, 2017; Stridsland et al., 2024). Scope 2 can be reported using two methodological; location-based (regional grid-average emission factor) and market-based (specific emission factors derived from a contractual agreement) (Bjørn, Lloyd, et al., 2022; Brander et al., 2018).

Therefore, targets cover one of the three scopes or a combination thereof (Dahlmann, 2023; Gieseckam et al., 2021a). However, targets may cover specific country operations, or business division rather than company-wide, resulting in the disclosure of a percentage of scope covered by a target. (CA100+, 2022b; CDP, 2020b).

Base year, base year emissions and base year emissions covered by the target

The base year could be the year in which the company first disclosed the target or any prior year. In the same disclosure year, the base year emissions reported for a given year may differ from the target base year. For instance, a company might report 2018 base year emissions, while the target base year is 2015. In this case, the 2018 base year emissions correspond to the company-wide annual emissions for a specified scope.

Since a target may not cover 100% of a specified scope, the base year emissions covered by a target is the percentage of the company's base year emissions for the scope covered by the target. For instance, if the target coverage reported by a company is 80% with 2010 base year emissions of 100,000 t CO₂e, the base year emissions covered by the target is 80,000 t CO₂e.

Target year, target year emissions and target year emissions covered by the target

The target ambition is applied to the target base year and the target coverage. Therefore, the emissions that a company aims to reach by the target year depend on the base year emissions covered by the target. By default, the target year emissions are the target emissions covered by the target. As briefly demonstrated, disclosed targets by companies are intrinsically linked to the

quality of their carbon data reporting (completeness and consistency), with their assessment depending on their reliability.

2.2.2 Target Ambition: The Expected Future Corporate Carbon Performance

Due to external pressures and the value investors place on ambitious targets, such targets have grown in popularity in recent years (Bendig et al., 2022; Bolton & Kacperczyk, 2023a; Hale et al., 2022; Khandelwal et al., 2022; SBTi, 2022a). However, the widely varying target parameters chosen by companies, combined with insufficient information to scrutinize companies' claims due to the lack of regulation, complicate the comparability of their target ambitions between companies and could even hinder the assessment of their true ambition (Dahlmann et al., 2019; Dragomir, 2023; In & Schumacher, 2021; Montgomery et al., 2023).

Net-zero and science-based targets

To gain credibility, many companies rely on recognized practices to authenticate and differentiate their target ambition, framed by stringent design features and solid foundation, such as net-zero targets and those approved by the SBTi (Hale et al., 2022; SBTi, 2022a). However, self-claimed net-zero targets can vary in robustness due to differences in target-setting parameters and the lack of mandatory oversight, leaving scrutiny to investors and other stakeholders (Hale et al., 2024; Robiou du Pont et al., 2024).

Following the SBTi Corporate Net-Zero standard, claiming net-zero target(s) should imply: 1) a 2030 science-based target(s) covering a minimum of 95% of company's scope 1 and 2 emissions and a minimum coverage of 67% of scope 3 emissions when they represent more than 40% of total company emissions, and 2) 100% reduction by 2050 at the latest on a minimum of 90% of total company emissions (SBTi, 2024a). Therefore, a company reporting net-zero by 2050 without adhering to scope coverage and 2030 target expectations would be less robust. In other words, 100% reduction on 100% coverage is not equivalent to 100% on 60% of the same coverage.

Investors seem to view having an approved SBTi target as strengthening the integrity of the company' targets (Eurosif, 2023; Robiou du Pont et al., 2024). To be considered compliant with 1.5 degree warming limit, SBTi accepts two approaches for setting targets: 1) an absolute contraction approach, requiring an annual reduction of minimum 4.2%, and 2) a sectoral decarbonization approach, corresponding to intensity targets where companies in a given sector

will converge to a same intensity at a given year (Bjorn et al., 2021). The first approach, which can easily be replicated to assess if a company target that is not approved by the SBTi is equivalent, is not accepted for every sector. Certain sectors can only use the second approach. However, the second approach is not available for every sector and requires underlying company inputs, such as production growth, to determine if a target is compliant with the 1.5-degree warming limit (Bjorn et al., 2021; Bjørn et al., 2023). This results in the annualized reduction of targets approved by the SBTi varying considerably (Bjørn et al., 2023; Bolton & Kacperczyk, 2023a), making it more difficult for investors to determine whether a non-approved target would be compliant with the 1.5-degree warming limit and comparable to the ambition of an approved SBTi target.

Given these comparability challenges, investors typically evaluate whether targets disclosed by companies fulfill acceptable parameters, such as net-zero by 2050 with a defined scope coverage, or have approved-SBTi target(s), often using a checklist approach like that of the Climate Action 100+ Net Zero Benchmark (CA100+, 2022a). This approach limits a comprehensive understanding of targets that do not meet these specific criteria and reduces comparability across different targets. Comparing the ambition of companies' targets is relevant for many responsible investment approaches, such as best-in-class (positive screening based on comparison to peers) or identifying laggards for stewardship activities (see Table 2.1). Furthermore, it could help determining the remaining efforts to achieve their own portfolio emissions reduction targets by assessing the level of reduction occurring from companies' targets (Azoulay et al., 2023; Bolton et al., 2022; TCFD, 2021c).

Methods and indicators to compare the ambition of companies' targets

To exemplify methods and indicators used in the literature and the issues encountered due to the varying target parameters of companies' targets, Figure 2.2 presents three targets with their corresponding parameters from companies in the fossil fuel sector.

Previous studies directly used the percentage of reduction announced by companies in their analysis (Ioannou et al., 2016; Sullivan & Gouldson, 2016; D. Wang, 2017), lacking the integration of the timeframe of targets. For instance, the 26% reduction in 13 years announced by Naturgy (which they claimed to be science-based) does not represent the same ambition as the 25% reduction in 11 years announced by Shell, because one target reduces emissions faster than the other due to a shorter target timeframe.

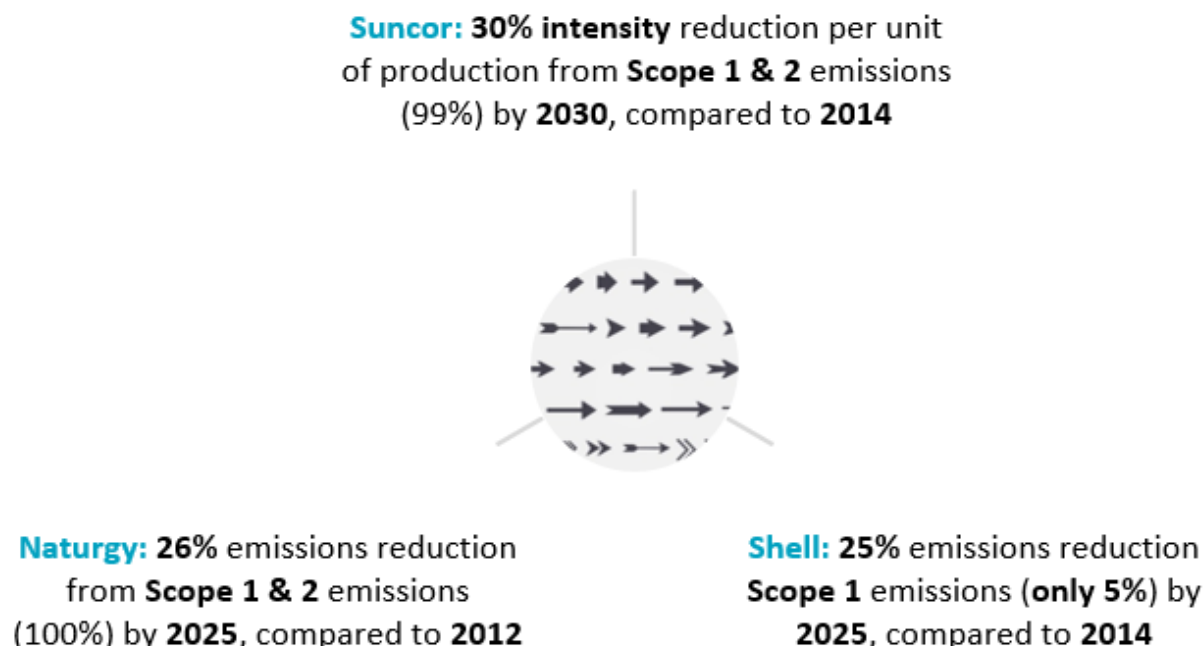


Figure 2.2: Emissions reduction targets publicly disclosed by three companies operating in the fossil fuels sector. Extracted from CDP (2018). The number in brackets corresponds to the percentage of scope covered by the target.

Other studies have annualized the target ambition of companies, assuming a constant reduction rate per year (linear reduction trajectory) (Aldy et al., 2023; Dahlmann et al., 2019; Gouldson & Sullivan, 2013; D. D. Wang & Sueyoshi, 2018). Hence, the annualized reduction rate of Naturgy's target is 2% per year (26% divided by 13 years), compared to Shell's target of 2.27% per year (25% divided by 11 years). However, these two targets are not covering the same scope either than the same percentage of scope.

Regarding Suncor, they have an intensity target while the two other companies have absolute targets. As briefly explained, a percentage of reduction in intensity usually results into a different percentage of reduction in absolute emissions. Therefore, even if Suncor and Naturgy have the same target coverage (with slight differences in the percentage of scope covered), their target ambitions, even when annualized, cannot be directly compared. To contravene this, some studies only assessed targets with similar parameters (e.g., only absolute targets covering scope 1). However, it remain often unclear whether correction were made regarding the percentage of scope covered by the target, or resulted in the exclusion of targets not covering 100% of their scope (see D. D. Wang & Sueyoshi, 2018).

The last approach involves projecting the companies emissions based on their ambition, harmonizing them to a scope coverage and timeframe, as done by the Transition Pathway Initiative (TPI) to compare companies' target ambitions to Paris-aligned benchmarks by sector, building on the methodology of Dietz et al., (2018). When the target scope coverage is lower, the emissions not covered by the target are assumed to be constant. This approach enhances comparability; however, its current application is limited to homogeneous sectors due to the use of a physical intensity metric (e.g., ton of steel), which uses production growth projection estimates based on company or sectoral data to transform absolute targets into these metrics (Dietz, Gardiner, Jahn, et al., 2021; Immink et al., 2018). For instance, sectors such as retail, apparel, and services are excluded due to the lack of a common physical intensity metric.

Limitations identified in methods and indicators to compare the ambition of companies' targets

Previous studies comparing the ambitions of companies' targets, therefore, either show a gap by lacking comparability between companies' targets with varying parameters, constrained to targets with similar parameters, or limited in their sectoral coverage. Hence, it restricts its broad applicability across different sectors and thus, portfolios. This literature gap underscores the need for methods and indicators that can comprehensively compare the ambition of corporate targets across diverse parameters and sectors.

(Climate) benchmark

Given these challenges in comparing the ambitions of companies' targets due to their varying parameters and the limitations of existing methods and indicators, benchmarking offers a structured approach to assess relative performance against peers or across sectors. Benchmarking can take various forms and typically involves two key aspects: 1) the objects of the benchmarking study, and 2) the entities or subjects against which comparisons are made (Carpinetti & De Melo, 2002; Kyrö, 2003; Stapenhurst, 2009). It can be performed on processes, products, or strategies, such as management and business practices (strategic benchmarking) (Carpinetti & De Melo, 2002; Kyrö, 2003). Comparisons can be internal (against itself), against peers (competitors in the same sector), functional (focused on specific functions or technologies), or generic (best practices regardless of the sectors) (Kyro, 2003; Carpinetti, 2002). For example, companies can benchmark their current

GHG performance against their peers based on publicly available data, to assess their own relative performance and understand whether they are leaders or laggards (Tomar, 2023).

Investors are well-known for benchmarking practices, such as comparing companies' financial performance against various entities (Deville, 2008; L. B. Siegel, 2003; Stapenhurst, 2009). In this dissertation, the term 'benchmark' refers to this practice, specifically focusing on the comparison of companies' target ambitions, either against peers within the same sector or across sectors, to help investors evaluate relative performance.

It is important to differentiate this use of benchmarking from the climate policy context, where the term "benchmark" is associated with alignment towards the 1.5°C trajectory (Dietz et al., 2018; Dietz, Gardiner, Jahn, et al., 2021; Krabbe et al., 2015; Kuramochi et al., 2018). These benchmarks focus on assessing the alignment of companies and their targets with the sectoral 1.5°C pathway, rather than direct comparisons of performance among peers. In the climate policy context, benchmarks correspond to the sectoral 1.5°C trajectory required for a company to be considered aligned, not to how ambitious a company's target is relative to others in its sector. This distinction has been recently reinforced by the European Union adoption of minimum standards for climate benchmarks (financial indices), namely Climate Transition and Paris-aligned benchmarks, (Galoppo et al., 2023; Hodges et al., 2022).

2.2.3 Target Progress: Walking the Talk or Just Talking?

Investors' interest in companies that disclose ambitious targets is based on the broad assumption that their future corporate carbon footprint will reduce, implying that they will attain their goals (Bendig et al., 2022; Campbell, 2021; Cheng et al., 2023; Eurosif, 2023; Khandelwal et al., 2022). However, there is a risk that companies may fail to meet their targets.

Current literature confirms that companies do not necessarily make sufficient progress toward their goals and may fail to meet them (Callery & Kim, 2021; Kuramochi et al., 2021; Ruiz Manuel & Blok, 2023; SBTi, 2022a, 2023; D. Wang, 2017; Yeo et al., 2022). Furthermore, failure to progress might indicate that the company had no genuine intention to reduce their emissions and disclosed a symbolic target, resulting in reputational risks due to this misleading behavior (Campbell, 2021; Dahlmann et al., 2019; Dragomir, 2023; Montgomery et al., 2023).

To address these risks, it is important that investors measure the progress of companies' targets and compare them to identify which companies are making better progress. This comparison can reveal that companies progressing slightly less than others might pose lower risks compared to those not progressing at all, even if they are not fully on track to achieve their targets.

Indicators to compare the progress of companies' targets

Figure 2.3 and Figure 2.4 present fictive examples of different targets' progression for a company. The black line in both figures corresponds to the target linear reduction trajectory between the base year and the target year (constant yearly reduction rate; equivalent to annualizing the target ambition). This linearity assumption is common in the literature, as companies do not report information on the planned reduction trajectory of their targets (Aldy et al., 2023; Bjørn et al., 2023; Dietz, Gardiner, Jahn, et al., 2021; Gieseck et al., 2021a; Hale et al., 2021; A. Hsu et al., 2020; Kuramochi et al., 2021).

The target progress indicators found in the literature are: 1) percentage of the target achieved (Dragomir, 2023; Ioannou et al., 2016; SBTi, 2022a), with an adaptation proposed by Yeo et al. (2022); 2) categorical variables using terminology such as 'on track', 'not on track', or 'achieved' (Callery & Kim, 2021; Gieseck et al., 2021a; Kuramochi et al., 2021; D. Wang, 2017; Yeo et al., 2022); and 3) progress ratio (A. Hsu et al., 2020).

As illustrated in Figure 2.3, the percentage of the target achieved corresponds to the reduction in emissions attained at the assessed progression year compared to the total targeted emissions reduction. The percentage of time elapsed refers to the proportion of the target timeframe that has passed at the assessed progression year. In both fictive examples 1 and 3, 60% of the target is achieved; however, their percentage of time elapsed differs, with one progressing faster than the other. In other words, achieving 60% of the targeted reduction after 5 years on a 10-year timeframe (example 1; 50% time elapsed) does not represent the same attainment as achieving it after 8 years (example 3; 80% time elapsed). Furthermore, example 1 is 'on track' to achieve its target, assuming a linear reduction trajectory (below the black line in Figure 2.3), while example 3 is 'not on track' (above the black line). This indicator lacks the integration of a time perspective, which lead to comparability issues between target not having the same time elapsed. Nevertheless, it avoids assuming a linear reduction trajectory, in contrast to other indicators.

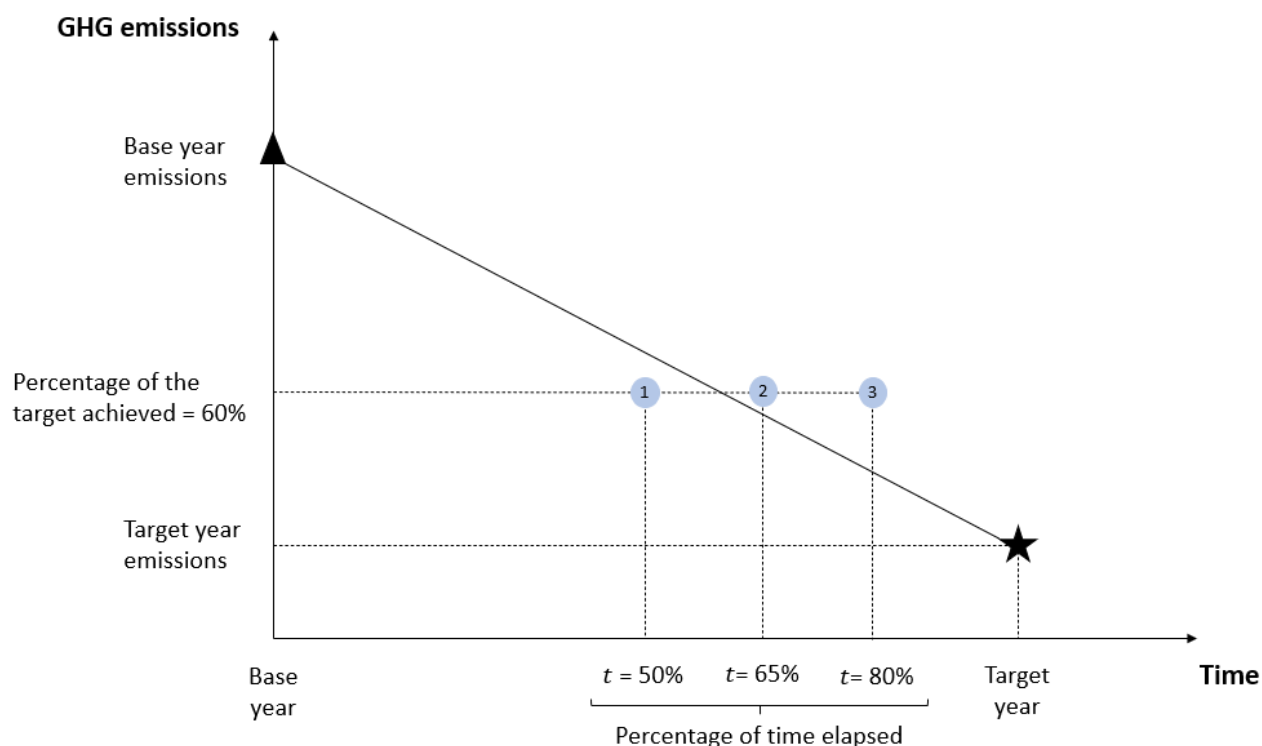


Figure 2.3: Illustrative examples of the target progression of a company assuming a linear reduction rate between the base year and the target year (black line), showing the percentage of the target achieved with different percentages of time elapsed (t).

Yeo et al. (2022) proposed an adaptation of this indicator by dividing the percentage of target achieved by the number of years passed since the base year. This shows the average annual percentage of the target achieved since the base year. However, it does not account for the remaining time left to achieve the target, by omitting the target year information. For instance, example 1 achieves 12.5% per year (60% achieved, over 5 years), while example 3 has a shorter timeframe of 4 years passed on 5 years (still 80% of time elapsed) resulting in 15% per year. It indicates that example 3 has a higher achievement per year since its base year compared to example 1. Assuming these maintain the same average annual percentage of target achieved until their target year, example 1 would achieve 122.5% of its targeted reduction (60% already achieved + 12.5% for 5 remaining years), while example 3 attain 75% (60% already achieved + 15% for 1 remaining year). Therefore, example 3, despite a higher annual achievement rate, is indeed lagging compared to example 1, as shown in Figure 2.3. Omitting the target year information and by extension different target timeframes lead to a lack of comparability between companies' targets.

The categorical variables are easily understandable. As mentioned, example 1 is ‘on track’, and example 3, ‘not on track’. These categories do integrate a time perspective, enhancing comparability between targets with different timeframes. Furthermore, Gieseke et al. (2021a) study integrates the category ‘achieved’, labelling targets that attained their expected target year emissions regardless of their timeframe, which is a valuable information. However, it still lacks in differentiation between progress results. As shown in Figure 2.3, examples 2 and 3 are both ‘not on track’ (above the black line), but example 2 is slightly behind its target linear reduction trajectory compared to example 3. A company that has increased their emissions compared to its target base year (0% achieved), potentially disclosing a symbolic target, would not be differentiated from example 2; both being ‘not on track’. This also demonstrates a more pronounced limitation caused by the linear reduction trajectory assumption.

The last indicator is a progress ratio, developed by A. Hsu et al., (2020). The progress value represents the speed to which a target is progressing compared to their target linear reduction trajectory. It alleviates the differentiation issue of the categorical variables, while maintaining a similar interpretability. A value of 1 or above indicates ‘on track’ and below indicates ‘not on track’. However, Yeo et al. (2022) found substantial variability in achievement of corporate targets near the base year. As shown in Figure 2.4, the percentage of target achieved for example 4 is -600%, with example 5 at 250%, and both having a 5% time elapsed. This will result in a progress value of -120 for example 4 ($-600\%/5\%$) and 50 for example 5 ($250\%/5\%$).

The progress ratio can generate extreme outliers due to the specificity of corporate targets, which is the opposite problem of categorical variables. A. Hsu et al., (2020) utilized the progress ratio for a study focused on city targets with a 2020 target year (a homogeneous sample), contrasting with the different types of companies’ targets with varying parameters. Depending on the analysis type, these outliers can undermine the validity of the results. However, legitimate outliers (those not resulting from data errors) can provide valuable insights (Hadi et al., 2009; Orr et al., 1991; Osborne & Overbay, 2004).

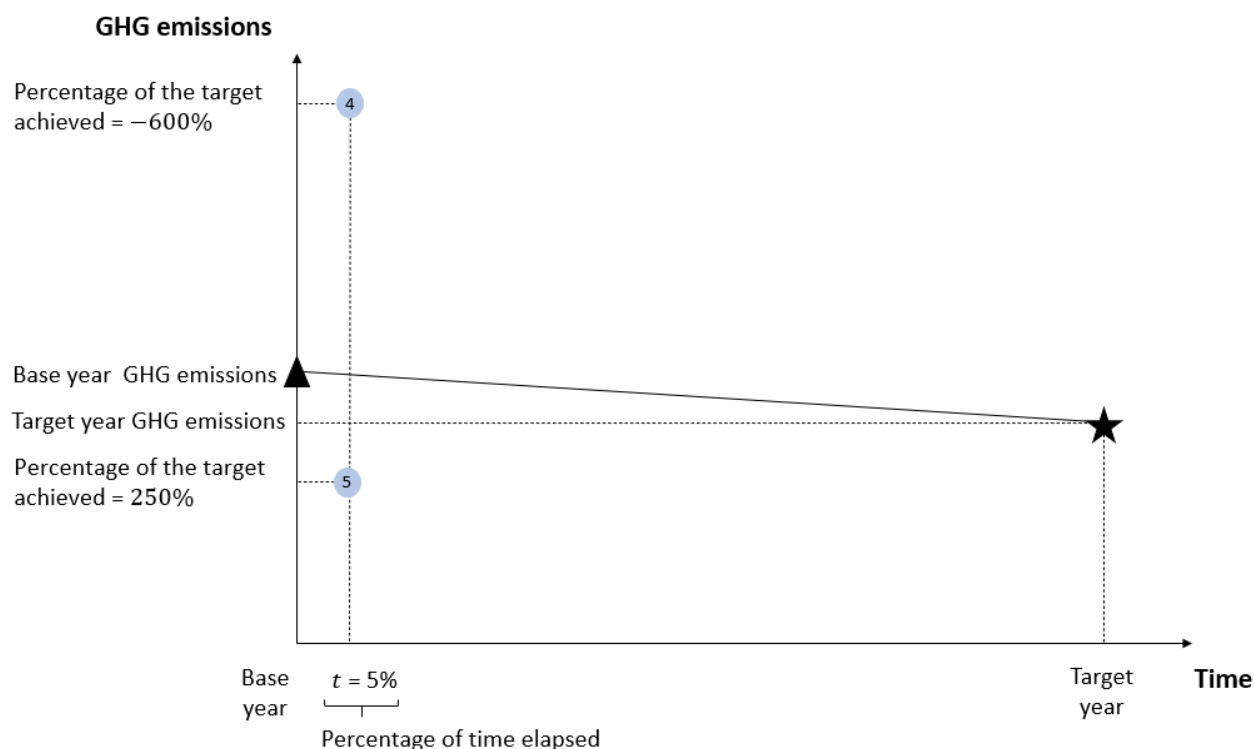


Figure 2.4: Illustrative examples of the target progression of a company assuming a linear reduction rate between the base year and the target year (black line), showing the percentage of time elapsed (t) with different percentages of the target achieved.

Limitations identified in indicators to compare the progress of companies' targets

To the exception of the progress ratio, other progress indicators either lack comparability between companies' targets with varying timeframes or lack of differentiation in the progress results, thus limiting a broad applicability across different companies and sectors. While enhancing the comparability and allowing a broad applicability, the progress ratio would limit a comprehensive understanding of why some companies progress better than others by the exclusion of companies' targets that could provide new insights on differentiating best from poor corporate practices. This would help address concerns about the reliability and credibility of companies' targets (Campbell, 2021; Hale et al., 2021; Kuramochi et al., 2021). This literature gap highlights the need for a progress indicator that is specificity adapted for corporate targets and their comparison.

2.2.4 Target Reliability: Unveiling the Reality Behind Progress and Data Integrity

Literature on the drivers of companies' progress toward their targets is still nascent, possibly because the number of companies with targets has only recently surged (Bolton & Kacperczyk, 2023a; Hale et al., 2022; SBTi, 2022a). As a result, only a few determinants driving companies' progress towards targets have been assessed, with studies focusing primarily on target parameters (e.g., ambition) (Aldy et al., 2023; Dahlmann et al., 2019; Dragomir, 2023; Gieseckam et al., 2021a; Ioannou et al., 2016; D. Wang, 2017; Yeo et al., 2022).

While examples given on existing target progress indicators focused on the limitations related the varying timeframe, comparability issues regarding other parameters remains. For instance, Ioannou et al., (2016) used directly the percentage of reduction as indicator for the target ambitions of companies as one of the independent variables. Nevertheless, this study covers corporate practices related to monetary incentives towards management and found that these were associated with higher target progression. On the other hand, Gieseckam et al. (2021) constrained their study to the progression of companies with science-based targets, with the assessment of their target parameters. Similar narrow focus to the targets parameters and few companies characteristics related to their progress towards theirs targets applies to the other studies (Aldy et al., 2023; Dahlmann et al., 2019; Dragomir, 2023; Yeo et al., 2022). Furthermore, Aldy et al., (2023) and Dahlmann et al. (2019) used change in companies' emissions over time rather than a target progress indicator, which correspond to similar issues to the progress indicator proposed by Yeo et al. (2022). However, none of the other studies used the progress ratio indicator as dependent variable in their statistical analysis.

Previous studies, therefore, either show a gap by focusing on a limited number of determinants and the use of target progress indicators with important limitations. Accordingly, the determinants driving companies' progress toward their targets remain unclear. It's uncertain whether analyzing a more comprehensive list of determinants or integrating a time perspective into the target progress indicator could render previously identified drivers to be less relevant. For instance, such determinants could include the disclosure of energy targets, the use of internal carbon pricing, engagement practices with value chain actors, board oversight of climate-related issues, or revenue from low-carbon products. This gap in the literature underscores the necessity for a thorough

investigation and a more comprehensive analysis of the factors influencing corporate climate target progress.

Companies' targets are tied to their voluntary carbon disclosures, raising concerns about their credibility due to their inherent voluntary nature and quality of companies' disclosures (Armour et al., 2023; Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Dragomir, 2012; Hale et al., 2024; Montgomery et al., 2023; Talbot & Boiral, 2018). Previous studies have shown that there is not always enough information available to adequately assess companies' targets (Dietz, Gardiner, Jahn, et al., 2021; Giesekeam et al., 2021a). While outliers might be legitimate and provide new insights, they could arise from underlying data reliability issues, requiring careful examination (Hadi et al., 2009; Orr et al., 1991; Osborne & Overbay, 2004).

Inconsistencies in voluntary corporate carbon data across various channels have been identified, including CDP questionnaires, sustainability reports, mandatory reporting programs and third-party data providers (Depoers & Jeanjean, 2016; Kölbel et al., 2020; Papadopoulos, 2022; Stanny, 2018). These inconsistencies are also observed through different reporting years (Callery & Perkins, 2021; Dragomir, 2012), and even in the same reporting year period (Garcia-Vega et al., 2023).

The literature has emphasized the importance of the reliable voluntary carbon data disclosures to assess companies' progress towards their targets (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Dragomir, 2012; Hoepner & Rogelj, 2021; Talbot & Boiral, 2018). However, the assessment of the reliability of disclosed targets by companies through the lens of potential inconsistencies in their self-reported carbon data remains unexplored. It is unclear whether inconsistencies differ between companies with and without targets, or how these affect the evaluation of the ambition and progress of companies' targets.

CHAPTER 3 RESEARCH PROBLEM, RESEARCH OBJECTIVES AND GENERAL METHODOLOGY

This chapter presents the process for the research project as a whole, by demonstrating the coherence between the research problem arising from the literature review and the research objectives. It also provides an overview of the methodology used for this dissertation.

3.1 Research Problem

Investors encounter difficulties in finding forward-looking approaches to assess and compare corporate performance in addressing climate transition risks with methods and indicators that are reliable and decision-useful. Such methods should possess the qualities of being transparent, consistent, broadly applicable across sectors, and easily replicable to facilitate continuous monitoring.

Corporate emissions reduction targets can be useful to understand how companies project their future performance. However, comparing the ambition and progress of all types of climate mitigation targets between different companies faces challenges due to their varying target parameters. Existing methods and indicators comparing the ambition and progress of companies' targets exhibit similar gaps, by constraining their assessments to companies with similar targets or parameters, restricting their applicability to limited sectors, and lack comparability between disclosed targets from companies. These gaps limit a broad applicability across sectors and contravenes to a comprehensive understanding of disclosed targets by companies.

Given the credibility concerns surrounding companies' targets and their related reporting, better understanding why some companies progress more towards their targets than others would help improve assessment of their reliability. Furthermore, understanding how inconsistencies in voluntary carbon data reporting relates to companies with targets and affect the assessment of the ambition and progress could contribute to improve assessment of their reliability.

To address these challenges, this research aims to answer the following general research question: How can the ambition and progress of corporate climate mitigation targets be compared across sectors to generate a comprehensive evaluation of their disclosed targets and enable better informed investment decisions?

3.2 Research Objectives

The general objective of this dissertation is to: **Develop methodologies and indicators to compare the ambition and progress of corporate climate mitigation targets across sectors to generate a comprehensive evaluation of their disclosed targets to enable better-informed investment decision-making.** More specifically, this general objective addresses three main topics of interest enabling the evaluation of corporate climate mitigation targets:

- How can the **ambition and progress** of corporate climate mitigation targets with different parameters be **compared** to each other and **evaluated**?
- How can the **reliability** of corporate climate mitigation targets be **evaluated**, resulting to:
 - What are the key determinants of corporate climate mitigation targets progress?
 - How does the reliability of corporate carbon data relate to companies with climate mitigation targets and their assessment?

To address the general objective and the research questions, six objectives have been identified and grouped according to the three main topics of interest:

- **Ambition** of corporate climate mitigation targets:
 - Objective 1: Develop a harmonization process comparing corporate climate mitigation target ambition.
 - Objective 2: Establish absolute and intensity sectoral benchmarks based on climate mitigation targets.
- **Progress** of corporate climate mitigation targets:
 - Objective 3: Develop an indicator comparing corporate climate mitigation targets progress.
 - Objective 4: Determine the key determinants of corporate climate mitigation targets progress.
- **Reliability** of corporate climate mitigation targets:
 - Objective 5: Develop indices allowing to measure inconsistencies in voluntary corporate carbon disclosures.
 - Objective 6: Assess the implications of current inconsistencies in corporate carbon data disclosures on corporate climate mitigation targets.

3.3 General Methodology

Figure 3.1 presents a general overview of the methodology applied to address the objectives of this dissertation. Responses to the six objectives led to the writing of three scientific articles, each focusing on one main topic with two objectives. These articles used voluntary corporate climate-related disclosures, with the input data presented in Section 3.3.1. Sections 3.3.2, 3.3.3, and 3.3.4 briefly introduce each main topic, followed by an overview of the corresponding objectives' methodology. The results, as shown in Figure 3.1 under 'level of analysis', were either at the global level (all sectors), by sector, or by country. The detailed methodology, along with the corresponding results and discussions, are elaborated in the succeeding three chapters. Chapter 7 provides the dissertation's general discussion, including general outcomes, overall contribution, future research, limitations, and recommendations.

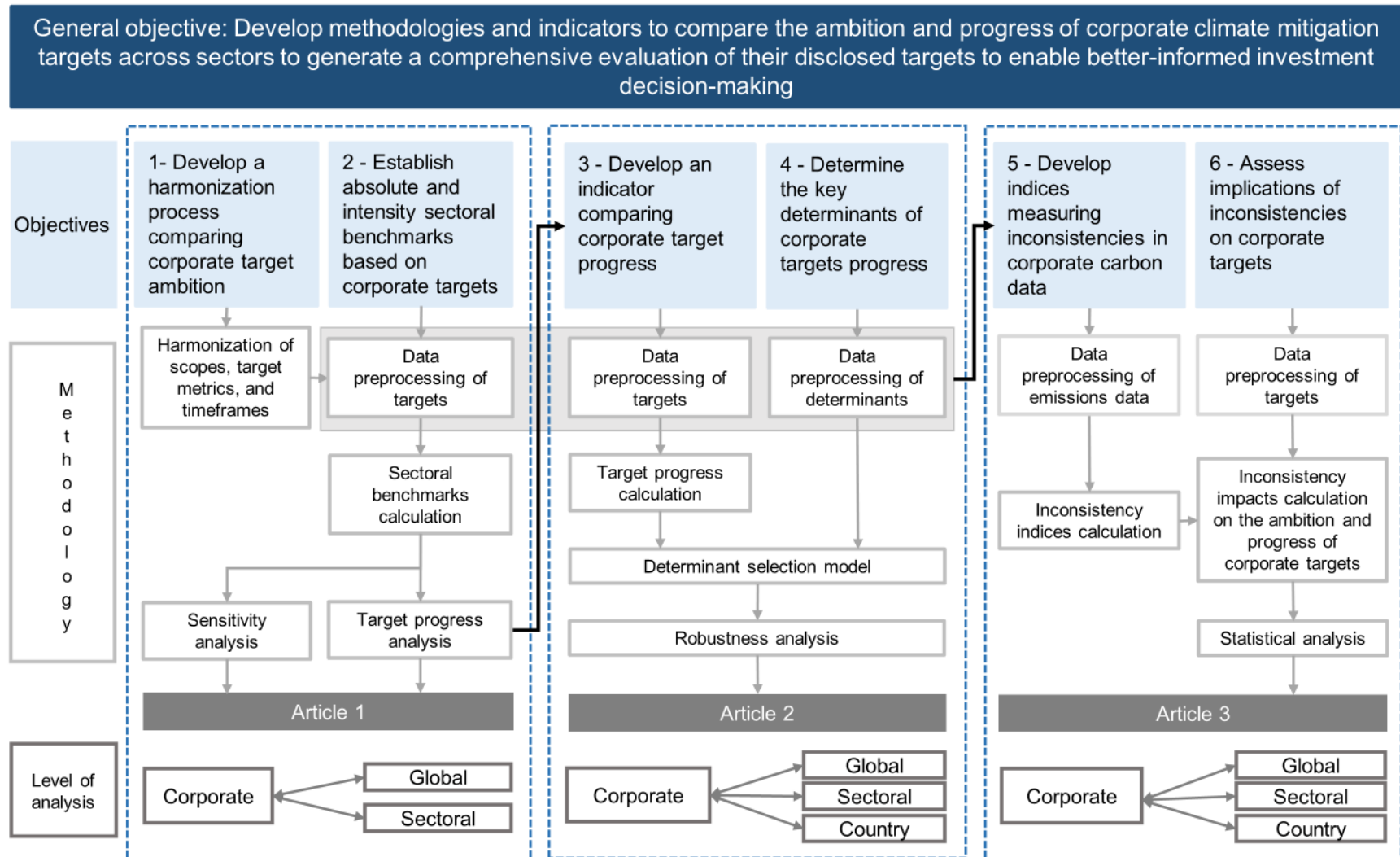


Figure 3.1: Flowchart of the general methodology per research objectives and articles.

3.3.1 Data Source and Selection

To generate a comprehensive evaluation of disclosed targets across sectors, the three scientific articles use voluntary carbon disclosures from the CDP climate change questionnaires as input data, specifically drawing on the ‘Corporate Response Data’ (dataset, see CDP, 2023), which contains target-related information disclosed by companies.

The CDP, which collects data on behalf of investors and suppliers through questionnaires, is the largest database of voluntary corporate carbon disclosures (Busch, Johnson, et al., 2022; Ott et al., 2017; Zhang & Liu, 2020). This was a key criterion in selecting this database. Additionally, the questionnaire format results in a highly structured and standardised dataset (Depoers & Jeanjean, 2016; Zhang & Liu, 2020), covering a wide range of information disclosed by companies across sectors and countries, making it the most extensive dataset of its kind (Busch, Johnson, et al., 2022; Ott et al., 2017).

The CDP dataset is generally regarded as a reliable source of corporate climate-related information (Garcia-Vega et al., 2023; Stanny, 2018) and is frequently used by investors and academic researchers (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Zhang & Liu, 2020). However, there may be potential inaccuracies in the information submitted by companies, as the ‘Corporate Response Data’ is not corrected by the CDP (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; CDP, 2023; Depoers & Jeanjean, 2016; Garcia-Vega et al., 2023). This necessitated data cleaning steps, which are outlined in Figure 3.1 under ‘Data preprocessing’, and reflected in the results of the third article (see Section 3.3.4).

3.3.2 Ambition of Corporate Climate Mitigation Targets

The first article, provided in Chapter 4, combines objectives 1 and 2. The main interest was to **compare** the target **ambition** of companies with **different types of targets** with that of their **peers**, in order to provide insights for investors using strategies such as best-in-class and engagement.

The first objective consisted of developing a uniform and coherent analysis structure to harmonize corporate targets, followed by the **measurement** of sectoral **ambitions** based on self-declared corporate targets. The latter includes the development of an absolute GHG sectoral benchmark, economic intensity sectoral benchmarks (per revenue and per enterprise-value), and physical

intensity benchmark (per activity measure for homogeneous sectors). The end results (level of analysis in Figure 3.1) are at the sectoral level, but also given at the global level.

3.3.2.1 Objective 1: Develop a harmonization process comparing corporate climate mitigation target ambition.

This objective proposes a consistent harmonization process to ensure comparability between companies' targets with different parameters, following a critical analysis that identified the limitations in existing approaches. This harmonization process unifies the parameters of targets to a same scope of emissions, timeframe, and target metric. The choice of parameters partly depends on the target data used, in this case from the 2018 CDP climate change questionnaire for Objective 2. This results to targets being harmonized to scopes 1 and 2 emissions, a common reference year of 2017, common target years (2020, 2025, and 2030), and to the unit of the corresponding benchmark. For example, the unit for the absolute GHG emissions benchmark was t CO₂e. In this context, absolute targets require no transformation, while intensity targets were transformed into absolute targets.

3.3.2.2 Objective 2: Establish absolute and intensity sectoral benchmarks based on climate mitigation targets.

Objective 2 includes four main steps: 1) data preprocessing of targets, 2) sectoral benchmarks calculation, 3) sensitivity analysis, 4) target progress analysis. Data preprocessing ensured all target data were complete and accurate, based on the harmonization choices. GHG emissions and target data required were extracted from the 2018 CDP climate change questionnaires, and financial data from Bloomberg. Targets with missing or inaccurate data, identified through developed criteria, were excluded.

The harmonization process was applied to calculate the absolute and intensity sectoral benchmarks. The methodological sub-steps varied depending on whether the sectoral benchmarks were in absolute or intensity metrics, with the latter requiring additional steps. Sensitivity analysis was performed for these additional steps, focusing on the method used to estimate the activity measure value.

Another sensitivity analysis for all sectoral benchmarks focused on targets being achieved by the common base year. To understand these achievements, companies' progress towards their targets

was analysed by categorizing their performance at the common base year and the start year of their target, which can differ from the target base year. The categories include three cases that do not assume a linear reduction trajectory for targets: 1) target already achieved, 2) absolute emissions reduced since the target base year, 3) absolute emissions increased since the target base year.

3.3.3 Progress of Corporate Climate Mitigation Targets

The analysis of corporate target progress in the first article has led to further questioning, as indicated by the black arrow to Objective 3 in Figure 3.1. In the second article (Chapter 5), the main interest was in **understanding** why some companies have a better **progress** toward their targets than others, with the target ambition (first main topic) becoming one of the potential reasons. Acknowledging what makes a corporate target successful or not could provide investors with insights into their **reliability** (more likely to be attained) and relevant ESG factors to consider in their assessment.

Beforehand, an indicator to **compare** target **progress** with that of their **peers** was developed (Objective 3). For the target progress, the end results (level of analysis in Figure 3.1) are provided at the global level in Chapter 5 and at the sectoral and country levels in Appendix B. An explanatory analysis was performed to identify the determinants (significant explanatory variables) that explain the variability in the target progress of companies (dependant variable). The end results for this fourth objective are only available at the global level, as the regions and sectors were part of the determinants assessed.

3.3.3.1 Objective 3: Develop an indicator comparing the corporate climate mitigation targets progress.

Following a critical analysis of existing target progress indicators, the proposed indicator overcomes issues identified: 1) lack of differentiation between categorical variable results, 2) lack of time perspective, and 3) high variability in targets progression near the base year (extreme values). To address these issues, the proposed indicator is a continuous variable, bounded by construction while still maintaining interpretability, and considers the remaining time left to achieve a target.

The proposed indicator penalizes more severely as the target year approaches, while rewarding earlier-than-expected reductions. In the case of Objective 4, this indicator assumes a linear

reduction trajectory between the base year and target year (constant reduction rate); however, simple adaptation allows for non-linear reduction trajectory.

Objective 3 includes two other main steps: 1) data preprocessing of targets, 2) calculation of the target progress results with the proposed indicator. Data preprocessing is similar to Objective 2, except it uses data from the 2020 CDP climate change questionnaires and applies stricter data accuracy criteria. To increase comparability between progress results and determinants analyzed in Objective 4, the calculation step involves harmonizing targets to absolute scope 1 and 2 targets, following the process previously developed in Objective 1.

3.3.3.2 Objective 4: Determine the key determinants of corporate climate mitigation targets progress.

Objective 4 includes three main steps: 1) data preprocessing of determinants, 2) determinant selection model, 3) robustness analysis. The explanatory analysis includes 120 determinants (explanatory variables), sourced from each section of the CDP questionnaire, ensuring that determinants analyzed in previous studies are included, as long as they are included in the CDP questionnaire. These determinants were grouped into 11 categories i.e., target parameters, emissions reporting and other targets, governance, carbon price, risks and opportunities, strategy, engagement, verification, and additional reporting elsewhere, sector, and region. During the data preprocessing step for the explanatory variables, corresponding targets were excluded if the necessary data were incomplete.

The determinant selection model used is an ordinary least squares (OLS) regression with a backward stepwise selection, considering a p-value of 0.05 as the significance threshold. To test the robustness of the results, two additional models were tested: 1) least absolute shrinkage and selection operator (LASSO; different variable selection method for regression), and 2) random forest regressor (non-linear model). In addition, a bootstrap (resampling technique) was applied on the main model and the two additional models.

3.3.4 Reliability of Corporate Carbon Disclosure

The results from the data preprocessing steps of objectives 1 and 3 raised concerns about the consistency of voluntary corporate carbon data (indicated by the black arrow to Objective 5 in Figure 3.1). An important number of targets were disregarded from the two previous articles due

to data quality criterion developed in earlier objectives. Hence, the main interest in the third article (Chapter 6) was to **measure** the extent of **inconsistencies** in voluntary corporate carbon data (Objective 5) to better understand their **impacts**, using target **ambition** (first main topic) and the target **progress** (second main topic) indicators to exemplify their potential consequences (Objective 6). Acknowledging these impacts and firms' behaviors could enhance investors' awareness of data reliability as well as inform their assessment on the credibility of companies' targets. The end results are provided at the global level in Chapter 6, where the sectoral and country levels are available in Appendix B.

3.3.4.1 Objective 5: Develop indices allowing to measure inconsistencies in voluntary corporate carbon disclosures.

Objective 5 is composed of two main steps: 1) data preprocessing, 2) inconsistency indices calculation. First, data preprocessing involves identifying relevant parts of the 2020 CDP investor climate change questionnaire for the inconsistency analysis. This corresponds to instances where a company aggregated total emissions are compared to the total sum of emissions disaggregated by a breakdown per activity (e.g., GHG or country), resulting in 18 comparisons between responses reported by a company to two different questions. Second, comparisons for a company were excluded when one (or both) of the responses were missing.

The measure of inconsistency consists of three components:

- inconsistency indicator: assessing difference between two data points compared,
- frequency inconsistency index: share of company's disclosure with inconsistency considering the number of comparisons with sufficient information to be assessed,
- presence inconsistency index: when a company has reported inconsistencies for at least one of the data points compared.

Over- or understated aggregated emissions were identified for each comparison and company, with respect to different tolerance levels. These measures differ from Garcia-Vega et al. (2023) study by considering different tolerance levels, acknowledging that discrepancies in a company's reported data by a company may be acceptable depending on the stakeholders and their use of the data.

3.3.4.2 Objective 6: Assess the implications of current inconsistencies in corporate carbon data disclosures on corporate climate mitigation targets

To evaluate the reliability of current companies' targets through the inconsistencies in their corporate carbon data disclosures, two evaluations are proposed, both assessed with statistical analysis:

- 1) Evaluation of whether companies with targets are significantly more consistent than companies without targets, using results from Objective 5. Companies with targets were divided in groups to test three hypotheses, such as companies with approved SBTi targets versus those without targets.
- 2) Evaluation of whether variations generated by inconsistencies significantly impact the assessment of the ambition and progress of corporate targets, through two scenarios using a min-max approach.

Unlike the first part, the second part requires two additional steps: 1) data preprocessing, and 2) calculation of two scenarios for the ambition and progress of corporate targets. Data preprocessing involve absolute scope 1 and/or 2 targets, excluding those with incomplete information to assess the variations in target indicators.

The min-max approach implies that scenario 1 used the maximum value for parameter 1 and the minimum for parameter 2, while scenario 2 uses the opposite. For instance, the calculation of targets ambition includes the inconsistencies reported in the base year emissions (parameter 1) and the calculation of the target year emissions (parameter 2), following process of Objective 2. The calculation of targets progress, as developed in Objective 4, considers inconsistencies in base year emissions (parameter 1) and reporting year emissions (parameter 2).

The statistical test used for the first evaluation is the Mann-Whitney U test, since two independent groups are being compared (e.g., companies with approved SBTi targets vs. companies without targets). The second evaluation uses the Wilcoxon-Signed-Rank test, as scenarios for a target indicator include the same set of companies' targets (dependent groups).

CHAPTER 4 ARTICLE 1: PROSPECTIVE SECTORAL GHG BENCHMARKS BASED ON CORPORATE CLIMATE MITIGATION TARGETS

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Supplementary material in Appendix A.

4.1 Abstract

As climate change becomes firmly acknowledged as a financial risk, shareholders must consider corporate GHG performance to inform responsible investment decisions. To mitigate future climate risks, prospective benchmarks based on corporate climate mitigation targets are increasingly demanded by shareholders. However, existing benchmarks often lack sufficient sectoral coverage or fail to appropriately harmonize target metrics, scope, and corresponding timeframes. A harmonization process was developed which allows the calculation of sector-level prospective GHG benchmarks in terms of absolute or intensity GHG metrics. This process was applied to harmonize scope 1 and 2 emission targets of 1,697 companies reporting in 2018 CDP questionnaires across 13 sectors using 2017 as the common reference year. Results indicate the importance of using a sectoral approach and applying a common reference year to avoid considering reductions occurring before the target was launched due to company choice of target reference year. In 2030, the lowest and highest median reduction rates values are -9% and -36% for fossil fuels and power generation sectors respectively. The findings obtained strongly suggest targeted percentage of reductions should not be the only metric considered when comparing corporate climate mitigation targets amongst peers. Target progress when the target was announced and at a common reference year was found to be an important metric to assess potential greenwashing or poor ambition. In 14% of cases, targets were already achieved when company launched them.

4.2 Manuscript

4.2.1 Introduction

Climate change is increasingly recognized as a financial risk by practitioners and academics (Battiston et al., 2017; Carney, 2015; Dietz et al., 2016). If not anticipated and correctly accounted for, climate risks may become systemic risks and cause financial instability across global markets (Bolton et al., 2020; Dafermos et al., 2018; Saha & Viney, 2020).

Climate-related financial risks come from two main sources: physical risks and transition risks (Campiglio et al., 2018; Giuzio et al., 2019; TCFD, 2017a). Physical risks involve climate induced weather events causing damage to physical assets, natural capital, and/or human capital (Monasterolo et al., 2017). These events may have significant financial impacts to countries (Hsiang et al., 2017; Kompas et al., 2018; Nordhaus, 2017), companies (Bernstein et al., 2019; Dessaint & Matray, 2017; Goldstein et al., 2019; Pankratz et al., 2019), and citizens (Hasegawa et al., 2016; McMichael et al., 2006; Vicedo-Cabrera et al., 2021).

To mitigate the financial impacts associated with physical climate-induced events, a transition to a low carbon economy is required (Campiglio et al., 2018). However, this process presents another set of financial risks and uncertainties i.e., transition risks (Monasterolo et al., 2017; TCFD, 2017a), stemming from climate-mitigation policies (such as carbon pricing), technology obsolescence, and changes in consumer preference (Feyen et al., 2020; Semieniuk et al., 2020).

Climate policies have grown rapidly in number throughout the globe, passing from 72 in 1997 to 1,500 in 2018 (Nachmany & Setzer, 2018). Additionally, the ambition and effectiveness of such policies are expected to increase carbon constraints on both the consumption and production sides (Erickson et al., 2018). Furthermore, carbon prices are expected to increase from a median value of USD\$ 10/tCO₂e in 2020 (World Bank, 2020) to a minimum value of USD\$ 50-100/tCO₂e for a two-degree pathway by 2030 (Stiglitz et al., 2017); up to an average price of USD\$ 179/tCO₂e for a 1.5 degree pathway by 2030 (Rogelj et al., 2018).

Shareholders increasingly demand forward-looking approaches and industry data to effectively assess climate transition risks (Monnin, 2018; NGFS, 2019, 2021). Corporate GHG benchmarks have previously focused on current or historical performance, which is insufficient for assessing future risks (Byrd et al., 2013; Sueyoshi & Wang, 2014; Van Atten et al., 2021; Wiedmann et al.,

2009; Y. Yu et al., 2016). However, prospective benchmarks based on corporate GHG performance are useful to mitigate climate financial risks (Climate Action 100+, 2019; TCFD, 2021b) and facilitate responsible investment strategies (Busch et al., 2011). Indeed, Boiral et al. (2012) found a significant positive link between corporate climate mitigation targets, corporate GHG performance, and financial performance.

Corporate climate mitigation targets are commonly expressed as a percentage reduction of GHG emissions within a stated emission scope¹ between a base year (BY) and target year (TY). Corporate climate mitigation targets can be reported as absolute or intensity targets (relative to a measure of activity or economic value) (Dahlmann et al., 2019; Herzog et al., 2006; Kolk & Pinkse, 2004). Corporate climate mitigation targets and future corporate GHG performance are difficult to compare across organizations without harmonization of scopes, target metrics, and timeframes (Institut Louis Bachelier, 2020).

Existing studies on corporate climate mitigation targets have focused on target determinants (Dahlmann et al., 2019; Ioannou et al., 2016; Yin et al., 2017), target-setting approaches (Bjorn et al., 2021; Krabbe et al., 2015; Randers, 2012), and more recently, science-based targets (Giesekam et al., 2021a; Kuo & Chang, 2021). Other studies have done specific sector and country prospective GHG benchmarks based on corporate climate mitigation targets. For example, Gouldson and Sullivan, 2013 scrutinized targets from supermarkets in the UK, while Sullivan and Gouldson, 2016 compared targets from US and UK companies in the retail sector. Giesekam et al. (2018) examined targets from the UK construction sector, while Immink et al. (2018) focused on the mining sector in South Africa. These type of studies are limited in the broadness of firms included (D. D. Wang & Sueyoshi, 2018).

Prospective GHG benchmarks based on corporate climate mitigation targets, including different sectors and a broad number of firms, have been previously developed (Dietz, Bienkowska, et al., 2021; D. Wang, 2017; D. D. Wang & Sueyoshi, 2018). Wang (2017) and Wang and Sueyoshi (2018) used targeted percentage reductions without passing by absolute GHG emissions. Absolute GHG metrics are expressed as the total amount of carbon equivalent emissions and are useful to

¹ Scope 1 represent direct GHG emissions of the corporation (WRI & WBCSD, 2004). Scope 2 is GHG emissions generated from purchased electricity which could be reported as location-based (regional grid-average emission factor data) or market-based (specific emission factors from contractual agreement) (WRI, 2015). Scope 3 is all the remaining value chain GHG emissions (GHG Protocol, 2011).

ensure respect of the global carbon equivalent budget (Hoffmann & Busch, 2008). However, misleading variations may occur due to a simple decrease in activity, or events such as mergers and acquisitions; both of which tend to influence intensity metrics less (Hoffmann & Busch, 2008). Wang (2017) compared 989 companies from Europe and United States, 75% of which reported targets, and compared targeted percentage reductions between BY and TY, as previously done by Ioannou et al. (2016). Wang and Sueyoshi (2018) analysed 1495 companies, of which 26.5% did not have a target, and took differences in timeframe into account by comparing annualized targeted reductions. None of these two studies harmonized the target timeframes by using a common BY and TY, the target metrics, and the scopes. Reported absolute and intensity reduction targets are directly compared (D. Wang, 2017; D. D. Wang & Sueyoshi, 2018), even when a percentage reduction in emission intensity generally translates to a different percentage reduction in absolute emissions. Accordingly, harmonizing the target to an equivalent unit is essential when using reduction targets to assess climate change risks. Reported targets with a different scope are also directly compared (D. Wang, 2017; D. D. Wang & Sueyoshi, 2018). The target can be incomparable when they do not have the same scope coverage (Day et al., 2022) unless they are harmonized in this regard (Institut Louis Bachelier, 2020).

Building on the methodology of Dietz *et al.* (2018), the Transition Pathway Initiative (TPI) has harmonized target timeframes by calculating an annualized reduction rate using 2019 as a common BY for projections to 2030 and 2050 (Dietz, Bienkowska, et al., 2021) and the target scope (Dietz, Gardiner, Hastreiter, et al., 2021). If a target does not cover the same scope as the benchmark, the remaining emissions (not covered by the target scope) are assumed to be constant (Dietz et al., 2021b). However, TPI only provided physical GHG intensity metrics, i.e. absolute GHG emissions divided by a unit of production (e.g. kWh, ton of steel, etc.) which can only be applied to homogeneous sectors (Koellner et al., 2005). As of 2021, 401 companies have been analysed by TPI, of which 66% reported quantitative climate mitigation targets (Dietz, Bienkowska, et al., 2021).

Another metric often used is economic GHG intensity (Institut Louis Bachelier, 2020; TCFD, 2021b). Economic intensity metrics include absolute GHG emissions divided by a financial measure (Hoffmann & Busch, 2008; P. Yu et al., 2016). At the time of writing, no studies developed economic GHG intensity benchmarks based on reported corporate climate mitigation targets. Intensity targets pursue performance improvements which do not necessarily lead to substantial

reductions in absolute emissions (Dahlmann et al., 2019). The most commonly used financial measures are market capitalization, revenue, and enterprise value (Thoma et al., 2018). Revenue and enterprise value are recommended by Net-Zero Asset Owner Alliance (2020). Economic intensity metrics can be applied to highly diversified sectors. However, they are highly susceptible to the price volatility associated with the denominator used (Thoma et al., 2018). In contrast, physical intensity metrics are recommended for homogenous sectors (Koellner et al., 2005) to avoid the influence of economic price volatility (TCFD, 2021b).

Previous studies either show a gap in their sectoral coverage (only considering a single sector or homogeneous sectors) or do not sufficiently harmonize scopes, timeframes, and target metrics. Accordingly, the main objective of this study is to establish absolute and intensity benchmarks with harmonized scopes, target metrics and timeframes based on self declared corporate climate mitigation targets i.e., absolute GHG emission, economic GHG intensity (per revenue and per enterprise-value), and physical GHG intensity targets (per activity measure for homogeneous sectors). Once comparability is enabled through harmonized metrics, some targets may already be achieved at the chosen common BY. To better assess these, further analysis is needed regarding target progress and achievement. Accordingly, the second objective of this study is to assess companies' progress towards their GHG reduction targets.

4.2.2 Methodology

Sector-specific benchmarks are calculated for 2020, 2025 and 2030. The main displayed statistical metrics are the first quartile (Q1) and median which help determine if a company is targeting emission reductions greater than 75% or 50% of their peers. Target progress is assessed at different points in time by calculating whether targets are already achieved, absolute emissions have reduced since the company-specified base year, or if those emissions have increased.

4.2.2.1 Benchmark Development

The methodological process to develop absolute and intensity GHG benchmarks consists of multiple steps as presented in Figure 4.1 and explained in the following subsections. Note that Steps 4b and 4c are only needed to adjust intensity benchmarks when the unit of reduction target is not the same as the intensity benchmark metric. Sensitivity analysis is described in Section 4.2.2.8. Fictitious examples are provided in supplementary information.

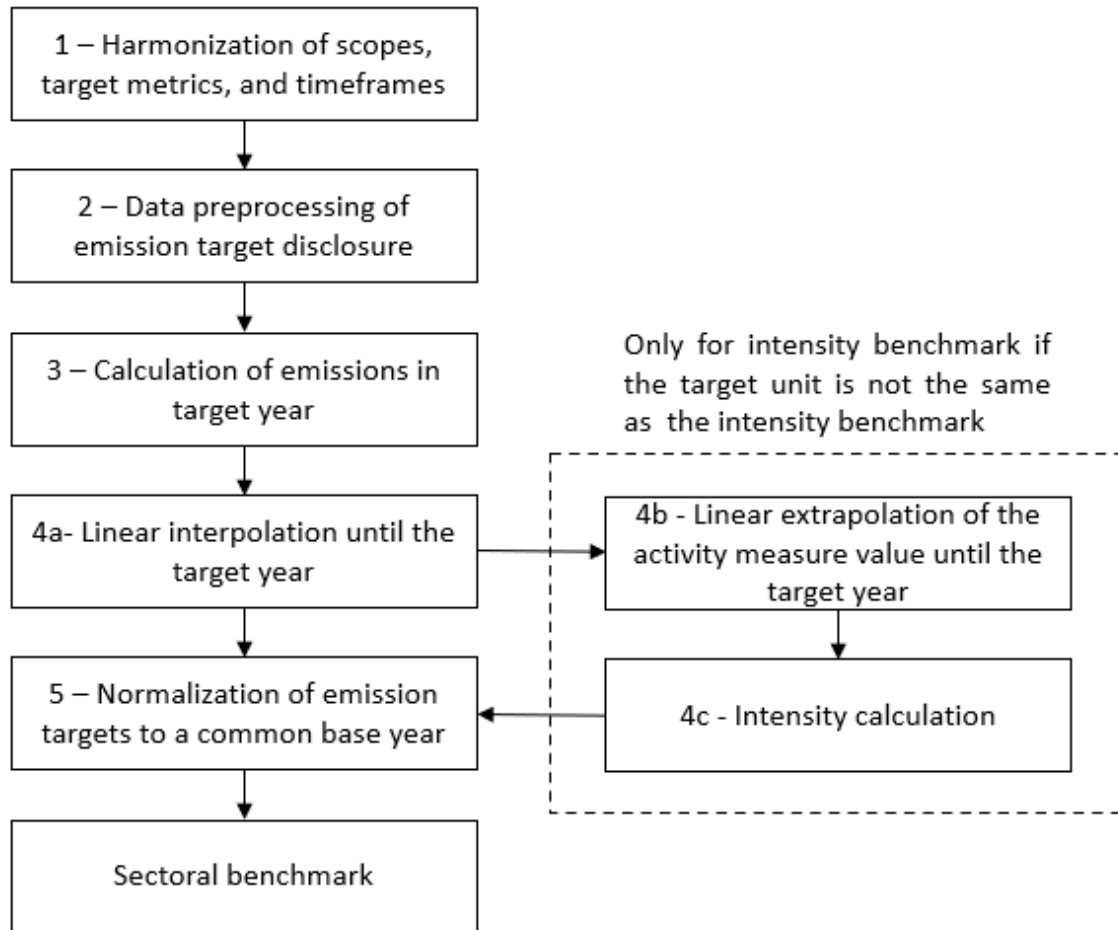


Figure 4.1: Flowchart of the methodological process to determine absolute and intensity GHG benchmarks.

4.2.2.2 Harmonization of Scopes, Target Metrics and Timeframes

Harmonization is required to allow target comparisons as previously discussed. As such, step 1 involves harmonization of choices regarding scope of emissions, reference year, and target metrics.

This study only harmonized target on scope 1 and 2 and excluded scope 3. As shown by Klaaßen and Stoll (2021), reported scope 3 emissions for most organizations are often found to be either too incomplete or inconsistent. In addition, most companies only report scope 1 and 2 emissions. When the reported scope 2 market-based emissions were available, they have been used over scope 2 location-based data.

The company-specified base year significantly vary from one organization to another, ranging from 1990 to 2018. In this study, 2017 is selected as the common BY across all organizations for two

reasons. First, 2017 is the latest year available in the dataset. Second, 2017 is the year with the most data available. Indeed, 98.8% of companies have data available for 2017, compared to 95% for 2016. The presented harmonization procedure can also be applied to more recent and future datasets and to different target scopes.

Targets were harmonized to the same unit as the benchmark by transforming intensity targets into absolute targets, or the opposite depending on the benchmark unit. The following units are defined for each benchmark: tCO₂e for absolute GHG emissions, tCO₂e per million US dollars of revenue and enterprise-value for economic intensity, and tCO₂e per activity measure for physical intensity.

4.2.2.3 Data Preprocessing of Emission Target Disclosure

Step 2 consists of ensuring target data completeness and accuracy. Table 4.1 identifies the completeness of company data required and corresponding data sources for each benchmark. The two main sources of company GHG emissions data and intensity metrics used here are Carbon Disclosure Project (CDP) and Bloomberg (Bloomberg L.P., 2020; CDP, 2018). The data identified in Table 4.1: Input data required to derive sectorial benchmarks. were extracted from the corresponding sources and compiled into a consolidated dataset.

To ensure robustness, any data entry that is incomplete or judged to be unsuitable has been removed. The units or classifiers adopted in this study are identified in brackets in Table 4.1. Reported targets that do not adhere to the specified unit or classifier type are considered unsuitable and excluded from the benchmark of concern. For example, targets reported with the status ‘expired’ are unsuitable and thus excluded.

Some company data required for this study are subject to harmonization choices such as scope covered and 2017 emissions. The presented procedure can also be applied to different harmonization choices leading to different company data required.

Table 4.1: Input data required to derive sectorial benchmarks.

Benchmark's type	Data type	Company data required (unit or classifier)	Sources
All	Target	BY (year) TY (year) Target scope (scope 1, scope 2 location-based, scope 2 market-based, scope 1 & 2 location-based, or scope 1 & 2 market-based) Target status (underway or new) Targeted reduction from BY (%) Scope covered (%) BY emissions covered by target (tCO ₂ e)	2018 CDP
	GHG emissions	BY emissions for scope 1 (tCO ₂ e) BY emissions for scope 2 market-based or location-based (tCO ₂ e)	2010 - 2018 CDP
		2017 emissions for scope 1 (tCO ₂ e) 2017 emissions for scope 2 market-based or location-based (tCO ₂ e)	2017 - 2018 CDP
	Sector	CDP's Activity Classification System	2018 CDP
Absolute GHG emission	Target	Corresponding absolute emissions change for intensity targets (%)	2018 CDP
Economic GHG intensity	Target	Corresponding absolute emissions change for intensity targets (%)	2018 CDP
	Economical	Company Ticker (Ticker value)	2018 CDP
		Up to 1990 to 2019 revenues (\$M US current 2019 value)	Bloomberg
Physical GHG intensity	Target	Activity metric of intensity target (homogeneous sectoral activity measure unit)	2018 CDP
	Physical	Up to 1990 to 2017 activity values (homogeneous sectoral activity measure unit)	2010 - 2018 CDP

The next part of Step 2 involves evaluating data consistency for each company across years, target type, and between data sources. Because multiple inconsistencies were found in the reported data, targets have been disregarded if they did not meet the following conditions:

1. The reported period given for the BY and 2017 must cover a full year.

2. The sum of scope 1 and 2 emissions for the BY and the sum of scope 1 and 2 emissions for 2017 (common BY) must be above zero (entries of zero annual emissions were assumed to be errors).
3. The BY emissions reported must be within +/-20% of the adjusted value with the percentage of scope covered by the target and the field 'Base year emissions covered by target' in CDP questionnaire.

Finally, when companies report multiple targets for the same TY, typically covering different scopes, only the most comprehensive / inclusive target has been included. For instance, if a company reports two targets for the year 2025, one covering scope 1 + 2 and the other only covering scope 2, only the former was included.

4.2.2.4 Calculation of Emissions in Target Year

Step 3 calculates the TY emissions as expressed in Equation 4.1, where the part in brackets calculates the reduced emissions relative to the BY. $\%SC \times \mathcal{E}_{BY}^{SC}$ correspond to the value found in the field 'Base year emissions covered by target' reported in the CDP questionnaires (See Table 4.1). Targets included cover scope 1, scope 2 location-based, scope 2 market-based, scope 1 & 2 location-based, or scope 1 & 2 market-based. Note that when a target does not fully cover the harmonized scope (1 & 2), the uncovered emissions are assumed to remain constant between the BY and TY, following Dietz et al. (2021b).

$$\mathcal{E}_{TY} = \mathcal{E}_{BY} - (\%R_{BY}^{SC} \times \%SC \times \mathcal{E}_{BY}^{SC}) \quad (4.1)$$

Where:

$\mathcal{E}_{TY}$	TY annual emissions for scope 1 and 2 in tCO ₂ e
$\mathcal{E}_{BY}$	BY annual emissions for scope 1 and 2 in tCO ₂ e
$\%R_{BY}^{SC}$	targeted percentage reduction from the BY for given scope covered
$\%SC$	percentage of given scope covered
$\mathcal{E}_{BY}^{SC}$	BY annual emissions for given scope covered in tCO ₂ e

4.2.2.5 Linear Interpolation until the Target Year

Step 4a establishes a reduction trajectory by calculating the emissions in every year between the common BY (2017) and TY. Since no information is given by companies for their reduction trajectory, a linear interpolation is applied as follows:

$$\mathcal{E}_y = \frac{\mathcal{E}_{TY} - \mathcal{E}_{CBY}}{TY - CBY} \times (y - CBY) + \mathcal{E}_{CBY} \quad (4.2)$$

Where:

$\mathcal{E}_y$	annual emissions for scope 1 & 2 in tCO ₂ e in year y
TY	target year
CBY	common BY
y	given calendar year
$\mathcal{E}_{CBY}$	common BY annual emissions for scope 1 and 2 in tCO ₂ e

The linear interpolation is only carried out if the common BY emissions $\mathcal{E}_{CBY}$ is higher than the TY emissions. Hence, if a company has reduced emissions between its company-specified BY and the common BY sufficiently to already meet its reduction target, it is assumed that the absolute emissions remain constant until the TY. The only exception from this assumption is when companies explicitly report an expected increase in absolute emissions when disclosing an intensity target.

If a company has multiple target years, linear interpolation is applied from the common BY to the first TY, from the first TY to second TY, and so on. In Equation 4.2, ‘CBY’ and ‘ $\mathcal{E}_{CBY}$ ’ are replaced by the first TY and emissions for the first TY, respectively, etc. This allows emissions reductions to be calculated and compared for years before the TY.

4.2.2.6 Linear Extrapolation of the Activity Measure Value until the Target Year and Intensity Calculation

Steps 4b and 4c establish intensity values up to the TY via the extrapolation of linear regression models established from historical data. These steps are only necessary for intensity benchmarks when reported targets do not match the homogeneous unit for a given sector. That is, for absolute

emission targets where activity information such as production or revenue are also known. Step 4b extrapolates the activity measure value for the corresponding intensity type.

Step 4c calculates the emission intensities by combining the results of Step 4a and Step 4b as described in Equation 4.3. Note that a negative activity measure value for some years may occur from Step 4b if the linear extrapolation based on historical data results in a negative slope. For such cases, emission intensities for those years are not included because the result is a model artefact.

$$\mathcal{E}I_y = \mathcal{E}_y \div I_y \quad (4.3)$$

Where:

$\mathcal{E}I_y$	annual emission intensity in tCO ₂ e per activity measure
I_y	annual activity measure value in unit of the corresponding benchmark

For instances in which intensity targets are reported in the homogeneous unit, Steps 4b and 4c are excluded, and Steps 1 through 4 apply with a unit modification for the emissions variable ‘ $\mathcal{E}$ ’. i.e., tCO₂e will become tCO₂e per activity measure. Physical activity unit measures for homogeneous sectors can be MWh for the power generation sector, MJ for the fossil fuels sector, and so on.

4.2.2.7 Normalization of Emission Targets to a Common Base Year

Step 5 calculates the relative reduction of GHG emissions normalized to the common BY (2017) as given by Equation 4.4.

$$\hat{R}_y = X_y \div X_{2017} - 1 \quad (4.4)$$

Where:

$\hat{R}_y$	percentage of normalized reduction
X_y	annual emissions for scope 1 & 2 in the benchmark target metric unit
X_{2017}	annual emissions for scope 1 & 2 for the common BY (2017) in the benchmark target metric unit

A sectoral benchmark is then determined for the 13 sectors reported in the CDP Activity Classification System by consolidating targets for each company through a statistical representation (median, 1st, and 3rd quartiles).

4.2.2.8 Sensitivity Analysis

Sensitivity analysis is performed on methodological Steps 4a and 4b to evaluate the impact of various assumptions and linear extrapolation techniques on final benchmark results. The first sensitivity analysis is applied for all benchmark types. The default case assumes that absolute emissions will stay constant if TY emissions are already achieved in 2017, unless specified otherwise by an intensity target. The sensitivity analysis case involves performing a linear interpolation from the common BY to the TY i.e., the company of concern may have already achieved the TY emissions in 2017 which would lead to an increase of interpolated values.

The second sensitivity analysis evaluates two linear extrapolation methods and two data exclusion conditions. The default case applies a linear extrapolation and includes all resulting data regardless of how well the linear model fits historical data values. The sensitivity analysis case applies a two-part discontinuous piecewise linear regression model to the data and extrapolates based on the last linear segment. This method identifies trend reversals that may occur throughout historical data and bases the extrapolation on the most recent trend. The breakout year for each company is determined by maximizing the coefficient of determination (R^2) for each model independently. Adjusted cases exclude companies that produce an R^2 value less than 0.4.

4.2.2.9 Target Progress

The target progress of companies is assessed from the start year (when a target was announced) and 2017 (the common BY) considering three cases: 1) target already achieved, 2) absolute emissions reduced, 3) absolute emissions increased.

4.2.3 Results

4.2.3.1 Data Completeness and Accuracy

In total, 2,607 companies reported information in the 2018 CDP questionnaire. Of these, 27% did not report emission reduction targets, 8% reported targets for scope 1, 2, and 3 emissions, and 65% for scope 1 and/or 2 emissions. 1,697 companies reported 3,009 targets for scope 1 and/or 2.

After data preprocessing (step 2), only 44% of scope 1 and/or 2 targets were considered complete and accurate, i.e., 964 companies and 1,325 targets. Exclusions were due to incomplete information (39%), unsuitable target status such as expired targets (33%), targets with overlapping scopes and

same TY (13%), and data inconsistencies (15%). 36% of data were removed due to inconsistencies involving contradictory information reported for different questions in the same CDP questionnaire.

4.2.3.2 Final Sample Description

For the 964 companies with useable target data, total revenue and enterprise values exceed 16.3 trillion and 28.5 trillion USD\$, respectively. Scope 1 emissions for 2017 was 2.6 GtCO₂e, which represents 7% of global fossil fuels and industrial emissions (Jackson et al., 2018). Scope 2 emissions for 2017 was 0.6 GtCO₂e. Emissions in 2017 per sector and their distribution are available in supplementary information. Among the 964 companies, 34% have their headquarters in the European region, 26% in the USA, 10% in Japan, and 6% in China. The number of companies per region or country is available in supplementary information. For the 1,325 targets included, 70% cover at least 95% of their scope 1 and 2 emissions.

Table 4.2 presents the number of companies and targets by sector included in the final sample, and general descriptive statistics for the target timeframe. The timeframe represents the difference between company-specified BY and TY. The results are separated between targets reported as absolute or intensity by companies and include their number by sector. On average, reported absolute targets tends to have longer timeframes than intensity.

Table 4.3 shows the number of companies included in each benchmark according to sector and year, which represents the number of data points included in further results as all duplicate targets per year has been excluded (see Section 4.2.2.3). Year 2017 includes all the companies having an ongoing target with a TY later than 2017, while other years represent the numbers of companies included with a target for that year or later.

Table 4.2: Number of companies and targets by sector included in the final sample and descriptive statistics on the target timeframe. The target timeframes are separated depending on whether companies reported them as absolute or intensity targets. No C. represents the number of companies while No T. is the number of targets, and Med., the median.

	General		Timeframe of target reported as absolute						Timeframe of target reported as intensity					
Sector/Metrics	Nbr C.	Nbr T.	Nbr	Min	Med.	Max	Mean	Std.	Nbr	Min	Med.	Max	Mean	Std.
Apparel	13	14	10	5	8.5	17	9.60	4.55	4	2	5	13	6.25	4.72
Biotech, health care & pharma	48	60	39	1	10	40	11.31	8.68	21	3	7	18	7.81	3.89
Food, beverage & agriculture	55	71	41	1	12	37	14.39	9.20	30	4	10	25	9.37	4.54
Fossil Fuels	23	31	21	4	8	20	9.29	4.99	10	4	11	38	13.50	10.00
Hospitality	16	23	8	5	10	39	14.00	12.04	15	3	15	40	16.13	10.85
Infrastructure	70	100	65	3	10	60	14.23	11.59	35	3	9	43	12.00	10.39
Manufacturing	316	414	232	1	11	60	14.21	10.24	182	1	7	40	8.73	5.69
Materials	52	61	25	1	10	45	14.00	11.60	36	1	14.5	40	16.33	11.76
Mineral extraction	13	20	12	3	10	33	12.50	9.32	8	2	10	15	8.50	4.07
Power generation	28	44	25	3	15	45	16.96	10.91	19	1	12	40	15.68	10.34
Retail	31	51	32	4	10.5	44	16.59	11.17	19	4	9	15	8.68	3.06
Services	265	392	272	1	11	45	14.63	10.37	120	1	7	34	8.83	5.88
Transportation services	34	44	14	1	12	45	14.57	13.44	30	4	9.5	39	11.37	8.01
Overall	964	1325	796	1	11	60	14.19	10.32	529	1	8	43	10.16	7.50

Table 4.3: Number companies per year and sector included for each benchmark. The acronym Abs. corresponds to the absolute GHG benchmark, Rev. to the economic intensity per revenue, E.V. to the economic intensity per enterprise value, and Ph. to the physical intensity one.

	2017				2020				2025				2030			
Sector/Benchmark	Abs.	Rev.	E.V.	Ph.	Abs.	Rev.	E.V.	Ph.	Abs.	Rev.	E.V.	Ph.	Abs.	Rev.	E.V.	Ph.
Apparel	13	10	9	0	12	9	8	0	4	4	3	0	2	2	2	0
Biotech, health care & pharma	48	46	42	0	43	42	39	0	15	14	12	0	10	9	8	0
Food, beverage & agriculture	55	50	48	0	54	50	48	0	22	20	19	0	16	14	12	0
Fossil Fuels	23	23	23	0	23	23	23	0	12	12	12	0	8	8	8	0
Hospitality	16	16	15	0	15	15	14	0	8	8	7	0	8	8	7	0
Infrastructure	70	65	62	0	65	59	57	0	30	28	28	0	26	24	24	0
Manufacturing	316	259	251	0	274	225	218	0	117	101	97	0	75	64	62	0
Materials	52	50	46	0	48	46	43	0	24	22	20	0	16	16	12	0
Mineral extraction	13	13	13	0	10	9	10	0	4	4	4	0	3	3	3	0
Power generation	28	27	25	32	27	26	24	31	22	21	19	24	20	20	17	22
Retail	31	31	31	0	31	31	30	0	17	17	17	0	9	9	9	0
Services	265	240	177	0	243	214	156	0	122	108	81	0	91	81	58	0
Transportation services	34	31	29	0	31	28	25	0	10	9	9	0	7	6	6	0
Overall	964	861	771	32	876	777	695	31	407	368	328	24	291	264	228	22

4.2.3.3 Absolute GHG Sectoral Benchmark

The percentage of change per sector including median and Q1 for from 2017 to 2020, 2025 and 2030 are presented in Table 4.4. The values displayed show a substantial difference in reduction between sectors. In 2030, the median values for fossil fuels and power generation sectors are -9% and -36% respectively; a difference of 27 percentage points. Q1 results for 2030 ranges from -14% for apparel to -62% for materials; a difference of 48 percentage points. These differences show the importance of taking a sectoral approach when developing benchmarks based on corporate climate mitigation targets to guide investment decisions.

Table 4.4: Absolute GHG benchmarks results. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY.

	2020		2025		2030	
Sector/Metrics	Median	Q1	Median	Q1	Median	Q1
Apparel	-4%	-11%	-28%	-58%	-9%	-14%
Biotech, health care & pharma	-3%	-16%	-18%	-30%	-27%	-36%
Food, beverage & agriculture	-6%	-15%	-16%	-24%	-21%	-33%
Fossil Fuels	-4%	-12%	-4%	-13%	-9%	-19%
Hospitality	-4%	-8%	-12%	-14%	-21%	-27%
Infrastructure	-6%	-13%	-16%	-23%	-29%	-37%
Manufacturing	-5%	-15%	-15%	-23%	-27%	-35%
Materials	-5%	-23%	-12%	-26%	-29%	-62%
Mineral extraction	-5%	-12%	-20%	-30%	-29%	-34%
Power generation	-7%	-11%	-22%	-29%	-36%	-45%
Retail	-11%	-19%	-14%	-34%	-25%	-41%
Services	-4%	-13%	-15%	-34%	-24%	-42%
Transportation services	-5%	-18%	-9%	-23%	-22%	-35%
Overall	-5%	-15%	-15%	-26%	-25%	-39%

Targets with longer timeframes do not necessarily have higher ambition (Callery & Kim, 2021). For the apparel sector, for example, the percentage of change for the median and Q1 is higher in

2025 than in 2030. The targets of this sector cover four companies in 2025 and two in 2030, implying a different subset (See Table 4.2)

Sensitivity Analysis

Figure 4.2 presents the sectoral results for the default and sensitivity analysis cases in 2020, 2025, and 2030.

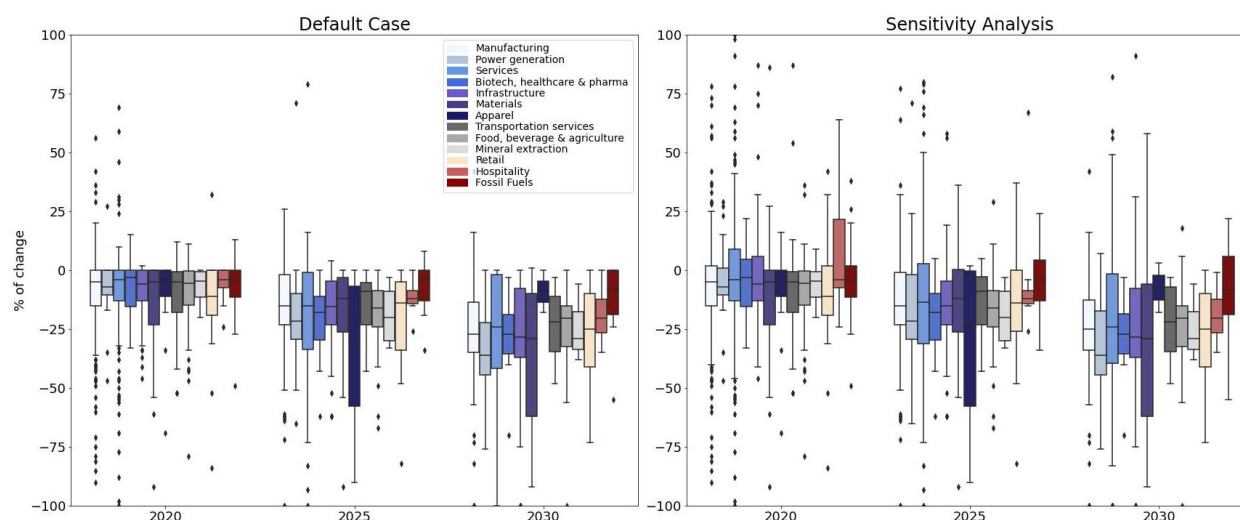


Figure 4.2: Absolute benchmarks scenario results for default case and the sensitivity analysis.

The default case is a conditional interpolation between the common base year emissions and target year emissions if the target is already achieved, the emissions are assumed to stay constant unless an expected increase in absolute emissions is reported by an intensity target. The sensitivity analysis is a linear interpolation between the common base year and the target year even if the target is already achieved. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY. In the boxplot, the bottom of the box represents the first quartile (Q1), the line is the median while the top of the box is the third quartile (Q3). The whiskers are at 1.5 times the interquartile range.

The main difference between the two cases is for the third quartile (Q3) and the maximum values as illustrated in Figure 2.3. When a target is already achieved, the common base year emissions are lower than the target year emissions resulting in an increase in the sensitivity analysis. While in the default case, the common base year emissions are assumed to remain constant until the target year (conditional interpolation) which explains the difference between the two cases for the Q3 and maximum values. The percentage of targets already achieved is detailed in the Section 4.2.3.6.

The Q1 and the median values of the default case and the sensitivity analysis are similar. Of the 39 observations for Q1 (13 sectors for three years), Q1 values are the same in 34 cases. The same number of differences occur for the median. The average annualized difference between the two cases is 0.32% for the median and 0.2% for Q1.

4.2.3.4 Economic Intensity Sectoral Benchmarks

Economic intensity benchmarks have been calculated with respect to revenue and enterprise-value. The percentage of change per sector including median and Q1 from 2017 to 2020, 2025 and 2030 are presented in Table 4.5. Since financial information was not available for all companies in the final sample (964), the revenue-based intensity benchmark builds on 868 companies, while enterprise value-based intensity benchmark builds on 771 companies. The number of companies included in each sector and year is available in Table 4.2

From the results displayed in Table 4.5, 2030 median values for the revenue benchmark range from -12% for apparel to -67% for power generation; a difference of 55%. Q1 value varies from -26% for apparel to -73% for materials; a difference of 47%. For the enterprise value benchmark, median values vary from -1% for apparel to -63% for mineral extraction and from -29% for apparel to -75% for mineral extraction for Q1 value; a difference of 62% and 46% respectively.

Notable differences are occurring between absolute GHG emissions and economic intensity benchmarks. Inflation and other economic parameters were assumed to be already considered by companies in their targets. Perhaps this is not always the case and that can explain some of these differences. However, differences in sector ranking occur between the benchmarks. For example, 2030 median value for the fossil sector in the revenue benchmark is -60% (sector ranking: 2nd position on 13 sectors) while value for the enterprise value benchmark is -41% (sector ranking: 11th position on 13 sectors). In the absolute GHG emission benchmark, the fossil fuels sector has a 2030 median value of -9% (sector ranking: 13th position on 13 sectors). These differences show the importance of adequately choosing the benchmark type to guide appropriate investment decisions.

Table 4.5: Economic intensity benchmarks results. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY.

	Revenue (tCO ₂ e / \$M USD of revenue)						Enterprise Value (tCO ₂ e / \$M USD of enterprise value)					
	2020		2025		2030		2020		2025		2030	
Sector/Metrics	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1
Apparel	-9%	-18%	-40%	-64%	-12%	-26%	-11%	-19%	-44%	-49%	-1%	-29%
Biotech, health care & pharma	-18%	-24%	-36%	-48%	-50%	-59%	-11%	-18%	-38%	-53%	-44%	-64%
Food, beverage & agriculture	-18%	-31%	-32%	-43%	-41%	-55%	-8%	-20%	-22%	-36%	-37%	-51%
Fossil Fuels	-36%	-44%	-47%	-56%	-60%	-68%	-20%	-34%	-29%	-40%	-41%	-53%
Hospitality	-17%	-22%	-34%	-35%	-44%	-48%	-10%	-17%	-25%	-30%	-35%	-43%
Infrastructure	-25%	-33%	-39%	-50%	-55%	-66%	-18%	-29%	-35%	-46%	-43%	-62%
Manufacturing	-19%	-31%	-35%	-46%	-52%	-59%	-5%	-23%	-25%	-40%	-44%	-56%
Materials	-23%	-38%	-36%	-43%	-50%	-73%	-9%	-28%	-16%	-43%	-45%	-72%
Mineral extraction	-26%	-35%	-50%	-57%	-59%	-64%	-32%	-43%	-55%	-68%	-63%	-75%
Power generation	-31%	-41%	-53%	-59%	-67%	-73%	-19%	-30%	-26%	-50%	-51%	-65%
Retail	-25%	-30%	-38%	-48%	-49%	-61%	-20%	-35%	-46%	-51%	-57%	-60%
Services	-18%	-27%	-36%	-50%	-48%	-63%	-14%	-23%	-33%	-47%	-46%	-62%
Transportation services	-19%	-33%	-33%	-38%	-48%	-57%	-16%	-36%	-31%	-40%	-45%	-52%
Overall	-20%	-31%	-37%	-49%	-50%	-63%	-12%	-26%	-29%	-46%	-45%	-61%

Sensitivity Analysis

A sensitivity analysis was performed on the financial extrapolation method corresponding to Step 4b (see Section 4.2.2.7). The results for the default and sensitivity analysis cases are presented in Figures 4.3 and 4.4 for revenue and enterprise value respectively. The adjusted cases are presented in supplementary information.

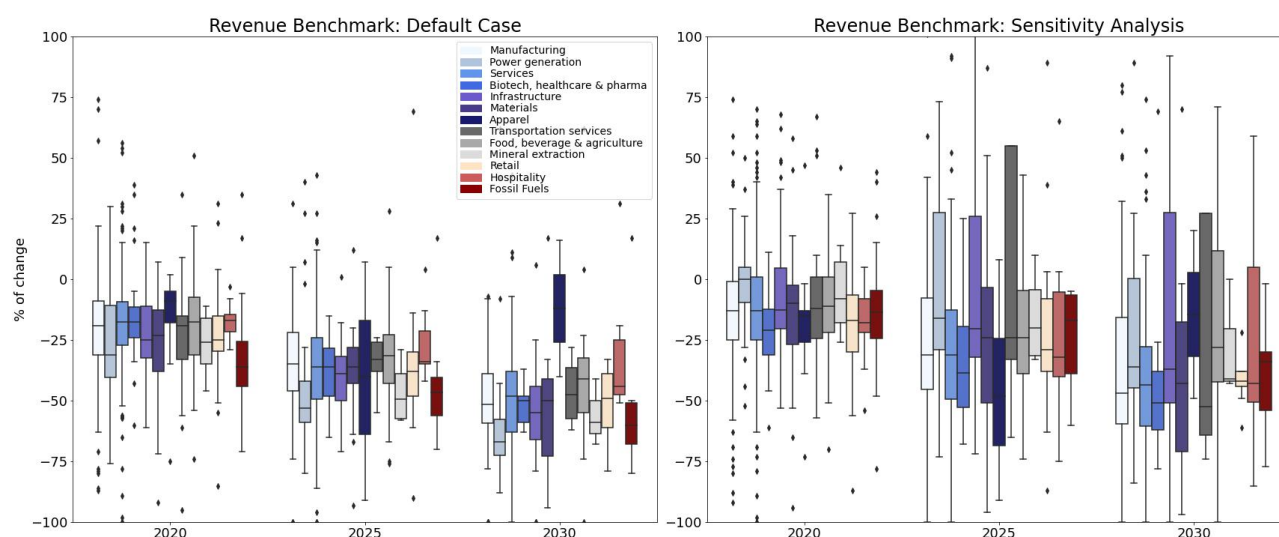


Figure 4.3: Revenue-based intensity benchmarks results for default case and the sensitivity analysis. The default case is a financial extrapolated values based on a linear regression model and the sensitivity analysis is a financial extrapolated values based on the last segment of a discontinuous piecewise linear regression model. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY. In the boxplot, the bottom of the box represents the first quartile (Q1), the line is the median while the top of the box is the third quartile (Q3). The whiskers are at 1.5 times the interquartile range.

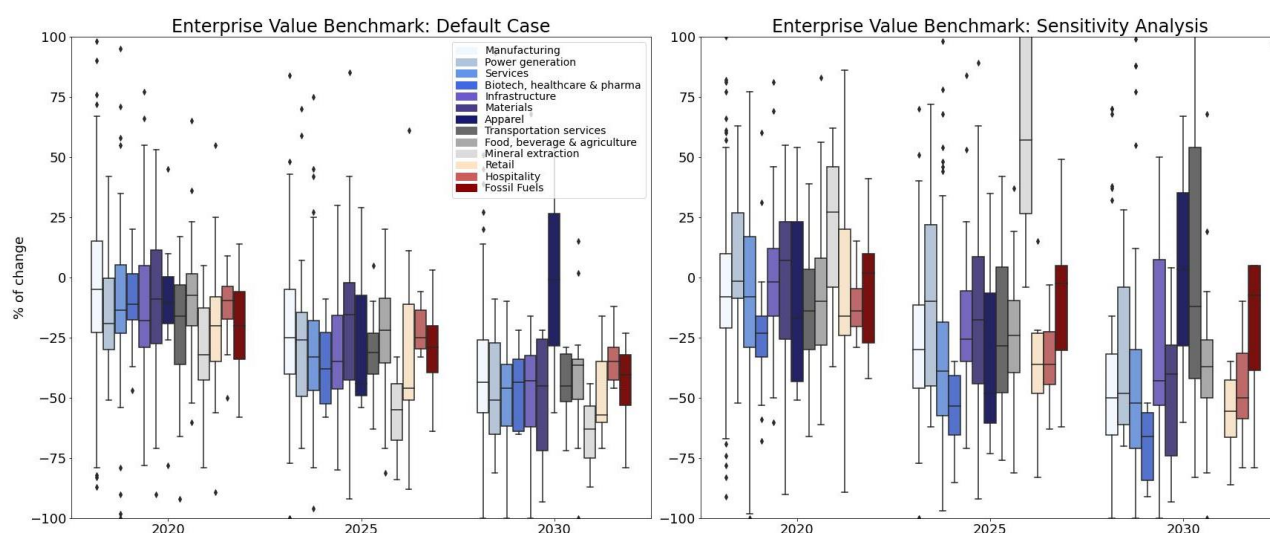


Figure 4.4: Enterprise value-based intensity benchmarks results for default case and the sensitivity analysis. The default case is a financial extrapolated values based on a linear regression model and the sensitivity analysis is a financial extrapolated values based on the last segment of a discontinuous piecewise linear regression model. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY. In the boxplot, the bottom of the box represents the first quartile (Q1), the line is the median while the top of the box is the third quartile (Q3). The whiskers are at 1.5 times the interquartile range.

Differences between cases are substantial as indicated by the large difference in data dispersion displayed in Figures 4.3 and 4.4. The discontinuous piecewise linear regression captures the last trend of a company historical financial values which leads to an increased number of extrapolated financial values based on a negative growth (negative slope) compared to the default case which captures the global trend. For the sensitivity analysis, the mix of an increasing number of negative slopes and lower number of positive slopes leads to substantial differences and an extended interquartile range as shown in Figures 4.3 and 4.4.

Both economic benchmarks are very sensitive to the financial extrapolation methods used. Some sectors are more sensitive than others such as infrastructure, mineral extraction, and power generation which have at least 3% differences per year for both statistical metrics (median and Q1) in both economic benchmarks. For the revenue benchmark, the average annualized difference is 2% for the median and 1.87% for Q1. For the enterprise value benchmark, the average annualized

difference is 3.38% for the median and 2.84% for Q1. However, the mineral extraction sector is skewing the average difference results by contributing to a much larger proportion.

4.2.3.5 Physical Intensity Sectoral Benchmark

Only the power generation sector had a relevant number of companies (more than 20) reporting physical intensity benchmarks with consistent physical units (TCO₂e/MWh) and represents 25% of all 2017 emissions from the data in this study. The physical intensity benchmark for the power generation sector includes 19 companies with reported intensity targets, and 13 companies with 22 absolute targets converted using production data into physical intensity targets.

The percentage of change including median and Q1 from 2017 to 2020, 2025 and 2030 for all benchmarks regarding the power generation sector are presented in Table 4.6. No substantial difference occurs between the physical intensity and absolute GHG emission benchmarks. However, notable differences occur between those two benchmarks and the two economic intensity benchmarks. Economical intensity benchmarks include financial growth which further diminish the intensity reduction. Nevertheless, the sector ranking is similar with 1st position in the absolute GHG emissions and economic intensity per revenue benchmarks, and 3rd position in the economic intensity per enterprise value.

Table 4.6: Benchmark results for the power generation sector. All displayed values are harmonized to cover scope 1 and 2 emissions and refer to 2017 as common BY.

	2020		2025		2030	
Sector/Metrics	Median	Q1	Median	Q1	Median	Q1
Physical intensity	-7%	-16%	-19%	-29%	-35%	-47%
Absolute GHG emission	-7%	-11%	-22%	-29%	-36%	-45%
Economic intensity (per revenue)	-31%	-41%	-53%	-59%	-67%	-73%
Economic intensity (per enterprise value)	-19%	-30%	-26%	-50%	-51%	-65%

Sensitivity Analysis

A sensitivity analysis was performed on the extrapolation method corresponding to Step 4b (see Section 4.2.2.7). Only the default case and adjusted default case have been applied since there was

insufficient data to establish a piecewise model. In total, the default case includes 32 companies while the adjusted case includes 27 companies. No substantial difference was found to occur between these two cases. The average annualized differences between the two cases are 0.09% for the median and 0.15% for Q1.

4.2.3.6 Target Progress

For the 964 companies, 22% had already achieved their most long-term target in 2017, 46% have reduced their absolute emissions compared to the company-specified BY, and 32% have increased them since. The median annualized absolute emission reductions across all sectors between the reported BY and 2017 is 1.76%. Differences between 2017, the common BY defined in this study, and the BY reported by companies in the CDP is 3 years for the median and 4.36 years on average.

The progress on climate mitigation targets per sector in 2017 are presented in Figure 4.5. Some sectors have more companies with achieved targets than others as shown in Figure 4.5. The Hospitality, Fossil Fuels, and Infrastructure sectors have more than 30% of their companies with achieved targets.

Some progress may be due to the use of offsets by companies if they have improperly included them in their absolute emissions reporting. Nevertheless, 152 of the 964 companies studied reported purchasing 10.5 MtCO₂e of compliance carbon credits or voluntary offsets. The reduced emissions from all the company-specified BY to 2017 represent 302.3 MtCO₂e. Another part of the progress may be due to the use of renewable energy certificates (RECs) as they are allowed in the scope 2 market-based accounting approach (WRI, 2015). The use of REC is reported by 352 companies studied for a total of 90.7 TWh while the total energy purchased by the 964 companies studied represents 3,213.6 TWh. However, some companies may have not shared information about the use of offsets or RECs and these numbers are potentially underestimated. Nevertheless, companies with a scope 2 market-based targets tend to have more ambitious targets than those with a scope 2 location-based target (Bjørn, Lloyd, et al., 2022), indicating that companies with market-based targets generally intend to purchase RECs.

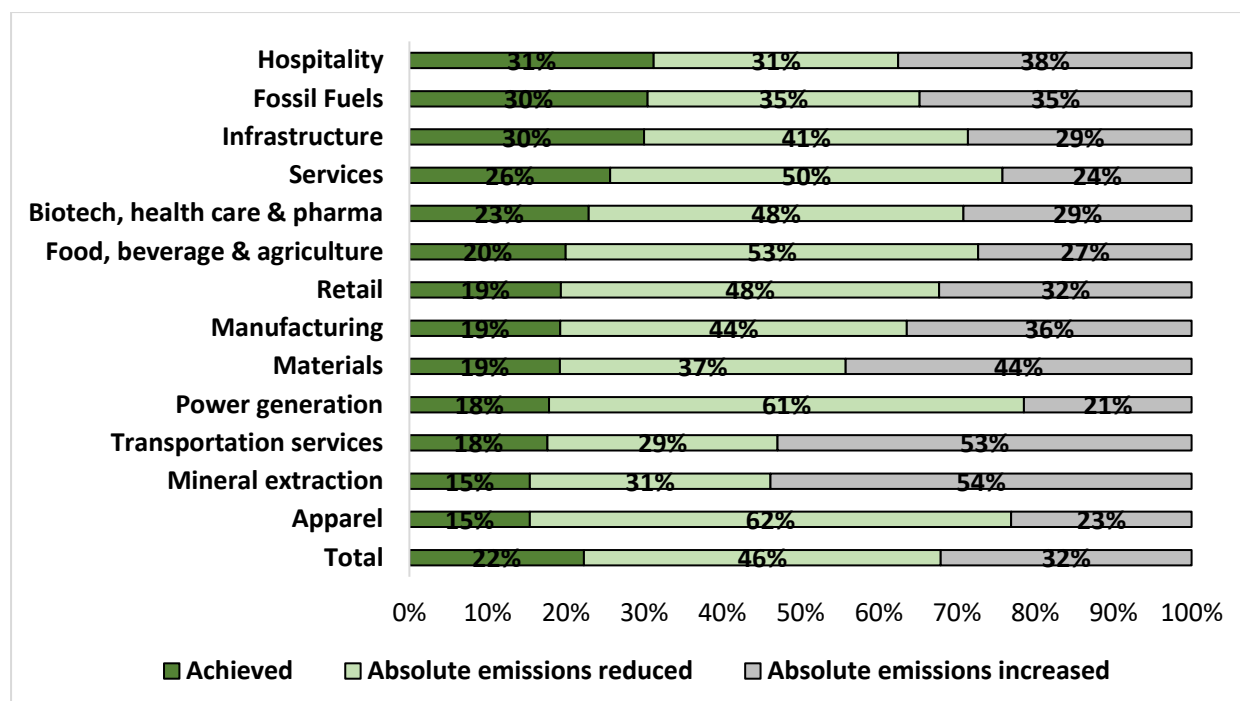


Figure 4.5: Target progress in 2017 by percentage of companies per sector. Results presented by the highest percentage of achieved targets.

Depending on the company choice of target BY, emission reductions may occur before the target was announced (start year). As such, target progress results have been analysed between the company-specified BY and the target start year, and are presented in Figure 4.6. In 14% of cases, targets were already achieved in the year they were announced which indicates a potential lack of ambition (Figure 4.6). The fossils fuels sector had 30% of companies with achieved targets in 2017, while an analysis of target progress at the start year shows that 20% of sector targets were achieved when launched demonstrating the importance of such analysis.

Differences between the company-specified BY and target start year is one year for the median and two years on average. On average, 27% of target emission reductions occurred between the company-specified BY and the target start year. Nevertheless, 36% of targets have the same BY and start year, meaning that those companies did not have reductions caused by their choice of target BY.

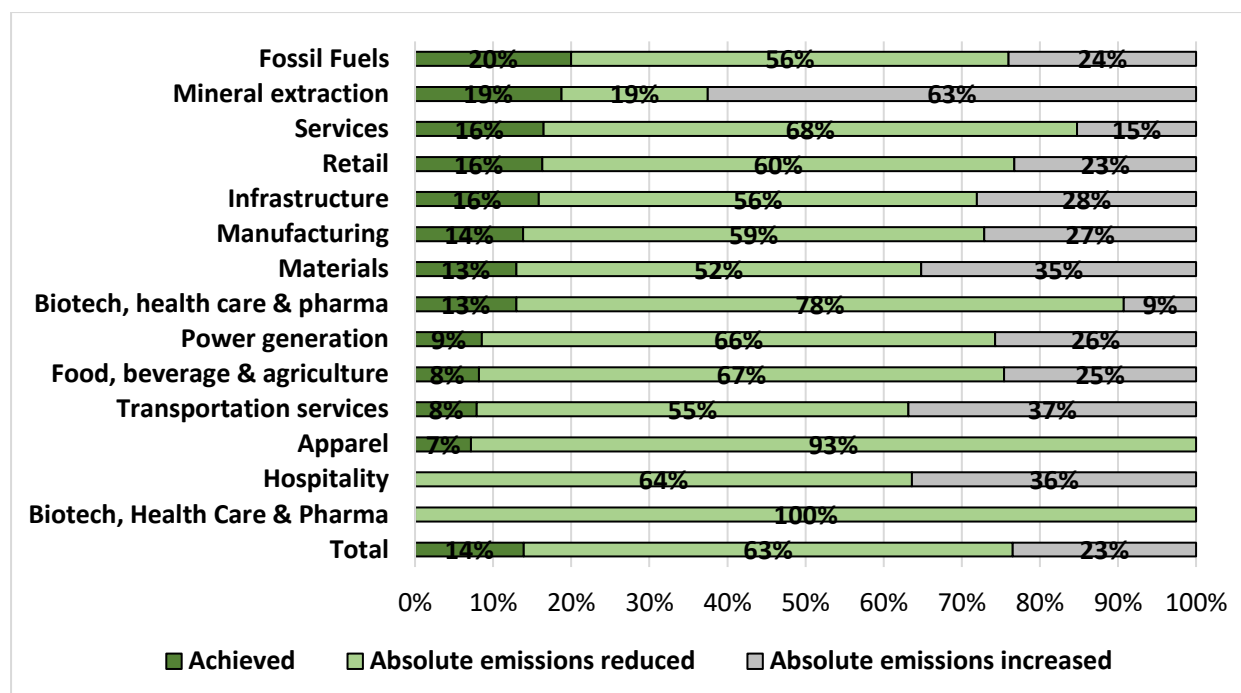


Figure 4.6: Target progress at the start years by percentage of target per sector. Results presented by the highest percentage of achieved targets.

4.2.4 Discussion

4.2.4.1 Comparison to Existing Literature

In total, 2,607 reporting companies were assessed in this study, which is a substantial increase compared to previous studies (989 companies for Wang (2017), 1495 companies for Wang and Sueyoshi (2018), and 401 companies for Dietz et al. (2021)). The share of companies not reporting a climate mitigation target (27%) is consistent with previous studies using earlier CDP questionnaires (25 % for Wang (2017) and 26.5% for Wang and Sueyoshi (2018)) or more recent database, (34% for Dietz et al. (2021)).

Only 44% of the 3,009 scope 1 and/or 2 targets reported in CDP questionnaires were considered complete and accurate. Some exclusions such as unsuitable target status or duplicate entries can not be avoided. However, 46% of the excluded targets could have been avoided by more diligent reporting. Giesekam et al. (2021a) which studied the science-based emission reduction targets (final sample of 133 targets) mentioned an exclusion rate of 21% due to insufficient information being available. Here, the exclusion rate due to incomplete information is 39%. Since both science-

based and non-science-based targets were included, non-science-based targets may be more prone to having incomplete information.

Differences in targeted absolute emission reductions between sectors in 2030 were found to range from -9% to -62% depending on the metrics used (see Section 4.2.3.3). Dietz et al. (2021), Wang, (2017), and Wang and Sueyoshi (2018) used a different sectoral classification, but substantial differences in targeted emission reductions between sectors also occurred in those studies. Wang (2017) used the target percentage reduction without annualizing it between the BY and TY, making it difficult to compare with our results. Wang and Sueyoshi (2018) annualized the percentage of reduction from the BY to the TY but did not present aggregated results at the sector level, instead focusing on regional differences. To allow comparison with the results of Wang and Sueyoshi (2018), the results here have been annualized and aggregated per region (see Supplementary Information). The percentage of absolute emission reductions obtained are generally lower than that of Wang and Sueyoshi (2018), even though the data used in this study is 5 years more recent and companies should be expected to have increased their ambition. For example, the US annualized average reduction rate in Wang and Sueyoshi (2018) is -3.14% while here is 2.4% for 2020, 2.5% for 2025 and 2.2% for 2030. As explained in the Section 4.2.3.6, part of the reduction occurred before the target start year (14% of targets were already achieved by that time) and between the target start year and the common BY, which can explain some of the difference with Wang and Sueyoshi (2018) results. Further studies should correct for the reduction occurring before the target start year which represents 27% of the reduction target on average. Nevertheless, it is interesting to note that amongst developed countries, Canadian firms have the lowest annualized average reduction rate in 2025 (-0.7%) and 2030 (-1%), in agreement with the findings of Wang and Sueyoshi (2018).

Dietz et al. (2021) displayed an annual average percentage of emission reductions with a 2019 BY for their sectoral physical intensity benchmarks. The data used by TPI come from the latest version of FTSE Russell (TPI, 2022), while data for this study comes from 2018 CDP academic package. To allow a better comparison, a normalisation with a 2017 BY has been performed using the TPI (2021) database for power generation companies assessed in 2019 (see Supplementary Information). The TPI sample included 31 companies while our sample included 32. Median targeted reductions are identical for TY 2025 and 2030, while TPI finds lower median targeted reductions for TY 2020 and lower Q1 of targeted reductions for all TY. These differences can be

explained by the targets included in each sample and the sampling year: TPI covers targets reported in 2020, while 2018 is covered here. As should be expected, some companies have more ambitious targets which will decrease Q1 sectoral results.

Regarding progress on climate mitigation targets, 22% of companies have achieved their most long-term target, while 46% have reduced from the company-specified BY, and 32% have increased. This is consistent with Wang (2017) and Kuramochi et al. (2021) for the combined results of achieved and reduced from their BY results and Gieseckam et al. (2021a) for the achieved target. However, Wang (2017) and Kuramochi et al. (2021) only defines whether a target is on track or not compared to the linear reduction trajectory between the BY and TY, while Gieseckam et al. (2021a) also assess if the target is achieved. Our approach to evaluate the progress in respect to climate mitigation targets avoids the linear trajectory assumption while still differentiating achieved, reduced, or increased compared to the company-specified BY. Due to their low sample size, Gieseckam et al. (2021b) did not include a sectoral comparison. Our results show substantial difference between sectors for the target progress ranging from 15% to 31% for achieved targets, to 29% to 62% for the one reducing, and 23% to 54% for targets increasing their absolute emissions compared to the company-specified BY (see Figure 4.6). While these achievements are promising for some sectors, further research is needed to assess whether the targets progression actually correspond to more emission reduction than companies' business-as-usual trajectory, as mentioned by Kuramochi et al. (2021).

Gieseckam et al. (2021a) mentioned some targets were achieved before official SBT approval. In this study, it was examined whether targets were achieved before their start year. Such cases were found to correspond to 14% of the final sample. This raises questions concerning poor ambition by companies as also indicated by Gieseckam et al. (2021a). However, most of those targets are not science-based and their achievement is primarily due to the choice of the BY. Choosing targets parameters in such a manner can be considered 'greenwashing' as defined by Delmas and Burbano (2011), and also, Lyon and Montgomery (2015).

4.2.4.2 Limitations and Future Research

The main limitations of the present study are the exclusion of scope 3 targets, the data accuracy of reported information, the assumption of linear reductions for benchmark results and the emissions

not covered by a target, the high sensitivity to the extrapolation method used for economic-intensity targets, and the lack of physical production data in CDP questionnaires for most sectors.

Scope 3 targets were not assessed in this study since scope 3 emissions for company-specified BY were generally incomplete or inaccurate, as also found by Busch et al. (2020), Klaaßen and Stoll (2021), and GRAIN and Institute for Agriculture and Trade Policy (2018). Blanco et al. (2016) assessed scope 3 emissions disclosed by US companies and found that on average, only 22% reported scope 3 values. In this study, only 8% of companies were found to disclose scope 1, 2 and 3 targets. These results are consistent with previous studies that found scope 3 targets are much less common than targets for direct emissions (Gouldson & Sullivan, 2013; D. Wang, 2017; D. D. Wang & Sueyoshi, 2018). However, scope 3 emissions can make up for over 75% of the total company emissions (Huang et al., 2009). As such, it is important that more companies disclose scope 3 targets and BY emissions.

This study is based on reported information from companies which may lack accuracy. One of the main issues concerns BY emissions, which may change over time due to mergers and acquisitions or changes in company emissions coverage. The third criteria in Section 4.2.2.3 was designed to minimize this issue. Additional data accuracy criteria should be developed to prevent such problems in future studies. In 26% of cases, companies did not report BY emissions corresponding to their target in the same questionnaire where they report their target. Companies should report the same BY used for their target in the ‘Emissions Methodology’ section of the CDP Questionnaire. In our study, 91 companies were excluded due to data mismatch between the ‘Targets’ and the ‘Methodology’ sections in the 2018 CDP questionnaires. Therefore, companies should update their BY emissions in order to match the information reported in the ‘Targets’ section of the CDP questionnaires.

Since no information was given on the reduction trajectory of reported targets, a linear reduction was assumed when developing benchmarks as done in previous studies (see Section 4.2.4.1). The integration of intermediary targets as done in Step 4a help to diminish consequences of this assumption. Accordingly, companies should report intermediary targets when they have long-term targets. Ideally, companies should give more information on their reduction trajectory to avoid the need for assuming a linear pathway. Since no information was provided on emissions not covered by targets, these emissions were assumed to stay constant over time, following Dietz et al. (2021b).

To reduce uncertainties on benchmarks, companies should report additional information on the expected trajectory of these emissions.

An important limitation of economic intensity benchmarks developed in this study is high sensitivity to the extrapolation method used for economic values i.e., average annualized differences ranging from 1.87% to 3.38% were observed depending on the statistical metric and benchmark (see Section 4.2.3.4). Unfortunately, no relevant studies were found to allow a comparison. Nevertheless, intensity-metrics are often used by investors to perform portfolio GHG footprint assessments. Extrapolation methods used for long-term economical values should be decided by the investor as different forecasting methods may be preferred from one investor to another for various reasons.

The present study shows the limitations of relying on CDP data for developing benchmarks for intensity-based reduction targets, given its lack of physical production data and standardized measures. Only the power generation sector had enough intensity targets with similar physical units or production data available to surpass 20 companies. Therefore, other information sources such as corporate sustainability reporting should be used to complement CDP questionnaires where possible. However, physical intensity metrics can only be applied to homogeneous sectors (Koellner et al., 2005).

The benchmarks developed here can be used to compare companies' stated emission reduction intentions with those of peers. However, companies do not always achieve their targeted emission reductions. For example, considering that the materials industry contains "hard to abate" emissions (e.g., from cement and steel production), it is not a given that the relatively high abatement ambition of that sector will be realized. More advanced models could alleviate this problem by adjusting projected reductions with an assessment of target progress performance determinants and past target achievements. Furthermore, 21% of the 2,000 biggest companies in the world have committed to a net-zero target by 2050 (Hale et al., 2022). Since most of these net-zero targets were not included in this study, it is important to update the analysis in the upcoming years with a more recent CDP dataset or with another database.

Additional work to this study has been conducted (see Supplementary Information) regarding the comparison of benchmarks developed here to the Paris Agreement goal and to determine if high-

emitting companies are planning to reduce more in the coming years compared to their peers. Nevertheless, further work is still needed on these topics.

4.2.4.3 Contributions and Recommendations

The present study contributes to the scientific literature on corporate climate mitigation targets. First, the extent and breadth concerning the number of companies considered has made it the largest study on the matter, with 2,607 companies being assessed. Second, the methodological approach allows the harmonization of targets with respect to scope, timeframe, and target metrics, to produce a uniform and coherent analysis structure. A comparison with Wang and Sueyoshi (2018) shows that annualizing reductions from a company-specified BY to the TY can overestimate the percentage of reduction, as reductions occurring before the target is launched are also integrated. This reveals the importance of a common BY in the development of benchmarks based on corporate climate mitigation targets. Third, target progress results indicate the relevance of tracking such indicators at the common BY and a target start year to determine poor ambition or greenwashing.

Results obtained from the study have produced insights leading to recommendations for practitioners such as companies, investors, and governments. Companies need to improve the quality of their GHG emissions and target data reporting. To track target ambition more accurately and avoid linear reduction trajectory assumptions, companies should report more intermediary targets. Investors and governments should pressure companies to do so in order to maximize the quality and accuracy of analysis results.

For investors, a sectoral perspective should be taken when comparing the ambition of corporate climate mitigation targets. Sectoral results from this study can help investors assess companies ambition compared to their peers in order to apply a best-in-class responsible investment strategy. These results can also be useful for an engagement and voting responsible investment strategies by giving more suitable and achievable targets coming from best-in-class peers for lagging companies. Investors should also track target progress through time and engage for more ambitious reductions once companies have achieved their target, since 22% of companies kept their target active even if they were already achieved. To identify poor ambition and greenwashing, investors should also assess the target progress at the start year, since 14% of companies have achieved their target before announcing them. These results can also help investors better understand their position to avoid

financial climate risks or to determine their own reduction trajectory based on corporate climate mitigation targets. However, not all companies report a target. For such cases, a precautionary approach as suggested by Hoepner and Rogelj (2021) should be taken to estimate the trajectory.

For governments and policymakers, the results can help to better understand how much could be achieved through corporate climate mitigation targets if realized. However, the reduction resulting from corporate climate mitigation targets will not be sufficient to respect national mitigation targets (Kuramochi et al., 2020). Nevertheless, understanding where sectors are projecting themselves can be useful to policymakers to know where more efforts and regulations are required. In supplementary information, the annualized reduction rates of firms aggregated per country are valuable information for comparing firms from one country to another. For example, Canadian firms have the lowest annualized average reduction rate amongst developed countries in 2025 and 2030. Monitoring target progress from corporate climate mitigation targets is also important, considering that 32% of companies have increased their absolute emissions since setting their reduction targets.

4.2.5 Conclusion

This study is the largest study establishing benchmarks based on corporate climate mitigation targets by assessing 2,607 companies. After the target data preprocessing step, the final sample included 964 companies for absolute GHG emission benchmarks, 868 for the economic intensity benchmark per revenue, 771 for the economic intensity benchmark per enterprise value, and 32 for the power generation physical intensity benchmark.

Results confirm the importance of taking a sectoral perspective when determining or comparing target ambitions. The methodological approach consisting of harmonizing every target to the same scope, timeframe, and target metric show the importance of having a common base year to avoid overestimating the percentage of reductions by considering those occurring before the target was launched due to company choice of target base year.

Furthermore, the percentage of reductions should not be the only metric considered. Target progress is an important parameter to assess potential greenwashing or poor ambition. In 2017, 22% of companies had achieved their most long-term target, 46% have reduced their absolute emissions compared to the company-specified base year, and 32% have increased their absolute

emissions since. Substantial sectoral differences occurred in those rates. Nevertheless, 14% of targets were achieved before the target was even announced.

Although the results of this study have produced valuable contributions, further work should be performed to develop more advanced models including a readjustment of corporate climate mitigation target reductions based on an assessment of target progress determinants and past target achievements to increase the accuracy and applicability of such benchmarks.

CHAPTER 5 ARTICLE 2: WHAT DRIVES COMPANIES' PROGRESS ON THEIR EMISSION REDUCTION TARGETS?

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Supplementary material in Appendix B.

5.1 Abstract

As the importance of non-state mitigation actions in the transition to a low-carbon economy becomes firmly established, a rapidly growing number of companies are setting corporate climate mitigation targets. Shareholders increasingly value these commitments, conveying the impression of good future carbon performance. However, a critical question emerges: why do some companies progress better than others toward their climate mitigation targets? There is currently a lack of empirical literature assessing companies' progress against their mitigation targets. Using a new indicator to evaluate the progress against individual corporate climate mitigation targets in a comparable manner, this study presents an explanatory analysis of 120 determinants applied to 4,341 climate mitigation targets (scope 1 and 2 emissions) of 2,975 companies reporting to the 2020 CDP questionnaire. The target progress assessment shows that 30% of targets have increased emissions since their base year, 15% have reduced their emissions but not at a sufficient pace, while 55% were on track to achieving or had already achieved their targets. In addition, 18% of targets were already achieved the year the target was set, which may be due to choosing a base year with unusually high emissions. The findings reveal 19 key determinants significantly associated with the progress against corporate targets and highlight future research orientation. Our results indicate better progression by companies having absolute targets with longer timeframes and disclosing additional, as well as remuneration links to climate-related issues. Companies with more ambitious targets progress less than others, except when the ambitious targets are approved by the Science-Based Targets initiative. The latter implies ambitious targets from some firms may only be symbolic, and that investors should consider both target ambition and progress. Clear guidance and regulations should be implemented by policymakers to prevent misleading target information.

Future research should address limitations related to reliance on self-reported data and exclusion of scope 3 emissions targets, along with the research directions suggested by the findings.

5.2 Manuscript

5.2.1 Introduction

To mitigate climate change risks, a transition to a low-carbon economy is needed (Campiglio et al., 2018; Daumas, 2024; Lee et al., 2023; Semieniuk et al., 2020). The importance of non-state actor mitigation actions is increasingly recognized in order to achieve such a transition (Hampton & Whitmarsh, 2023; A. Hsu et al., 2023; Kuramochi et al., 2020). Indeed, investors and companies have a major role to play in climate change mitigation (Bolton et al., 2022; Busch et al., 2024; Millar et al., 2018).

To manage their climate risks, several institutional investors are transitioning their investment portfolio to align with a goal of global net-zero emissions by 2050 or sooner (Bolton et al., 2022; Gosling & Macneil, 2023; Hoepner & Rogelj, 2021; Popescu et al., 2021). In response to such external pressures, companies are setting climate mitigation targets (Abreu et al., 2021; Babcock et al., 2022; Bjørn, Tilsted, et al., 2022; Cadez et al., 2019; Sullivan & Gouldson, 2017) which are commonly expressed as a percentage reduction for a given emission scope² between a base year and target year (Bolay et al., 2022; Campbell, 2021). Investors react positively to corporate climate mitigation targets by adding a premium value when the reduction announced is aggressively ambitious (Cheng et al., 2023; A. He, 2022; Khandelwal et al., 2022). However, investors are currently rarely considering if these targets are likely to be met (Campbell, 2021). Without an assessment of target progress, there is increased risk that symbolic targets will mislead investors regarding the future carbon performance and reputation of companies (Campbell, 2021).

Existing studies have confirmed that companies are often not on track to achieving their climate mitigation targets (Bolay et al., 2022; Callery & Kim, 2021; Kuramochi et al., 2021; Ruiz Manuel & Blok, 2023; SBTi, 2022a, 2023; D. Wang, 2017; Yeo et al., 2022). However, these studies have

² Following the GHG Protocol corporate accounting and reporting standard, scope 1 describes the direct emissions of the company while scope 2 are indirect emissions linked to the purchased of electricity purchased and scope 3, any remaining indirect emissions within the value chain (Harangozo & Szigeti, 2017; Stridsland et al., 2024). Two methodological approaches can be used to report the scope 2 emissions; location-based (regional grid-average emission factor) and market-based (specific emission factors derived from a contractual agreement) (Bjørn, Lloyd, et al., 2022; Brander et al., 2018).

not explored why this is the case. Despite the growing number of companies setting climate mitigation targets (Bolton et al., 2022; Hale et al., 2022; SBTi, 2023), there is currently a gap in the literature in understanding why some companies progress better than others. Addressing this gap is crucial, as a better understanding of what makes a corporate climate mitigation target successful would guide various stakeholders, including investors, in recognizing best practices and increasing the credibility and accountability of such actions (Hale et al., 2021; Kuramochi et al., 2021). Moreover, identifying best practices would allow investors to engage with companies to ensure their implementation.

Most scientific literature on corporate climate mitigation targets have mainly focused on firms attributes and external context associated with the decision to set a target (Armour et al., 2023; Bryant et al., 2020; Cadez et al., 2019; Desai et al., 2023; Eleftheriadis & Anagnostopoulou, 2017; Reid & Toffel, 2009; Yin et al., 2017), target setting approach (Bjorn et al., 2021; Krabbe et al., 2015; Lux et al., 2023; Moshrefi et al., 2022; Poschmann et al., 2023; Randers, 2012; Schweitzer et al., 2023) and target ambition (Bolton & Kacperczyk, 2023a; Dietz et al., 2018; Dietz, Gardiner, Jahn, et al., 2021; Doda et al., 2016; Rekker et al., 2022, 2023), with an emerging literature on science-based and net-zero targets (Bjørn et al., 2023; Bjørn, Tilsted, et al., 2022; Fankhauser et al., 2022; Freiberg et al., 2021; Gieseckam et al., 2021a; Hale et al., 2022, 2024; Kuo & Chang, 2021; Robiou du Pont et al., 2024). However, only few studies have assessed the determinants of companies' progress against their targets, and these are often limited to specific aspects, including target type, specific company characteristics, or distinct emission reduction initiatives implemented by companies (Aldy et al., 2023; Dahlmann et al., 2019; Dragomir, 2023; Gieseckam et al., 2021a; Ioannou et al., 2016; D. Wang, 2017; Yeo et al., 2022). For instance, Gieseckam et al. (2021) restricted their study to the influence of target type on the progression of 81 science-based targets, and concluded that firms progress less towards targets covering scope 3 emissions than other scopes. Wang (2017) constrained his study to a sectoral comparison of 989 European and US firms disclosing in 2013 and found that US target progression is significantly higher than European in 8 out of 24 sectors. Dahlmann et al. (2019) assessed the target type of 1,335 firms disclosing between 2010 and 2013, and determined that firms with an absolute and ambitious target with a longer timeframe are associated with emission reductions (the study did not directly assess target progress). Ioannou et al. (2016) assessed 1,127 companies and determined that firms with higher target ambitions and monetary incentives towards management have a higher target progression.

Yeo et al. (2022) confirmed that firms with more ambitious targets are correlated to higher target progression, via an assessment of 1,500 firms reporting in 2021. However, recent studies by Aldy et al. (2023) and Dragomir (2023) suggest the opposite: firms with less ambitious targets tend to progress better than others. These two studies assessed, respectively, the target progression of companies included in the Russell 3000 index (roughly 450 companies) and the STOXX All Europe 100 Index, focusing only on limited aspects of target type and company characteristics. In addition to target type, Ioannou et al. (2016) assessed other target progress determinants such as: monetary incentives to management (board members, executive team members, and managers), number of initiatives to reduce emissions, carbon savings per initiatives, and amount of investments per initiative. Meanwhile, Day et al., (2022) assessed target credibility with a wider extent of determinant categories (e.g., strategy, risks, opportunities, carbon pricing, engagement with the value chain actors, and third-party verification), without assessing target progression, and without exploring which determinants are key to their progress.

In summary, existing studies on determinants of target progress do not provide a complete overview as they focus on sub-groups of targets, specific company characteristics, or limited emission reduction initiatives. This leaves unanswered questions, such as: Do monetary management incentives produce better end-results towards target progression than having science-based targets, or other strategies such as engaging with value chain actors? Do companies progress better against science-based targets than against other ambitious targets? This literature gap highlights the need for an in-depth investigation with a more comprehensive analysis of the determinants of corporate climate target progress. Therefore, this study aims to assess the target progress of a wide range of companies (across several sectors and regions), target types, and determinants to address the following research question: What are the key determinants that explain companies' progress towards their climate mitigation targets?

To answer this research question, an explanatory analysis will be carried out to identify the key determinants (significant explanatory variables) explaining the variability of corporate climate mitigation target progress (dependent variable). Identifying the key determinants of target progression requires the ability to consistently harmonize the measurement of target progress across companies. Due to the limitations of existing indicators to measure target progress, including the specificity of the sample data used, a new corporate target progress indicator that includes time-left to achieve a target was first developed (see Section 5.2.2.2). By combining a broad extent of

determinants and target types, answering this research question will provide guidance on best practices for shareholders. Furthermore, it will better inform future research orientation, i.e., characteristics of targets to be further assessed separately.

5.2.2 Methodology

The following provides an outline of methodological steps applied to address the previously posed research question. Section 6.2.2.1 describes the sample of companies and targets covered for this study. Section 5.2.2.2 presents the dependent variable (target progress), while a brief description of explanatory variables (key determinants) is given in Section 5.2.2.3. Section 5.2.2.4 outlines the model used to conduct the explanatory analysis. To confirm the significance of explanatory variables obtained, robustness analysis has been performed as explained in Section 5.2.2.5.

5.2.2.1 Sample: Companies and targets covered

The Carbon Disclosure Project (CDP) database has been used for this study as it is the most comprehensive and inclusive dataset containing companies across all sectors and various countries, as well as different target types and a wide range of explanatory variables. Indeed, the CDP database is the most extensive database of voluntary corporate carbon reporting (Busch, Johnson, et al., 2022; Ott et al., 2017) and is commonly used by academics (Stanny, 2018; Zhang & Liu, 2020). Furthermore, the CDP database is in a standardized format as it is compiled from questionnaires sent on behalf of investors and/or supply chain actors (Depoers & Jeanjean, 2016; Ott et al., 2017; Zhang & Liu, 2020). This standardized format further facilitates the comparison of information reported by companies. However, it is important to note that the data are entirely self-reported by companies, and the CDP does not systematically verify responses provided by companies, which means there could be inaccuracies (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; CDP, 2023; Garcia-Vega et al., 2023).

All the input data required for this study were extracted from the 2020 CDP climate change questionnaire, and compiled into an aggregated dataset, except for base year emission information, which in some cases was extracted from previous questionnaires year due to its unavailability in the current year. Accordingly, the data sample assessed consist of all companies reporting to the 2020 CDP climate change questionnaire that disclosed one or more emission reduction target. No exclusions or limitations have been placed on the industry sector or operational region.

The targets assessed in this study include absolute and intensity targets covering scope 1 emissions, scope 2 location-based emissions, scope 2 market-based emissions, scope 1 and 2 location-based emissions combined, and scope 1 and 2 market-based emissions combined. Although scope 3 often dwarf scope 1 and 2 emissions (CDP, 2024c; Mejia & Kajikawa, 2024; Schmidt et al., 2022), our study excludes targets covering scope 3 emissions, due to previously documented pervasive accuracy and consistency issues in scope 3 emissions accounting and reporting (C. Blanco et al., 2016; Busch, Johnson, et al., 2022; Hansen et al., 2022; Klaaßen & Stoll, 2021) and due to the challenge of applying the data consistency filter developed for scope 1 and 2 emissions (described below) to scope 3 emissions.

To allow a direct comparison of different target types and scope coverage, all targets have been harmonized to absolute targets for combined scope 1 and 2 emissions, following the methodology of Bolay et al., 2022. For the harmonization of targets covering scope 1 only, scope 2 location-based emissions have been considered instead of scope 2 market-based for both the year assessed and base year emissions. Targets have been excluded from the sample if the input data required to calculate target progress were not disclosed or if the missing data on explanatory variables required estimation (see Section 5.2.2.3).

To filter inconsistent data to avoid biasing results, a basic set of criteria was applied. The first criterion involves checking for inconsistencies between the base year emissions reported for the scope covered by the target³ and the corresponding base year emissions reported elsewhere in the 2020 CDP questionnaire. Targets have been excluded if there was a difference greater than +/- 1% between these base year emissions values. Note that the structure of the CDP questionnaire prevents this filter from being applied to scope 3 emissions, which is one reason behind the exclusion of scope 3 targets from this study. Additionally, targets with obvious erroneous emissions values across the reporting scope have been excluded. For example, entries of zero annual scope 1 and 2 emission were assumed to be errors. Furthermore, a factor near 1,000 or 1,000,000 between base year emissions and the reporting year, without appropriate justification, was assumed to be a 'unit error' and excluded from the analysis.

³ Value proportionally adjusted to 100% from the percentage of scope covered by the target.

5.2.2.2 Target progress: Dependent variable

To justify the development of a new target progress indicator, existing indicators are first presented and critically evaluated in the context of our study. Based on identified shortcomings, a new progress indicator is developed. Existing studies have used the three following progress indicators: a) percentage of the target achieved (Dragomir, 2023; Ioannou et al., 2016; SBTi, 2022a; Yeo et al., 2022), b) categorical variables, such as ‘on track’ or ‘not on track’, under the assumption of a linear reduction trajectory between the base year and target year, (Aldy et al., 2023; Callery & Kim, 2021; Gieseckam et al., 2021a; Kuramochi et al., 2021; D. Wang, 2017; Yeo et al., 2022), and c) progress ratio, which is equivalent to the percentage of the target achieved divided by the percentage of the time elapsed with respect to a linear target reduction trajectory (A. Hsu et al., 2020). Below, we identify issues with these three existing progress indicators (details in the Supplementary Information; SI).

The two primary issues identified regard the lack of comparability between target progress results; 1) no integration of the remaining time left to achieve the target; indicator ‘percentage of the target achieved’ used alone (represented by Equation 5.2), and 2) lack of differentiation between target progress results; indicator ‘categorical variables’ (as for example slightly or highly on track in a same category). To overcome these issues, the present study integrates the percentage of time elapsed since the base year (Equation 5.3), and uses a continuous value for target progress results. The third issue identified is the high variability in the target progress results, which is most pronounced near the indicated base year of corporate climate mitigation targets (Yeo et al., 2022), i.e. with indicator ‘progress ratio’, a large numerator (high or low percentage target achieved) with a small denominator (low percentage time elapsed), results in extreme values, which poses challenges for statistical analysis. While outliers (extreme values) are often sacrificed to improve statistical analysis results, legitimate outliers (ones that are not data errors) may contain useful information (Hadi et al., 2009; Orr et al., 1991; Osborne & Overbay, 2004). To address variability and allow the inclusion of legitimate outliers in our study, our proposed target progress indicator does not use ratios and is bounded by construction.

Equation 5.1 presents our new target progress indicator $P_{k,t}$ for the target of the company k at year t . This indicator reflects that the more time a company has left to achieve its target, the higher the likelihood of achieving it, while accounting for the emission reductions occurring at the year

assessed. In other words, this indicator penalizes more severely when closer to the target year, as there is less time left for the company to achieve its target.

$$P_{k,t} = E_{k,t} - T_{k,t} + 1 \quad (5.1)$$

$$\text{with } E_{k,t} = \frac{e_{k,t}^{base} - e_{k,t}}{e_{k,t_k}^{base} - e_{k,t_k}^{target}} \quad (5.2) \text{ and } T_{k,t} = \frac{t_k^{base} - t}{t_k^{base} - t_k^{target}} \quad (5.3)$$

Where:

k : target of the company assessed.

t : year assessed.

$E_{k,t}$: percentage of the target achieved at t of the company k .

$T_{k,t}$: percentage of the time elapsed at t of the company k .

t_k^{base}, t_k^{target} : base year and target year for the target of the company k .

$e_{k,t}, e_{k,t_k}^{base}, e_{k,t_k}^{target}$: scope 1 and 2 emissions for the company k at t, t_k^{base} and t_k^{target}

The target progress indicator $P_{k,t}$ is bounded from 0 to 2 by artificially limiting $E_{k,t}$ and $T_{k,t}$ from 0% to 100%. Hence, when the year assessed has lower emissions than the target year (target achieved), $E_{k,t}$ is 100%, and when the year assessed has higher emissions than the base year (no emissions reduction), $E_{k,t}$ is 0%. When the year assessed passes the target year (target year reached), $T_{k,t}$ is 100%, while $T_{k,t}$ is 0% when the year assessed is the same as the base year (target not started). The latter leads to disregarding the target, as there is no progression to assess.

Figure 5.1 depicts a hypothetical scenario to illustrate how a target progress with 60% of the target achieved and 70% of time left will obtain a higher progress value ($E_{k,t} = 60\%$ and $T_{k,t} = 30\%$, then $P_{k,t} = 1.3$)⁴ compared to another with the same percentage achieved but less time left ($E_{k,t} = 60\%$ and $T_{k,t} = 50\%$, then $P_{k,t} = 1.1$). Furthermore, Figure 5.1 illustrates cases of different percentages target achieved and time elapsed can have the same progress value (for example, see $P_{k,t} = 1.5$). While having a same progress value, these targets deviate to the same extent from their

⁴ In the published version, $E_{k,t} = 60\%$ is incorrectly noted as $e_{k,t} = 60\%$ in Figure 5.1, which is an error. The journal will be contacted to correct this discrepancy.

linear reduction trajectory (perpendicular line to the $P_{k,t} = 1$). Assuming these companies continue to reduce emissions at the same rate initially targeted between the year assessed and the target year, they would reach the same progress value in their target year (same percentages target achieved and time elapsed).

Regarding the interpretation of the target progress results, a value between 1 and 2 indicates the company is on track to reaching the target faster than a linear reduction trajectory (yellow to green part in Figure 5.1). A value of 1 implies the company is exactly following a linear reduction trajectory, or that the target is achieved in the target year ($E_{k,t} = 100\%$ and $T_{k,t} = 100\%$, then $P_{k,t} = 1$). The extreme case of $P_{k,t} = 2$ means that the target was already achieved in the base year ($E_{k,t} = 100\%$ and $T_{k,t} = 0\%$). A value between 0 and 1 indicates that the company reducing emissions at a slower pace than a linear reduction trajectory (orange to red part in Figure 5.1). A value of 0 implies no emissions reduction between the base year and target year ($E_{k,t} = 0\%$ and $T_{k,t} = 100\%$).

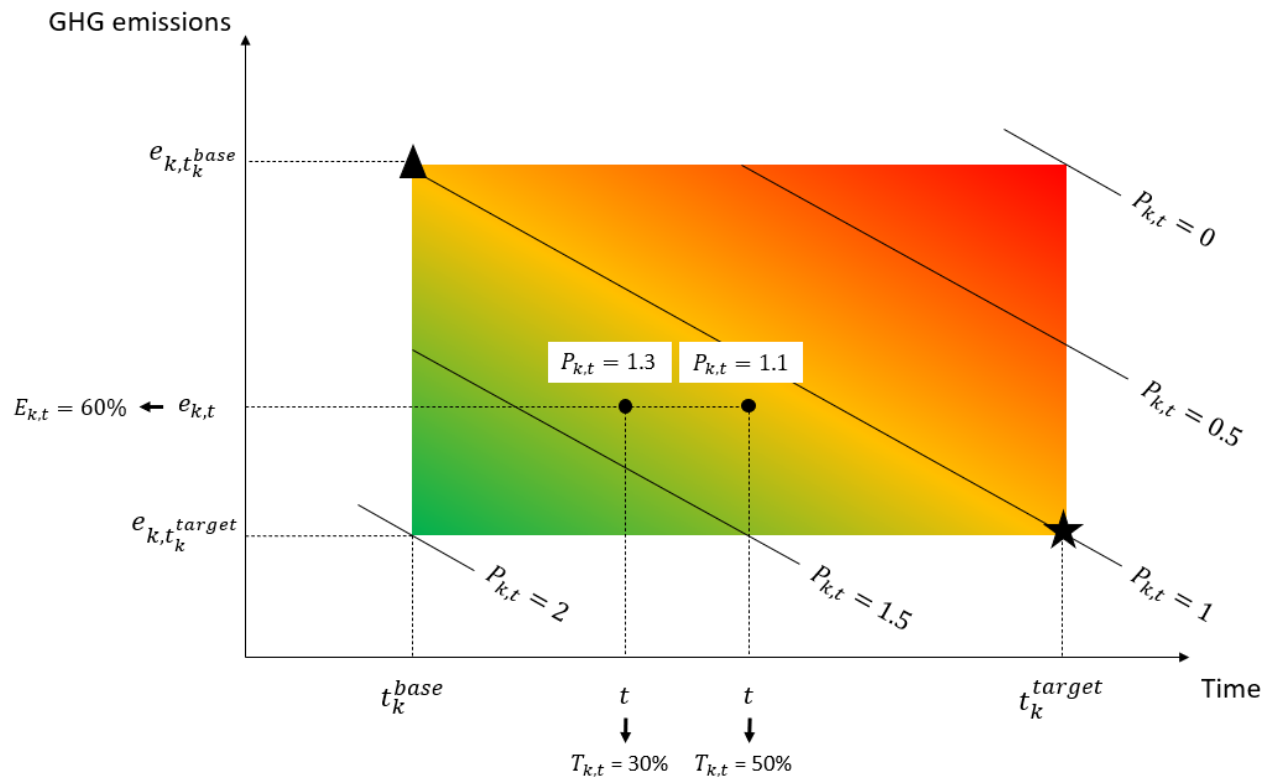


Figure 5.1: Graphical representation of emissions for company k at the base year (triangle), year assessed (circle), and target year (star) with potential target progress indicator values, $P_{k,t}$, displayed with color gradient and level lines.

5.2.2.3 Determinants of target progress: Explanatory variables

The explanatory variables, i.e., determinants of the target progress, include data from each section of CDP questionnaire (CDP, 2020a) and thereby includes determinants analyzed in previous studies (Aldy et al., 2023; CA100+, 2022b; Dahlmann et al., 2019; Day et al., 2022; Dragomir, 2023; Gieseckam et al., 2021a; Ioannou et al., 2016; Yeo et al., 2022), to the extent they are covered in the CDP questionnaire.

A total of 120 explanatory variables are considered, grouped into 11 categories, of which 16 are continuous variables and 104 are categorical variables. Categorical variables facilitate qualitative answers and are here assigned a value of 1 or 0 for affirmative and negative statements respectively. Missing responses to CDP questions with qualitative answers were assigned a default value of 0 (negative). For example, if a company did not respond to the question ‘Does the board oversee climate-related issues?’, the response was assumed to be a no (negative). The model described in Section 5.2.2.4 permits the inclusion of both continuous and categorical variables.

Table 5.1 lists the 11 categories and the number of corresponding determinants evaluated, while providing examples of determinants and their respective units accordingly. The complete list of determinants including their corresponding CDP questions, preprocessing, and units are available in the SI. The following six categories are directly based on the CDP sections: ‘Governance’, ‘Carbon price’, ‘Risks and Opportunities’, ‘Strategy’, ‘Engagement’, and ‘Verification’ (CDP, 2020a). The remaining five categories have been developed specifically for this study. The ‘Target parameters’ category includes determinants corresponding to the target analyzed. In the ‘Targets and performance’ and ‘Emissions data’ sections of the CDP, information for other targets or emissions reported than for the target analyzed are included in the ‘Emissions reporting and other targets’ category. The ‘Additional reporting’ category incorporates determinants relating to number of reporting years and additional reporting practices, and the ‘Sector’ and ‘Region’ categories describe company activities and headquarters information.

Table 5.1: Number of determinants assessed for each of the 11 categories. Examples of determinants per category are provided with their respective unit (complete list of determinants in the SI).

#	Category	Number of determinants	Examples of determinants	Unit
1	Target parameters	20	Annualized target ambition, Percentage of the target achieved at the year the target was set, Absolute target (not intensity target)	% % 1 or 0
2	Emissions reporting and other targets	33	Energy target, Scope 3 target, Use renewable energy certificate in their scope 2 market-based accounting	1 or 0 1 or 0 1 or 0
3	Governance	6	Board oversight climate-related issues, Management remuneration link to climate-related issues, CEO remuneration link to climate-related issues	1 or 0 1 or 0 1 or 0
4	Carbon price	4	ETS or carbon taxes regulation, Internal carbon price	1 or 0 1 or 0
5	Risks and Opportunities	4	Physical risks considered relevant, Transition risks considered relevant	1 or 0 1 or 0
6	Strategy	13	Low-carbon transition plan, Revenue for low-carbon products, Climate-related scenario analysis (quantitative and qualitative)	1 or 0 % 1 or 0
7	Engagement	9	Engage with value chain actors, Direct influence on policymakers, Position consistent with trade associations where are members	1 or 0 1 or 0 1 or 0
8	Verification	1	Third-party verification	1 or 0
9	Additional reporting	4	Report for five years in CDP, Report in financial statement	1 or 0 1 or 0
10	Sector	13	CDP classification	1 or 0
11	Region	13	Based on the company headquarter location	1 or 0

5.2.2.4 Statistical modelling

The main model used to identify key determinants of target progress is an Ordinary Least Squares (OLS) regression with a backward stepwise selection. The explanatory variables will be considered as key determinants of the target progress if they are significant, i.e., p-value of 0.05 as a threshold. To do so, all explanatory variables are entered into the model and the least significant variables are excluded one at a time until only statistically significant explanatory variables remain (Sanchez-pinto et al., 2018; Xu & Zhang, 2001). This method was chosen due to its wide use for variable selection in multiple fields (Sanchez-pinto et al., 2018).

To ensure the reliability and interpretability of results obtained, the correlation between explanatory variables have been tested to avoid multicollinearity as it can make significant explanatory variables statistically insignificant (Daoud, 2017; Shrestha, 2020). To identify multicollinearity, different methods have been applied depending on the variable types, i.e., categorical vs categorical variables; Phi Coefficient, categorical vs continuous variables; Point Biserial, continuous vs continuous variables; Pearson, Spearman, and Kendall correlation coefficients (Onwuegbuzie & Daniel, 1999; Shrestha, 2020). To ensure no significant multicollinearity remained in the model, the Variance Inflation Factor (VIF) has been used with a maximum threshold value of 5 (Akinwande et al., 2015; Daoud, 2017; Shrestha, 2020).

To make the explanatory variables comparable, a z score has been applied to scale their units into a standard deviation (Abdi, 2007; Turlach et al., 2005). The mean of each explanatory variable is normalized to a value of 0 and the standard deviation to 1 (Abdi, 2007; Turlach et al., 2005).

5.2.2.5 Robustness analysis

To ensure the robustness of results identifying key target progress determinants, two alternative models (i.e., Lasso and Random Forest Regressor), and a resampling technique (i.e., Bootstrapping) have been applied. The Least Absolute Shrinkage and Selection Operator (Lasso) model allows to test a different variable selection method than that used in the main model (i.e., p-value; Section 5.2.2.4). Indeed, Lasso is a regularization technique for regression models which applies a L1 penalty forcing some variable coefficients to 0 (Sanchez-pinto et al., 2018; Turlach et al., 2005; Zou & Hastie, 2005). Accordingly, explanatory variables with a coefficient higher than 0 are selected in this model.

Since the main model captures linear relationships between the dependent and explanatory variables, a non-linear model (random forest regressor) has been tested (Breiman, 2001; Nguyen et al., 2021). The random forest regressor is an ensemble of decision trees, where the training process selects the variables by splitting the entire dataset into nodes, and the reduction in the sum of the squared error is used for estimating the average relative importance for each variable (Breiman, 2001; Nguyen et al., 2021). To do so, the dataset has been split to train the model, and parameters tuned such as the number of splits and nodes to avoid overfitting (Probst et al., 2019; Segal, 2004).

Since some results may be inferred by a low number of appearances of a variable value in the dataset, bootstrapping techniques have been applied to the three models (the main and the two alternative models) to test the robustness and the stability of the variable selection process (Austin & Tu, 2004; Heinze et al., 2018; Hesterberg, 2011). The original dataset has been resampled 1,000 times to an identical size with randomly replaced data for a whole row, i.e., target progress with its corresponding explanatory variable information (Austin & Tu, 2004; Efron & Tibshirani, 1994; Hesterberg, 2011). The variables are selected based on a minimum of 60% of appearances on the 1,000 resampling of each model.

5.2.3 Results

5.2.3.1 Final sample

The total number of companies reporting in the 2020 CDP climate change questionnaires is 4,524 of which 2,975 disclosed a climate mitigation target (66%). The total number of targets reported by those companies is 6,058, involving 4,341 scope 1 and/or 2 targets (72%) and 1,717 scope 3 related targets (28%).

After compiling all required information for the target progress calculation and determinants, 2,734 targets were deemed ‘complete’. However, 1,206 targets did not pass the data consistency test (see Section 6.2.2.1), reducing the final sample to 1,528 targets from 1,030 companies. The number of targets exceeds the number of companies as some report multiple targets, e.g., absolute and intensity targets, different scope coverage, or short-term and long-term targets. The total scope 1 and 2 emissions of the 1,030 companies represents 4.7 GTCO₂e, which corresponds to 80% of United States annual emissions in 2021 (Friedlingstein et al., 2022). The expected reduced emissions from the 1,528 targets are 1.8 GTCO₂e.

Table 5.2 presents the number of companies and targets by sector contained in the final sample, including the scope covered by the targets. Information per country and region is available in the SI. For the 1,528 targets, 45% cover combined scope 1 and 2 location-based, and 31% cover combined scope 1 and 2 market-based. Targets covering only scope 1 represent 13%, scope 2 location-based, 8%, and scope 2 market-based, 3%.

Table 5.2: Number of companies and targets by sector included in the final sample. The scopes covered by the targets are represented in the last five columns. Abbreviations: SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based.

Sector	Number of companies	Number of targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Apparel	25	31	15	11	2	2	1
Biotech, health care & pharma	53	76	23	37	6	7	3
Food, beverage & agriculture	56	73	32	28	7	5	1
Fossil Fuels	26	36	18	6	9	2	1
Hospitality	17	25	13	10	1	0	1
Infrastructure	63	100	50	28	17	5	0
International bodies	1	1	1	0	0	0	0
Manufacturing	348	483	239	132	52	48	12
Materials	111	155	70	55	19	6	5
Power generation	30	57	25	2	28	0	2
Retail	58	91	32	42	6	10	1
Services	208	350	156	118	28	34	14
Transportation services	34	50	18	11	19	2	0
Total	1030	1528	692	480	194	121	41

5.2.3.2 Target progress

Figure 5.2 shows the distribution of the target progress indicator for the 1,528 targets ($P_{k,t}$). The average target progress is 0.97, corresponding to being slightly behind a linear reduction pathway, see Figure 1. The variability in target progress is relatively high, with a standard deviation of 0.5, a first quartile of 0.67, a median of 1, and a third quartile of 1.3. No outliers are present in the progress results using an interquartile range approach for identification, as the target progress

indicator is bounded from 0 to 2 by construction. In contrast, other progress indicators show outliers due to targets being over- or underachieved, resulting in values exceeding 100% or falling below 0%. These are included in the targets represented by white bars with dots or hatching in Figure 2, respectively.

As displayed in Figure 5.2, 844 targets (55% of the sample) are achieved or on track to be achieved ($P_{k,t} \geq 1$). Of those 844 targets, 475 (31% of the sample) are achieved, while 108 of them (7%) also reached their target year ($P_{k,t} = 1$; grey parts with dots in Figure 5.2). The remaining 369 of the 844 targets with $P_{k,t} \geq 1$ (24% of the sample) correspond to companies reducing faster than their target linear trajectory, without having reached their target year or their targeted emissions reduction (white bars with values over 1 and no dots in Figure 2). Furthermore, 684 targets (45% of the sample) correspond to companies that are running late against their target linear reduction trajectory ($P_{k,t} < 1$). Of those 684 targets, 457 (30%) correspond to companies that increased emissions after the base year (hatching parts in Figure 5.2), of which 96 companies' targets (6%) reached their target year ($P_{k,t} = 0$; grey hatch parts in Figure 5.2). The remaining 227 targets out of the 684 (15%) pertain to companies reducing their emissions after the base year but are behind their target linear reduction trajectory (white bars with values under 1 and no hatching in Figure 2).

Some sectors were found to progress better than others. The power generation sector has a median target progress above other sectors, while the transportation services and fossil fuels sectors are lagging the most. Companies with headquarters in Southern Europe and Northern Europe have median target progress values ahead of all other regions. A deeper analysis of the target progress results per sector and region is available in the SI.

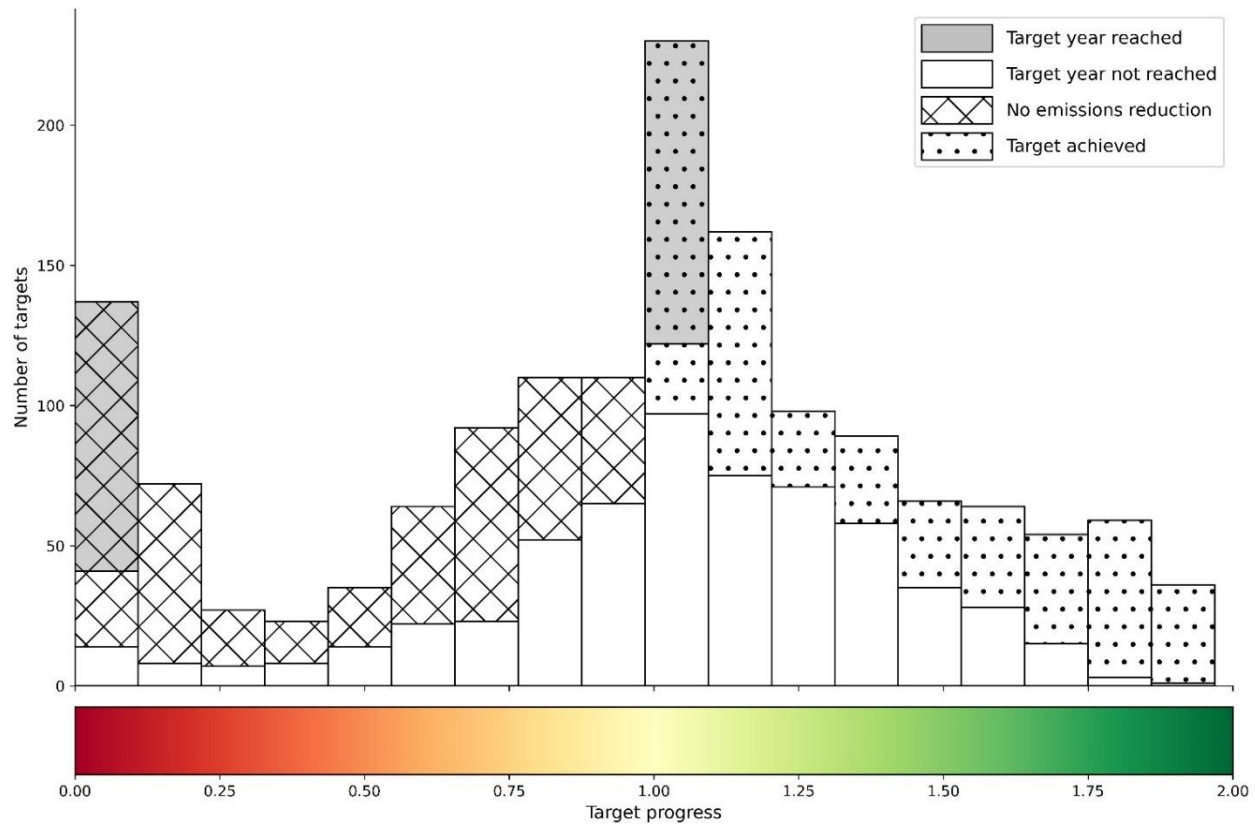


Figure 5.2: Distribution of target progress indicator $P_{k,t}$. The color bar ranging from orange to red indicates targets behind linear reduction trajectory, while the range from yellow to green indicates targets ahead of that trajectory (see Figure 1). Targets that have reached their target year are shown in grey (% time elapsed = 100%), while targets that have not reached their target year in white (% time elapsed < 100%). Among the targets that have not reached their target year, those with no emissions reduction are indicated with hatching (% target achieved = 0%), and those with 100% of their target achieved are indicated with dots.

5.2.3.3 Key determinants of target progress

Using the backward stepwise OLS regression with a p-value threshold of 0.05 (the main model), 19 key determinants were identified, as listed in Figure 5.3. Of the 120 explanatory variables analyzed, 34 have been disregarded due to multicollinearity (correlation between explanatory variables). The remaining 86 have a variance inflation factor under 5, implying no major multicollinearity left in the model (Akinwande et al., 2015; Daoud, 2017; Shrestha, 2020).

The main model, including the 19 selected determinants, is highly significant with a p-value far below 0.01 (F-statistic probability) and explains 35.4% of target progress variance in the sample (R-squared). The 19 key determinants in Figure 5.3 are ranked from most to least significant p-

value. The three most significant determinants are linked to the ‘Target parameters’ category, followed by determinants of the categories ‘Region’, ‘Risks and opportunities’, ‘Governance’, ‘Emissions reporting and other targets’, and ‘Carbon price’. No determinants have been selected for the categories ‘Strategy’, ‘Verification’, ‘Engagement’, ‘Sector’, and ‘Additional reporting elsewhere’ (see Table 1).

Regarding the coefficients presented in Figure 5.3, a positive value means that an increase of one standard deviation of the determinant value will increase the average value of the target progress by the coefficient value (positive association), while a negative coefficient implies a decrease in target progress values (negative association) (A. F. Siegel & Wagner, 2016). The coefficient interpretation arises from the determinant units associated with the z-score standardization (standard deviation; see Section 5.2.2.4). The coefficients and p-values for each key determinant are available in the SI.

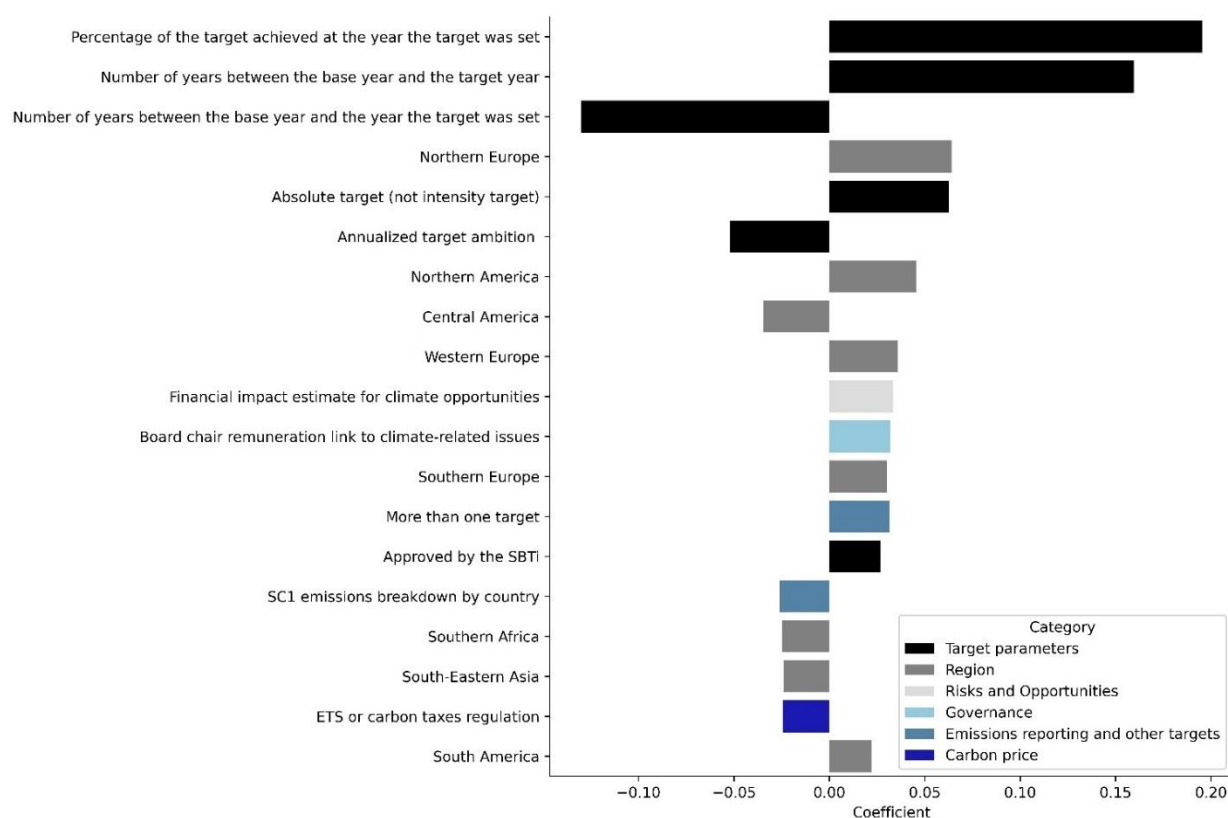


Figure 5.3: Coefficient values for the 19 key determinants selected with the backward stepwise OLS regression model. Determinants are ordered from the most to least significant p-value (under 0.05). Abbreviations: SBTi = Science-Based Target Initiative; SC1 = scope 1; ETS = Emissions Trading System.

The determinant *Percentage of the target achieved at the year the target was set* is the most significant and positively associated with target progress. These results can be explained by 19% of the sample having targets already being achieved by the year the target was set. On average, 32% of the targeted emission reductions are realized by the year the target was set.

The determinant *Number of years between the base year and the target year* is the second most significant determinant. Since positively associated, companies progress better against targets with longer timeframe than shorter ones. On the other hand, the *Number of years between the base year and the year the target was set* is negatively associated. Accordingly, progress is worse for targets with many years between the base year and the year the target was set (first key determinant). Indeed, some targets announced in 2015 or later have base years extending back to 1990.

Regarding the other key determinants linked to the ‘Target parameters’ category, *Absolute target (not intensity target)* is positively associated with target progress, meaning that companies progress better towards absolute targets than intensity targets. *Annualized target ambition* is negatively associated with target progress, suggesting firms setting more ambitious targets are less likely to attain them compared to firms setting less ambitious targets. The overall median annualized ambition for the sample is 2%, which is higher than the 1.4% median annualized ambition for targets already achieved (31% of the sample). Furthermore, targets that were achieved at the year the target was set have a 1% median annualized ambition. However, companies reporting ambitious targets as approved by the Science-Based Target Initiative (SBTi) progress better towards their targets than companies with other ambitious targets, hence *Approved by the SBTi* being identified as a positively associated determinant. These targets represent 17% of the sample, with a 2.5% median annualized ambition.

Of the 19 key determinants, 8 are linked to the region of company headquarters. Some regions (generally hosting developed economies) are positively associated with target progression, i.e., *Northern Europe, Northern America, Western Europe, Southern Europe, and South America*. However, *Central America, Southern Africa, and South-Eastern Asia* are negatively associated. Note that we could not identify key determinants related to sectors, suggesting that the type of product or service offered by a company does not influence its target progress.

Regarding the ‘Risks and Opportunities’ category, companies that have identified opportunities leading to a substantive financial impact, e.g., resource or production efficiency and development

of new products or services, are positively associated with target progress. However, CO₂ savings, monetary annual savings and investment required for mandatory or voluntary initiatives implemented were, perhaps surprisingly, not identified as being significant ('Strategy' category). Concerning the 'Governance' category, progress was found to be better when the board chair remuneration is linked to climate-related issues, while CEO and manager remunerations were not significantly associated with target progress.

Regarding the 'Emissions reporting' category and other targets, companies disclosing more than one target, i.e., short-term and long-term targets, absolute and intensity targets, or multiple targets covering different scopes, progress better against their targets than companies only disclosing a single target. However, companies specifically reporting an energy target were not significantly associated with target progress. The determinant *SC1 emissions breakdown by country* is negatively associated with target progress, as with companies operating under an *ETS or carbon taxes regulation*. However, these determinants are less significant with p-values between 0.01 and 0.05, and less robust, as discussed in the following section.

5.2.3.4 Robustness of key determinants

Figure 5.4 presents the results of robustness analysis performed on the main model selection, as well as additional determinants selected by the other models, i.e., lasso (selection by coefficient constrained), random forest regressor (selection by average relative importance), and three bootstrap models (selection by 60% appearance threshold in its model). Five of the most significant determinants in the main model (see Figure 3) are also selected by the other five models, confirming a strong robustness throughout, i.e., *Percentage of the target achieved at the year the target was set*, *Number of years between the base year and the target*, *Number of years between the base year and the year the target was set*, *Absolute target (not intensity target)*, and *Annualized target ambition*. The determinants linked to the category 'Region' are not as strongly selected by the other models. Four determinants identified as significant by the main model have not been selected by any of the other models, i.e., *Approved by the SBTi*, *SC1 emissions breakdown by country*, *South-Eastern Asia*, and *ETS or carbon taxes regulation*. Those determinants have a p-value significance greater than 0.01 in the main model.

Eight additional determinants are selected by the other models with some from the 'Strategy' and 'Engagement' categories (bottom rows of Figure 4). In contrast to the main model, three of the

other models (random forest regressor, lasso and its bootstrap model) found a relationship between the disclosure of scope 3 targets and progress on scope 1 and 2 targets. The use of a different variable selection method with a linear regression model (lasso and its bootstrap) identified one supplementary determinant, i.e., *Company reporting their SC2 MB emissions* (positive association). Nevertheless, six supplementary determinants have been selected by non-linear models (random forest regressor and its bootstrap), i.e., companies reporting their SC3 emissions, the percentage of revenue for low-carbon products, target covering SC12 MB, CEO oversight and remuneration link to climate-related issues, and company engaging with their scope 3 suppliers. Determinants selected by the random forest regressor or its bootstrap model have no positive or negative association, since no coefficient is estimated in contrast to other models (Breiman, 2001; Nguyen et al., 2021).

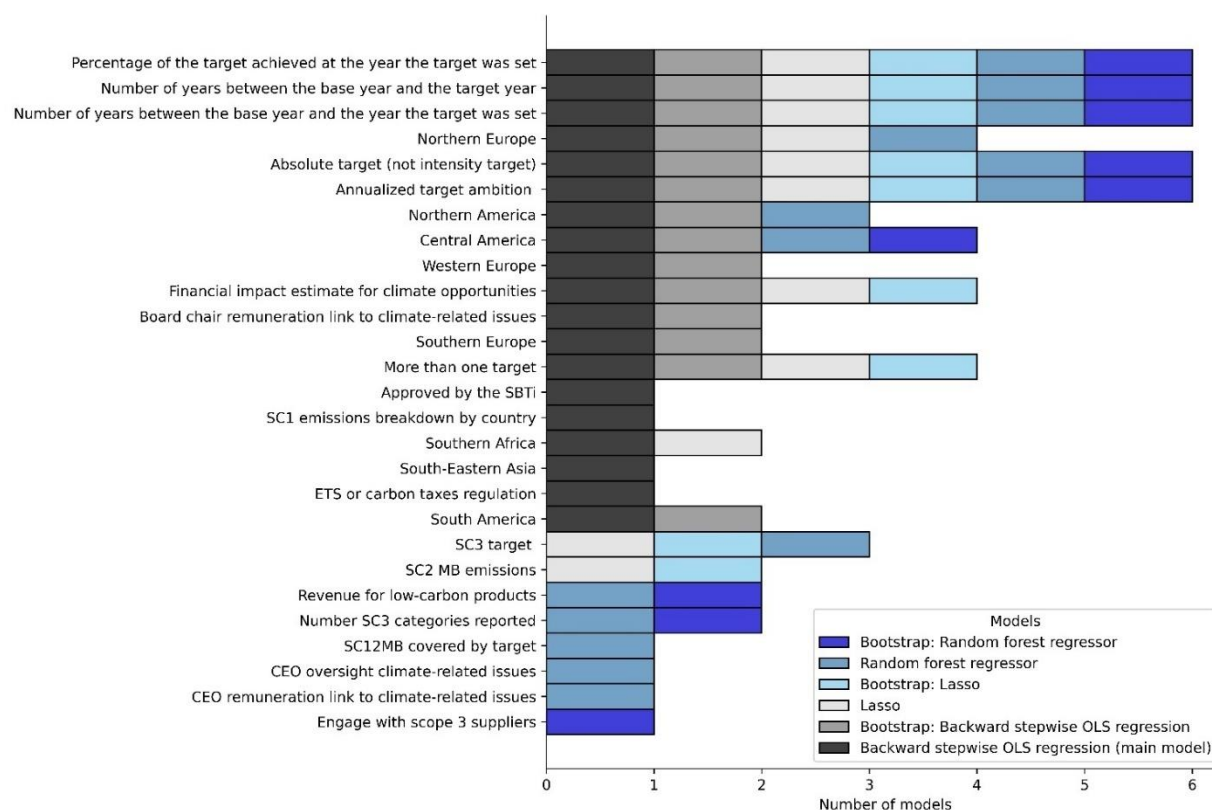


Figure 5.4: Determinant selection for the main model (dark grey) and the five other models used to analyse the results robustness. Determinants are in the same order as in Figure 3 if selected by the main model. Abbreviations: SBTi = Science-Based Target Initiative; SC1 = scope 1; ETS = Emissions Trading System, SC3; scope 3, SC2 MB; scope 2 market-based, SC12MB; scope 1 and scope 2 market-based.

5.2.4 Discussion

The present study contributes to the scientific literature on corporate climate mitigation targets. This has been established through assessing the progression of 1,528 targets from 1,030 companies, considering 120 explanatory variables grouped in 11 categories (see Section 5.2.2.3). This represents a substantial increase in variables and categories compared to existing studies (Dahlmann et al., 2019; Gieseke et al., 2021a; Ioannou et al., 2016; D. Wang, 2017; Yeo et al., 2022). Through the development of a new target progress indicator, the results obtained shed new light on ambitious targets compared to existing literature and identify some best practices, but also poor ones (Section 5.2.4.1). Furthermore, the findings reveal the significance of certain target characteristics and identify future research orientation to be further examined (Section 5.2.4.2). The study's limitations are addressed in Section 5.2.4.3 and recommendations to stakeholders are given in Section 5.2.4.3.

5.2.4.1 Comparison with existing literature

The findings suggest that companies with absolute targets and longer timeframes progress better than others. Furthermore, companies with more ambitious targets generally progress less, except when these ambitious targets are approved by the SBTi. Previous studies have stated that firms with higher ambition are more likely to be attained (Dahlmann et al., 2019; Ioannou et al., 2016; Yeo et al., 2022). While our results support Dahlmann et al. (2019) findings regarding absolute targets with longer timeframes and Ioannou et al. (2016) findings regarding monetary incentives, our findings suggest the opposite of their statement for companies with higher ambition. Recent studies by Dragomir (2023) and Aldy et al. (2024), however, support our findings that companies with less ambitious targets generally progress better, although our results differ from Dragomir (2023) findings on targets with shorter timeframes progressing more.

The differences observed with previous studies might be partly explained by the progress indicators used (see SI), reducing the comparability of study results. Additionally, earlier study did not annualize target ambitions (Ioannou et al., 2016), while recent studies from Dragomir (2023) and Aldy et al. (2023) included companies with extremely high or low target achievements. In contrast, Yeo et al. (2022) did not include such extremes, further increasing the differences from our current study sample.

Another possible reason for these discrepancies could be the evolution of corporate target disclosures. Earlier studies by Dahlmann et al. (2019) and Ioannou et al. (2016) with companies disclosing targets over 10 years ago might have included a higher proportion of early adopters genuinely committed to reducing their emissions (leaders). In contrast, more recent studies have larger sample sizes, and may include a higher proportion of companies reporting targets as a disclosure exercise rather than genuine commitment (Dragomir, 2023; Montgomery et al., 2023). These cases might involve low ambition targets that were easily (and overly) achieved, including those achieved at the year the target was set (related to the first key determinants, see Section 5.2.3.3), showing the importance of considering extreme values in the analysis. As suggested by Aldy et al. (2023), companies with ambitious targets might not have properly accounted for future sales growth when setting their targets, potentially indicating these targets were more about disclosure than genuine commitment. However, Freiberg et al. (2021) determined that firms committing to SBTi targets are associated with increased investment in initiatives towards emission reductions, perhaps explaining why progress is better for targets approved by the SBTi than other ambitious targets. In this regard, our study found an association between the target progress and companies that have identified opportunities leading to substantive financial impacts as well as the percentage of revenue generated from low-carbon products (other models, see Figure 5.4).

Giesekam et al. (2021) results have shown that firms with SBTi approved targets covering scope 3 emissions progress significantly less than companies only including scope 1 and 2 emissions and later progress reports by SBTi confirm this pattern (SBTi, 2023). Our study's sample exclude scope 3 targets due to accounting and reporting issues (Section 6.2.2.1). However, results obtained indicate that companies reporting scope 3 targets progress better on their targets covering a scope 1 and 2 (selected by three of the other models, see Figure 5.4). Furthermore, the number of scope 3 category reported and engaging with suppliers appear to impact the progression of scope 1 and 2 targets (non-linear relationship with target progress). Further research should investigate why scope 3 disclosure, including targets and initiatives, may influence the progress of scope 1 and 2 targets. Moreover, different models should be tested to capture non-linear relationships between target progress and key determinants (six additional determinants, see Figure 5.4).

Regarding executive remuneration, our results support the findings of Ioannou et al. (2016) concerning a link with target progress. Ioannou et al., 2016 found a positive association between monetary incentives to the management which combined the board, CEO, COO, directors, and

managers. Results from the main model suggest board remuneration is specifically associated with target progress. Nevertheless, CEO remuneration and corresponding oversight of climate-related issues is selected by one other model (see Figure 5.4) but does not include the managers remuneration. Companies having headquarters located in Northern Europe or North America progress better than others while in Central America, less than others. To a certain extent, this is inconsistent with the findings of Wang (2017), since the present study identifies European firms as being more significantly associated to target progress than North American firms. However, Wang (2017) only assessed US and European firms without including other North American firms.

5.2.4.2 Future research orientation

The findings highlight that the ‘Target Parameters’ category is of most significance for determining target progress (see Figure 5.3). Moreover, the five most robust determinants, across statistical models, belong to this category (see Figure 5.4). The key relevant determinants are combined into three main target characteristics needing further investigation: the choice of base year, target trajectory, and target ambition.

The choice of base year from companies is mainly implied in the first and third key determinants which led to opposite target progression directions, i.e., respectively, *Percentage of the target achieved at the year the target was set* and *Number of years between the base year and the year the target was set*. While in some cases a high percentage of target achieved at the year the target was set may indicate genuinely impressive emission reductions, it may also reflect poor practices by a company, i.e., low target ambition (targeting a low percentage reduction), and base year ‘cherry-picking’ (selecting a base year with unusually high emissions) (Bjørn et al., 2023; Bolton & Kacperczyk, 2023a; Callery & Kim, 2021; Dragomir, 2023). Further research is needed to better understand the base year choice and its implications for target progress. For example, what types of companies ‘cherry-pick’ a base year with unusually high emissions? Are companies with approved SBTs less likely to ‘cherry-pick’ base years than companies with other type of targets?

While the choice of base year may have some implications, the emission trajectory and its timeframe may also explain some findings for the first three key determinants. The trajectory of emission towards long-term targets may not be linear (second key determinant; *Number of years between the base year and the target year*), with a higher progress achieved in the beginning, where companies are picking low-hanging fruits (first key determinant), and lower later when easy

options have been depleted (third key determinant). An inverse ‘s-shaped’ curve may potentially apply in some cases, when initial investments take years to yield their potential for emission reductions. Future investigation is deeply needed to understand the different trajectories and the target characteristics related to them. Such crucial research would provide the basis required to use non-linear trajectories when assessing the progression of companies toward their targets. For example, what types of company and targets relate to slower initial progress? Are companies with longer timeframes and interim targets more likely to reduce rapidly in the beginning than companies with no interim targets?

The findings regarding target ambition underpin the relevance of continuing to assess companies based on their ambition, i.e., *Percentage of the target achieved at the year the target was set*, *Annualized target ambition*, and *Approved by the SBTi*. For example, future research could assess a sub-group of firms with ambitious targets, like approved SBTs as previously done by Giesekam et al., 2021, or compare firms with ambitious targets and different characteristics, such as approved SBTs versus other ambitious targets. Additional scrutiny is needed to understand why companies with approved SBTs appear to progress better than other companies with ambitious targets (see Section 5.2.4.1). Similarly, the type of targets, i.e., *Absolute target (not intensity target)* could be used to determine subgroups since it is one of the important key determinants and include additional components such as *More than one target*, e.g., net-zero targets with absolute interim targets vs net-zero targets with intensity interim targets.

Furthermore, the contrasting results regarding target ambitious between our study and earlier studies suggest the need for closer investigation into target progress indicators, the evolution of target disclosures over time, and the impact of extreme values in study samples (see Section 5.2.4.1). For example, future research could compare progress using different indicators for the same disclosure year and varying sample restraint (including or excluding extreme values) to better understand their effect on study results, particularly for ambitious targets.

5.2.4.3 Limitations

The main limitations of this study are the accuracy of the information reported by companies, the exclusion of scope 3 targets in the dependent variable, the assumption of a linear reduction trajectory, and the choice of explanatory variables (see Table 5.1). Since this study relies on the use of self-reported information by companies, one issue concerns the potential lack of reliability

of the data, particularly for emissions data used to calculate the progression of companies' targets. Companies may have over- or understated their emissions (and misreported information related to determinants assessed), either unintentionally or intentionally (Callery & Perkins, 2021; Garcia-Vega et al., 2023), leading to potential distortions in the analysis. To minimize this issue, our study implemented a set of criteria to filter out inconsistencies (see Section 6.2.2.1), mainly found in base year emissions of companies' targets. These inconsistencies resulted in the exclusion of 44% of targets that had all the input data required for our analysis (see Section 5.2.3.1). This indicates a pervasive issue around reliability of self-reported climate data, at large. Our findings should therefore be interpreted with caution, although we emphasize that a study of this size (number of companies and target progress determinants) could not have been realized without voluntarily reported information. Indeed, disclosures are not mandatory in every country and mandatory disclosures do not include the extent of information used in this study (Busch, Johnson, et al., 2022; R. He et al., 2020; World Bank, 2023).

As previously mentioned in Section 6.2.2.1, targets covering scope 3 have been excluded since consistency assessment of their base year emissions was not possible in the CDP year assessed. Many studies stated that companies often struggle with scope 3 emissions accounting (Dahlmann et al., 2023; Patchell, 2018; Puschmann & Quattrocchi, 2023), making their disclosures relatively uncertain despite recent improvements (C. C. Blanco, 2021; Busch, Johnson, et al., 2022; Hansen et al., 2022; Klaaßen & Stoll, 2021). Including scope 3 targets without cross-validation of related emission disclosures could bias results, as their inconsistencies would likely exceed the 44% exclusion rate observed with scope 1 and 2 targets. However, scope 3 emissions could represent more than 75% of the total company emissions (CDP, 2024c; Huang et al., 2009; Mejia & Kajikawa, 2024; Schmidt et al., 2022), meaning that excluding scope 3 targets risks overlooking an important corporate lever for reducing global emissions. To mitigate this limitation, determinants with scope 3 perspective were incorporated into our analysis. Future research could extend to scope 3 target progress and their determinants; CDP has recently introduced more extensive scope 3 content (CDP, 2024a). Using our criteria for filtering inconsistencies, these studies could provide rich insights for future assessments and stakeholders.

Since companies did not provide information on the expected reduction trajectory of their targets, the target progress indicator assumes a linear reduction trajectory, as commonly done in previous studies (Aldy et al., 2023; Dietz, Gardiner, Jahn, et al., 2021; Giesekam et al., 2021a; Hale et al.,

2021; A. Hsu et al., 2020; Kuramochi et al., 2021). Our findings suggest that mitigation efforts may not always follow a linear path, particularly for targets with longer timeframes (see Section 4.2). The target progress indicator can be adapted for non-linear reduction trajectories. Applying an exponent on the percentage of time elapsed results in higher progress initially and slower later (mitigation efforts already started, exponent > 1), or slower progress initially and faster later, (mitigation efforts starting later due to time to initiate them, exponent between 0 and 1). Without further investigation or specific information from companies regarding their planned reduction trajectories, assuming these alternative trajectories currently lacks basis and risks mislabeling targets with minimal initial reductions as ‘on track’.

Different determinants or a higher number of determinants may lead to different results. Increasing the number of determinants, disaggregating more CDP questions, or including data outside CDP are new avenues for future research. For example, CDP does not include variables related to company size or financial information. Such variables may lead to a higher variance of the target progress explained. However, not all companies assessed are public, which implies a lack of financial information for the full sample of this study.

5.2.4.4 Implications of findings

The findings of this study have generated valuable insights leading to future research orientation (see Section 5.2.4.2), as well as recommendations for companies, policymakers, and investors. Companies need to improve the quality and completeness of their target disclosure. Inconsistencies, such as those found with target base year emissions (1,206 targets disregarded out of 2,734 initially judged complete), can be viewed as poor practice and damage a company's reputation. Furthermore, companies should provide additional information regarding their target reduction trajectory (Bjørn et al., 2023; Bolay et al., 2022). This would facilitate non-linear trajectory assumptions and prevent companies from being assessed as ‘not on track’ if their reduction plans involve slower initial reductions followed by accelerated reductions due to scheduled investments.

Understanding companies’ behaviors and how they are progressing towards their targets can help policymakers identify areas needing increased efforts and regulation. In addition to poor corporate behaviors, such as inconsistencies, and disparities in target parameters, our findings suggest that ambitious targets from some firms may only be symbolic due to their lower progression.

Governments should implement regulations to prevent misleading information for investors and other stakeholders and provide clear guidance on appropriate target parameters and disclosures. The CDP should require companies to specify the expected reduction trajectory in their questionnaire.

The key determinants leading to lower or higher progression of companies' targets can be useful for investors to inform their market-value assessment of firms, such as with ambitious targets. Investors should exercise caution and conduct deeper investigations before increasing a firm's market value based on ambitious targets. Following target progression should be integrated into investment assessments, given that 30% of firm targets have increased their emissions compared to their base year and another 19% achieved at the year the target was set. Investors could use the poor practices identified in this study to inform their engagement strategies. Meanwhile, companies should account for the key determinants by carefully choosing their target parameters, favoring absolute targets over intensity, setting more than one target such as those covering scope 3 emissions, linking remuneration to climate-related issues, and getting their ambitious targets approved by the SBTi.

5.2.5 Conclusion

This study contributes to the understanding of corporate climate mitigation targets and is the most comprehensive study of the determinants influencing their progress, with the analysis of 120 determinants applied to a final sample of 1,528 targets from 1,030 companies. Using a new indicator to evaluate progress in a comparable way, this study identifies 19 key determinants that explain why companies progress better or worse than others towards their targets. These determinants provide valuable insights by revealing future research directions and recommendations for companies, policymakers, and investors.

The findings highlight that companies with absolute targets, longer timeframes, disclosing additional targets, and remuneration associated with climate-related issues tend to progress better. The results reveal that companies with ambitious targets progress less, except when these targets are approved by the SBTi. This suggests that some ambitious targets may be more symbolic than genuine. Investors should investigate the progression and ambition of corporate targets when assessing companies, and policymakers should provide clear guidance and regulations to prevent misleading information target information.

The progression of companies' targets shows that 19% of targets were achieved in the year they were set. Furthermore, 30% had increased their emissions compared to their base year, with an additional 15% of targets 'not on track' and the remaining 55% being on track (or already achieved).

Despite its valuable contributions, this study is not without limitations, including the reliance on self-reported data by companies and the exclusion of scope 3 emissions targets. Future research should address these limitations and explore the implications of target progress indicators, non-linear reduction trajectories, base year choices, and target ambitions to provide a more comprehensive understanding of corporate target progression.

CHAPTER 6 ARTICLE 3: HOW RELIABLE IS CORPORATE CARBON DISCLOSURE? EVALUATING INCONSISTENCIES AND THEIR IMPACTS ON CORPORATE EMISSIONS REDUCTION TARGETS

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Supplementary material in Appendix C.

6.1 Abstract

Stakeholders need high-quality, reliable, and comparable corporate carbon data to inform decision making. While concerns have been raised about the (in)consistency of corporate carbon data, existing literature provides limited answers, focusing on undifferentiated reliability issues or a small number of companies in specific sectors. As a result, it remains unclear how widespread inconsistencies are in voluntary corporate carbon disclosures, leaving the following questions unanswered: how instances of unreliable disclosure relate to companies with and without emissions reduction targets, and how these inconsistencies impact the assessments of companies' targets. This study presents an in-depth analysis of the extent of inconsistencies reported by 2,241 companies in the 2020 CDP dataset and their relation to companies reporting emissions reduction targets. The findings reveal a concerning prevalence of inconsistencies in companies' Scope 1 and 2 emissions disclosures. Forty-six percent of companies had inconsistencies, such as differences between global Scope 1 emissions and the sum of their breakdowns per greenhouse gas, or location. The share of companies with inconsistent disclosures reduces to 22% when tolerating differences of up to 5%, with companies reporting emissions reduction targets, including those approved by the Science Based Targets initiative and net-zero targets, being as inconsistent as companies without targets. Furthermore, the findings highlight issues surrounding the reliability of base year emissions covered by companies' targets, which significantly obscure the actual ambition of these targets and even lower ambitions initially announced. Additionally, inconsistencies substantially bias assessments of companies' target progress, showing partially achieved targets due to inconsistent disclosures.

6.2 Manuscript

6.2.1 Introduction

Companies are increasingly pressured to report their carbon footprints (Cadez et al., 2019; Chithambo et al., 2022; Liesen et al., 2015). A variety of stakeholders demand and use corporate carbon data, such as governments to address climate change and inform regulations (Hale et al., 2024; The World Bank, 2022), firms to better understand and reduce their supply chain emissions (C. Blanco et al., 2016; Y. Yu et al., 2020), and investors to assess firm-market valuations (Choi & Luo, 2021; Matsumura et al., 2014). Accordingly, stakeholders need high-quality, reliable, and comparable data to better inform their decisions (Busch, Cho, et al., 2022; Hoepner & Rogelj, 2021; Talbot & Boiral, 2013). For example, poor data quality could impact assessments of companies' progress against their emissions reduction targets and mislead investors about companies' future carbon performance (Busch, Cho, et al., 2022; Talbot & Boiral, 2018).

Corporate carbon disclosure continues to be voluntary in most parts of the world, even where emissions trading schemes or carbon taxes exist, as these regulations often cover individual facilities rather than the overall company (Busch, Johnson, et al., 2022; Stanny, 2018; The World Bank, 2022). Owing to its voluntary nature, the quality of corporate carbon disclosures, such as those collected by the Carbon Disclosure Project (CDP), has been questioned (Depoers & Jeanjean, 2016; R. He et al., 2020; Zhang & Liu, 2020).

The CDP, the largest dataset of voluntary corporate carbon disclosures, sends questionnaires directly to corporations to collect data on behalf of investors (Busch, Johnson, et al., 2022; Ott et al., 2017; Zhang & Liu, 2020). The resulting CDP dataset is highly structured (Depoers & Jeanjean, 2016; Zhang & Liu, 2020) and broadly perceived as a reliable source of corporate climate-related data (Garcia-Vega et al., 2023). As such, CDP data have been widely used in academic research (Stanny, 2018; Zhang & Liu, 2020) and integrated into several third-party carbon databases (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Papadopoulos, 2022). However, the CDP does not provide quality assurance, allowing for the possibility that firms may submit unreliable data. Although firms may face penalties on their CDP scoring, the CDP does not correct the 'Corporate Response Data', which includes target-related information disclosed by firms (CDP, 2020c, 2023). While the CDP has improved the completeness of corporate carbon disclosure over time (Liesen et al., 2015; L. Luo & Tang, 2014; Matisoff et al., 2013), the consistency of the voluntarily

disclosed carbon data remains a concern (Busch, Johnson, et al., 2022; Hoepner & Rogelj, 2021; Stanny, 2018).

Previous consistency studies have assessed corporate carbon data across communication channels and found inconsistencies, i.e., corporate sustainability reports (Depoers & Jeanjean, 2016), mandatory reporting programs (Stanny, 2018), and third-party data providers (Busch, Johnson, et al., 2022; Papadopoulos, 2022). Part of the reason appears to be that the underlying accounting choices of some companies differ across communication channels, with respect to reporting boundaries (i.e., equity, financial, or operational) and activity coverages (e.g., facilities included) or different methodological approaches (e.g., GHG Protocol Standard) (Busch, Johnson, et al., 2022; Depoers & Jeanjean, 2016; Papadopoulos, 2022; Stanny, 2018). This accountability flexibility in voluntary reporting has been shown to result in companies generally disclosing lower carbon values in their corporate sustainability reports than to the CDP, which has a more standardized format (Depoers & Jeanjean, 2016). However, carbon data reported through mandatory programs (all facilities not necessarily covered) tend to be generally lower than in the CDP dataset (Busch, Johnson, et al., 2022; Stanny, 2018). This leads to inconsistencies between third-party providers, as companies report different data across communication channels (Busch, Johnson, et al., 2022; Papadopoulos, 2022).

Other studies have assessed corporate carbon data within a specific communication channel across time and found inconsistencies (Callery & Perkins, 2021; Dragomir, 2012). This may be partially driven by companies changing their accounting choices over time (e.g., reporting boundaries), so that disclosures made at different points in time may report different emissions data for the same year (Dragomir, 2012; Liesen et al., 2015; Papadopoulos, 2022). Thus, Callery and Perkins (2021) found that companies declared different percentages of change in emissions than the authors' calculations based on reported emissions for the current and previous year.

Only one study, that we are aware of, has assessed inconsistencies within a specific communication channel and disclosure year (Garcia-Vega et al., 2023). In this case, inconsistencies, such as when a company reports global Scope 1 emissions that differ from the total sum of Scope 1 emissions broken down per facility level, cannot logically be explained by differences in accounting choices. Furthermore, Garcia-Vega et al. (2023) proposed two types of inconsistencies; 1) a company lacking the ability to correctly report its carbon data (when the global emissions do not equal to the

total sum of a corresponding breakdown), 2) a company not acting in good faith (when the global emissions are lower than the total sum). Apart from companies failing to follow the precautionary principle, as discussed by Garcia-Vega et al. (2023), the second type of inconsistency could misguide investors. Indeed, when investors assess firm-market valuations (Choi & Luo, 2021; Matsumura et al., 2014), the progress of firms against their emissions reduction targets (Busch, Cho, et al., 2022; Talbot & Boiral, 2018), or their portfolio carbon footprint and climate-related transition risks (IIGCC, 2021; PCAF, 2022; TCFD, 2021a), they are, to our knowledge, more likely using the global emissions per scope disclosed by a company rather than summing a corresponding breakdown. This implies that companies reporting too low global emissions mislead investors.

By assessing the Scope 1 emissions of 33 oil and gas companies, Garcia-Vega et al. (2023) showed that both types of inconsistencies were present (39% of companies “lacking basic bookkeeping ability”; 16% of companies “not acting in good faith”). As required by the CDP, these data should have been consistent, yet firms only face minor penalties on their CDP scoring when they exceed a 5% difference between their global emissions and corresponding breakdowns (CDP, 2020c, 2020b). As such, the extent of unreliable carbon data voluntarily disclosed by companies exceeding different potential tolerance levels is unclear, as are the implications of unreliable data for the data users.

An important consideration is how unreliable data affects assessments of companies’ progress against their commitment to reduce emissions, which has not yet been assessed (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Dragomir, 2012; Hoepner & Rogelj, 2021; Talbot & Boiral, 2018). The reliability of this assessment depends on additional data, such as base year emissions for Scope 1, which are not penalized in the CDP scoring even if discrepancies were to occur (CDP, 2020c). Nevertheless, base year emissions are central in the assessments of companies’ targets, as they state a percentage reduction for a given emissions scope between a base year and a target year (Bolay et al., 2022; Campbell, 2021). Furthermore, another important question is how unreliable data relates to companies with and without emissions reduction targets.

To increase their credibility towards climate change mitigation, a growing number of companies are setting emissions reduction targets. Among these, ambitious targets framed by stringent design features such as science-based targets and net-zero targets are becoming more common (Hale et al., 2022; SBTi, 2022a). Since companies with targets are broadly expected to demonstrate better

carbon performance in the future, investors value companies with emissions reduction targets (Campbell, 2021; Cheng et al., 2023), especially high-ambition targets (Bendig et al., 2022; Khandelwal et al., 2022). However, previous studies have shown that sufficient information was not necessarily available to adequately assess companies' targets (Bolay et al., 2022; Dietz, Gardiner, Jahn, et al., 2021; Giesekam et al., 2021a), raising concerns about transparency and the effectiveness of these commitments (Bjørn et al., 2023; Day et al., 2024). Moreover, the credibility of these commitments has been questioned due to their voluntary nature and the pressure from stakeholders to set targets (Armour et al., 2023; Hale et al., 2024). According to the legitimacy theory, such reporting of targets may only serve to legitimize their operations without genuinely committing to climate change mitigation (R. He et al., 2020; Talbot & Boiral, 2018). This suggests that companies with targets may not necessarily report more consistent carbon data than those without, challenging the assumption of their advancing efforts for climate change mitigation. To the best of the author's knowledge, no studies have yet assessed whether the reliability of carbon data differs across companies with and without targets.

Building on the work of Garcia-Vega et al. (2023), this study aims to assess (in)consistencies in carbon data disclosed by more than 2,000 companies within the 2020 CDP questionnaires, specifically addressing the following research question: (RQ1) To what extent do inconsistencies, including both over- and understated global emissions per scope, exceed specified tolerance levels in corporate carbon disclosures? Furthermore, this study aims to deepen understanding of corporate emissions reduction targets by addressing the following research questions: RQ2) Are companies with emissions reduction targets less inconsistent? (RQ3) How does inconsistent data affect the assessment of corporate emissions reduction targets and their progression?

To answer the first research question, the number of companies with inconsistent disclosures, including those with either over- or understated global emissions per scope compared to elsewhere within the 2020 CDP questionnaire, and the share of individual companies' disclosures that are inconsistent will be calculated according to different tolerance levels. To answer the second research question, three hypotheses will be tested where more consistent carbon data can reasonably be expected from companies with these characteristics:

H1 Companies reporting a science-based target approved by the SBTi disclose more consistent carbon data than companies not reporting a target.

H2 Companies reporting a net-zero target (without reporting a target approved by the SBTi) disclose more consistent carbon data than companies not reporting a target.

H3 Companies reporting other emissions reduction targets (without reporting a net-zero or SBTi approved target) disclose more consistent carbon data than companies not reporting a target.

The underlying assumption is that if companies are genuinely committed to reducing emissions, they should demonstrate more consistent reporting than those without targets. If as much inconsistencies are found among companies with targets, this could challenge the credibility of their commitments to emissions reduction. In the third research question, the implications of assessed inconsistencies will be then investigated, with the potential for unreliable data to bias target ambition assessments and target progress results.

6.2.2 Methodology

The methods to evaluate inconsistencies in voluntary corporate carbon data are described in the following sections.

6.2.2.1 Sample: Companies and targets covered

All companies submitting information to the 2020 CDP climate change questionnaire, which was sent on behalf of investors, were included in this study. The study focuses on comparing aggregated and unaggregated carbon data corresponding to annual GHG emissions for the reporting year, up to three previous years and base year emissions for the Scope 1, Scope 2 location-based, and Scope 2 market-based, but excluded Scope 3 emissions⁵. Scope 3 emissions, available only by category as suggested by the GHG Protocol and limited to the reporting year, prevented a consistency assessment.

Therefore, eighteen data comparisons, each expected to be identical, were evaluated (RQ1). These comparisons, detailed in Section 6.2.2.2, are presented in Table 6.1, with corresponding CDP question numbers available in supplementary information (SI).

⁵ Scope 1; direct company emissions, Scope 2; indirect company emissions from purchased electricity, Scope 3; other indirect company emissions from the value chain (WRI & WBCSD, 2004). Scope 2 approaches; location-based using regional grid-average emission factors and market-based using specific emission factors from contractual agreement (WRI, 2015).

Table 6.1: Comparisons included in the inconsistency assessment of companies' disclosures. Abbreviations: SC1 = Scope 1; SC2 LB = Scope 2 location-based; SC2 MB = Scope 2 market-based; BY = base year.

Comparison number	Global emissions per scope (aggregated carbon data)	Corresponding breakdown (usually unaggregated carbon data)
1	SC1 for reporting year	SC1 per GHG
2		SC1 per country
3		SC1 per business division
4		SC1 per business facility
5		SC1 per business activity
6	SC2 LB for reporting year	SC2 LB per country
7		SC2 LB per business division
8		SC2 LB per business facility
9		SC2 LB per business activity
10	SC2 MB for reporting year	SC2 MB per country
11		SC2 MB per business division
12		SC2 MB per business facility
13		SC2 MB per business activity
14	SC1 and corresponding SC2 (LB or MB as stated in intensity figure) for reporting year	SC1 and SC2 (LB or MB), with combined disclosure from intensity figure for the reporting year, such as emissions per revenue (disclosed separately).
15	SC1 for base year	SC1 for reporting year or previous years
16	SC2 LB for base year	SC2 LB for reporting year or previous years
17	SC2 MB for base year	SC2 MB for reporting year or previous years
18	SC1 and/or corresponding SC2 for base year, reporting year or previous years	SC1 and/or SC2 covered by an absolute emissions reduction target for the base year, corresponding to the percentage of scope covered by the target.

To test whether companies with emissions reduction targets are more credible than companies without by having a more consistent disclosure (RQ2), all sample companies were divided into groups following the characteristics defined in the three hypotheses. Each hypothesis contains two

independent groups: companies disclosing a certain type of target and companies without targets. For H1, a company reporting that its absolute target or its intensity target is approved by the SBTi was assigned to the group *Approved SBTi targets* (for CDP question numbers, see SI). Conversely, companies that did not report any target (no absolute or intensity target) were assigned to the *No targets* group, which is used in all three hypotheses.

For H2, the characteristics to identify net-zero target are based on the Net-Zero Benchmark of CA100+ for partial or total net-zero. Specifically, this corresponds at a minimum to companies reporting an intensity or an absolute target with an ambition of 100% covering at least 95% of their scope 1 and 2 emissions (CA100+, 2022a), without being in the group *Approved SBTi targets*. The group *Targets (not approved SBTi or net-zero)* from H3 includes companies reporting intensity or absolute targets not part of either the *Approved SBTi targets* or *Net-zero targets* groups.

Corporate emissions reduction targets assessed in RQ3 include absolute targets covering Scope 1 and/or 2. Intensity targets, providing solely emissions intensity information (detailed absolute emissions not included), and Scope 3 targets, following the same rationale as Scope 3 emissions, precluded assessments. Therefore, RQ3 assessment does not include the total sample of companies unlike the other two research questions.

6.2.2.2 Inconsistency indicator

Recognizing that a certain level of inconsistency may be acceptable, the inconsistency indicator incorporates predetermined tolerance levels, while using the inconsistency types outlined by Garcia-Vega et al. (2023). Therefore, the inconsistency indicator tests whether a company's disclosed data for a given comparison is inconsistent or consistent with respect to a specified tolerance. The inconsistent category distinguishes whether global emissions per scope are over- or understated compared to corresponding breakdowns reported by companies (see Table 6.1). The inconsistency indicator is calculated for each comparison of every company and for each tolerance level tested, with the calculation detailed in SI.

The inconsistency indicator relies on two variables: the difference and the accepted tolerance, both of which depend on a specific comparison and company. The difference, subtracting the total corresponding emissions breakdown from the global emissions per scope, is based on their functional relationship for each comparison (see details below), making them equivalent to one another when the company carbon disclosure is consistent.

This difference is then assessed against an accepted tolerance, which is the maximum value between two components:

- 1) Relative tolerance: Based on a percentage of tolerance allowed, which is applied to the global emissions per scope for a specific comparison and company. The percentages tested are 0%, 1%, 2.5%, 5%, 10%, 15%, 25%, 50%, and 75%.
- 2) Rounding tolerance: Based on the number of elements in the corresponding breakdown for a specific comparison and company, with each element incremented by one, and the absolute variation calculated between the totals with and without increments. When the tolerance allowed is 0%, only the rounding tolerance is accepted.

The inconsistency indicator for a specific comparison and company results in three possible outcomes:

- Consistent: When the difference is within the accepted tolerance range (between negative and positive tolerance values), this indicator is labelled as consistent.
- Inconsistent (Overstated): When the difference is greater than the positive value of the accepted tolerance. For example, a company's global Scope 1 emissions are higher than its total Scope 1 emissions broken down per country (comparison 2, see Table 6.1).
- Inconsistent (Understated): When the difference is less than the negative value of the accepted tolerance, meaning global emissions per scope are lower.

Each functional relationship defines how global emissions per scope are assessed with their corresponding breakdowns for a specific comparison (presented in Table 6.1). Comparisons 1 to 14 relate to reporting year emissions, while comparisons 15 to 18 involve base year emissions. Comparisons 1 to 13 compare global emissions per scope with a summation of the corresponding breakdowns. In comparison 14, global emissions per scope is a sum of Scope 1 and 2 emissions, with Scope 2 being either location-based or market-based as specified in the intensity figure. This is compared against a single value of combined Scope 1 and 2 emissions disclosed within the intensity figure, with both the numerator and denominator disclosed separately (e.g., emissions and revenue). Comparisons 15 to 17 compare single values corresponding to the same year and scope. For comparison 18, global emissions per scope (1 and/or 2), which may involve a sum, depend on the absolute target coverage and corresponding base year. This is compared to the base year emissions disclosed in the absolute target, which may be proportionally adjusted to cover 100% of

the target scope (see Section 6.2.2.6). In cases where a company reported multiple values for global emissions per scope (same year through base year, reporting year and previous years), the base year emissions were retained to avoid conflicts with comparisons 15 to 17. Note that if a company disclosed multiple targets⁶, comparison 18 is considered *Inconsistent* if any of these comparisons are *Inconsistent*.

Inconsistent implies that over- and understated inconsistencies are combined. This means that any difference outside the accepted tolerance range for a specific comparison and company is considered as *Inconsistent*. For the same accepted tolerance, *Understated* alone is less restrictive than *Inconsistent* as it disregards cases where the inconsistencies are overstated.

6.2.2.3 Inconsistency index: Frequency

The frequency inconsistency index measures how often a company has reported inconsistent comparisons. This index considers the fraction of comparisons that are inconsistent for a company. For example, a company reported sufficient information to assess four comparisons and one of them is inconsistent, its frequency inconsistency index result is 0.25.

6.2.2.4 Inconsistency index: Presence

The presence inconsistency index measures whether a company has inconsistency in their reporting. A company is inconsistent if at least one of the comparisons is inconsistent.

By aggregating the results of the respective companies, the two inconsistency indices (frequency and presence) permit to assess what share of companies' disclosures are inconsistent (frequency) and how many companies are inconsistent (presence) across and within the 18 comparisons (RQ1).

6.2.2.5 Statistical analysis of company with emissions reduction targets

To answer the three hypotheses (RQ2), statistical analyses were conducted to assess if companies with targets were significantly more consistent than those without. These analyses were performed twice for each hypotheses using the frequency inconsistency index (from RQ1), first with a 1% tolerance to exclude small differences from being classified as inconsistent, and second with a 5% tolerance to allow for more generous differences.

⁶ Targets with a status as expired or revised were not assessed.

For the statistical analysis, the Mann-Whitney U test was employed. This non-parametrical test evaluates whether two independent groups differ significantly in their distributions (two-tailed test) and the directionality of these differences (one-tailed test, i.e., whether one group is more or less consistent than the other) (Nachar, 2008). The Mann-Whitney U test is preferred over the T-test when distributions are skewed, as with values predominantly near 0% for the share of companies' inconsistency disclosure, or contain extreme values, such as 100% (Lombardi & Hurlbert, 2009; Nachar, 2008). Given the absence of prior evidence suggesting that companies with certain types of targets are frequently more or less consistent, a significant difference must be observed (two-tailed test, $p\text{-value} < 0.05$) before the directionality can be assessed (Lombardi & Hurlbert, 2009). As such, rejecting the null hypothesis indicates that the two groups do not come from the same population, suggesting they are significantly different with one group being more consistent than the other. Note that companies with insufficient data for all comparisons were excluded, as there is no assessment of the (in)consistency.

6.2.2.6 Implications of inconsistent disclosures on emissions reduction target assessments

To determine how inconsistencies affect the ambition and progress of companies' emissions reduction targets (RQ3), we evaluated variations in the results of target ambition and progress indicators using a min-max approach. For each company, two scenarios were developed: one using the maximum value for parameter 1 (base year emissions) and the minimum value for parameter 2—target year emissions for the ambition indicator and reporting year emissions for the progress indicator—with the other scenario reversing these values. This min-max approach manages the complexity of multiple values per parameter and target indicator by simplifying the analysis to only two scenarios.

Corporate emissions reduction targets translate to emissions reduced for a given scope over the period between the base year and target year, resulting in the target year emissions a company aims to achieve. Instances of base year emissions restatement, due to accounting choices and company changes (such as mergers and acquisitions), are expected to result in adjustments of target-related information (CDP, 2020b). The target ambition indicator was calculated using the (in)consistent disclosure of base year emissions collected in comparison 18 (see Table 6.1), and calculated target

year emissions. This approach demonstrates how inconsistencies in base year emissions cause variations in companies' target ambition indicators, and thus their implications.

For example, if a company announces a 50% emissions reduction target covering 100% of its Scope 1 emissions, with base year emissions of 100,000 tCO₂e reported alongside other target-related information (in the CDP section 'Target and performance'; corresponding breakdown for comparison 18), it aims to reach 50,000 tCO₂e in the target year. However, if the company reports lower emissions of 80,000 tCO₂e for the same year and scope elsewhere (in the CDP sections 'Emissions methodology' or 'Emissions data'; global emissions per scope for comparison 18), the target ambition would be 37.5% (scenario 1; $(80,000 - 50,000) / 80,000$), indicating lower ambition than initially announced. Conversely, if target year emissions are 40,000 tCO₂e, the target ambition would be 60% (scenario 2; $(100,000 - 40,000) / 100,000$).

As specified in Section 6.2.2.2, a target scope coverage lower than 100 % was proportionally adjusted, such as targets covering specific country operations rather than company-wide. For instance, if the target coverage reported by the company was 80%, the adjusted base year emissions would be 125,000 tCO₂e ($100,000 / 80\% * 100\%$), and the adjusted target ambition announced by the company would be 40% ($50\% * 40\% / 100\%$), resulting in target year emissions of 75,000 tCO₂e ($125,000 - 40\%$ of 125,000) instead of 50,000 tCO₂e. Other base year emissions (global emissions per scope) represent 100% coverage by default (company-wide). This adjustment approach was also applied for evaluating the companies' target progression.

To assess the progression of companies' targets, the indicator used measured whether the progression at the reporting year is above or below a linear reduction trajectory between the base year and the target year, as defined by Bolay et al. (2023). This indicator ranges from 0 to 2, where the percentage of the target achieved and time elapsed are limited from 0% to 100%. A value equal to or higher than 1 represents a company 'on track' (above), while a value less than 1 indicates 'not on track' (below). The target progress indicator was calculated using the (in)consistent disclosure collected through comparisons 1 to 18 (see Table 6.1) for the base year and reporting year emissions, parameters 1 and 2 respectively (example provided in SI). Note that targets with no time elapsed were excluded, as there is no progress to assess when the base year is the same as the reporting year, and targets with time elapsed over 100%.

Statistical analysis was applied to determine if there was a significant difference between the results of scenarios 1 and 2 for a target indicator due to assessed inconsistencies. Since scenarios for a target indicator include the same set of companies' targets (dependent groups), the Wilcoxon-Signed-Rank two-tailed test was employed with a significance level (p-value) of 0.05. This non-parametrical test evaluates whether two dependent groups differ significantly in their distributions (Rey & Neuhäuser, 2011). When scenarios 1 and 2 have the same value (company with consistent reporting for these parameters), the Pratt (1959) method was used for handling zero difference. Thus, rejecting the null hypothesis suggests that the extent of found inconsistencies (RQ1) was sufficient to significantly affect assessments of companies' targets and could potentially bias data users' assessments (RQ3). Companies' targets with insufficient data (fewer than two values for at least one parameter) were excluded, as this would result in assessing only one scenario.

6.2.3 Results

The results section mirrors the structure of the methodology, with each subsection corresponding directly to its counterpart.

6.2.3.1 How many companies are reporting carbon data and emissions reduction targets?

The sum of Scope 1 and 2 emissions reported to CDP by the 2,241 companies for the reporting year (company specific, but usually calendar of financial year 2019) is 9.18 GtCO₂e, considering Scope 2 location-based emissions where available, over market-based emissions. This total may include overlaps between companies; Scope 1 emissions reported by power generation companies in the CDP could correspond to other companies' Scope 2 emissions. The sum of Scope 1 emissions alone is 7.05 GtCO₂e, which accounts for around 13% of 2021 global emissions (UNEP, 2022) and represents 77% of the combined Scope 1 and 2 emissions.

Of the 2,241 companies, 98% disclosed their Scope 1 emissions for the reporting year, 96% for the base year and only 35% for a year previous to the reporting year. Companies more often reported Scope 2 location-based emissions than market-based emissions (see SI), with several companies reporting both as required by the GHG Protocol (WRI, 2015).

Of the 2,241 companies, 83% reported a total of 4,095 emissions reduction targets. Among these targets, 61% are absolute, while 39% are intensity targets. Target scope coverage is similar among

absolute and intensity targets, with 73% of total targets covering Scope 1 and/or 2 emissions, and the remaining 27% including Scope 3 emissions.

6.2.3.2 Where are companies typically inconsistent?

Figure 6.1 presents the percentage of companies with inconsistent disclosures for the 18 comparisons (Table 6.1) at a tolerance level of 0% (i.e., only the rounding tolerance is accepted). The number of companies reporting sufficient information to assess inconsistency varies by comparison (see brackets in Figure 6.1).

As shown in Figure 6.1, companies with inconsistent reporting are found for each of the 18 comparisons (RQ1). Of the 718 companies reporting sufficient information to assess comparison 18, 33% are inconsistent, making it the comparison with the highest percentage of companies being inconsistent. As comparison 18 relates to base year emissions related to targets, this high level of inconsistency has important implications for the assessment of companies' targets, as presented in Section 6.2.3.6 (RQ3). Comparisons 1, 8, 12, and 4 follow, respectively, with the next highest percentages of companies being inconsistent. Comparison 1 refers to Scope 1 emissions reported per GHG, while the others involve emissions per business facility for different scopes. Comparison 14 has the highest number of companies reporting sufficient information (2,116 companies), of which 15% are inconsistent, resulting in comparison 14 yielding the highest absolute number of companies with inconsistencies.

Understated inconsistencies are systematically lower than overstated inconsistencies across all comparisons. On average, *Understated* represents 38% of total inconsistencies. However, comparison 18 stands out with 61% of its total inconsistencies being *Understated*. This indicates that the base year emissions reported alongside other target-related information in the 'Target and performance' CDP section are generally higher, potentially giving the impression of a larger amount of targeted emissions reduction (RQ3, see fictive example in Section 6.2.2.6).

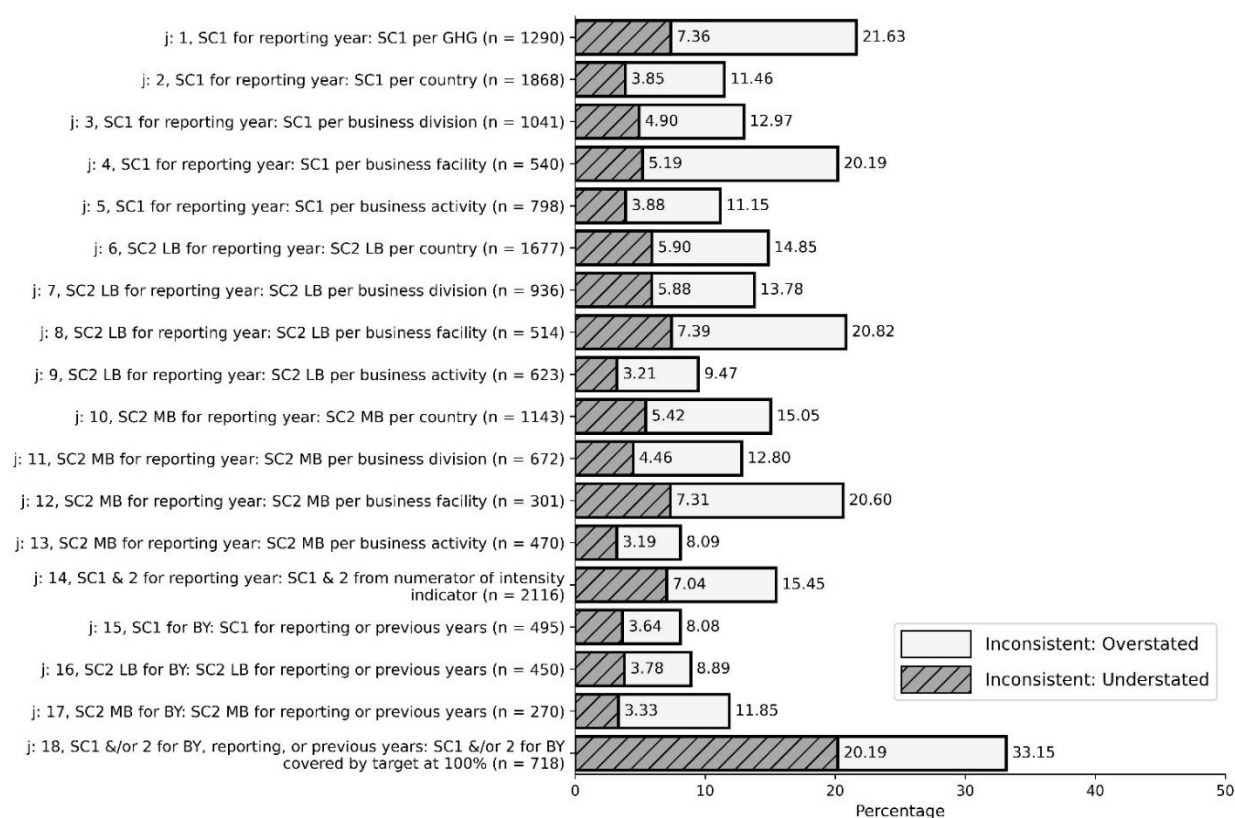


Figure 6.1: Percentage of inconsistent companies for each comparison with 0% tolerance level (n = number of companies reporting sufficient information per comparison, j = comparison number). Numbers following hatched parts represent *Understated* (where global emissions per scope are lower than the total of a corresponding breakdown), while numbers at the ends of the bars represent *Inconsistent* (combining *Overstated* and *Understated*). Abbreviations: SC1 = Scope 1; SC2 LB = Scope 2 location-based; SC2 MB = Scope 2 market-based; BY = base year.

As the tolerance increases, the percentage of companies being inconsistent greatly decreases for all comparisons except comparison 18 (see SI). For example, comparison 1 decreased from 21% to 9% as the tolerated difference increased from 0% to 1%, while comparison 18 only declines slightly, from 33.15% to 32.87%. The limited decrease is caused by the rounding tolerance, where each element is incremented by one (see Section 6.2.2.2). In comparison 18, this increment results in a higher tolerance at 0% because it applies to the percentage of emissions covered by the target rather than to figures summed up as in other comparisons. Therefore, comparison 18 at 0% tolerance yields a more conservative result than other comparisons, despite being the most inconsistent.

6.2.3.3 What share of companies' disclosures are inconsistent?

Of the 2,241 companies, 2% did not report enough data to assess inconsistency for any of the 18 comparisons. On average, companies disclosed sufficient information to evaluate seven comparisons. Based on the aggregated results from the frequency inconsistency index, companies with inconsistent reporting (0% tolerance level) had an average of 33% of their compared data found to be inconsistent (RQ1). This indicates that these companies tend to be inconsistent across more than one comparison, with an average of two out of seven comparisons being inconsistent.

As the tolerance for differences increases, the number of companies with at least one inconsistent comparison decreases (as detailed in Figure 6.2), while the average share of inconsistent disclosures for the remaining companies remains stable (see SI; average of around 25%). For instance, 729 companies are labeled inconsistent with a 1% tolerance and 387 companies with a 5% tolerance. In both cases, an average of around 25% of their comparisons were found to be inconsistent. This suggests that for the same company, the relative differences between figures are similar among inconsistent comparisons.

6.2.3.4 How many companies are inconsistent?

The percentage of companies with inconsistent reporting for at least one comparison for different tolerance levels is illustrated in Figure 6.2, based on the aggregated results from the presence inconsistency index (RQ1). When only rounding tolerance is accepted, 51% of companies were always consistent in all comparisons where they disclosed sufficient information, and 46% of companies reported mismatching numbers in one or more comparisons.

As shown in Figure 6.2, 33% of companies report inconsistencies above a 1% tolerance level, meaning 14% of companies have differences of less than 1% between corresponding numbers (46.45% at 0% and 32.53% at 1%, totaling 13.92%). As the tolerance increases, the number of companies labeled as inconsistent decreases. However, even with generous tolerances for differences, a substantial percentage of companies remain inconsistent despite CDP scoring penalties for differences exceeding 5% (22% of companies, see Figure 6.2). These penalties, however, only apply to 11 of the 18 assessed comparisons.

On average, across tolerance levels, 45% of total inconsistencies correspond to companies understating their global emissions per scope compared to the total of a corresponding breakdown,

suggesting a general pattern of underreporting. On the other hand, the remaining 55% (*Overstated*) indicates a relatively balanced distribution between over- and underreporting.

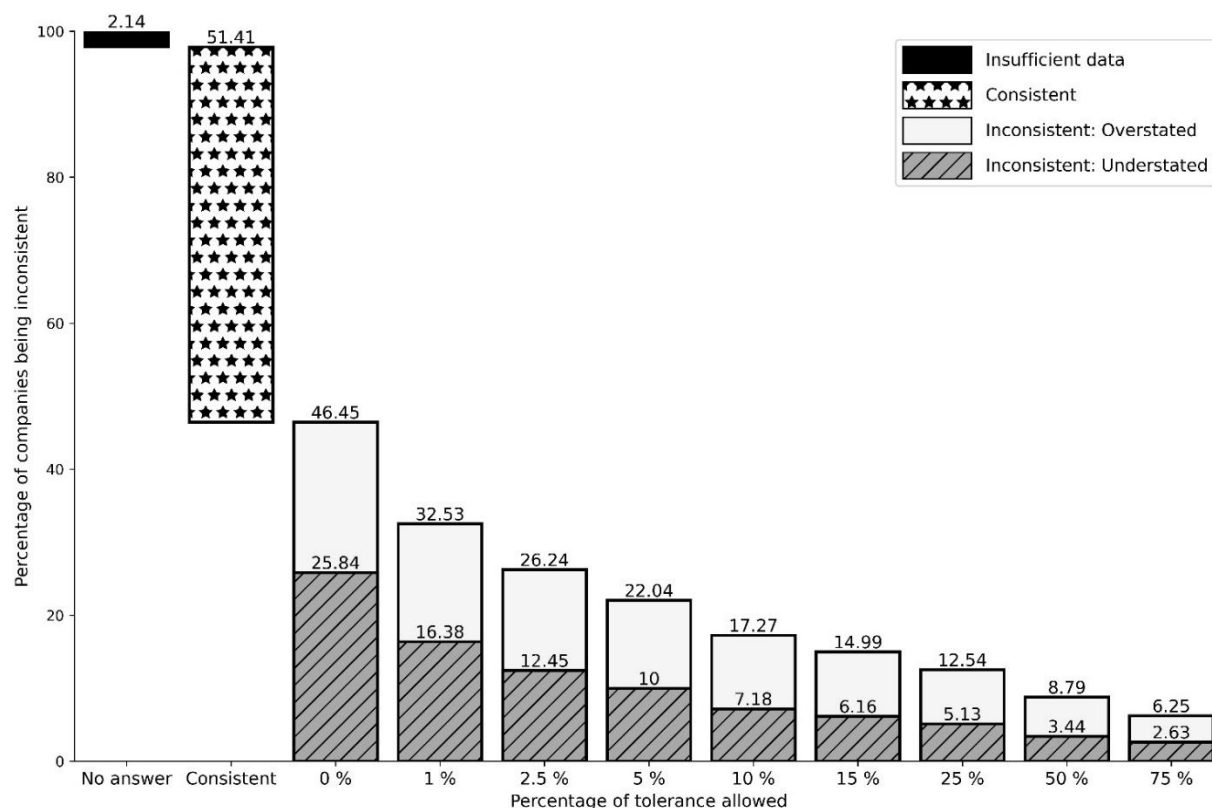


Figure 6.2: Percentage of companies being inconsistent in one or more of the 18 comparisons while considering different tolerance levels. Numbers above hatched parts represent *Understated* (where global emissions per scope are lower than the total of a corresponding breakdown), while numbers at the ends of the bars represent *Inconsistent* (combining *Overstated* and *Understated*).

The fossil fuels sector has the highest percentage of companies being inconsistent across tolerances from 0% to 25% (see SI). Of the 86 companies in this sector, 66% are inconsistent with 0% tolerance level (compared to 46% of all companies, Figure 6.2), 41% with differences above 1%, and 20% with differences above 25%. Excluding a sector with only one company, the power generation sector has the lowest percentage of companies being inconsistent with differences above 1%, at 24% of the 74 companies.

6.2.3.5 Are companies with emissions reduction targets less inconsistent?

Of the 2,193 companies with an inconsistency assessment, 1,851 reported emissions reduction targets, whereas 342 did not. Among these target-reporting companies, 20% had SBTi-approved targets (H1), 5% had net-zero targets without having SBTi-approved targets (H2), and 75% had targets that were neither SBTi-approved nor net-zero (H3). Table 6.2 presents the statistical analysis results for each hypothesis based on the share of inconsistent individual companies' disclosures with 1% and 5% tolerance levels, testing for significant difference between groups (RQ2). The percentage of companies with inconsistent reporting for at least one comparison is presented as a complement; these imply that companies have shares of inconsistent disclosure higher than 0%.

At a 5% tolerance level, the companies in the three groups with distinct target types (H1 to H3) are not different from companies with no targets ($p\text{-value} > 0.05$), meaning they are neither more nor less consistent. The percentage of companies with inconsistent reporting for at least one comparison is closer between the target groups and the no-target group at 5% tolerance than at 1% tolerance.

At the 1% tolerance level, the analysis reveals that companies with *Net-zero targets* (H2) and *Targets (not approved SBTi or net-zero)* (H3) are in fact more often inconsistent than companies reporting no targets. Specifically, a significance in the opposite direction of what was expected for H2 and H3 was found ($p\text{-value} < 0.05$). Companies with SBTi-approved targets (H1) are not significantly different from those with no targets, but the result is close to significant ($p\text{-value} = 0.053$, see Table 6.2). Furthermore, the percentage of companies with inconsistencies is higher for the group *Approved SBTi targets* (H1) than for *Targets (not approved SBTi or net-zero)* (H3), which is statistically significant. This is caused by companies in the group *Targets (not approved SBTi or net-zero)* (H3) having a higher share of inconsistent disclosures than those in *Approved SBTi targets* (H1). However, these two groups are not different from one another ($p\text{-value} > 0.05$). Further analysis suggests that companies with SBTi-approved targets (H1) tend to be less consistent than those with no targets. Excluding 43 companies that had both net-zero and SBTi-approved targets leads to significance ($p\text{-value} = 0.049$), showing they are more often inconsistent than companies reporting no targets.

For both tolerances tested, none of the three groups with distinct target types (H1 to H3) are less inconsistent than companies without targets, thus refuting all three hypotheses. Since companies could be more frequently inconsistent due to a more complete disclosure (higher number of comparisons assessed), a Pearson and Spearman correlation analysis was performed between the results of the frequency inconsistency index and the number of comparisons for which companies disclosed sufficient data. Both correlations were significant ($p\text{-value} < 0.05$), but associations were very weak, with correlation coefficients of -0.09 for Pearson and 0.06 for Spearman. Thus, companies reporting more data are not more often inconsistent than other companies, and therefore cannot explain why companies with *Net-zero targets* (H2) and *Targets (not approved SBTi or net-zero)* (H3) are significantly less consistent than companies without targets at the 1% tolerance level.

Table 6.2: Statistical analysis results for each hypothesis (Mann-Whitney U two-tailed test) based on the share of inconsistent individual companies' disclosures with 1% and 5% tolerance levels (frequency inconsistency index). Asterisk (*): statistical significance ($p\text{-value} < 0.05$), indicating a difference between groups. Sample size: number of companies included per groups. Presence inconsistency index: percentage of companies with inconsistent reporting for at least one comparison (presented as a complement).

Hypothesis	Group name	Sample size	1% tolerance level		5% tolerance level	
			Presence inconsistency index	P-value	Presence inconsistency index	P-value
H1	Approved SBTi targets	375	35.20%	0.053	19.73%	0.919
	No targets	342	25.73%		18.71%	
H2	Net-zero targets (not approved SBTi)	91	39.56%	0.027*	27.47%	0.118
	No targets	342	25.73%		18.71%	
H3	Targets (not approved SBTi or net-zero)	1,385	34.15%	0.026*	23.90%	0.091
	No targets	342	25.73%		18.71%	

6.2.3.6 How does inconsistent data impact the assessment of the ambition and progress of corporate emissions reduction targets?

Of the companies with emissions reduction targets, 1,133 companies reported a total of 1,819 Scope 1 and/or 2 absolute targets (excluding intensity or Scope 3 targets in RQ3; see Section 6.2.2.1). Among these targets, 43% did not have enough data to assess the implications of inconsistencies on target ambition, and 13% to assess target progress (or had no progression to assess, see Section 6.2.2.6).

Inconsistencies generated a significant difference between the two scenario results calculated for the ambition and progress of targets (RQ3; both Wilcoxon signed-rank tests with $p\text{-value} < 0.05$). This indicates that identified inconsistencies affect the ability to correctly assess the ambition and progress of companies' targets. The remainder of this section details targets where inconsistencies caused variations in their ambition or progress results, implying that other targets in the samples obtained the same ambition or progress outcomes.

Figure 6.3 presents differences found between scenarios (variations) for the ambition of 314 targets from 221 companies due solely to inconsistent reporting in base year emissions covered by targets (comparison 18; see Table 6.1). These inconsistencies result in wide variations in target ambition (bars) compared to the initially announced ambitions by companies (red line; proportionally adjusted, see Section 6.2.2.6), with an average variation of 26 percentage points (bars length). This high level of inconsistency in base year emissions includes 60% of targets being *Understated* (black bars), where global emissions per scope are lower than proportionally adjusted base year emissions reported alongside other target-related information in the 'Target and performance' CDP section. Furthermore, these inconsistencies lead to lower target ambitions (part of the bars below the red line; scenario 1), implying that a part of a target may appear achieved simply due to inconsistent disclosure.

For instance, in the fictive example given in Section 6.2.2.6, a target ambition of 50% was announced, but inconsistency led to a 12.5% lower result in scenario 1 (red line; 50%, part of the bar below the red line; 12.5 percentage points). This resulted in 25% of the targeted reduction being potentially achieved. Such a situation occurs for 41% of the 314 targets, where more than 25% of the targeted reduction appears to have been achieved as a result of inconsistent disclosure in their respective base year emissions. Additionally, 39% of the 314 targets result in 0% ambition (bottom

of bars), of which 51% correspond to *Understated* (bottom of black bars). This indicates that the minimum value for the base year emissions is lower than the target year emissions, suggesting no reduction in emissions remains for these targets when accounting for inconsistencies in their base year emissions. However, target ambition announced by companies of 100% does not result in any variation despite inconsistencies in base year emissions, but it could lead to different results when following the progression of targets due to changes in the reduction trajectory.

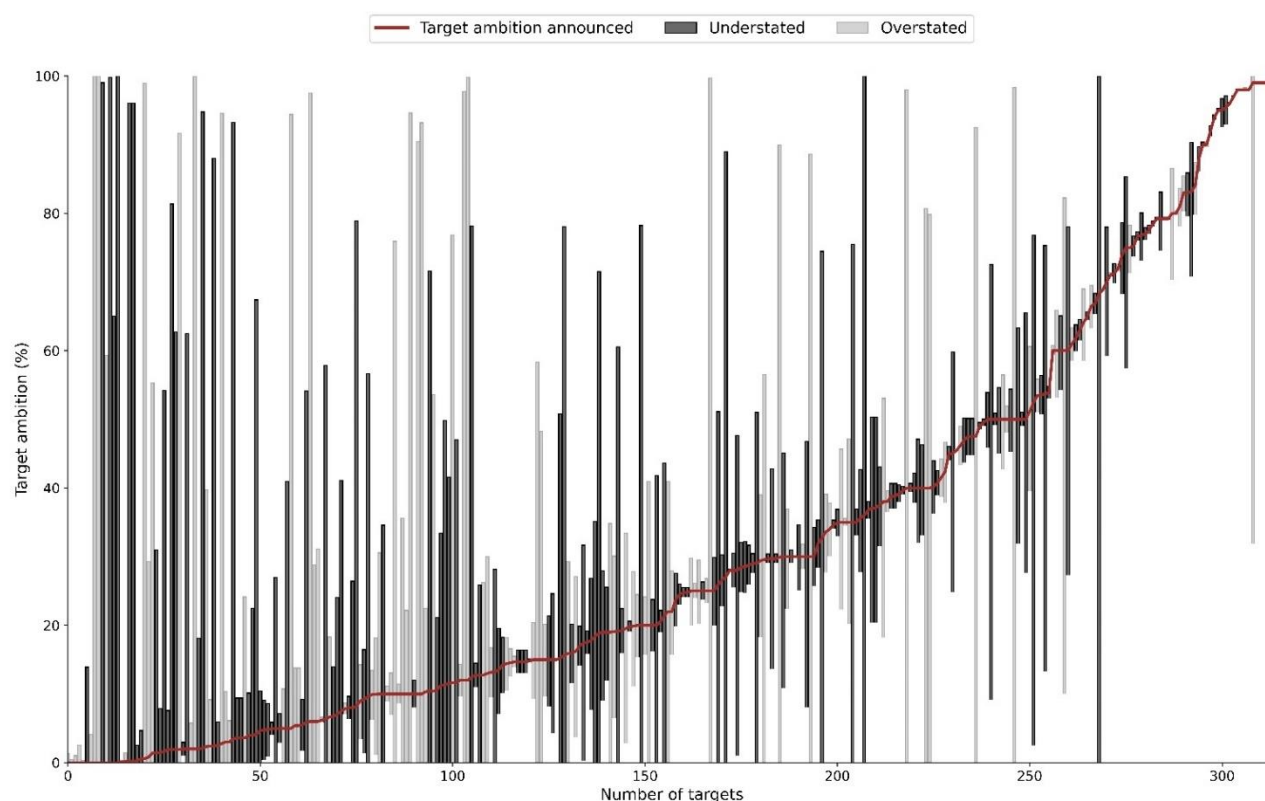


Figure 6.3: Variation in 314 companies' target ambition (bars) due to inconsistencies found in the base year emissions of targets (comparison 18; See Table 1). Black bars (*Understated*): global emissions per scope are lower than proportionally adjusted base year emissions reported alongside other target-related information. Grey bars: *Overstated*. Red line: target ambition initially announced by companies (proportionally adjusted).

Figure 6.4 presents variations in progress indicators found for 437 corporate targets due to inconsistent disclosure in the base year emissions of the targets and in their reporting year emissions (comparisons 1 to 18; see Table 6.1). Of these 437 targets (317 companies), 62% involve understated inconsistencies (black bars), while 11% are both over- and understated for either the base year or reporting year emissions of the targets (black bars). As a result of inconsistent

disclosures, 27% have conflicting progress conclusions, shown by bars passing through the value of 1 (dotted line) in Figure 4, indicating a reversal from ‘on track’ (green shades above the dotted line) to ‘not on track’ (red shades below the dotted line) and vice versa. Among these, 61% are caused by understated inconsistencies.

Furthermore, 30% of the 437 targets appear with differences of more than 20% in their targeted reduction due to inconsistent disclosure (bar length > 0.20), with 18% of targets showing differences of more than 50%. Differences between scenarios arise solely from variations in the percentage of the target achieved, implying that targets may appear partially achieved due to inconsistencies. Additionally, 5% of targets involves a 100% target ambition announced by companies with base year emissions inconsistencies that did not affect target ambition results.

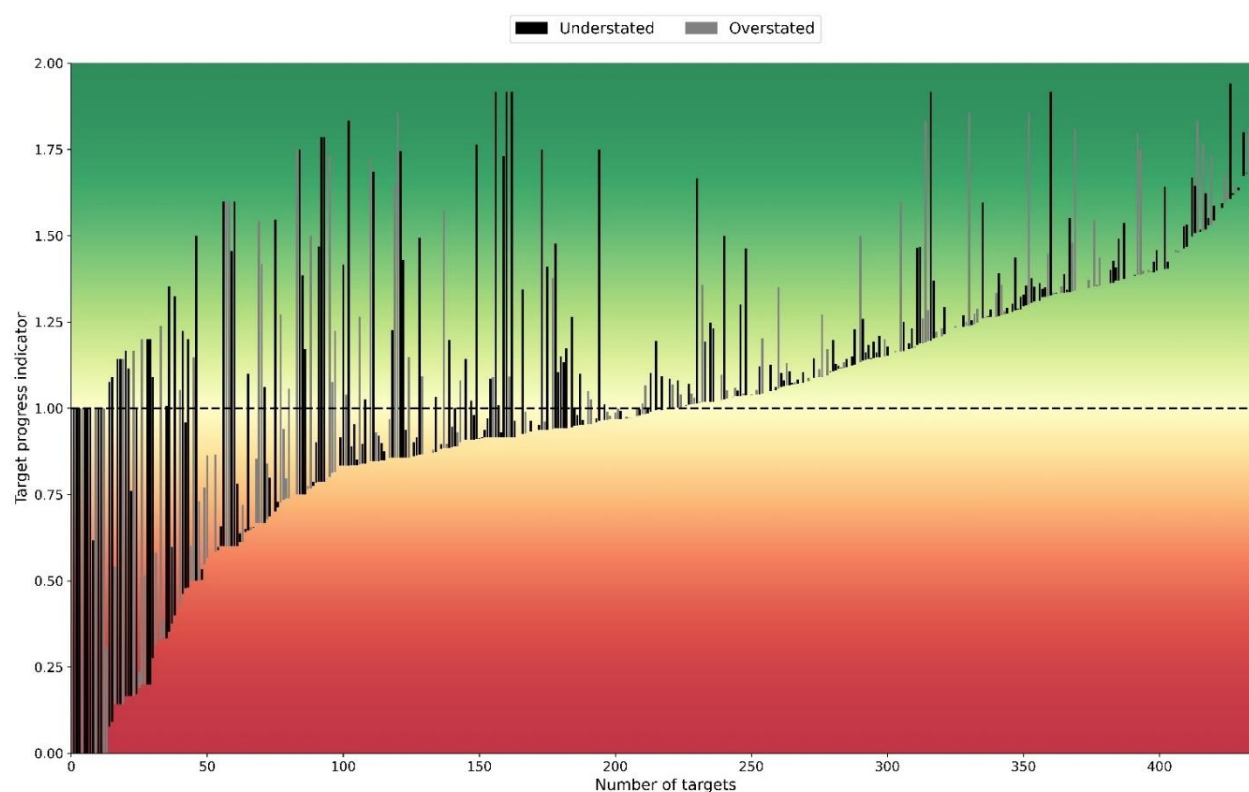


Figure 6.4: Variation in 437 companies' target progress (bars) due to inconsistencies found in the base year emissions of targets and in their reporting year emissions. Bars passing through the value of 1 (dotted line) indicate an inversion of results from ‘on track’ (green shades above the dotted line) to ‘not on track’ (red shades below the dotted line) and vice versa. Black bars: *Understated*. Grey bars: *Overstated*.

6.2.4 Discussion

The present study contributes to the scientific literature on the (in)consistency of corporate carbon data, the assessment of corporate emissions reduction targets, and their credibility. This has been established through an in-depth analysis of 2,241 companies reporting to the 2020 CDP climate change investor questionnaire measuring how widespread inconsistency is within a single communication channel for a single year. This substantially expands on the work of Garcia-Vega et al. (2023) by increasing the number of companies assessed and accounting for specified tolerances levels (RQ1). Furthermore, to the best of the author's knowledge, no existing studies have assessed whether inconsistency differs between companies with and without emissions reduction targets (RQ2) or evaluated whether inconsistencies are sufficiently significant to bias data users' assessments, as shown here with assessments of corporate emissions reduction targets (RQ3).

6.2.4.1 Contributions to existing literature

The general findings demonstrate that Scope 1 and 2 corporate carbon data are often unreliable, particularly base year emissions data (RQ1), and that users of such data can be severely affected by its unreliability, as evidenced by the considerable impacts on corporate emissions reduction target indicators (RQ3). Indeed, the inconsistency is extensive, with 46% of the 2,241 companies assessed reporting numbers not adding up throughout the 2020 CDP questionnaire (see Figure 6.2).

The results obtained suggest a higher level of inconsistency than the 39% of fossil fuels companies previously found by Garcia-Vega et al. (2023). Even when accepting all the rounding possibilities used by companies, as done by Garcia-Vega et al. (2023), we found that 64% of fossil fuels companies are inconsistent, compared to 44% of all companies. However, the previous study referred only to Scope 1 emissions (comparisons 1 to 5, see Table 6.1), whereas the present study additionally assessed Scope 2 and base year emissions, which may explain the higher inconsistency observed. Therefore, our findings indicate that inconsistency is widespread throughout sectors (not merely limited to the fossil fuels sector; see SI), emission scopes, and years (e.g., base year; see Section 6.2.3.2). Furthermore, our findings reveal that a concerning number of companies remain with inconsistencies even when tolerating higher differences between reported numbers (e.g., above 5%; 22% of companies, see Figure 6.2).

The inconsistencies found suggest that companies are experiencing accounting difficulties, where better internal verification processes could avoid part of it (Garcia-Vega et al., 2023; Talbot & Boiral, 2013). Indeed, inconsistencies accounted for include apparent filling/typing mistakes and unit errors, which roughly 1% of companies had. Furthermore, some companies appeared to have misunderstood the CDP question for comparison 1 (Scope 1 per GHG) or lacked internal expertise (Talbot & Boiral, 2013), and (based on comparisons with other parts of a given disclosure) reported the quantities by mass of GHG instead of by mass of CO₂-equivalent. In contrast, some companies appeared to lack transparency by using rounding to avoid accurate assessments of their emissions progression (Depoers & Jeanjean, 2016). For example, four sample companies were found to round to the nearest 10 million tCO₂e.

Garcia-Vega et al. (2023) suggested that inconsistencies identified here with *Overstated* inconsistencies indicate that companies failed the “acting in good faith test”, thus raising concerns about potential bad faith actions. However, our results suggest that an important part of these inconsistencies involves only minor numerical differences that likely offered no benefit to these companies (less than 1%; corresponding to 9.5% of companies, see Figure 6.2). Nevertheless, other companies may benefit from inconsistencies in their reporting; 10% of companies show differences in their disclosed data of more than 5%, presenting lower numbers in the data typically used by investors (e.g., companies reporting global Scope 1 emissions that are lower than the sum of Scope 1 emissions per business facility). This might have led to an undeserved reward through investors' firm-market valuations, as it enhanced their carbon performance assessment and reputation (Choi & Luo, 2021; Matsumura et al., 2014). Previous studies have shown that firms might intentionally report advantageous figures to improve external assessments (Callery & Perkins, 2021; Talbot & Boiral, 2013), as could be the case here. While this study was not designed to demonstrate such intentionality, which the balanced distribution of over- and understated among companies brings into question, investors may still be misled by the use of such lower annual emissions compared to data reported elsewhere.

Previous studies have suggested that companies benefit from having emissions reduction targets, especially ambitious ones such as targets approved by the SBTi or net-zero targets, by increasing their firm valuations (Bendig et al., 2022; Cheng et al., 2023; Khandelwal et al., 2022). However, the inconsistencies identified raise substantial doubts about the credibility of these targets. In fact, companies with targets are not significantly more or less consistent than companies without targets

when differences up to 5% between reported numbers are tolerated (RQ2; H1 to H3). This questions the supposed advanced efforts toward climate change mitigation that companies with targets should demonstrate, considering their laxity in correctly reporting their carbon data. Furthermore, companies not reporting a target are significantly more consistent than those reporting net-zero targets (H2) and targets other than net-zero and SBTi (H3) when smaller differences are tolerated (1%). Although companies reporting targets approved by the SBTi are not significantly more or less consistent than those not reporting a target, the statistical result is close to significance (H1; see Table 6.2), with further analysis suggesting they may be less consistent than those without targets. This implies that many companies with targets, including ambitious ones, might benefit from an underserved reward in their firm valuations by investors (Bendig et al., 2022; Cheng et al., 2023; Khandelwal et al., 2022). These findings support the legitimacy theory, as an important number of firms seem to report their carbon data and set targets due to external pressure (CA100+, 2022a; Ott et al., 2017), and given their unreliable carbon data, their true commitment to reducing emissions can be questioned (Talbot & Boiral, 2018).

The implications of unreliable data can be substantial for users, as confirmed by its extensive impact on the assessment of companies' emissions reduction targets (RQ3). Indeed, unreliable carbon data significantly affects the possibility of assessing target progression and even creates doubts about the real ambition of targets, as demonstrated in Figure 6.3. The consequences of inconsistent data are undeniable, as shown by the variability of the target progress indicators illustrated in Figure 6.4, and can even inverse the conclusion of whether targets are on track. Inconsistencies, particularly in the base year emissions of targets, are critical and lead to the appearance that part of the targets have been achieved (see Section 6.2.3.6). This might give stakeholders a false impression of companies' efforts and the global reduction trajectory, as in such cases where there has been no real change in companies' emissions. Rather, there is a lack of expertise, a lack of internal verification processes, deliberate opacity, or misleading behavior on the part of these companies (Callery & Perkins, 2021; Depoers & Jeanjean, 2016; Garcia-Vega et al., 2023; Talbot & Boiral, 2013). These findings about the credibility of companies' targets support concerns and needs for regulations brought by Armour et al. (2023) and Hale et al. (2024).

The magnitude of all the inconsistencies is substantial. When only one of the inconsistencies per company (the highest) is accounted for⁷, the total amounts to 1.5 GtCO₂e. This corresponds to 16% of Scope 1 and 2 emissions assessed for the reporting year. The CDP's scoring approach and third-party verification do not appear to be sufficient to guarantee reliable data in the assessed companies' disclosures. CDP's methodology only marginally penalizes companies' scores when a difference of 5% between disclosed data is exceeded, without including verifications of the base year emissions related to companies' targets (CDP, 2020c), resulting in a worrying prevalence of inconsistencies even above this tolerated 5% difference (see Figure 6.2). Additional results suggest third-party verification fails to ensure reliable data throughout the reporting (see SI), which supports the findings of Garcia-Vega et al. (2023) and Talbot et al. (2018). Furthermore, the inconsistencies identified are expected to extend beyond companies' voluntary disclosure. For example, the found inconsistencies proliferate into third-party data providers databases (Busch, Johnson, et al., 2022; Callery & Perkins, 2021; Papadopoulos, 2022), where in some cases, scrutiny and verification of the data may be lacking (Boiral & Talbot, 2021). In addition, the reliability of the data does not seem to be questioned by users once these data have entered third-party databases (Callery & Perkins, 2021). Furthermore, voluntary corporate carbon data are used as inputs by investors and third-party providers for estimating the data of non-reporting companies (Hoepner & Rogelj, 2021; Papadopoulos, 2022), thereby adding to the uncertainty of these estimations.

6.2.4.2 Limitations and future research

This study is based solely on the CDP 2020 questionnaires, meaning that the findings cannot be directly generalized to other databases or years. However, other communication channels, such as corporate sustainability reports, are not as highly structured as CDP questionnaires (Depoers & Jeanjean, 2016; Zhang & Liu, 2020) and do not necessarily include sufficient information for in-depth analysis. Nevertheless, the inconsistency indices and approaches to studying the implications of inconsistencies on emissions reduction targets developed here can be applied to other datasets and time periods or used to compare data between communication channels. The results obtained can serve as a baseline for future assessments. Future inconsistency assessments may be extended

⁷ Differences corresponding to more than 1 GtCO₂e have been excluded (5 observations with the highest over 10 GtCO₂e).

to Scope 3, considering that the CDP 2022 questionnaire introduced more extensive content on Scope 3 compared to previous years (CDP, 2022).

An improved understanding of corporate practices causing data inconsistencies would be beneficial for stakeholders to understand how better accounting and disclosure practices can be achieved. For instance, deficient internal processes and aggregation procedures at the company's headquarters (Adamsson et al., 2017; Dragomir, 2012), lack of expertise, and greenwashing practices (Talbot & Boiral, 2013) have previously been mentioned by studies as reasons for inconsistent disclosures. However, what are the corporate practices associated with reliable data? For example, are board-level oversight, executive management-level responsibility, company size, and the number of years they report determinants of reliability?

Nevertheless, this study did not explore the characteristics of companies with and without targets that could be associated with inconsistent disclosures, such as company size, headquarter location, number of countries in which they operate, or whether they are subject to carbon pricing regulations, which is a limitation. Future research could integrate these characteristics into inconsistency analysis using other statistical models, such as multivariate regression.

The present research demonstrates the consequences of inconsistency in a specific case, i.e., assessments of corporate emissions reduction targets. Further cases should be assessed. For example, how does the ambiguity introduced by data inconsistency change investors' firm-market valuation? What is the variability induced on portfolio carbon footprints and their decarbonization strategies? How does this change our probability of staying within the 1.5-degree ceiling?

6.2.5 Conclusion

The present study enhances the understanding of the (in)consistency of corporate carbon data and the credibility of corporate emissions reduction targets. An in-depth analysis of 2,241 companies reporting to the 2020 CDP climate change investor questionnaire reveals a high level of inconsistency in companies' Scope 1 and 2 emissions disclosures, with 46% of companies exhibiting inconsistent disclosures. Even when tolerating differences up to 5% between disclosures that should be equal, 22% of companies remain inconsistent.

Companies with targets, including those approved by the Science Based Targets initiative and net-zero targets, are generally more often inconsistent or as inconsistent as those without targets

depending on the differences between reported numbers that are tolerated. This raises important doubts about the credibility of targets for companies with inconsistencies, considering their laxity in correctly reporting their carbon data. Furthermore, the present study highlights issues surrounding the reliability of base year emissions covered by targets, which significantly obscure the true ambition of companies' targets. Additionally, the assessment of companies' target progress is significantly biased by inconsistent disclosures, with targets appearing as partly achieved due to inconsistent disclosures, which further discredits their credibility.

Given our findings and the reliance on voluntary corporate carbon disclosures by various stakeholders, including academics, companies, policymakers, and investors (Hale et al., 2024; Hoepner & Rogelj, 2021; Stanny, 2018), several recommendations can be made. For academics, an extensive data cleaning process is recommended. Carbon data should be scrutinized prior to analysis, corrected when possible, and disregarded when needed. Companies need to improve their data gathering processes, implement an internal verification process to avoid reporting inconsistent data, and increase internal training to ensure employees understand the data requirements. Additionally, companies should be cautious when using their peers' data for benchmarking. Disclosure platforms, such as CDP, should nudge and incentivize companies towards reporting consistent data, e.g., by alerting companies in real time about inconsistent entries in online systems and by counting instances of inconsistency more negatively in disclosure scores. To improve the reliability of corporate carbon data, policymakers should implement stringent regulations with a verification process similar to that of the financial system (Dragomir, 2012), supported by a highly standardized and consistent framework covering all of the companies' direct emissions. Regarding investors, care should be exercised when adding a premium value based on corporate emissions reduction targets, as inadequate data inhibits assessments of ambition level and target progress. Accordingly, assessing the consistency of carbon data should be integrated into investment analysis, and investors should engage with companies where inconsistencies are found. For instance, such parameters could be included in the Climate Action 100+ Net-Zero Benchmark. Furthermore, investors need to engage with third parties to enforce a better verification process.

CHAPTER 7 GENERAL DISCUSSION

This chapter presents how the research work has achieved the general objective and provides an overview of the attainment of the six objectives outlined in Chapter 3. Additionally, it discusses the contribution of the research project as a whole, suggests potential future research, identifies the main limitations, and provides recommendations.

7.1 Achievement of Research Objectives and Contributions

The general objective of this dissertation, ‘Develop methodologies and indicators to compare the ambition and progress of corporate climate mitigation targets across sectors to generate a comprehensive evaluation of their disclosed targets to enable better-informed investment decision-making’, was achieved through the fulfillment of the six objectives.

The first main achievement of this dissertation involved the development of methodologies and indicators, accomplished by completing objectives 1, 3 and 5. By overcoming the identified limitations in previous studies, the developed methodologies and indicators can consistently compare the ambition and progress of any type of targets across different companies, regardless of varying target parameters. This results in broad applicability across portfolios. Furthermore, these methodologies and indicators are easily reproducible, which permits recurrent yearly analysis by investors.

The second main achievement was the in-depth and comprehensive evaluation of disclosed targets by companies, applying the developed methodologies and indicators. This evaluation primarily occurred through objectives 2, 4, and 6. Table 7.1 compiles the study coverage, sample size, and final sample for the analyses conducted in Chapters 4, 5, and 6.

The considerable number of companies and targets assessed in each scientific article enhances the understanding of corporate climate mitigation targets, by highlighting current best and worst practices and suggesting future research directions. At the time of publication (or submission for those not yet published), these scientific articles represent the largest or among the largest assessments of companies on their respective research topics. Therefore, these results could serve as baselines for future assessments by the scientific community or practitioners.

Finally, the other achievements of this dissertation relate to the specific fulfilment of the six research objectives, which are briefly summarized and discussed below.

Table 7.1: Coverage and sample of the analyses conducted in Chapters 4, 5, and 6.

	Chapter 4	Chapter 5	Chapter 6
	Article 1: Prospective Sectoral GHG Benchmarks based on Corporate Climate Mitigation targets	Article 2: What drives Companies' Progress on their Emissions Reduction Targets?	Article 3: How reliable is corporate carbon disclosure? Evaluating Inconsistencies and Their Impacts on Corporate Emissions Reduction Targets
Study coverage	Targets covering scopes 1 and/or scope 2 emissions.	Targets covering scopes 1 and/or scope 2 emissions, 120 explanatory variables divided in 11 categories.	Scopes 1 and 2 emissions for reporting year, previous years, and base year. Absolute targets covering scope 1 and/or 2
Sample size	2018 CDP investor and supply chain questionnaires: 2,607 companies of which 1,697 reported a total of 3,009 targets covered by the study.	2020 CDP investor and supply chain questionnaires: 4,524 companies of which 2,925 reported a total of 4,341 targets covered by the study.	2020 CDP investor questionnaires: 2,241 companies of which 1,113 reported a total of 1,813 targets covered by the study.
Final sample	964 companies, with 1,325 targets for the absolute benchmark, 868 companies for intensity benchmark per revenue, 771 companies for intensity benchmark per enterprise value, 32 companies for power generation physical intensity benchmark.	1,030 companies with 1,528 targets for 120 explanatory variables.	2,193 companies for the evaluation of inconsistencies, 1,005 companies with 1,584 targets for the assessments of the consequences of found inconsistencies on target indicators analysis.

Objective 1: Develop a harmonization process comparing corporate climate mitigation target ambition.

A harmonization process was indeed developed in the first article and subsequently applied in the second article to enable comparability of corporate targets with different parameters. This process involves transforming targets to a same scope of emissions, timeframe, and target metric. This coherent and uniform analysis structure allows for flexibility in parameter selection, such as extending to include targets covering scope 1, 2, and/or 3 emissions in future research.

As demonstrated in the first article compared to previous literature, the harmonization process demonstrated its value by:

- 1) Preventing overestimation of companies' target ambition,
- 2) Expanding the number of companies and targets analyzed in a benchmark, leading to a more comprehensive understanding of the situation.

Firstly, the use of a common base year indicates the remaining ambition of companies for a given target year, avoiding to account for part of targets achieved due to companies' choice of base year. Uniformizing the scope of emissions prevents overestimation resulting from partial corporate target ambition, considering that some companies' targets cover only a portion of emissions within a given scope.

Secondly, it increases the number of companies and targets compared to one another, as not all companies have targets covering different emissions scopes. Furthermore, some companies have absolute emission targets, when others have intensity targets, with certain companies having both (Dietz et al., 2018; Gieseke et al., 2021a; D. D. Wang & Sueyoshi, 2018). Therefore, this enhances the representativeness of the benchmark by transforming corporate targets to the same parameters.

Objective 2: Establish absolute and intensity sectoral benchmarks based on climate mitigation targets.

Prospective absolute, and intensity sectoral benchmarks, based on a subsequent number of corporate targets (see Table 7.1), were developed using the harmonization process, showcasing its value. The results confirmed the importance that stakeholders adopting a sectoral approach to assess and compare companies' target ambition. For the year 2030, the fossil fuels sector had the

lowest median reduction rates in the absolute benchmark, while the power generation sector had the highest.

To better assess benchmark results with their chosen common reference year, additional analysis was conducted regarding target progress and achievement. This analysis emphasized the necessity for stakeholders to consider target indicators beyond target ambition alone. Specifically, some companies may have achieved their targets at the year they were launched (14% of targets, see Figure 4.6), while others might have increased their emissions since their company-specified target base year (32% of companies, see Figure 4.5). The latter scenario results in a remaining ambition for these companies higher than their initially announced target ambition, further highlighting the need for additional indicators.

Objective 3: Develop an indicator comparing corporate climate mitigation targets progress.

In the second article, a target progress indicator was developed to enhance understanding through an explanatory analysis of why some companies progress better than others towards their targets. The characteristics of this indicator, which revealed its value by shedding new light on determinants of corporate target progress previously analyzed in existing literature, include:

- 1) Integrating a time perspective, which considers the remaining time left to achieve a target.
- 2) Being a continuous variable, providing greater differentiation between progress results compared to categorical variables.
- 3) Ranging from 0 to 2 by construction, the indicator maintains interpretability while also accommodating for the high variability observed in progression near base years. This prevents the occurrence of extreme values that could have compromised the integrity of the statistical models used in this explanatory analysis.

Previous literature suggested that companies with more ambitious targets progress better than others (Dahlmann et al., 2017; Ioannou et al., 2016; Yeo et al., 2022), while findings in the second article stated otherwise. This discrepancy could be explained by their use of a progress indicator not integrating the remaining time left to the targets or by the exclusion of extreme values (variability) from their analysis, emphasizing the importance of the characteristics of the indicator developed. For instance, recent literature, which included companies with extremely high or low target achievements (variability), supports our findings (Aldy et al., 2023; Dragomir, 2023).

Additionally, the analysis of companies' target progression showed that approximately one-third of the targets (30%) have increased since their base year, while the majority (55%) are either on track to be achieved or have already been achieved. The prevalence of targets achieved in the year they were set has increased compared to two years prior, rising from 14% of targets as mentioned above in Objective 2 to 19% of targets reported by companies in the 2020 CDP questionnaires.

Objective 4: Determine the key determinants of corporate climate mitigation targets progress.

In the explanatory analysis, out of the 120 determinants assessed, 19 were identified as significantly associated with the progress of corporate targets. Beyond the insights provided by the target progress indicator developed, the comprehensive range of determinants analysed compared to previous literature, and the utilization of different selection models in the robustness analysis yielded valuable findings:

- 1) Future research orientation, based on the category of most significance, 'Target Parameters', and the key determinants identified as most robust, leading to three main research directions: base year choice, target trajectory, and target ambition.
- 2) Confirmation of companies with absolute targets with a longer timeframe, as well as remuneration links to climate-related issues, progress better than others.
- 3) Differentiation between the better progression of companies with ambitious targets approved by the SBTi compared to other ambitious targets, resulting from the range of determinants not previously assessed in prior research. Additionally, companies with more than one target were identified by the wider range of determinants assessed as leading to better progression towards their targets.
- 4) Additional determinants highlighted by a non-linear model in the robustness analysis suggested that determinants related to scope 3 emissions are important, even when targets analyzed do not encompass these emissions.

Furthermore, the results reinforced warnings raised in the first article regarding the exclusive reliance on assessing target ambition alone, emphasized companies' poor practices about carbon data quality issues related to their target parameters, and misleading information stemming from companies' target-setting decisions.

Objective 5: Develop indices allowing to measure inconsistencies in voluntary corporate carbon disclosures.

Scrutiny of the corporate carbon data in the preceding two articles instigated the third article. In the first article, 15% of the corporate targets were excluded due to data quality issues, while the second article excluded 27% due to more stringent criteria.

In the third article, the inconsistency indicator of Garcia-Vega et al. (2023) was refined to better understand disparities within reported carbon data by considering different tolerance levels. Specifically, this new index revealed that approximately one-third of companies with inconsistencies (14% out of the total 46%) had small differences between reported numbers (less than 1%), while around half exhibited differences of more than 5% (22% out of the total 46%).

As pointed out by Garcia-Vega et al. (2023), some of these inconsistencies arise from companies understating their aggregated emissions per scope compared to data reported elsewhere in the same CDP questionnaire-year. The developed index indicated that 10% of companies understated their aggregated emissions per scope by more than 5%, an inconsistency that could have greater materiality in stakeholder assessments than differences of less than 1%.

Furthermore, expanding the analysis beyond the scope 1 emissions of fossil fuel companies, as researched by Garcia-Vega et al. (2023), demonstrated that inconsistencies were widespread across sectors, emissions scopes (1 and 2), and multiple years, particularly prominent in base year emissions data. Given that base year emissions are a crucial target parameter for harmonizing targets, assessing target ambition, or tracking their progression, the prevalence of inconsistencies in them has important implications for the assessment of corporate targets.

Objective 6: Assess the implications of current inconsistencies in corporate carbon data disclosures on corporate climate mitigation targets.

To understand these implications, the maximum variations in the assessment of companies' target ambition and progress were analyzed. This involved examining two scenarios for each company: one retaining the maximum value for target parameter 1 (base year emissions) and the minimum value for target parameter 2 (target year emissions for the ambition indicator and reporting year emissions for the progress indicator). The other scenario reversed these values.

Statistical tests confirmed significant differences between the calculated values for the two scenarios of each target indicator. These findings underscored the considerable implications on the ability to accurately assess companies' target ambition and progression. Additionally, it was observed that inconsistencies in base year emissions led to an average variation in target ambition of 26 percentage points, with 60% of companies' targets with inconsistencies having overstated target ambitions. In these instances, aggregated base year emissions were lower than those reported alongside other target-related information in the CDP questionnaire, resulting in lower target ambition than announced by companies. These inconsistencies result in part of targets appearing achieved simply due to inconsistent disclosure. Regarding companies' target progression, inconsistencies led to inversion in progression results for 27% of the targets with variations due to inconsistent disclosure. This occurred when the progression of a company changes from 'on track' to 'not on track'.

Lastly, statistical analysis utilizing companies' inconsistency results from Objective 5 revealed that companies with targets, including SBTi-approved and net-zero targets, were as inconsistent as companies without targets when tolerating up to 5% differences in reported numbers. Furthermore, companies with non-SBTi-approved targets were more often inconsistent than companies without targets when tolerating 1% differences, while companies with SBTi-approved targets showed a similar trend, nearing statistical significance. These findings raised substantial doubts about the credibility of companies' targets, calling into question the true commitment of companies to reduce their emissions due to their laxity in correctly reporting their carbon data.

The results of the third article reinforced the findings of the preceding two articles regarding companies' poor practices and the reporting of potentially misleading information to stakeholders, whether intentional or not.

7.2 Limitations

Although the research objectives have been met, this doctoral thesis is not without limitations, and there remain a number of important constraints. Table 7.2 lists the main limitations that cut across the three articles. The X marks in parentheses indicate limitations that, while still present, are considered to be of lesser importance within that specific chapter when compared with other chapters.

Each transversal limitation is briefly presented and discussed below. The specific limitations of each article are available in their respective chapters.

Table 7.2: Transversal limitations in analyses conducted in Chapters 4, 5, and 6.

	Chapter 4 Article 1: Prospective Sectoral GHG Benchmarks based on Corporate Climate Mitigation targets	Chapter 5 Article 2: What drives Companies' Progress on their Emissions Reduction Targets?	Chapter 6 Article 3: How reliable is corporate carbon disclosure? Evaluating Inconsistencies and Their Impacts on Corporate Emissions Reduction Targets
1- Generalization of results	X	X	X
2- Data quality (completeness and inconsistency)	X	(X)	
3 – Linear reduction trajectory assumption	(X)	X	(X)

Limitation 1: Generalization of results

The results cannot necessarily be generalized to every type of companies, nor can they be generalized over time. They are based solely on data reported by companies in different years of the CDP climate change questionnaires, which primarily include large public companies and lack extensive coverage of smaller private companies. However, the CDP launched a pilot private markets small and medium-sized enterprise questionnaire in 2023, resulting in a dedicated 2024 CDP small and medium-sized enterprise questionnaire with a reduced and simplified question format to ease their reporting burden (CDP, 2024b). Future assessments using the CDP responses should have a better representation of these companies in the upcoming years. Furthermore, text-mining approaches could be used to assess sustainability reports (Ding et al., 2023; Ning et al., 2021; Spinder et al., 2023) and increase the representativity of these companies in future assessments.

The number of companies with approved SBTi targets and net-zero targets are rapidly increasing (Hale et al., 2022; SBTi, 2024b). Meanwhile, some companies seem to restate their targets or remove them if they are ‘not on track’ (Jiang et al., 2023). This implies that the relevance of certain identified corporate practices may be short-lived. However, the results remain useful as baselines for assessing the evolution in companies’ target disclosures. For instance, targets achieved in the year they were set increased from 14% in 2018 to 19% in the 2020 CDP questionnaires (see Section 7.1; results are from the first and second articles).

Limitation 2: Data quality, including completeness and inconsistency.

Notwithstanding the measures taken to disregard inconsistent data, the reliance on self-reported carbon data from companies is an inherent limitation, particularly in the first article where the criteria developed were less stringent than in the second article. Remaining inconsistencies in these two articles, including misreported information related to the determinants of target progress, can potentially distort the analysis and results interpreted with caution. Nonetheless, studies of this size (see Table 7.1) could not have been realized without voluntarily reported information, as mandatory reporting is limited and not enforced in every country (Busch, Johnson, et al., 2022; R. He et al., 2020; World Bank, 2023)

As explained in the third article, corporate carbon data often differ between sustainability reporting, CDP questionnaires, and mandatory reporting. Data reported in CDP questionnaires generally tend to be higher than in other forms of reporting (Depoers & Jeanjean, 2016; Stanny, 2018). However, some CDP corporate carbon data may be understated compared to other sources, as the CDP does not correct company responses. Additionally, third-party verified carbon data in the CDP were not found to be more consistent than those without verification (see Appendix C). Future assessments could improve reliability by cross-checking with other sources, though different accounting choices by companies complicate this verification.

Furthermore, data quality issues led to the exclusion of scope 3 targets from this research project, as scope 3 emissions were often found incomplete and inaccurate in the first article, consistent with previous studies (C. C. Blanco, 2021; Busch, Johnson, et al., 2022; Hansen et al., 2022; Klaaßen & Stoll, 2021). The criteria used in the first two articles could not be applied to cross-check the consistency of their target base year emissions, resulting in potentially biased results if included. The third article demonstrates that inconsistencies in scope 1 and 2 emissions significantly impact

the assessment of the ambition and progress of scope 1 and 2 targets. It is likely that inconsistencies in scope 3 emissions exceed those found in scope 1 and 2 emissions. However, excluding scope 3 targets diminishes the general understanding of disclosed targets for several reasons: 1) companies did not necessarily disclose targets for each scope, resulting in some scope 3 targets to combine with scopes 1 and 2 coverage, 2) their representativeness in the sample studies has increased during the years assessed, and 3) scope 3 emissions can represent a substantial part of total company emissions (see, for example, CDP, (2024c)). Nevertheless, the methodologies and indicators developed can be applied to scope 3 targets.

Limitation 3: Linear reduction trajectory

Throughout this research project, a linear reduction was assumed since companies did not provide information on their planned reduction paths for disclosed targets. This assumption is widely held in the literature, both when evaluating the ambition of company targets and their progress (Aldy et al., 2023; Dietz, Bienkowska, et al., 2021; Dietz, Gardiner, Jahn, et al., 2021; Giesekam et al., 2021a; Hale et al., 2021; A. Hsu et al., 2020; Kuramochi et al., 2021; D. D. Wang & Sueyoshi, 2018).

As shown in Table 7.2, this limitation is more pronounced in the second article than in the other two: i) less present in the first article due to the inclusion of intermediary targets disclosed by companies, which break the reduction trajectory into multiple linear segments, ii) it is less relevant in the third article due to the study's context. However, the findings of the second article suggest that companies' progression towards their targets may not always follow a linear path, particularly for targets with longer timeframes. The target progress indicator can easily be adapted for non-linear trajectories (see Section 5.2.4.3). Despite this, without additional information from companies or future investigation, the assumption of an alternative non-linear trajectory lacks a sound basis, as it may lead to targets with minimal initial reductions being mislabeled as 'on track'.

7.3 Future Research

From the limitations, and more broadly, the explorations of this doctoral thesis, several potential avenues for future research emerged.

Target parameters

The explanatory analysis in the second article identified three main research directions specific to target parameters: choice of base year, target ambition, and target trajectory (detailed in Section 5.2.4.2). Given the findings in the third article and investor interests (see Section 2.1.2.3), research should focus on companies with targets approved by the SBTi compared to others. Although research on these companies is rapidly increasing, they are often not compared to other ambitious targets, such as net-zero targets. Additionally, particular attention should be given to early adopters of science-based targets versus recent adopters, which may include less committed followers.

As previously explained, this research project did not assess these targets due to the impossibility to cross-check the reliability of their base year emissions. However, the CDP has recently expanded its scope 3 content (CDP, 2024a). With the application of the developed inconsistency indices, evaluation as conducted in this project can now extend to these targets, potentially providing valuable insights for stakeholders and deepening the understanding of corporate targets.

Reduction trajectory

Future research should establish the foundation for using non-linear trajectories to evaluate companies' progress toward their targets by identifying the characteristics of companies and their targets associated with varying reduction trajectories. While this research is essential, it may encounter several challenges and could lead to inconclusive findings. However, overcoming these challenges would enhance the robustness of the assessment of corporate targets and support more informed decision-making. For instance, investigating the annual progression of past targets could confirm the various types of reduction trajectories. Additionally, examining current targets set years ago can provide valuable insights into progression patterns and the effectiveness of different reduction strategies.

Nevertheless, data preprocessing will most likely be daunting. First, companies seem to often restate their target parameters over time (Callery & Kim, 2021; Jiang et al., 2023), diminishing the number of consistent targets over time. This corporate practice should be further investigated (detailed below). Second, the unreliability of self-reported carbon data found in the third article, exacerbated by changes in base year emissions due to companies' accounting choices may pose a challenge, leading to the exclusion of a substantial number of companies. A solution could be to target only understated inconsistencies with low tolerance levels (e.g., 1%, 2.5%) using the

developed inconsistency index, combined with sensitivity analysis. Third, the annual progression of the remaining companies' targets will likely encounter data noise from changes in company activities, sector-specific consumer preferences, or regional economic factors. A thorough examination of these noises and the application of techniques to smooth trajectories where appropriate will be required. Finally, companies' characteristics and target parameters need to align with specific trajectories, avoiding multiple contradictory trajectories that could hinder later applicability.

Techniques such as clustering analysis and feature selection can be employed to categorize these groups. In addition, probabilistic approaches could be used to assess the likelihood of companies achieving their targets, based on categories previously determined.

Target indicators

Depending on the reduction trajectories found in future research, the target progress indicator in this research project can easily be adapted and used for future evaluation of corporate targets (see Section 5.2.4.3). However, further evaluation could integrate in cumulative reductions of a company's target into the progression assessment, similar to the approach developed by Rekker et al. (2022), but based specifically on the company's target rather than their carbon budget for 1.5 degrees compliance. Such evaluation would prevent a company's target from being deemed 'on track' for a specific year if they have been substantially lagging in their reduction trajectory since their base year (over multiple years).

Furthermore, combining the assessment of the ambition and progress of corporate targets into a single indicator would be an interesting development and valuable for decision-making. However, this indicator should maintain interpretability, distinguishing between a highly ambitious target with increased emissions since the base year and a less ambitious target that has successfully reduced emissions. This approach ensures that one aspect does overshadow the other. Nevertheless, future research should compare progress using various indicators (with and without time perspective integrated) for the same disclosure year and adjust sample criteria (including or excluding extreme values) to better illustrate their strength and flaws by showing their impact on study outcomes, particularly for ambitious targets. This would help to clearly demonstrate which indicators are appropriate (or not) under certain circumstances.

Credibility of companies with targets

The credibility of companies with targets emerged as a prominent concern throughout this research, despite not being its original focus. Companies making promises without intent to reduce their emissions seem to rise (symbolic targets). This is a form of greenwashing, with Montgomery et al., (2023) proposing the term ‘futurewashing’. Deepening the understanding of how to identify and flag these companies is key for advancing confidence in corporate climate actions.

Developing an index incorporating a comprehensive evaluation of the credibility of a company’s target based on their history of achieving previous targets, consistency in reporting, and adherence to best practices could be an avenue for research. Various research questions should be investigated concerning the (in)consistency in reporting, such as:

- What corporate practices are associated with consistency in reporting?
- Are executive remunerations tied to the achievement of disclosed targets, company size, and the number of years they have been reporting determinants of data reliability?
- Are there differentiating characteristics between companies with and without targets that are associated with inconsistent data, such as headquarter location, number of countries in which they operate, or whether they are subject to carbon pricing regulations?
- Are there differentiating characteristics between companies with under- and overstated inconsistencies?

Other research questions should explore the history of companies' success or failure in achieving previous targets:

- Do companies that fail to achieve their previous targets continue to lag on their current targets?
- What changes in determinants (e.g., corporate practices, target ambition) have occurred in companies that were previously failing but are now successful, compared to those that continue to lag behind on their targets?
- Do companies intentionally hide their past failure by restating their targets?
- What are the specific characteristics of companies with restated targets that result in lower ambition or longer timeframes, giving more space to sell a future that will not occur soon?

- How frequently do companies revise their targets, and what justifications do they provide for these revisions?
- Do companies temporarily avoid reporting the information needed to assess their progress towards targets when they were lagging in previous years?

Furthermore, a better understanding of companies with symbolic targets could be included in this index by answering to:

- What are the determinants explaining companies with symbolic targets?
- Is pressure from external stakeholders, including investors, a determinant of symbolic targets?
- Are companies with symbolic targets prevalent in specific types of corporate culture?

By addressing these questions, future research could help build a more accurate assessment of the credibility of corporate targets and enhances the overall accountability in corporate climate actions.

7.4 Recommendations

In light of the contributions of this research, a number of recommendations can be proposed for the diverse stakeholders involved in corporate carbon data and targets, in addition to the future research directions.

For the financial community:

- Assess both the ambition and progression of companies' targets to have a more realistic understanding of their credibility in achieving their targets:
 - 1) When comparing the target ambition and progress of companies' targets, use the harmonization process to ensure a uniform and coherent analysis structure across different types of targets with varying parameters. This evaluation can be useful for various responsible investment approaches, such as comparing companies to their peers (e.g., best-in-class), incorporating this factor into ESG analysis to mitigate climate transition risks, and determining the remaining efforts to achieve portfolio emissions reduction targets by harmonizing companies' targets to their own target parameters (e.g., capital reallocation and engagement activities).

- 2) Preferably use a progress indicator that integrate the remaining time left to achieve a target, such as the one developed here, or at minima, that incorporate a time perspective.
 - 3) Use the inconsistency indices to assess the reliability of companies' targets through their carbon data disclosures. These indices can be adapted by accounting for either or both over- and understated aggregated emissions and different tolerance levels, depending on investors' sensitivity to inconsistencies. At a minimum, assess understated inconsistencies with a 5% tolerance level, focusing on the scope covered by the disclosed targets, considering the impact of inconsistencies on the assessments of corporate targets. The prevalence of inconsistencies found in target base year emissions is concerning.
- Integrate the corporate best practices associated with target progression into the assessment, to further evaluate the reliability of companies' targets. These practices include companies reporting absolute targets with longer timeframes, disclosing of additional targets, like scope 3 targets, and having the executive and board remunerations linked to climate-related issues (see Section 5.2.3.3). Furthermore, investors should exercise particular vigilance regarding ambitious targets, such as net-zero targets, as it appears some might only be symbolic.
 - Pay particular attention to the choice of base year made by companies in their targets to identify those that may 'cherry-picking' their base year. This might be signaled by:
 - 1) A base year that differ from the year the target was set, with important progress already achieved by that year. Targets achieved by that year should be deeply investigated. The average value for the targeted emission reductions of companies' targets by that year could be relevant as a threshold (which was 32% for targets disclosed in the 2020 CDP questionnaires, see Section 5.2.3.3).
 - 2) An assessment of the year before the base year (and after if different than the year the target was set). For the year before, this can be evaluated by readjusting the target base year.
 - Monitor annually the ambition and progress of companies. Such recurrent analysis could help identify companies restating their targets, which may:

- 1) Mask a ‘downgrade’ in ambition compared to the previous year analyzed. For example, longer timeframes with higher reduction announced could result in lower target ambition than previously or changing the coverage to scope with lower emissions compared to previous one would also result in downgrade of their ambition.
 - 2) Signal credibility concerns in the targets disclosed by the company, especially if the progression of the previous targets was lagging the year before. This further underscore the importance of a combined assessment of the ambition and progress of corporate targets.
- Engage with companies when their credibility to achieve their targets is in doubt (progression lagging, company identified with poor or questionable practices). Furthermore, investors should encourage companies to provide additional information regarding the planned reduction trajectory of their targets.
 - To determine the potential percentage of the target ambition that could be attained by the target year, unbound the progress indicator, allowing the ‘percentage of target achieved’ to exceed 100% or fall below 0%, using the same underlying calculations (see Section 5.2.2.2). This assumes that between the year analyzed and the target year, the company would maintain the same reduction pace as initially set for their target.

For governments and policymakers:

- Implement stringent regulations to prevent the disclosure of misleading information for stakeholders:
 - 1) Mandate corporate carbon data disclosure through a highly standardized framework, with a verification process similar to financial reporting. This should ideally cover the total companies’ emissions, but at minima the scope 1 and 2 emissions.
 - 2) If the above is not mandatory, require companies publicly disclosing targets to report annually on the emissions corresponding to the scope covered by the target, enabling stakeholders to track progress effectively. This could help to prevent symbolic targets.

3) Standardize target-setting approaches by providing clear guidance on appropriate target parameters, especially the base year setting, to prevent ‘cherry-picking’.

- Monitor both companies’ target ambition and progress to identify where additional efforts and regulations are required to align with the country’s nationally determined contribution.

For companies:

- Implement internal verification of the carbon data disclosed to avoid inconsistencies in disclosed carbon data.
- Report annually the necessary information allowing stakeholders to assess the progression of disclosed targets, such as the base year emissions and current annual emissions corresponding to the scope covered by the targets.
- Carefully choose the target parameters, to prevent the appearance of base year ‘cherry picking’, favor absolute targets over intensity. Furthermore, disclose more than one targets, such as scope 3 target or with different timeframes, and get disclosed targets approved by the SBTi when ambitious.
- Provide additional information regarding the planned reduction trajectory of the disclosed target disclosed.
- Tie executive and board remunerations to the achievement of disclosed targets or, at a minimum, to climate-related issues.

For the CDP:

- Request information from companies on the planned reduction trajectory of disclosed targets.
- Encourage consistent reporting by alerting companies in real-time about inconsistent entries. The CDP's data entry platform underwent significant changes in 2024, this may have already been implemented.
- Signal the presence of inconsistencies in company reporting to stakeholders within the CDP ‘Corporate Response Data’, which includes all company responses to the climate change questionnaire. This could be highlighted alongside instances where inconsistencies can be verified, by adding a column - particularly in the CDP 'Target and performance' section - helping stakeholders exercise caution when assessing companies’ targets.

- Label inconsistencies in company reporting within the CDP scores by adding an asterisk to the company scores for easy identification by stakeholders of the reliability of companies' targets. Furthermore, the CDP scores are provided in a separate dataset for both investors and academics.
- Increase penalties in company scoring for persistent inconsistencies, particularly for: 1) understated aggregated emissions, and 2) base year emissions of disclosed target.

For the scientific community:

- For assessing the ambition and progress of corporate targets, either: 1) coherently harmonize companies' targets, such as with the developed process, or 2) compare only similar targets, such as absolute scope 1 targets.
- Preferably use target progress indicators that integrate a time perspective and accommodate the high variability in progression, such as the one developed in this research project. This approach could provide useful insights.
- Recommended for any studies including corporate carbon data to apply an extensive data cleaning process by scrutinizing carbon data prior to analysis, correcting them when possible, and disregard when needed. For studies assessing corporate targets, particular attention should be given to the base year emissions of targets, considering their importance and potential impact on the study results.

CHAPTER 8 CONCLUSION

The main contributions of this doctoral dissertation have enabled the fulfillment of the general objective of ‘developing methodologies and indicators to compare the ambition and progress of climate mitigation targets across different companies, generating a comprehensive evaluation of disclosed targets to enable better-informed investment decision-making’. However, the findings should be interpreted with caution considering the identified limitations. The main contributions of this research project are:

- A harmonization process to coherently compare the ambition of any type of climate mitigation targets across different companies and sectors, preventing overestimation of target ambition due to companies’ choice of target base year or their limited target scope coverage.
- An application of this process through a methodological framework establishing sectoral prospective GHG benchmarks based on companies’ targets, which led to a reflection on the importance of assessing both the ambition and progress of companies’ targets.
- An indicator quantifying the progress of companies’ targets while considering the remaining time left to achieve a target and accommodating for the high variability in target achievement, which, when combined with the harmonization process allows for coherent comparisons of ambition and progress across different companies’ targets. This indicator can easily account for non-linear reduction trajectories when future research determines appropriate circumstances for its use.
- An application of the target progress indicator, coupled with an explanatory analysis of the determinants significantly associated with the progress companies’ targets, which highlighted companies current best (and worst) practices, confirmed the importance of assessing both the ambition and progress, and suggested future research directions.
- Inconsistency indices assessing the reliability of companies’ targets through their carbon data disclosures, which can be adapted by accounting for either or both over- and understated aggregated emissions and different tolerance levels, depending on stakeholders’ sensitivity to inconsistencies and use of data.
- An application of the inconsistency indices to the carbon data reporting of companies with and without targets, combined with a demonstration of their impact on the assessment of

the ambition and progress of companies' targets, highlights concerning prevalence of inconsistencies throughout carbon data reporting of companies. It shows that companies with targets are not more consistent than those without, and demonstrates the importance of verifying their reliability, as it can significantly bias the assessment of the ambition and progress of companies' targets.

- Results from the three applications - the ambition and progress of companies' targets and the reliability of corporate carbon data disclosures - can serve as baselines for future assessments, as their corresponding scientific articles represent the largest or among the largest assessments of companies on their respective research topics.

Despite its valuable contributions, this doctoral thesis is not without limitations, which include (1) the generalization of the results, as they are based solely on data from companies reporting in the CDP questionnaires, which mainly include large public companies and lack extensive coverage of small and private companies; (2) the reliance on firms' self-reported data, which may lack reliability and led to the exclusion of scope 3 targets due to incomplete and inconsistent emissions reporting from companies; and (3) the assumption of a linear reduction trajectory, as companies did not provide information on the planned trajectory of their disclosed targets. Solutions have been suggested to address specific aspects of these limitations, such as the adaptation of the developed target progress indicator to account for non-linear reduction trajectories.

Additionally, future research directions have been suggested: (1) prioritizing specific target parameters, including the choice of target base year, differentiation between companies with ambitious targets (e.g., net-zero targets versus those with approved SBTi targets), and the inclusion of scope 3 targets, enabled by recent improvements in the CDP questionnaires and enhanced filtering with developed inconsistency indices; (2) establishing the foundation for employing non-linear trajectories by identifying the characteristics of companies and their targets associated with varying reduction trajectories, which will require overcoming challenges; (3) refining target indicators, such as combining ambition and progress into a single indicator while addressing interpretability concerns; (4) enhance the credibility assessment of companies with targets by developing an index based on historical target achievement, reporting consistency, and adherence to best practices, while investigating several research questions.

Ultimately, this research project contributes to broaden and deepen the understanding of corporate targets. Throughout this research, the credibility of companies with targets, including ambitious ones such as net-zero and science-based targets, emerged as a prominent concern, despite not being its original focus. The findings emphasize the importance of assessing both the ambition and progress of companies' targets, as well as their reliability through the lens of corporate practices and the consistency of their carbon data reporting. This research should encourage investors to go beyond evaluating whether targets are sufficiently ambitious to align with the goals of the Paris Agreement, following guidelines such as the SBTi. Instead, it advocates for a more comprehensive assessment of companies' targets, incorporating the developed indicators and findings of this research project.

REFERENCES

- Abdi, H. (2007). Z-scores. *Encyclopedia of Measurement and Statistics*, 3, 1055–1058.
- Abreu, M. C. S. de, Webb, K., Araújo, F. S. M., & Cavalcante, J. P. L. (2021). From “business as usual” to tackling climate change: Exploring factors affecting low-carbon decision-making in the canadian oil and gas sector. *Energy Policy*, 148(April 2020). <https://doi.org/10.1016/j.enpol.2020.111932>
- Adamsson, H., Hoepner, A. G. F., & Yu, P. (2017). Science based targets without science based disclosure ? Towards a complete Carbon Data Science. *CSEAR 2017 Paper*. <https://doi.org/http://dx.doi.org/10.2139/ssrn.2715101>
- Agrawal, A., & Hockerts, K. (2021). Impact Investing: Review and Research Agenda. *Journal of Small Business and Entrepreneurship*, 33(2), 153–181. <https://doi.org/10.1080/08276331.2018.1551457>
- Akinwande, M. O., Dikko, H. G., & Samson, A. (2015). Variance Inflation Factor : As a Condition for the Inclusion of Suppressor Variable (s) in Regression Analysis. *Open Journal of Statistics*, 5(December), 754–767.
- Aldy, J. E., Bolton, P., & Halem, Z. M. (2023). Behind Schedule: The Corporate Effort to Fulfill Climate Obligations. *Journal of Applied Corporate Finance*, 35(2), 26–34. <https://doi.org/10.1111/jacf.12560>
- Amel-Zadeh, A., & Serafeim, G. (2018). Why and How Investors Use ESG Information: Evidence from a Global Survey. *Financial Analysts Journal*, 74(3), 87–103. <https://doi.org/https://doi.org/10.2469/faj.v74.n3.2>
- Araos, M., Berrang-ford, L., Ford, J. D., Austin, S. E., Biesbroek, R., & Lesnikowski, A. (2016). Environmental Science & Policy Climate change adaptation planning in large cities: A systematic global assessment. *Environmental Science and Policy*, 66, 375–382. <https://doi.org/10.1016/j.envsci.2016.06.009>
- Arjalie, D. (2010). A Social Movement Perspective on Finance : How Socially Responsible Investment Mattered. *Journal of Business Ethics*, 92, 57–78. <https://doi.org/10.1007/s10551-010-0634-7>

- Armour, J., Enriques, L., & Wetzer, T. (2023). Green Pills: Making Corporate Climate Commitments Credible. *Arizona Law Review*, 65, 285. <https://arizonalawreview.org/pdf/65-2/65arizlrev285.pdf>
- Austin, P. C., & Tu, J. V. (2004). Bootstrap Methods for Developing Predictive Models. *The American Statistician*, 58(2), 131–137. <https://doi.org/10.1198/0003130043277>
- Avetisyan, E., & Hockerts, K. (2017). The Consolidation of the ESG Rating Industry as an Enactment of Institutional Retrogression. *Business Strategy and the Environment*, 26(3), 316–330. <https://doi.org/10.1002/bse.1919>
- Ayling, J., & Gunningham, N. (2017). Non-state Governance and Climate Policy : The Fossil Fuel Divestment Non-state governance and climate policy : the fossil fuel divestment movement. *Climate Policy*, 17(2), 131–149. <https://doi.org/10.1080/14693062.2015.1094729>
- Azoulay, M., Mikkelsen, D., Muchembled, E., Eceiza, J., Gibbs, S., & McDaniels, J. (2023). *Financing the net-zero transition: From planning to practice*. https://www.iif.com/portals/0/Files/content/32370132_mck-iif_report-v5.pdf
- Babcock, A., He, A., & Ramani, V. (2022). Building Investor Trust in Net Zero. *Journal of Applied Corporate Finance*, 34(2), 52–59. <https://doi.org/10.1111/jacf.12505>
- Badenhoop, N., Hackmann, A., Mücke, C., & Pelizzon, L. (2023). *Quo Vadis Sustainable Funds? Sustainability and taxonomy-aligned disclosure in Germany under the SFDR* (No. 94; SAFE White Paper). <https://www.econstor.eu/bitstream/10419/273716/1/1854330292.pdf>
- Baldwin, M. P., Ayarzagüena, B., Birner, T., Butchart, N., Butler, A. H., Charlton-perez, A. J., & Domeisen, D. I. V. (2021). Sudden Stratospheric Warmings. *Reviews of Geophysics*, 59(1), 1–37. <https://doi.org/10.1029/2020RG000708>
- Barber, B. M., Morse, A., & Yasuda, A. (2021). Impact Investing. *Journal of Financial Economics*, 139(1), 162–185.
- Barnard, J. W. (1990). Exxon Collides With the " Valdez Principles ". *Business and Society Review*, 74, 32–35.
- Battiston, S. (2019). The importance of being forward-looking: managing financial stability in the face of climate risk. *Financial Stability Review*, 23(23), 39–48.

- Battiston, S., Dafermos, Y., & Monasterolo, I. (2021). Climate risks and financial stability. *Journal of Financial Stability*, 54(100867), 1–13.
- Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017). A climate stress-test of the financial system. *Nature Climate Change*, 7(4), 283–288. <https://doi.org/10.1038/nclimate3255>
- Bello, Z. Y. (2005). Socially Responsible Investing and Portfolio Diversification. *The Journal of Financial Research*, 28(1), 41–57. <https://doi.org/10.1111/j.1475-6803.2005.00113.x>
- Bendig, D., Wagner, A., & Lau, K. (2022). Does it pay to be science-based green ? The impact of science-based emission-reduction targets on corporate. *Journal of Industrial Ecology*, 1–16. <https://doi.org/10.1111/jiec.13341>
- Benjamin, L. (2020). The Road to Paris Runs Through Delaware: Climate Litigation and Directors' Duties. *Utah L. Rev.*, 1, 313. https://lawcommons.lclark.edu/faculty_articles/22
- Benjamin, L., Setzer, J., Bhargava, A., Franta, B., Martinez Toral, K., & Tandon, A. (2022). *Climate-Washing Litigation: Legal Liability for Misleading Climate Communications* (Policy Briefing, Issue 1). <https://ora.ox.ac.uk/objects/uuid:59e6d33f-bd8a-4375-9268-730a845e8aae/files/sn870zs466>
- Berg, F., Ko, J. F., & Rigobon, R. (2022). Aggregate Confusion: The Divergence of ESG Ratings. *Review of Finance*, 26(6), 1315–1344. <https://doi.org/10.1093/rof/rfac033>
- Bergman, N. (2018). Impacts of the Fossil Fuel Divestment Movement: Effects on Finance, Policy and Public Discourse. *Sustainability*, 10(7), 2529. <https://doi.org/10.3390/su10072529>
- Berk, J. B., & Van Binsbergen, J. H. (2022). *The Impact of Impact Investing*.
- Bernstein, A., Gustafson, M. T., & Lewis, R. (2019). Disaster on the horizon : The price effect of sea level rise. *Journal of Financial Economics*, 134(2), 253–272. <https://doi.org/10.1016/j.jfineco.2019.03.013>
- Bingler, A. J., & Senni, C. C. (2022). Taming the Green Swan: a criteria-based analysis to improve the understanding of climate-related financial risk assessment tools. *Climate Policy*, 22(3), 356–370.
- Bingler, J. A., Senni, C. C., & Monnin, P. (2022). Understand what you measure: Where climate

transition risk metrics converge and why they diverge. *Finance Research Letters*, 50, 103265. <https://doi.org/10.1016/j.frl.2022.103265>

Bistline, J., Blanford, G., Brown, M., Burtraw, D., Domeshek, M., Farbes, J., Fawcett, A., Hamilton, A., Jenkins, J., Jones, R., King, B., Kolus, H., Larsen, J., Levin, A., Mahajan, M., Marcy, C., Mcfarland, J., Mcjeon, H., Orvis, R., ... Zhao, A. (2023). Emissions and Energy Impacts of the Inflation Reduction Act. *Science*, 360(6652), 1324–1327. <https://doi.org/10.1126/science.adg3781>

Bjørn, A., Lloyd, S. M., Brander, M., & Matthews, H. D. (2022). Renewable energy certificates threaten the integrity of corporate science-based targets. *Nature Climate Change*, 12, 539–546. <https://doi.org/10.1038/s41558-022-01379-5>

Bjorn, A., Lloyd, S., & Matthews, D. (2021). From the Paris Agreement to corporate climate commitments: evaluation of seven methods for setting “science-based” emission targets. *Environmental Research Letters*, 16(5), 054019. <https://doi.org/10.1088/1748-9326/abe57b>

Bjørn, A., Matthews, H. D., Hadziosmanovic, M., Desmoitier, N., Addas, A., & Lloyd, S. M. (2023). Increased transparency is needed for corporate science-based targets to be effective. *Nature Climate Change*, 13(8), 756–759. <https://doi.org/10.1038/s41558-023-01727-z>

Bjørn, A., Tilsted, J. P., Addas, A., & Lloyd, S. M. (2022). Can Science-Based Targets Make the Private Sector Paris-Aligned? A Review of the Emerging Evidence. *Current Climate Change Reports*, 8(2), 53–69. <https://doi.org/10.1007/s40641-022-00182-w>

Blanco, C. C. (2021). Supply Chain Carbon Footprinting and Climate Change Disclosures of Global Firms. *Production and Operations Management*, 30(9), 3143–3160. <https://doi.org/10.1111/poms.13421>

Blanco, C., Caro, F., & Corbett, C. J. (2016). The state of supply chain carbon footprinting: analysis of CDP disclosures by US firms. *Journal of Cleaner Production*, 135, 1189–1197. <https://doi.org/10.1016/j.jclepro.2016.06.132>

Bloomberg L.P. (2020). *Market Capitalisation and Enterprise Value for Company 01/01/1990 to 01/01/2019*. Bloomberg terminal

Boiral, O., Brotherton, M. C., Rivaud, L., & Talbot, D. (2022). Comparing the incomparable? An investigation of car manufacturers’ climate performance. *Business Strategy and the*

Environment, 31(5), 2213–2229. <https://doi.org/10.1002/bse.3017>

Boiral, O., Henri, J.-F., & Talbot, D. (2012). Modeling the impacts of corporate commitment on climate change. *Business Strategy and the Environment*, 21(8), 495–516.

Boiral, O., & Talbot, D. (2021). Sustainability rating and moral fictionalism : opening the black box of nonfinancial agencies. *Accounting, Auditing & Accountability Journal*, 34(8), 1740–1768. <https://doi.org/10.1108/AAAJ-12-2019-4356>

Bolay, A., Bjørn, A., Patouillard, L., Weber, O., & Margni, M. (2024). What drives Companies' Progress on their Emission Reduction Targets? *Journal of Cleaner Production*.

Bolay, A., Bjørn, A., Weber, O., & Margni, M. (2022). Prospective sectoral GHG benchmarks based on corporate climate mitigation targets. *Journal of Cleaner Production*, 376, 134220. <https://doi.org/10.1016/j.jclepro.2022.134220>

Bolton, P., Despres, M., Awazu, L., Da, P., Samama, F., & Svartzman, R. (2020). The green swan: Central banking and financial stability in the age of climate change. In *Bank for International Settlements* (Issue January).

Bolton, P., & Kacperczyk, M. (2023a). *Firm Commitments* (No. w31244). <https://doi.org/10.3386/w31244>

Bolton, P., & Kacperczyk, M. (2023b). Global Pricing of Carbon-Transition Risk. *The Journal of Finance*, 78(6), 3677–3754. <https://doi.org/10.1111/jofi.13272>

Bolton, P., Kacperczyk, M., & Samama, F. (2022). Net-Zero Carbon Portfolio Alignment. *Financial Analysts Journal*, 78(2), 19–33. <https://doi.org/10.1080/0015198X.2022.2033105>

Bos, K., & Gupta, J. (2019). Stranded assets and stranded resources: Implications for climate change mitigation and global sustainable development. *Energy Research and Social Science*, 56, 101215. <https://doi.org/10.1016/j.erss.2019.05.025>

Boykoff, M. T., & Roberts, J. T. (2007). Media Coverage of Climate Change: Current Trends, Strengths, Weaknesses. *Human Development Report*, 2008(3), 1–53.

Brander, M., Gillenwater, M., & Ascui, F. (2018). Creative accounting: A critical perspective on the market-based method for reporting purchased electricity (scope 2) emissions. *Energy Policy*, 112(January), 29–33. <https://doi.org/10.1016/j.enpol.2017.09.051>

- Bratspies, R. M. (2011). A Regulatory Wake-Up Call: Lessons From BP ' s Deepwater Horizon Disaster. *Golden Gate University Environmental Law Journal*, 5(1), 1–55.
- Breiman, L. (2001). Random Forests. *Machine Learning*, 45, 5–32.
- Brest, B. P., & Born, K. (2013). When Can Impact Investing Create Real Impact? *Stanford Social Innovation Review*, 11(4), 22–31.
- Brock, E. K., Justin, N., & Brackley, A. (2023). *Rate the Raters 2023: ESG Ratings at a Crossroads*.
<https://www.sustainability.com/globalassets/sustainability.com/thinking/pdfs/2023/rate-the-raters-report-april-2023.pdf>
- Bryant, A., Griffin, J. J., & Perry, V. G. (2020). Mitigating climate change: A role for regulations and risk-taking. *Business Strategy and the Environment*, 29(2), 605–618.
<https://doi.org/10.1002/bse.2391>
- Bugg-levine, A., & Emerson, J. (2011). A Mighty Wave. In *Impact Investing: Transforming How We Make Money while Making a Difference* (pp. 3–17). John Wiley & Sons.
- Busch, T., Barnett, M. L., Burritt, R. L., Cashore, B. W., Freeman, R. E., Henriques, I., Husted, B. W., Panwar, R., Pinkse, J., Schaltegger, S., & York, J. (2024). Moving beyond “the” business case: How to make corporate sustainability work. *Business Strategy and the Environment*, 33(2), 776–787. <https://doi.org/10.1002/bse.3514>
- Busch, T., Bauer, R., & Orlitzky, M. (2016). Sustainable Development and Financial Markets: Old Paths and New Avenues. *Business & Society*. <https://doi.org/10.1177/0007650315570701>
- Busch, T., Bruce-Clark, P., Derwall, J., Eccles, R., Hebb, T., Hoepner, A., Klein, C., Krueger, P., Paetzold, F., Scholtens, B., & Weber, O. (2021). Impact investments: a call for (re)orientation. *SN Business & Economics*, 1(33), 1–13. <https://doi.org/10.1007/s43546-020-00033-6>
- Busch, T., Cho, C. H., Hoepner, A. G. F., Michelon, G., & Rogelj, J. (2022). Corporate Greenhouse Gas Emissions ' Data and the Urgent Need for a Science - Led Just Transition : Introduction to a Thematic Symposium. *Journal of Business Ethics*, 0123456789.
<https://doi.org/10.1007/s10551-022-05288-7>
- Busch, T., Johnson, M., & Pioch, T. (2022). Corporate carbon performance data: Quo vadis?

- Journal of Industrial Ecology*, 26(1), 350–363. <https://doi.org/10.1111/jiec.13008>
- Busch, T., Weinhofer, G., & Hoffmann, V. H. (2011). The carbon performance of the 100 largest US electricity producers. *Utilities Policy*, 19(2), 95–103. <https://doi.org/10.1016/j.jup.2010.12.002>
- Busco, C., Consolandi, C., Eccles, R. G., & Sofra, E. (2020). A Preliminary Analysis of SASB Reporting: Disclosure Topics, Financial Relevance, and the Financial Intensity of ESG Materiality. *Journal of Applied Corporate Finance*, 32(2), 117. <https://doi.org/10.1111/jacf.12411>
- Byrd, J., Bettenhausen, K. L., & Cooperman, E. S. (2013). Context-Based Sustainability and Corporate CO2 Reduction Targets : Are Companies Moving Fast Enough? *International Review of Accounting , Banking and Finance*, 5(3).
- CA100+. (2022a). *Climate Action 100+ Net-Zero Company Benchmark: Summary of company assessments, March 2022*.
- CA100+. (2022b). *Disclosure Framework Assessed by TPI* (Vol. 1, Issue March).
- Cadez, S., Czerny, A., & Letmathe, P. (2019). Stakeholder pressures and corporate climate change mitigation strategies. *Business Strategy and the Environment*, 28(1), 1–14. <https://doi.org/10.1002/bse.2070>
- Caldecott, B. (2017). Introduction to special issue: stranded assets and the environment. *Journal of Sustainable Finance and Investment*, 7(1), 1–13. <https://doi.org/10.1080/20430795.2016.1266748>
- Calel, R., Stainforth, D. A., & Dietz, S. (2015). Tall tales and fat tails : the science and economics of extreme warming. *Climatic Change*, 132, 127–141. <https://doi.org/10.1007/s10584-013-0911-4>
- Callery, P. J., & Kim, E.-H. (2021). Moving Targets: Aggressiveness, Attainment, and Temporal Dynamics in Corporate Carbon Targets. *Academy of Management Proceedings*, 2021(1), 10873. <https://doi.org/https://doi.org/10.5465/AMBPP.2021.10873abstract>
- Callery, P. J., & Perkins, J. (2021). Detecting False Accounts in Intermediated Voluntary Disclosure. *Academy of Management Discoveries*, 7(1), 40–56.

<https://doi.org/10.5465/amd.2018.0229>

- Camilleri, M. A. (2017). Socially Responsible and Sustainable Investing. In *Corporate Sustainability, Social Responsibility and Environmental Management* (pp. 61–77). Springer Nature. https://doi.org/10.1007/978-3-319-46849-5_4
- Camilleri, M. A. (2020). The market for socially responsible investing: A review of the developments. *Social Responsibility Journal*, 17(3), 412–428. <https://doi.org/10.1108/SRJ-06-2019-0194>
- Campbell, N. (2021). The Duty to Update Corporate Emissions Pledges. *Vanderbilt Law Review*, 74(4), 1137–1186. <http://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=00422533&AN=150600358&h=y1RxVTNj5K6dgCJTypi5INahYo5Gdr06jMCmfakT7dRXs8fIwutr4Ji1O9xfUPRLI28ZA8E80ki7pKwRtJz1Tw%3D%3D&crl=c>
- Campiglio, E., Dafermos, Y., Monnin, P., Ryan-collins, J., Schotten, G., & Tanaka, M. (2018). Climate change challenges for central banks and financial regulators. *Nature Climate Change*, 8(June 2018), 462.468. <https://doi.org/10.1038/s41558-018-0175-0>
- Campiglio, E., Jagow, A. Von, Daumas, L., & Monnin, P. (2023). Climate-related risks in financial assets. *Journal of Economic Survey*, 37, 950–992. <https://doi.org/10.1111/joes.12525>
- Carney, M. (2015). Breaking the Tragedy of the Horizon – climate change and financial stability. *Speech given at Lloyd's of London*, 29, 220–230.
- Carpinetti, L. C. R., & De Melo, A. M. (2002). What to benchmark? A systematic approach and cases. *Benchmarking: An International Journal*, 9(3), 244–255. <https://doi.org/10.1108/14635770210429009>
- CDP. (2018). *CDP Academic Data Package (2010 to 2018)*. <https://www.cdp.net/en/data/corporate-data#84637b799821f4e01a65f9637ecb3548>
- CDP. (2020a). *CDP Climate Change 2020 Questionnaire*.
- CDP. (2020b). *CDP Climate Change 2020 Reporting Guidance*. <https://guidance.cdp.net/en/guidance?cid=13&ctype=theme&idtype=ThemeID&incchild=1µsite=0&otype=Guidance&tags=TAG-646%2CTAG-605%2CTAG-600>

- CDP. (2020c). *CDP Climate Change 2020 Scoring Methodology*. <https://guidance.cdp.net/en/guidance?cid=13&ctype=theme&idtype=ThemeID&incchild=1µsite=0&otype=ScoringMethodology&tags=TAG-599%2CTAG-605%2CTAG-646>
- CDP. (2021a). *What we do*. <https://www.cdp.net/en/info/about-us/what-we-do>
- CDP. (2021b). *Who we are*. <https://www.cdp.net/en/info/about-us>
- CDP. (2022). *CDP Climate Change 2022 Reporting Guidance*. www.cdp.net
- CDP. (2023). *CDP Academic Datasets 2023: The largest primary environmental dataset in the world*. https://cdn.cdp.net/cdp-production/comfy/cms/files/files/000/008/569/original/CDP_2023_Academic_Data_Brochure.pdf
- CDP. (2024a). *CDP Full Corporate Questionnaire: Module 7*. https://cdn.cdp.net/cdp-production/comfy/cms/files/files/000/009/101/original/CDP_2024_Corporate_Questionnaire_Guidance_Module_7.pdf
- CDP. (2024b). *CDP SME corporate questionnaire*. <https://www.cdp.net/en/2024-disclosure/cdp-sme-questionnaire>
- CDP. (2024c). *CDP Technical Note: Relevance of Scope 3 Categories by Sector*. https://cdn.cdp.net/cdp-production/cms/guidance_docs/pdfs/000/003/504/original/CDP-technical-note-scope-3-relevance-by-sector.pdf
- CFA Institute, GSIA, & PRI. (2023). *Definitions for Responsible Investment Approaches*. <https://www.gsi-alliance.org/members-resources/definitions-for-responsible-investment-approaches/>
- Chatterji, A., Durand, R., Levine, D., & Touboul, S. (2016). Do Ratings of Firms Converge? Implications for Managers, Investors and Strategy Researchers. *Strategic Management Journal*, 37(8), 1597–1614.
- Chatterji, A. K., Levine, D. I., & Toffel, M. W. (2009). How Well Do Social Ratings Actually Measure Corporate Social Responsibility? *Journal of Economics & Management Strategy*, 18(1), 125–169. <https://doi.org/10.1111/j.1530-9134.2009.00210.x>
- Chatzitheodorou, K., Skouloudis, A., Evangelinos, K., & Nikolaou, I. (2019). Exploring socially

- responsible investment perspectives: A literature mapping and an investor classification. *Sustainable Production and Consumption*, 19, 117–129. <https://doi.org/10.1016/j.spc.2019.03.006>
- Cheng, H., Feng, Y., & Dong, D. (2023). Will emission reduction commitments hedge the carbon risk premium? *Journal of Cleaner Production*, 430, 139747. <https://doi.org/10.1016/j.jclepro.2023.139747>
- Cherry, M. A., & Sneirson, J. F. (2011). Beyond Profit: Rethinking Corporate Social Responsibility and Greenwashing After the BP Oil Disaster. *Tulane Law Review*, 85(4), 983–1038. <https://doi.org/doi.org/10.2139/ssrn.1670149> This
- Chithambo, L., Tauringana, V., & Achiro, L. (2022). Stakeholder pressure and greenhouses gas voluntary disclosures. *Business Strategy and the Environment*, 31(July 2021), 159–172. <https://doi.org/10.1002/bse.2880>
- Chmel, L., Kathan, M. C., & Utz, S. (2023). Are Implied Temperature Rise Metrics as Inconsistent as ESG Ratings?: Examining Firm-Level Disagreement Among Data Providers. *SSRN Electronic Journal*. <https://doi.org/10.2139/ssrn.4494958>
- Choi, B., & Luo, L. (2021). Does the market value greenhouse gas emissions ? Evidence from multi-country fi rm data. *The British Accounting Review*, 53(1), 100909. <https://doi.org/10.1016/j.bar.2020.100909>
- Christensen, D., Serafeim, G., & Anywhere, S. (2022). Why is Corporate Virtue in the Eye of The Beholder? The Case of ESG Ratings. *The Accounting Review*, 97(1), 147–175. <https://doi.org/10.2308/TAR-2019-0506>
- Christophers, B. (2017). Climate Change and Financial Instability: Risk Disclosure and the Problematics of Neoliberal Governance. *Annals of the American Association of Geographers*, 107(5), 1108–1127. <https://doi.org/10.1080/24694452.2017.1293502>
- Climate Action 100+. (2019). 2019 Progress Report. <https://climateaction100.files.wordpress.com/2019/10/progressreport2019.pdf>
- Climate Action 100+. (2023). *Net Zero Company Benchmark 2.0: 2023 Results* (Issue October). <https://www.climateaction100.org/wp-content/uploads/2023/10/2023-Key-Findings.pdf>

- Condon, M. (2020). Externalities and the Common Owner. *Washington Law Review*, 95(1).
- Cowton, C. J. (1999). Accounting and financial ethics: from margin to mainstream. *Business Ethics: A European Review*, 8(2), 99–107.
- Cremasco, C., & Boni, L. (2022). Is the European Union (EU) Sustainable Finance Disclosure Regulation (SFDR) effective in shaping sustainability objectives? An analysis of investment funds' behaviour. *Journal of Sustainable Finance and Investment*, 0(0), 1–19. <https://doi.org/10.1080/20430795.2022.2124838>
- Cunha, F. A. F. de S., Meira, E., & Orsato, R. J. (2021). Sustainable finance and investment: Review and research agenda. *Business Strategy and the Environment*, 30(8), 3821–3838. <https://doi.org/10.1002/bse.2842>
- Dafermos, Y., Nikolaidi, M., & Galanis, G. (2018). Climate change , financial stability and monetary policy Climate change , financial stability and monetary policy. *Ecological Economics*, 152, 219–234.
- Dahlmann, F. (2023). Corporate Carbon Targets: The Role of Goal Setting in Driving Organisational Change for Climate Action. In *The Handbook of Climate Change Leadership in Organisations* (pp. 347–368). <https://doi.org/10.4324/9781003343011-21>
- Dahlmann, F., Brammer, S., & Roehrich, J. K. (2023). Navigating the “performing- organizing” paradox: tensions between supply chain transparency, coordination, and scope 3 GHG emissions performance. *International Journal of Operations & Production Management*, 43(11), 1757–1780. <https://doi.org/10.1108/IJOPM-09-2022-0622>
- Dahlmann, F., Branicki, L., & Brammer, S. (2019). Managing Carbon Aspirations: The Influence of Corporate Climate Change Targets on Environmental Performance. *Journal of Business Ethics*, 158, 1–24. <https://doi.org/10.1007/s10551-017-3731-z>
- Daley, P., & O'Neill, D. (1991). “ Sad Is Too Mild a Word ”: Press Coverage of the Exxon Valdez Oil Spill. *Journal of Communication*, 41(4), 42–57. <https://doi.org/10.1111/j.1460-2466.1991.tb02330.x>
- Daoud, J. I. (2017). Multicollinearity and Regression Analysis. *Journal of Physics: Conference Series*, 949(1), 012009. <https://doi.org/doi:10.1088/1742-6596/949/1/012009>

- Datt, R., Prasad, P., Vitale, C., & Prasad, K. (2021). International evidence of changing assurance practices for carbon emissions disclosures. *Meditari Accountancy Research*, 30(6), 1594–1628. <https://doi.org/10.1108/MEDAR-09-2020-1005>
- Daumas, L. (2024). Financial stability, stranded assets and the low-carbon transition – A critical review of the theoretical and applied literatures. *Journal of Economic Survey*, 38, 601–716. <https://doi.org/10.1111/joes.12551>
- Day, T., Hans, F., Mooldijk, S., Smit, S., Woollands, S., de Grandpré, J., Putri Salsabila, N., Fraser, E., Kuramochi, T., & Warnecke, C. (2024). *Corporate Climate Responsibility Monitor 2024*. https://newclimate.org/sites/default/files/2024-04/NewClimate_CCRM2024.pdf
- Day, T., Mooldijk, S., Smit, S., Posada, E., Hans, F., Fearnehough, H., Kachi, A., Warnecke, C., Kuramochi, T., Höhne, N., & Hohne, N. (2022). *Corporate Climate Responsibility Monitor 2022* (Issue February). <http://newclimate.org/publications/>
- Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California Management Review*, 54(1), 64–87. <http://journals.sagepub.com/doi/abs/10.1525/cm.2011.54.1.64> https://www0.gsb.columbia.edu/mygsb/faculty/research/pubfiles/14016/cm5401_04_printversion_delmasburbano.pdf
- Depoers. (2022). Une brève histoire du Carbon Disclosure Project ou les investisseurs institutionnels face au défi climatique. *Rencontres*, 544, 399–413.
- Depoers, F., & Jeanjean, T. (2016). Voluntary Disclosure of Greenhouse Gas Emissions : Contrasting the Carbon Disclosure Project and Corporate Reports. *Journal of Business Ethics*, 134, 445–461. <https://doi.org/10.1007/s10551-014-2432-0>
- Dépoues, V., Bouchet, V., Cardona, M., & Nicol, M. (2019). *Pour une autre approche du risque climatique en finance: Tenir pleinement compte des incertitudes*.
- Derwall, J., Koedijk, K., & Ter Horst, J. (2011). A tale of values-driven and profit-seeking social investors. *Journal of Banking and Finance*, 35(8), 2137–2147. <https://doi.org/10.1016/j.jbankfin.2011.01.009>
- Desai, H., Lam, P., Li, B., & Rajgopal, S. (2023). An Analysis of Carbon Reduction Pledges of the U.S. Oil and Gas Companies. *Management Science*, 69(6), 3748–3758.

- Dessaint, O., & Matray, A. (2017). Do managers overreact to salient risks? Evidence from hurricane strikes. *Journal of Financial Economics*, 126(1), 97–121.
- Deville, L. (2008). Exchange traded funds: History, trading, and research. In *Handbook of financial engineering* (pp. 67–97). Springer. https://doi.org/10.1007/978-0-387-76682-9_4
- Dietz, S., Bienkowska, B., Gardiner, D., Hastreiter, N., Jahn, V., Komar, V., Scheer, A., & Sullivan, R. (2021). *TPI State of Transition Report 2021*. <https://www.transitionpathwayinitiative.org/publications/82.pdf?type=Publication>
- Dietz, S., Bowen, A., Dixon, C., & Gradwell, P. (2016). Climate value at risk of global financial assets. *Nature Climate Change*, 6(7), 676–679. <https://doi.org/10.1038/nclimate2972>
- Dietz, S., Fruitiere, C., Garcia-manas, C., Irwin, W., Rauis, B., & Sullivan, R. (2018). An assessment of climate action by high-carbon global corporations. *Nature Climate Change*, 8(December), 1072–1075. <https://doi.org/10.1038/s41558-018-0343-2>
- Dietz, S., Gardiner, D., Hastreiter, N., Jahn, V., & Noels, J. (2021). Carbon Performance Assessment of Oil & Gas Producers: Note on Methodology. In *Transition Pathway initiative* (Issue November). <http://www.lse.ac.uk/GranthamInstitute/tpi/about/how-investors-can-use>
- Dietz, S., Gardiner, D., Jahn, V., & Noels, J. (2021). How ambitious are oil and gas companies' climate goals? *Science*, 374(6566), 405–408. <https://doi.org/10.1126/science.abh0687>
- Ding, D., Liu, B., & Chang, M. (2023). Carbon Emissions and TCFD Aligned Climate - Related Information Disclosures. *Journal of Business Ethics*, 182(4), 967–1001. <https://doi.org/10.1007/s10551-022-05292-x>
- Doda, B., Gennaioli, C., Gouldson, A., Grover, D., & Sullivan, R. (2016). Are Corporate Carbon Management Practices Reducing Corporate Carbon Emissions? *Corporate Social Responsibility and Environmental Management*, 23(5), 257–270. <https://doi.org/10.1002/csr.1369>
- Domeisen, D. I. V. (2019). Estimating the Frequency of Sudden Stratospheric Warming Events From Surface Observations of the North Atlantic Oscillation. *Journal of Geophysical Research: Atmospheres*, 124, 3180–3194. <https://doi.org/10.1029/2018JD030077>
- Domini, A. L. (2001). Past Is Prologue: How the SRI Movement Started, and How It Continuously

- Evolves. In *Socially Responsible Investing: Making a difference and making money* (pp. 28–48). Dearborn Trade.
- Dordi, T., Stephens, P., Geobey, S., & Weber, O. (2024). New bottle or new label? Distinguishing impact investing from responsible and ethical investing. *Accounting & Finance*, 64, 309–330. <https://doi.org/10.1111/acfi.13147>
- Doumpos, M., Eskantar, M., & Zopounidis, C. (2023). Socially and Environmentally Responsible Investments and Mutual Funds. In Palgrave Macmillan (Ed.), *Sustainable Finance and ESG* (pp. 71–89). Springer International Publishing. <https://doi.org/10.1007/978-3-031-24283-0>
- Dragomir, V. D. (2012). The disclosure of industrial greenhouse gas emissions: a critical assessment of corporate sustainability reports. *Journal of Cleaner Production*, 29(30), 222–237. <https://doi.org/10.1016/j.jclepro.2012.01.024>
- Dragomir, V. D. (2023). Carbon reduction and energy transition targets of the largest European companies: An empirical study based on institutional theory. *Cleaner Production Letters*, 4, 100039. <https://doi.org/10.1016/j.clpl.2023.100039>
- Drempetic, S., Klein, C., & Zwergel, B. (2020). The Influence of Firm Size on the ESG Score: Corporate Sustainability Ratings Under Review. *Journal of Business Ethics*, 167(2), 333–360. <https://doi.org/10.1007/s10551-019-04164-1>
- Dumas, C., & Louche, C. (2016). Collective Beliefs on Responsible Investment. *Business & Society*, 55(3), 427–457. <https://doi.org/10.1177/0007650315575327>
- Dwyer, B. O., & Unerman, J. (2020). Shifting the focus of sustainability accounting from impacts to risks and dependencies: Researching the transformative potential of TCFD reporting. *Accounting, Auditing & Accountability Journal*, 33(5), 1113–1141.
- Dyck, A., Lins, K. V., Roth, L., & Wagner, H. F. (2019). Do institutional investors drive corporate social responsibility? International evidence R. *Journal of Financial Economics*, 131(3), 693–714. <https://doi.org/10.1016/j.jfineco.2018.08.013>
- Eccles, N. S., & Viviers, S. (2011). The Origins and Meanings of Names Describing Investment Practices that Integrate a Consideration of ESG Issues in the Academic Literature. *Journal of Business Ethics*, 104(3), 389–402. <https://doi.org/10.1007/s10551-011-0917-7>

- Eccles, R. G. (2024, April 18). Untangling Climate Risk, Financial Risk, And Climate Impact. *Forbes*. <https://www.forbes.com/sites/bobeccles/2024/04/18/untangling-climate-risk-financial-risk-and-climate-impact/?sh=c5d0bc13a283>
- Eccles, R. G., Krzus, M. P., Rogers, J., & Serafeim, G. (2012). The Need for Sector-Specific Materiality and Sustainability Reporting Standards. *Journal of Applied Corporate Finance*, 24(2), 65–71. <https://doi.org/10.1111/j.1745-6622.2012.00380.x>
- Eccles, R. G., Lee, L.-E., & Strohle, J. (2019). The Social Origins of ESG: An Analysis of Innovest and KLD. *Organization & Environment*, 33(4), 575–596. <https://doi.org/10.2139/ssrn.3318225>
- Eccles, R., & Strohle, J. (2018). *Exploring Social Origins in the Construction of ESG Measures*. <https://www.esginvesting.co.uk/wp-content/uploads/2019/07/Judith-Stoehle.pdf>
- Edmans, A. (2011). Does the stock market fully value intangibles? Employee satisfaction and equity prices. *Journal of Financial Economics*, 101(3), 621–640. <https://doi.org/10.1016/j.jfineco.2011.03.021>
- Edmans, A. (2023). The end of ESG. *Financial Management*, 52(3), 3–17. <https://doi.org/10.1111/fima.12413>
- Edmans, A., Levit, D., & Schneemeier, J. (2022). *Socially Responsible Divestment* (823). Centre for Economic Policy Research. https://www.ecgi.global/sites/default/files/working_papers/documents/sociallyresponsibledivestment_0.pdf
- Edmans, A., Pu, D., Zhang, C., & Li, L. (2023). Employee Satisfaction, Labor Market Flexibility, and Stock Returns Around The World. *Management Science*.
- Efron, B., & Tibshirani, R. J. (1994). *An Introduction to the Bootstrap*. Chapman and Hall/CRC.
- Eleftheriadis, I., & Anagnostopoulou, E. (2017). Measuring the level of corporate commitment regarding climate change strategies. *International Journal of Climate Change Strategies and Management*, 9(5), 626–644. <https://doi.org/10.1108/IJCCSM-09-2016-0145>
- Erickson, P., Lazarus, M., & Piggot, G. (2018). Limiting fossil fuel production as the next big step in climate policy. *Nature Climate Change*, 8(12), 1037–1043.

- Escrig-Olmedo, E., Fernández-Izquierdo, M. ángeles, Ferrero-Ferrero, I., Rivera-Lirio, J. M., & Muñoz-Torres, M. J. (2019). Rating the raters: Evaluating how ESG rating agencies integrate sustainability principles. *Sustainability*, 11(3), 915. <https://doi.org/10.3390/su11030915>
- EU Technical Expert Group on Sustainable Finance. (2019). *HANDBOOK OF CLIMATE TRANSITION BENCHMARKS , PARIS-ALIGNED BENCHMARK AND BENCHMARKS ' ESG DISCLOSURES*.
- Eurosif. (2023). *Eurosif Report on Climate-related Data: The Investors' Perspective*. <https://www.eurosif.org/wp-content/uploads/2023/05/Eurosif-Report-on-Climate-related-Data.pdf>
- Falck, O., & Heblich, S. (2007). Corporate social responsibility: Doing well by doing good. *Business Horizons*, 50(3), 247–254. <https://doi.org/10.1016/j.bushor.2006.12.002>
- Fankhauser, S., Smith, S. M., Allen, M., Axelsson, K., Hale, T., Hepburn, C., Kendall, J. M., Khosla, R., Lezaun, J., Mitchell-larson, E., Obersteiner, M., Rajamani, L., Rickaby, R., Seddon, N., & Wetzler, T. (2022). The meaning of net zero and how to get it right. *Nature Climate Change*, 12, 15–21. <https://doi.org/10.1038/s41558-021-01245-w>
- Feyen, E., Utz, R., Zuccardi Huertas, I., Bogdan, O., & Moon, J. (2020). *Macro-Financial Aspects of Climate Change* (Vol. 1, Issue January).
- Findlay, S., & Moran, M. (2019). Purpose-washing of impact investing funds: motivations, occurrence and prevention. *Social Responsibility Journal*, 15(7), 853–873. <https://doi.org/10.1108/SRJ-11-2017-0260>
- Forzieri, G., Bianchi, A., Batista, F., Herrera, M. A. M., Leblois, A., Lavalle, C., Aerts, J. C. J. H., & Feyen, L. (2018). Escalating impacts of climate extremes on critical infrastructures in Europe. *Global Environmental Change*, 48, 97–107. <https://doi.org/10.1016/j.gloenvcha.2017.11.007>
- Freeman III, A. . M. (2002). Environmental Policy Since Earth Day I: What Have We Gained ? *Journal OfEconomic Perspectives*, 16(1), 125–146.
- Freiberg, D., Grewal, J., & Serafeim, G. (2021). Science-Based Carbon Emissions Targets. In *Harvard Business School Working Paper* (No. 21–108). <https://doi.org/10.2139/ssrn.3804530>

- Freshfields Bruckhaus Deringer. (2005). A legal framework for the integration of environmental, social and governance issues into institutional investment. In *Asset Management Working Group of the UNEP Finance Initiative*. https://www.unepfi.org/fileadmin/documents/freshfields_legal_resp_20051123.pdf
- Friede, G., Busch, T., & Bassen, A. (2015). ESG and financial performance: aggregated evidence from more than 2000 empirical studies. *Journal of Sustainable Finance & Investment*, 5(4), 210–233. <https://doi.org/10.1080/20430795.2015.1118917>
- Friedlingstein, P., O’sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., Le Quéré, C., Luijkx, I. T., Olsen, A., & Peters, G. P. (2022). Global carbon budget 2022. *Earth System Science Data*, 14(11), 4811–4900.
- FSB, & NGFS. (2022). *Climate Scenario Analysis by Jurisdictions* (Issue November). <https://www.fsb.org/wp-content/uploads/P151122.pdf>
- Galloppo, G., Aliano, M., & Paimanova, V. (2023). European Environmental Policy and Climate Benchmarks: What Happens to my Money? *Green Economics*, 1(1), 5–24.
- Garcia-Vega, S., Hoepner, A. G. F., Rogelj, J., & Schiemann, F. (2023). Abominable greenhouse gas bookkeeping casts serious doubts on climate intentions of oil and gas companies. *ArXiv Preprint ArXiv:2305.11906*. <http://arxiv.org/abs/2305.11906>
- Geobey, S., & Brierley, T. (2023). The Hidden Costs of Impact Measurement. In *The Routledge Handbook of Green Finance* (pp. 416–428). Routledge.
- GFANZ. (2023). *Scaling Transition Finance and Real-economy Decarbonization: Supplement to the 2022 Net-zero Transition Plans report*. <https://assets.bbhub.io/company/sites/63/2023/11/Transition-Finance-and-Real-Economy-Decarbonization-December-2023.pdf>
- GHG Protocol. (2011). *Corporate Value Chain (Scope 3) Accounting and Reporting Standard*. https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporting-Standard_041613_2.pdf
- Gibson Brandon, R., Glossner, S., Krueger, P., Matos, P., & Steffen, T. (2023). Do Responsible Investors Invest Responsibly? *Review of Finance*, 26(6), 1383–1432.

- Giesekam, J., Densley, D., & Cotton, I. (2018). Aligning carbon targets for construction with (inter) national climate change mitigation commitments. *Energy & Buildings*, 165, 106–117. <https://doi.org/https://doi.org/10.1016/j.enbuild.2018.01.023>
- Giesekam, J., Norman, J., Garvey, A., & Betts-davies, S. (2021a). Science-Based Targets: On Target? *Sustainability*, 13(4), 1657. <https://doi.org/https://doi.org/10.3390/su13041657>
- Giesekam, J., Norman, J., Garvey, A., & Betts-davies, S. (2021b). Science-Based Targets: On Target? Supplementary Materials. *Sustainability*, 13(4).
- Giglio, S., Kelly, B., & Stroebe, J. (2021). Climate Finance. *Annual Review of Financial Economics*, 13, 15–36. <https://doi.org/10.1146/annurev-financial-102620-103311>
- Gillan, S. L., & Starks, L. T. (2007). The Evolution of Shareholder Activism in the United States. *Journal of Applied Corporate Finance*, 19(1), 55–73.
- Ginglinger, E., & Moreau, Q. (2023). Climate Risk and Capital Structure. *Management Science*, 69(12), 7492–7516.
- Giuzio, M., Krusec, D., Levels, A., Melo, A. S., Mikkonen, K., & Radulova, P. (2019). Climate change and financial stability. *Financial Stability Review*, 1, 1–13. https://www.ecb.europa.eu/pub/financial-stability/fsr/special/html/ecb.fsrart201905_1~47cf778cc1.en.html#toc1
- Glaeser, E. L., & Scheinkman, J. (1998). Neither a Borrower Nor a Lender Be: An Economic Analysis of Interest Restrictions and Usury Laws. *Journal of Law and Economics*, 41(1), 1–36. <https://doi.org/10.1086/467383>
- Glossner, S. (2021). Repeat Offenders: ESG Incident Recidivism and Investor Underreaction. *SSRN Electronic Journal*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3004689
- Goldhammer, B., Busse, C., & Busch, T. (2017). Estimating Corporate Carbon Footprints with Externally Available Data. *Journal of Industrial Ecology*, 21(5), 1165–1179. <https://doi.org/10.1111/jiec.12522>
- Goldstein, A., Turner, W. R., Gladstone, J., & Hole, D. G. (2019). The private sector's climate change risk and adaptation blind spots. *Nature Climate Change*, 9(1), 18–25. <https://doi.org/10.1038/s41558-018-0340-5>

- Goranova, M., & Ryan, L. V. (2014). Shareholder Activism: A multidisciplinary review. *Journal of Management*, 40(5), 1230–1268. <https://doi.org/10.1177/0149206313515519>
- Gosling, T., & Macneil, I. (2023). Can investors save the planet? NZAMI and fiduciary duty. *Capital Markets Law Journal*, 18(2), 172–193. <https://doi.org/https://doi.org/10.1093/cmlj/kmad002>
- Gouldson, A., & Sullivan, R. (2013). Long-term corporate climate change targets: What could they deliver? *Environmental Science and Policy*, 27, 1–10. <https://doi.org/10.1016/j.envsci.2012.11.013>
- GRAIN, & Institute for Agriculture and Trade Policy. (2018). *Emissions imposible: How big mat and dairy are heating up the planet* (Issue July). <https://www.grain.org/article/entries/5976-emissions-impossible-how-big-meat-and-dairy-are-heating-up-the-planet>.
- Grasso, M., & Heede, R. (2023). Time to pay the piper: Fossil fuel companies ' reparations for climate damages. *One Earth*, 6(5), 459–463. <https://doi.org/10.1016/j.oneear.2023.04.012>
- GSIA. (2023). *Global Sustainable Investment Review 2022*. <https://www.gsi-alliance.org/wp-content/uploads/2023/12/GSIA-Report-2022.pdf>
- Gyönyörová, L., Stachoň, M., & Stašek, D. (2023). ESG ratings: relevant information or misleading clue? Evidence from the S&P Global 1200. *Journal of Sustainable Finance and Investment*, 13(2), 1075–1109. <https://doi.org/10.1080/20430795.2021.1922062>
- Hadi, A. S., Rahmatullah Imon, A. H. M., & Werner, M. (2009). Detection of outliers. *Wiley Interdisciplinary Reviews: Computational Statistics*, 1(1), 57–70. <https://doi.org/10.1002/wics.6>
- Hale, T., Chan, S., Hsu, A., Clapper, A., Elliott, C., Faria, P., Kuramochi, T., McDaniel, S., Morgado, M., Roelfsema, M., Santaella, M., Singh, N., Tout, I., Weber, C., Weinfurter, A., & Widerberg, O. (2021). Sub- and non-state climate action: a framework to assess progress, implementation and impact. *Climate Policy*, 21(3), 406–420. <https://doi.org/10.1080/14693062.2020.1828796>
- Hale, T., Smith, S. M., Black, R., Cullen, K., Fay, B., Lang, J., & Mahmood, S. (2022). Assessing the rapidly-emerging landscape of net zero targets. *Climate Policy*, 22(1), 18–29. <https://doi.org/10.1080/14693062.2021.2013155>

- Hale, T., Wetzter, T., Abebe, S. K., Allen, M., Amel-zadeh, A., Armour, J., Axelsson, K., Caldecott, B., Dias, L., Fankhauser, S., Franta, B., Hepburn, C., Mbeva, K., Rajamani, L., Smith, S., & Stuart-smith, R. (2024). Turning a groundswell of climate action into ground rules for net zero. *Nature Climate Change*, 14(April), 306–308. <https://doi.org/10.1038/s41558-024-01967-7>
- Hampton, S., & Whitmarsh, L. (2023). Choices for climate action: A review of the multiple roles individuals play. *One Earth*, 6(9), 1157–1172. <https://doi.org/10.1016/j.oneear.2023.08.006>
- Hansen, A. D., Kuramochi, T., & Wicke, B. (2022). The status of corporate greenhouse gas emissions reporting in the food sector: An evaluation of food and beverage manufacturers. *Journal of Cleaner Production*, 361(July 2021), 132279. <https://doi.org/10.1016/j.jclepro.2022.132279>
- Harangozo, G., & Szigeti, C. (2017). Corporate carbon footprint analysis in practice - With a special focus on validity and reliability issues. *Journal of Cleaner Production*, 167, 1177–1183. <https://doi.org/10.1016/j.jclepro.2017.07.237>
- Hasegawa, T., Fujimori, S., Takahashi, K., Yokohata, T., & Masui, T. (2016). Economic implications of climate change impacts on human health through undernourishment. *Climatic Change*, 136(2), 189–202. <https://doi.org/10.1007/s10584-016-1606-4>
- Hawley, J., & Williams, A. (2007). Universal owners: Challenges and opportunities. *Corporate Governance: An International Review*, 15(3), 415–420. <https://doi.org/10.1111/j.1467-8683.2007.00574.x>
- He, A. (2022). Unpacking the Value of Corporate Net Zero Commitments. *Available at SSRN* 4023591. <https://doi.org/10.2139/ssrn.4023591>
- He, R., Luo, L., Shamsuddin, A., & Tang, Q. (2020). Corporate carbon accounting: a literature review of carbon accounting research from the Kyoto Protocol to the Paris Agreement. *Accounting & Finance*, 62(1), 261–298. <https://doi.org/10.1111/acfi.12789>
- Heede, R. (2014). Tracing anthropogenic carbon dioxide and methane emissions to fossil fuel and cement producers, 1854-2010. *Climatic Change*, 122(1), 229–241. <https://doi.org/10.1007/s10584-013-0986-y>
- Heinze, G., Wallisch, C., & Dunkler, D. (2018). Variable selection – A review and

- recommendations for the practicing statistician. *Biometrical Journal*, 60(April 2017), 431–449. <https://doi.org/10.1002/bimj.201700067>
- Herremans, I. M., Akathaporn, P., & McInnes, M. (1993). An investigation of corporate social responsibility reputation and economic performance. *Accounting Organizations and Society*, 18(7/8), 587–604. [https://doi.org/10.1016/0361-3682\(93\)90044-7](https://doi.org/10.1016/0361-3682(93)90044-7)
- Herzog, T., Baumert, K. A., & Pershing, J. (2006). *Target: Intensity. An analysis of Greenhouse Gas Intensity Targets*. World Resources Institute.
- Hesterberg, T. (2011). Bootstrap. *Wiley Interdisciplinary Reviews: Computational Statistics*, 3(6), 497–526. <https://doi.org/10.1002/wics.182>
- Hochstadter, A. K., & Scheck, B. (2015). What's in a Name: An Analysis of Impact Investing Understandings by Academics and Practitioners. *Journal of Business Ethics*, 132, 449–475. <https://doi.org/10.1007/s10551-014-2327-0>
- Hockerts, K., Hehenberger, L., Schaltegger, S., & Farber, V. (2022). Defining and Conceptualizing Impact Investing: Attractive Nuisance or Catalyst ? *Journal of Business Ethics*, 179(4), 937–950. <https://doi.org/10.1007/s10551-022-05157-3>
- Hodges, P., Ren, H., Schwaiger, K., & Ang, A. (2022). Net Zero Investing for Multi-Asset Portfolios seeking to satisfy Paris Aligned Benchmark Requirements with Climate Alpha Signals. *Available at SSRN 4005308*.
- Hoepner, A. G. F., & Rogelj, J. (2021). Emissions estimations should embed a precautionary principle. *Nature Climate Change*, 11(8), 638–640. <https://doi.org/10.1038/s41558-021-01109-3>
- Hoffmann, V. H., & Busch, T. (2008). Corporate carbon performance indicators: Carbon intensity, dependency, exposure, and risk. *Journal of Industrial Ecology*, 12(4), 505–520. <https://doi.org/10.1111/j.1530-9290.2008.00066.x>
- Hsiang, S., Kopp, R., Jina, A., Rising, J., Delgado, M., Mohan, S., Rasmussen, D. J., Muir-wood, R., Wilson, P., Oppenheimer, M., Larsen, K., & Houser, T. (2017). Estimating economic damage from climate change in the United States. *Science*, 356(June), 1362–1369.
- Hsu, A., Chan, S., Roelfsema, M., Schletz, M., Kuramochi, T., Smit, S., & Deneault, A. (2023).

- From drumbeating to marching: Assessing non-state and subnational climate action using data. *One Earth*, 6(9), 1077–1081. <https://doi.org/10.1016/j.oneear.2023.08.021>
- Hsu, A., Tan, J., Ng, Y. M., Toh, W., Vanda, R., & Goyal, N. (2020). Performance determinants show European cities are delivering on climate mitigation. *Nature Climate Change*, 10(11), 1015–1022. <https://doi.org/10.1038/s41558-020-0879-9>
- Hsu, P., Li, K., & Tsou, C. (2023). The Pollution Premium. *The Journal of Finance*, 78(3), 1343–1392.
- Huang, Y. A., Weber, C. L., & Matthews, H. S. (2009). Categorization of scope 3 emissions for streamlined enterprise carbon footprinting. *Environmental Science and Technology*, 43(22), 8509–8515. <https://doi.org/10.1021/es901643a>
- Hunt, A., & Watkiss, P. (2011). Climate Change Impacts and Adaptation in Cities: A Review of the Literature. *Climatic Change*, 104(1), 13–49. <https://doi.org/10.1007/s10584-010-9975-6>
- IEA. (2019). *World Energy Outlook 2019*.
- IEA. (2020). *World Energy Outlook 2020*.
- IFRS. (2024a). *ISSB and TCFD*. <https://www.ifrs.org/sustainability/tcfd/#:~:text=The Financial Stability Board has also asked the IFRS Foundation,supporters is no longer active>.
- IFRS. (2024b). *Use around the world: Why global accounting standards*. <https://www.ifrs.org/use-around-the-world/why-global-accounting-standards/>
- IIGCC. (2021). *Net Zero Investment Framework 1.5* (Issue March).
- Immink, H., Louw, R. T., & Brent, A. C. (2018). Tracking decarbonisation in the mining sector. *Journal of Energy in Southern Africa*, 29(1), 14–23. <https://doi.org/10.17159/2413-3051/2018/v29i1a3437>
- In, S. Y., & Schumacher, K. (2021). *Carbonwashing: A New Type of Carbon Data-related ESG Greenwashing Working Paper Table of Contents* (Issue July). <https://assets.bbhub.io/company/sites/63/2023/11/Transition-Finance-and-Real-Economy-Decarbonization-December-2023.pdf>
- Institut Louis Bachelier. (2020). *The alignment cookbook: A Technical Review of Methodologies Assessing a Portfolio's Alignment with Low-Carbon Trajectories or Temperature Goal*.

- Ioannou, I., Li, S. X., & Serafeim, G. (2016). The effect of target difficulty on target completion: The case of reducing carbon emissions. *The Accounting Review*, 91(5), 1467–1492. <https://doi.org/10.2308/accr-51307>
- Ioannou, I., & Serafeim, G. (2017). The Consequences of Mandatory Corporate Sustainability Reporting. *Harvard Business School Research Working Paper*, 11(100), 1–45.
- IOSCO. (2021). *Recommendations on Sustainability-Related Practices, Policies, Procedures and Disclosure in Asset Management: Final Report*. <https://www.iosco.org/library/pubdocs/pdf/IOSCOPD688.pdf>
- Jackson, R. B., Le Quéré, C., Andrew, R. M., Canadell, J. G., Korsbakken, J. I., Liu, Z., Peters, G. P., & Zheng, B. (2018). Global energy growth is outpacing decarbonization. *Environmental Research Letters*, 13(12). <https://doi.org/10.1088/1748-9326/aaf303>
- Jebe, R. (2019). The Convergence of Financial and ESG Materiality: Taking Sustainability Mainstream. *American Business Law Journal*, 56(3), 645–702. <https://doi.org/10.1111/ablj.12148>
- Jiang, X., Kim, S., & Lu, S. (2023). Accountability of Corporate Emissions Reduction Targets. *Available at SSRN 4676649*, December.
- Kabeyi, M. J. B. (2019). Corporate Governance in Manufacturing and Management with Analysis of Governance Failures at Enron and Volkswagen Corporations. *American Journal of Operations Management and Information Systems*, 4(4), 109–123. <https://doi.org/10.11648/j.ajomis.20190404.11>
- Kalesnik, V., Wilkens, M., & Zink, J. (2021). Green Data or Greenwashing? Do Corporate Carbon Emissions Data Enable Investors to Mitigate Climate Change? *SSRN Electronic Journal*, 1–52. <https://doi.org/10.2139/ssrn.3722973>
- Kemfert, C., Präger, F., Braunger, I., Hoffart, F. M., & Brauers, H. (2022). The expansion of natural gas infrastructure puts energy transitions at risk. *Nature Energy*, 7(7), 582–587. <https://doi.org/10.1038/s41560-022-01060-3>
- Khandelwal, U., Sharma, P., & Nagarajan, V. (2022). Valuation effects of emissions reduction target disclosures. *Finance Research Letters*, 49(June), 103080. <https://doi.org/10.1016/j.frl.2022.103080>

- Kim, S., & Yoon, A. S. (2023). Analyzing active fund managers' commitment to ESG: Evidence from the United Nations Principles for Responsible Investment. *Management Science*, 69(2), 741–758.
- Klaaßen, L., & Stoll, C. (2021). Harmonizing corporate carbon footprints. *Nature Communications*, 12(1), 1–13. <https://doi.org/10.1038/s41467-021-26349-x>
- Kleimann, D., Poitiers, N., Sapir, A., Tagliapietra, S., Véron, N., Veugelers, R., & Zettelmeyer, J. (2023). *How Europe should answer the US Inflation Reduction Act* (Issue 04). <https://hdl.handle.net/10419/274198>
- Koellner, T., Weber, O., Fenchel, M., & Scholz, R. (2005). Principles for sustainability rating of investment funds. *Business Strategy and the Environment*, 14(1), 54–70. <https://doi.org/10.1002/bse.423>
- Kolaric, S. (2023). The impact of climate litigation and activism on stock prices: the case of oil and gas majors. *Review of Managerial Science*, 1–32. <https://doi.org/10.1007/s11846-023-00710-4>
- Kölbel, J. F., Busch, T., & Jancso, L. M. (2017). How Media Coverage of Corporate Social Irresponsibility Increases Financial Risk. *Strategic Management Journal*, 38, 2266–2284. <https://doi.org/10.1002/smj.2647>
- Kölbel, J. F., Heeb, F., Paetzold, F., & Busch, T. (2020). Can Sustainable Investing Save the World ? Reviewing the Mechanisms of Investor Impact. *Organization & Environment*, 33(4), 554–574. <https://doi.org/10.1177/1086026620919202>
- Kolk, A., & Pinkse, J. (2004). Market strategies for climate change. *European Management Journal*, 22(3), 304–314. <https://doi.org/10.1016/j.emj.2004.04.011>
- Kompas, T., Ha, P. Van, & Che, T. N. (2018). The Effects of Climate Change on GDP by Country and the Global Economic Gains From Complying With the Paris Climate Accord. *Earth's Future*, 6, 1153–1173. <https://doi.org/10.1029/2018EF000922>
- Krabbe, O., Linthorst, G., Blok, K., Crijns-Graus, W., Van Vuuren, D. P., Höhne, N., Faria, P., Aden, N., & Pineda, A. C. (2015). Aligning corporate greenhouse-gas emissions targets with climate goals. *Nature Climate Change*, 5(12), 1057–1060. <https://doi.org/10.1038/nclimate2770>

- Krueger, P., Sautner, Z., & Starks, L. T. (2020). The Importance of Climate Risks for Institutional Investors. *Review of Financial Studies*, 33(3), 1067–1111.
- Kuo, L., & Chang, B. G. (2021). Ambitious corporate climate action: Impacts of science-based target and internal carbon pricing on carbon management reputation-Evidence from Japan. *Sustainable Production and Consumption*, 27, 1830–1840. <https://doi.org/10.1016/j.spc.2021.04.025>
- Kuramochi, T., Höhne, N., Schaeffer, M., Cantzler, J., Hare, B., Deng, Y., Sterl, S., Hagemann, M., Rocha, M., Yanguas-Parra, P. A., Mir, G. U. R., Wong, L., El-Laboudy, T., Wouters, K., Deryng, D., & Blok, K. (2018). Ten key short-term sectoral benchmarks to limit warming to 1.5°C. *Climate Policy*, 18(3), 287–305. <https://doi.org/10.1080/14693062.2017.1397495>
- Kuramochi, T., Roelfsema, M., Hsu, A., Lui, S., Weinfurter, A., Chan, S., Hale, T., Clapper, A., Chang, A., & Höhne, N. (2020). Beyond national climate action: the impact of region, city, and business commitments on global greenhouse gas emissions. *Climate Policy*, 20(3), 275–291. <https://doi.org/10.1080/14693062.2020.1740150>
- Kuramochi, T., Smit, S., Hans, F., Horn, J., Lütkehermöller, K., Nascimento, L., Emmrich, J., Höhne, N., Hsu, A., Mapes, B., Wang, X., Roelfsema, M., Chan, S., Deneault, A., Nagasawa, B. de S., Mohan, M., Whitney, M., Brehm, J., Hassel, J., ... Hale, T. (2021). *Global climate action from cities, regions and businesses. 2021 edition*. <http://newclimate.org/publications/>
- Kyrö, P. (2003). Revising the concept and forms of benchmarking. *Benchmarking: An International Journal*, 10(3), 210–225. <https://doi.org/10.1108/14635770310477753>
- Laine, M. (2024). Accounting, reporting and verification of impact: Implications for sustainability: A commentary on Adams et al . (2023) “Styles of verification and the pursuit of organisational repair: The case of social impact.” *Accounting, Organizations and Society*, 101540. <https://doi.org/10.1016/j.aos.2023.101540>
- Lee, H., Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P., Trisos, C., Romero, J., Aldunce, P., & Barrett, K. (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. The Australian National University. <https://doi.org/10.59327/IPCC/AR6-9789291691647>

- Lewison, M. (1999). Conflicts of interest? The ethics of usury. *Journal of Business Ethics*, 22(4), 327–339.
- Liang, H., Sun, L., & Teo, M. (2022). Responsible Hedge Funds. *Review of Finance*, 26(6), 1585–1633. <https://doi.org/10.1093/rof/rfac028>
- Liesen, A., Hoepner, A. G., Patten, D. M., & Figge, F. (2015). Does stakeholder pressure influence corporate GHG emissions reporting? Empirical evidence from Europe. *Accounting, Auditing and Accountability Journal*, 28(7), 1047–1074. <https://doi.org/10.1108/AAAJ-12-2013-1547>
- Liu, W., & Song, Z. (2020). Review of studies on the resilience of urban critical infrastructure networks. *Reliability Engineering and System Safety*, 193, 106617. <https://doi.org/10.1016/j.ress.2019.106617>
- Lombardi, C. M., & Hurlbert, S. H. (2009). Misprescription and misuse of one-tailed tests. *Austral Ecology*, 34, 447–468. <https://doi.org/10.1111/j.1442-9993.2009.01946.x>
- Louche, C., Arenas, D., & van Cranenburgh, K. C. (2012). From Preaching to Investing: Attitudes of Religious Organisations Towards Responsible Investment. *Journal of Business Ethics*, 110(3), 301–320. <https://doi.org/10.1007/s10551-011-1155-8>
- Louche, C., & Lydenberg, S. (2006). Socially responsible investment: differences between Europe and the United States. *Proceedings of the International Association for Business and Society*, 17.
- Luo, L., & Tang, Q. (2014). Does voluntary carbon disclosure reflect underlying carbon performance? *Journal of Comporary Accounting & Economics*, 10(3), 191–205. <https://doi.org/10.1016/j.jcae.2014.08.003>
- Luo, X., & Bhattacharya, C. B. (2009). The Debate over Doing Good: Corporate Social Performance, Strategic Marketing Levers, and Firm-idiosyncratic Risk. *Journal of Marketing*, 73(9), 198–213.
- Lux, G., Fromont, E., & Le Hoa Vo, T. (2023). Green business: Growth or degrowth to meet IPCC targets? Discussion of an assessment tool: IPCC CAPRO change target. *Journal of Cleaner Production*, 420, 138364. <https://doi.org/10.1016/j.jclepro.2023.138364>
- Lyon, T. P., & Montgomery, A. W. (2015). The Means and End of Greenwash. *Organization and*

- Environment*, 28(2), 223–249. <https://doi.org/10.1177/1086026615575332>
- Mansouri, N. (2016). A Case Study of Volkswagen Unethical Practice in Diesel Emission Test. *International Journal of Science and Engineering Applications*, 5(4), 211–216.
- Marens, R. (2022). Investing Corporate Governance: The Mid-Century Emergence of Shareholder Activism. *Journal of Business and Management*, 8(4).
- Matisoff, D. C., Noonan, D. S., & O'Brien, J. J. (2013). Convergence in environmental reporting: Assessing the carbon disclosure project. *Business Strategy and the Environment*, 22(5), 285–305. <https://doi.org/10.1002/bse.1741>
- Matsumura, E. M., Prakash, R., & Vera-Munoz, S. C. (2014). Firm-Value Effects of Carbon Emissions and Carbon Disclosures. *The Accounting Review*, 89(2), 695–724. <https://doi.org/10.2308/accr-50629>
- McMichael, A. J., Woodruff, R. E., & Hales, S. (2006). Climate change and human health: Present and future risks. *Lancet*, 367(9513), 859–869. [https://doi.org/10.1016/S0140-6736\(06\)68079-3](https://doi.org/10.1016/S0140-6736(06)68079-3)
- Mejia, C., & Kajikawa, Y. (2024). Estimating scope 3 greenhouse gas emissions through the shareholder network of publicly traded firms. *Sustainability Science*, 1–17. <https://doi.org/10.1007/s11625-023-01460-8>
- Mews, C. J., & Abraham, I. (2007). Usury and Just Compensation : Religious and Financial Ethics in Historical. *Journal of Business Ethics*, 72, 1–15. <https://doi.org/10.1007/s10551-006-9151-0>
- Mikellidou, C. V., Shakou, L. M., Boustras, G., & Dimopoulos, C. (2018). Energy critical infrastructures at risk from climate change: A state of the art review. *Safety Science*, 110, 110–120. <https://doi.org/10.1016/j.ssci.2017.12.022>
- Millar, R. J., Hepburn, C., Beddington, J., & Allen, M. R. (2018). Principles to guide investment towards a stable climate. *Nature Climate Change*, 8(1), 2–4.
- Mitchell, D. T. (2006). Shareholders as Proxies: The Contours of Shareholder Democracy. *Washington and Lee Law Review*, 63(4), 1503–1578.
- Monasterolo, I. (2020). Climate Change and the Financial System. *Annual Review of Resource*

- Economics*, 12, 299–320. <https://doi.org/10.1146/annurev-resource-110119-031134>
- Monasterolo, I., & Angelis, L. De. (2020). Blind to carbon risk? An analysis of stock market reaction to the Paris Agreement. *Ecological Economics*, 170, 106571. <https://doi.org/10.1016/j.ecolecon.2019.106571>
- Monasterolo, I., Battiston, S., Janetos, A. C., & Zheng, Z. (2017). Vulnerable yet relevant : the two dimensions of climate-related financial disclosure. *Climatic Change*, 145, 495–507.
- Monnin, P. (2018). Integrating Climate Risks into Credit Risk Assessment - Current Methodologies and the Case of Central Banks Corporate Bond Purchases. In *Discussion note Council on Economic Policies* (Discussion Note 2018/4, Issue December 2018). <https://doi.org/10.2139/ssrn.3350918>
- Montgomery, A. W., Lyon, T. P., & Barg, J. (2023). No End in Sight? A Greenwash Review and Research Agenda. *Organization and Environment*, 1–36. <https://doi.org/10.1177/10860266231168905>
- Moshrefi, S., Kara, S., & Hauschild, M. (2022). A framework for future-oriented environmental impact assessment of companies considering Science-Based Targets. *Journal of Cleaner Production*, 373, 133719. <https://doi.org/10.1016/j.jclepro.2022.133719>
- Nachar, N. (2008). The Mann-Whitney U : A Test for Assessing Whether Two Independent Samples Come from the Same Distribution. *Tutorials in Quantitative Methods for Psychology*, 4(1), 13–20.
- Nachmany, M., & Setzer, J. (2018). Global trends in climate change legislation and litigation: 2018 snapshot. In *Grantham Research Center on Climate Change and the Environment and Center for Climate Change Economics and Policy*.
- Nascimento, L., Godinho, C., Kuramochi, T., Moisis, M., Elzen, M. Den, & Höhne, N. (2024). Climate policy in 2023. *Nature Reviews Earth & Environment*, 1–3. <https://doi.org/10.1038/s43017-024-00541-1>
- Net-Zero Asset Owner Alliance. (2020). *Draft 2025 Target Setting Protocol*. https://www.unepfi.org/wordpress/wp-content/uploads/2020/10/Alliance-Target-Setting-Protocol_Final-Consultation-Draft.pdf

- NGFS. (2019). *A call for action: Climate change as a source of financial risk* (Issue April).
https://www.ngfs.net/sites/default/files/medias/documents/ngfs_first_comprehensive_report_-_17042019_0.pdf
- NGFS. (2020). Synopsis of Environmental Risk Analysis by Financial Institutions. In J. Ma, B. Caldecott, & U. Volz (Eds.), *NGFS Occasional Paper: Case Studies of Environmental Risk Analysis Methodologies* (pp. 1–22).
- NGFS. (2021). *Progress report on bridging data gaps* (Issue May).
https://www.ngfs.net/sites/default/files/medias/documents/progress_report_on_bridging_data_gaps.pdf
- NGFS. (2022). *Enhancing market transparency in green and transition finance* (Issue April).
<https://www.ngfs.net/en/enhancing-market-transparency-green-and-transition-finance>
- NGFS. (2023a). *NGFS Climate Scenarios: Technical Documentation*.
https://www.ngfs.net/sites/default/files/media/2024/01/16/ngfs_scenarios_technical_documentation_phase_iv_2023.pdf
- NGFS. (2023b). *NGFS Scenarios for central banks and supervisors* (Issue November).
https://www.ngfs.net/sites/default/files/medias/documents/ngfs_climate_scenarios_for_central_banks_and_supervisors_phase_iv.pdf
- Nguyen, Q., Diaz-rainey, I., & Kuruppuarachchi, D. (2021). Predicting corporate carbon footprints for climate finance risk analyses : A machine learning approach. *Energy Economics*, 95, 105129. <https://doi.org/10.1016/j.eneco.2021.105129>
- Ning, X., Yim, D., & Khuntia, J. (2021). Online Sustainability Reporting and Firm Performance: Lessons Learned from Text Mining. *Sustainability*, 13(3), 1069.
- Nordhaus, W. D. (2017). Revisiting the social cost of carbon. *PNAS*, 114(7), 1518–1523.
<https://doi.org/10.1073/pnas.1609244114>
- OECD. (2022). *ESG ratings and climate transition: An assessment of the alignment of E pillar scores and metrics* (No. 06; OECD Business and Finance Policy Papers).
<https://doi.org/10.1787/2fa21143-en>
- Onwuegbuzie, A. J., & Daniel, L. G. (1999). *Uses and Misuses of the Correlation Coefficient*.

- Orlitzky, M., Schmidt, F. L., & Rynes, S. L. (2003). Corporate Social and Financial Performance : A Meta-analysis. *Organization Studies*, 24(3), 403–441. <https://doi.org/10.1177/0170840603024003910>
- Orr, J. M., Sackett, P. R., & Dubois, C. L. Z. (1991). Outlier Detection and Treatment in I/O Psychology: a Survey of Researcher Beliefs and an Empirical Illustration. *Personnel Psychology*, 44(3), 473–486. <https://doi.org/10.1111/j.1744-6570.1991.tb02401.x>
- Osborne, J. W., & Overbay, A. (2004). The power of outliers (and why researchers should ALWAYS check for them). *Practical Assessment, Research and Evaluation*, 9(6). <https://doi.org/https://doi.org/10.7275/qf69-7k43>
- Ott, C., Schiemann, F., & Günther, T. (2017). Disentangling the determinants of the response and the publication decisions : The case of the Carbon Disclosure Project. *Journal of Accounting and Public Policy*, 36(1), 14–33. <https://doi.org/10.1016/j.jaccpubpol.2016.11.003>
- Oudenhoven, A. P. E. Van, Schröter, M., Drakou, E. G., Geijzendor, I. R., Jacobs, S., Bodegom, P. M. Van, Chazee, L., Czúcz, B., Grunewald, K., Lillebø, A. I., Mononen, L., Nogueira, A. J. A., Pacheco-romero, M., Perennou, C., Remme, R. P., Rova, S., Syrbe, R., Tratalos, J. A., Vallejos, M., & Albert, C. (2018). Key criteria for developing ecosystem service indicators to inform decision making. *Ecological Indicators*, 95(June), 417–426. <https://doi.org/10.1016/j.ecolind.2018.06.020>
- PACTA. (2022). *PACTA for Investors Methodology Document*. https://pacta.rmi.org/wp-content/uploads/2024/04/PACTA-for-Investors-Methodology-document_v1.0_202404.pdf
- Paetzold, F., & Busch, T. (2014). Unleashing the Powerful Few : Sustainable Investing Behaviour of Wealthy Private Investors. *Organization Environment*, 27(4), 347–367. <https://doi.org/10.1177/1086026614555991>.Abstract
- Pankratz, N., Bauer, R., & Derwall, J. (2019). Climate Change, Firm Performance, and Investor Surprises. *SSRN Electronic Journal*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3443146
- Pankratz, N., Bauer, R., & Derwall, J. (2023). Climate Change, Firm Performance, and Investor Surprises. *Management Science*, 69(12), 7352–7398. <https://doi.org/10.1287/mnsc.2023.4685>
- Papadopoulos, G. (2022). *Discrepancies in Corporate GHG Emissions Data and Their Impact on*

- Firm Performance Assessment* (Issue August). <https://doi.org/10.2139/ssrn.4197950>
- Parella, K. (2018). Reputational Regulation. *Duke Law Journal*, 67(5), 907–977.
- Pargendler, M. (2020). The Rise of International Corporate Law. *Washington University Law Review*, 98, 1765–1820.
- Patchell, J. (2018). Can the implications of the GHG Protocol’s scope 3 standard be realized? *Journal of Cleaner Production*, 185, 941–958. <https://doi.org/10.1016/j.jclepro.2018.03.003>
- Pattberg, P. (2012). How climate change became a business risk : analyzing nonstate agency in global climate politics. *Environment and Planning C: Government and Policy*, 30(4), 613–626. <https://doi.org/10.1068/c1179>
- PCAF. (2022). *The Global GHG Accounting and Reporting Standard Part A: Financed Emissions. Second Edition.* (Issue December).
- Piggot, G. (2018). The influence of social movements on policies that constrain fossil fuel supply. *Climate Policy*, 18(7), 942–954.
- Plötz, P., Axsen, J., Funke, S. A., & Gnann, T. (2019). Designing car bans for sustainable transportation. *Nature Sustainability*, 2(7), 534–536. <https://doi.org/10.1038/s41893-019-0328-9>
- Pollman, E. (2022). *The Making and Meaning of ESG* (No. 659; Law Working Paper, Issue October). https://www.ecgi.global/sites/default/files/working_papers/documents/esgcoverecgifinal.pdf
- Popescu, I., Hitaj, C., & Benetto, E. (2021). Measuring the sustainability of investment funds: A critical review of methods and frameworks in sustainable finance. *Journal of Cleaner Production*, 314(November 2020), 128016. <https://doi.org/10.1016/j.jclepro.2021.128016>
- Poschmann, J., Bach, V., & Finkbeiner, M. (2023). Deriving decarbonization targets and pathways – A case study for the automotive industry. *Journal of Cleaner Production*, 409, 137256. <https://doi.org/10.1016/j.jclepro.2023.137256>
- Pratt, J. W. (1959). Remarks on Zeros and Ties in the Wilcoxon Signed Rank Procedures. *Journal of the American Statistical Association*, 54(287), 655–667. <https://doi.org/10.1080/01621459.1959.10501526>

- PRI. (2021). *PRI Strategic Plan 2021-24: Building a Bridge between Financial Risk, Opportunities and Real-World Outcomes* (Issue April). <https://www.unpri.org/download?ac=13269>
- Probst, P., Wright, M. N., & Boulesteix, A.-L. (2019). Hyperparameters and tuning strategies for random forest. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, 9(3), e1301. <https://doi.org/10.1002/widm.1301>
- Puschmann, T., & Quattrocchi, D. (2023). Decreasing the impact of climate change in value chains by leveraging sustainable finance. *Journal of Cleaner Production*, 429, 139575. <https://doi.org/10.1016/j.jclepro.2023.139575>
- Randers, J. (2012). Greenhouse gas emissions per unit of value added (“GEVA”) - A corporate guide to voluntary climate action. *Energy Policy*, 48, 46–55. <https://doi.org/10.1016/j.enpol.2012.04.041>
- Raynaud, J., Tankov, P., & Voisin, S. (2020). Portfolio alignment to a 2 ° C trajectory: science or art? *SSRN Electronic Journal*. <https://doi.org/http://dx.doi.org/10.2139/ssrn.3644171>
- Reid, E. M., & Toffel, M. W. (2009). Responding to public and private politics: Corporate disclosure of climate change strategies. *Strategic Management Journal*, 30, 1157–1178. <https://doi.org/10.1002/smj>
- Reimsbach, D., Hahn, R., & Gürtürk, A. (2018). Integrated Reporting and Assurance of Sustainability Information : An Experimental Study on Professional Investors ’ Information Processing. *European Accounting Review*, 27(3), 559–581. <https://doi.org/10.1080/09638180.2016.1273787>
- Rekker, S., Chen, G., Heede, R., Ives, M. C., Wade, B., & Greig, C. (2023). Evaluating fossil fuel companies’ alignment with 1.5 °C climate pathways. *Nature Climate Change*, 13(9), 927–934. <https://doi.org/10.1038/s41558-023-01734-0>
- Rekker, S., Ives, M. C., Wade, B., Webb, L., & Greig, C. (2022). Measuring corporate Paris Compliance using a strict science-based approach. *Nature Communications*, 13, 4441. <https://doi.org/10.1038/s41467-022-31143-4>
- Renneboog, L., Ter, J., & Zhang, C. (2008). Socially responsible investments : Institutional aspects, performance, and investor behavior. *Journal of Banking and Finance*, 32, 1723–1742. <https://doi.org/10.1016/j.jbankfin.2007.12.039>

- RepRisk. (2020). Overview of ESG Rating, Data Providers and Applications. In J. Ma, B. Caldecott, & U. Volz (Eds.), *NGFS Occasional Paper: Case Studies of Environmental Risk Analysis Methodologies* (pp. 480–493).
- Revelli, C. (2016). Re-embedding financial stakes within ethical and social values in socially responsible investing (SRI). *Research in International Business and Finance*, 38, 1–5. <https://doi.org/10.1016/j.ribaf.2016.03.003>
- Revelli, C. (2017). Socially responsible investing (SRI): From mainstream to margin? *Research in International Business and Finance*, 39, 711–717. <https://doi.org/10.1016/j.ribaf.2015.11.003>
- Rey, D., & Neuhäuser, M. (2011). Wilcoxon-Signed-Rank Test. In *International encyclopedia of statistical science* (pp. 1658–1659). Springer.
- Richardson, B. J. (2009a). Climate Finance and Its Governance: Moving To a Low Carbon Economy Through Socially Responsible Financing? *International and Comparative Law Quarterly*, 58(03), 597. <https://doi.org/10.1017/S0020589309001213>
- Richardson, B. J. (2009b). Keeping ethical investment ethical: Regulatory issues for investing for sustainability. *Journal of Business Ethics*, 87(4), 555–572. <https://doi.org/10.1007/s10551-008-9958-y>
- Richardson, B. J. (2011). Fiduciary Relationships for Socially Responsible Investing: A Multinational Perspective. *American Business Law Journal*, 48(3), 597–640. <https://doi.org/10.1111/j.1744-1714.2011.01121.x>
- Robiou du Pont, Y., Rogelj, J., Hsu, A., van Vuuren, D., Hoepner, A. G. F., Vuuren, D. Van, & Hoepner, A. G. F. (2024). Corporate emissions targets and the neglect of future innovators. *Science*, 384(6694), 388–390. <https://doi.org/10.1126/science.adl5081>
- Rogelj, J., Elzen, M. Den, Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., & Sha, F. (2016). Paris Agreement climate proposals need a boost to keep warming well below 2 °C. *Nature*, 534(7609), 631–639. <https://doi.org/10.1038/nature18307>
- Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Seferian, R., & Vilarino, M. V. (2018). *Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development*. <https://www.ipcc.ch/sr15>

- Roor, A., & Maas, K. (2024). Do impact investors live up to their promise? A systematic literature review on (im)proving investments ' impacts. *Business Strategy and the Environment*, November 2023, 1–26. <https://doi.org/10.1002/bse.3644>
- Ruiz Manuel, I., & Blok, K. (2023). Quantitative evaluation of large corporate climate action initiatives shows mixed progress in their first half-decade. *Nature Communications*, 14(1), 3487. <https://doi.org/10.1038/s41467-023-38989-2>
- Saha, S., & Viney, B. (2020). How climate change could spark the next financial crisis. *Journal of International Affairs*, 73(1), 205–216.
- Sánchez-García, I.-M., Hussain, N., Ferrero, J. M., & Barbadillo, E. R. (2019). Impact of disclosure and assurance quality of corporate sustainability reports on access to finance. *Corporate Social Responsibility and Environmental Management Published*, 26, 832–848. <https://doi.org/10.1002/csr.1724>
- Sanchez-pinto, L. N., Venable, L. R., Fahrenbach, J., & Churpek, M. M. (2018). Comparison of variable selection methods for clinical predictive modeling. *International Journal of Medical Informatics*, 116(May), 10–17. <https://doi.org/10.1016/j.ijmedinf.2018.05.006>
- Sandberg, J. (2011). Socially Responsible Investment and Fiduciary Duty: Putting the Freshfields Report into Perspective. *Journal of Business Ethics*, 101(1), 143–162. <https://doi.org/10.1007/s10551-010-0714-8>
- Sandberg, J., Juravle, C., Hedesstro, T. M., & Hamilton, I. (2009). The Heterogeneity of Socially Responsible Investment. *Journal of Business Ethics*, 87, 519–533. <https://doi.org/10.1007/s10551-008-9956-0>
- SASB. (2016). *Climate risk: Technical Bulletin*.
- Sato, M., Gostlow, G., Higham, C., Setzer, J., & Venmans, F. (2023). *Impacts of climate litigation on firm value* (No. 421; Working Paper, Vol. 5709, Issue 421). https://eprints.lse.ac.uk/119262/1/working_paper_421.pdf
- SBTi. (2019). *Foundations of Science-based Target Setting Version 1.0* (Issue April). <https://sciencebasedtargets.org/wp-content/uploads/2019/04/foundations-of-SBT-setting.pdf>
- SBTi. (2020). *Science-based Target Setting Manual – Version 4.1* (Issue April).

- <https://sciencebasedtargets.org/wp-content/uploads/2018/10/C2A-guidelines.pdf>
- SBTi. (2021a). *SBTi Corporate Manual, Version 1.1* (Issue June).
- SBTi. (2021b). *Sector Guidance*. <https://sciencebasedtargets.org/sectors>
- SBTi. (2022a). *Science-Based Net-Zero: Scaling Urgent Corporate Climate Action Worldwide* (Issue June).
- SBTi. (2022b). *Science-Based Net-Zero: Scaling Urgent Corporate Climate Action Worldwide (Appendix)* (Issue June).
- SBTi. (2023). *SBTi Monitoring Report 2022: Looking back at 2022 and moving forward to 2023 and beyond*. <https://sciencebasedtargets.org/resources/files/SBTiMonitoringReport2022.pdf>
- SBTi. (2024a). *SBTi Corporate Net-Zero Standard* (Issue March). <https://sciencebasedtargets.org/resources/files/Net-Zero-Standard.pdf>
- SBTi. (2024b). *SBTi Monitoring Report 2023: Looking back at 2023 and moving forward to 2024 and beyond* (Issue July). <https://sciencebasedtargets.org/resources/files/SBTiMonitoringReport2023.pdf>
- Schanzenbach, M. M., & Sitkoff, R. H. (2020). Reconciling Fiduciary Duty and Social Conscience The Law and Economics of ESG Investing by a Trustee. *Standard Law Review*, 72, 381–454.
- Scheitza, L., & Busch, T. (2024). SFDR Article 9: Is it all about impact? *Finance Research Letters*, 62, 105179. <https://doi.org/10.1016/j.frl.2024.105179>
- Schlütter, D., Schätzlein, L., Hahn, R., & Waldner, C. (2023). Missing the Impact in Impact Investing Research – - A Systematic Review and Critical Reflection of the Literature. *Journal of Management Studies*. <https://doi.org/10.1111/joms.12978>
- Schmidt, M., Nill, M., & Scholz, J. (2022). Determining the Scope 3 Emissions of Companies. *Chemical Engineering & Technology*, 45(7), 1218–1230. <https://doi.org/10.1002/ceat.202200181>
- Schoenmaker, D., & Schramade, W. (2018). Sustainability and the transition challenge: Three stages of sustainable finance. In *Principles of Sustainable Finance* (Issue January, pp. 19–27). Oxford University Press.

- Schoenmaker, D., & Schramade, W. (2019). Investing for long-term value creation. *Journal of Sustainable Finance and Investment*, 9(4), 356–377. <https://doi.org/10.1080/20430795.2019.1625012>
- Schwartz, M. S. (2003). The “Ethics” of Ethical Investing. *Journal of Business Ethics*, 43, 195–213.
- Schweitzer, V., Bach, V., Holzapfel, P. K. R., & Finkbeiner, M. (2023). Differences in science-based target approaches and implications for carbon emission reductions at a sectoral level in Germany. *Sustainable Production and Consumption*, 38, 199–209.
- Segal, M. R. (2004). *Machine learning benchmarks and random forest regression*. <https://escholarship.org/uc/item/35x3v9t4>
- Semieniuk, G., Campiglio, E., Mercure, J.-F., Volz, U., & Edwards, N. R. (2020). Low-carbon transition risks for finance. *Climate Change*, 12(1), e678. <https://doi.org/doi.org/10.1002/wcc.678>
- Semieniuk, G., Chancel, L., Saïssset, E., Holden, P. B., Mercure, J. F., & Edwards, N. R. (2023). Potential pension fund losses should not deter high-income countries from bold climate action. *Joule*, 7(7), 1383–1387. <https://doi.org/10.1016/j.joule.2023.05.023>
- Serafeim, G. (2021). *ESG: Hyperboles and Reality* (22-031). https://www.hbs.edu/ris/PublicationFiles/22-031_b9b34057-062a-48a8-8950-61e0cf37559a.pdf
- Setzer, J., & Higham, C. (2023). *Global trends in climate change litigation: 2023 snapshot* (London School of Economics and Political Science). https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2023/06/Global_trends_in_climate_change_litigation_2023_snapshot.pdf
- Shrestha, N. (2020). Detecting Multicollinearity in Regression Analysis. *American Journal of Applied Mathematics and Statistics*, 8(2), 1–5. <https://doi.org/10.12691/ajams-8-2-1>
- Siegel, A. F., & Wagner, M. R. (2016). Multiple Regression: Predicting One Variable from Several Others. *Practical Business Statistics*, 355–418.
- Siegel, L. B. (2003). *Benchmarks and Investment Management*. Research Foundation of AIMR Charlottesville. <https://doi.org/10.2469/dig.v33.n3.1341>

- Sievänen, R., Rita, H., & Scholtens, B. (2013). The Drivers of Responsible Investment: The Case of European Pension Funds. *Journal of Business Ethics*, 117, 137–151. <https://doi.org/10.1007/s10551-012-1514-0>
- Smith, M. P. (1996). Shareholder Activism by Institutional Investors: Evidence from CalPERS. *The Journal of Finance*, LI(1), 227–252.
- Solana, J. (2020a). Climate change litigation as financial risk. *Green Finance*, 2(4), 344–372. <https://doi.org/10.3934/GF.2020019>
- Solana, J. (2020b). Climate Litigation in Financial Markets: A Typology. *Transnational Environmental Law*, 9(1), 103–135. <https://doi.org/10.1017/S2047102519000244>
- Sparkes, R. (2001). Ethical investment: Whose ethics, which investment? *Business Ethics: A European Review*, 10(3), 194–205. <https://doi.org/10.1111/1467-8608.00233>
- Sparkes, R. (2002a). From the Beginning. In *Socially Responsible Investment: A Global Revolution* (pp. 45–38). John Wiley & Sons.
- Sparkes, R. (2002b). Screening in Practice. In *Socially Responsible Investment: A Global Revolution* (pp. 89–116). John Wiley & Sons.
- Sparkes, R. (2017). A historical perspective on the growth of socially responsible investment. In *Responsible Investment* (pp. 39–54). Routledge.
- Sparkes, R., & Cowton, C. J. (2004). The Maturing Of Socially Responsible Investment : A Review Of The Developing Link With Corporate Social Responsibility. *Journal of Business Ethics*, 52, 45–57. <https://doi.org/10.1023/B:BUSI.0000033106.43260.99>
- Spinder, S., Frasincar, F., Matsiiako, V., Bokestijn, D., & Brandt, T. (2023). A text mining approach to identifying sustainability in the private sector. *Computers in Industry*, 149, 103932. <https://doi.org/10.1016/j.compind.2023.103932>
- Stanny, E. (2018). Reliability and Comparability of GHG Disclosures to the CDP by US Electric Utilities. *Social and Environmental Accountability Journal*, 38(2), 111–130. <https://doi.org/10.1080/0969160X.2018.1456949>
- Stapenhurst, T. (2009). *The Benchmarking Book*. Routledge.
- Starks, L. T. (2023). Presidential Address: Sustainable Finance and ESG Issues — Value versus

- Values. *The Journal of Finance*, 78(4), 1837–1872. <https://doi.org/10.1111/jofi.13255>
- Steffen, W., Richardson, K., Rockstrom, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyer, B., & Sorlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, 347(6223), 1259855. <https://doi.org/10.1126/science.1259855>
- Stiglitz, J., Stern, N., Duan, M., Edenhofer, O., Giraud, G., Heal, G., Lebre la Rovere, E., Morris, A., Moyer, E., Pangestu, M., Shukla, P., Sokona, Y., & Winkler, H. (2017). *Report of the High-Level Commission on Carbon Prices*. https://static1.squarespace.com/static/54ff9c5ce4b0a53decccfb4c/t/59b7f2409f8dce5316811916/1505227332748/CarbonPricing_FullReport.pdf
- Stolowy, H., & Paugam, L. (2023). Sustainability Reporting: Is Convergence Possible? *Accounting in Europe*, 20(2), 139–165. <https://doi.org/10.1080/17449480.2023.2189016>
- Stridsland, T., Biørnstad, W., Vigen, K., Lange Østergaard, K., & Sanderson, H. (2024). No-one left behind: An open access approach to estimating the carbon footprint of a Danish clothing company. *Journal of Cleaner Production*, 426, 139126. <https://doi.org/10.1016/j.jclepro.2023.139126>
- Sueyoshi, T., & Wang, D. (2014). Sustainability development for supply chain management in U.S. petroleum industry by DEA environmental assessment. *Energy Economics*, 46, 360–374. <https://doi.org/10.1016/j.eneco.2014.09.022>
- Sullivan, R., & Gouldson, A. (2016). Comparing the Climate Change Actions, Targets and Performance of UK and US Retailers. *Corporate Social Responsibility and Environmental Management*, 23(3), 129–139. <https://doi.org/10.1002/csr.1364>
- Sullivan, R., & Gouldson, A. (2017). The Governance of Corporate Responses to Climate Change: An International Comparison. *Business Strategy and the Environment*, 26(4), 413–425. <https://doi.org/10.1002/bse.1925>
- Talan, G., & Sharma, G. D. (2019). Doing Well by Doing Good: A Systematic Review and Research Agenda for Sustainable Investment. *Sustainability*, 11(2). <https://doi.org/10.3390/su11020353>

- Talbot, D., & Boiral, O. (2013). Can we trust corporates GHG inventories ? An investigation among Canada ' s large final emitters. *Energy Policy*, 63, 1075–1085. <https://doi.org/10.1016/j.enpol.2013.09.054>
- Talbot, D., & Boiral, O. (2018). GHG Reporting and Impression Management : An Assessment of Sustainability Reports from the Energy Sector. *Journal of Business Ethics*, 147, 367–383. <https://doi.org/10.1007/s10551-015-2979-4>
- TCFD. (2017a). *Final Report - Recommendations of the Task Force on Climate-related Financial Disclosures*. <https://assets.bbhub.io/company/sites/60/2021/10/FINAL-2017-TCFD-Report.pdf>
- TCFD. (2017b). *Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures* (Issue June). <https://www.fsb-tcfd.org/wp-content/uploads/2017/12/FINAL-TCFD-Annex-Amended-121517.pdf>
- TCFD. (2021a). *Implementing the Recommendations of the Task Force on Climate-related Financial Disclosures*.
- TCFD. (2021b). *Measuring Portfolio Alignment: Technical Supplement* (Issue June). https://assets.bbhub.io/company/sites/60/2021/05/2021-TCFD-Portfolio_Alignment_Technical_Supplement.pdf
- TCFD. (2021c). *Measuring Portfolio Alignment: Technical Considerations*. https://www.tcfidhub.org/wp-content/uploads/2021/10/PAT_Measuring_Portfolio_Alignment_Technical_Considerations-9.8.pdf
- TCFD. (2021d). *Proposed Guidance on Climate-related Metrics, Targets, and Transition Plans*. https://assets.bbhub.io/company/sites/60/2021/05/2021-TCFD-Metrics_Targets_Guidance.pdf
- TCFD. (2023). *2023 Status Report*. <https://assets.bbhub.io/company/sites/60/2023/09/2023-Status-Report.pdf>
- The World Bank. (2022). *Carbon Pricing 2022*. <https://doi.org/10.1596/978-1-4648-1895-0>.
- Thoma, J., Dupré, S., & Hayne, M. (2018). A Taxonomy of Climate Accounting Principles for

- Financial Portfolios. *Sustainability*, 10(328). <https://doi.org/10.3390/su10020328>
- Tolliver, C., Keeley, A. R., & Managi, S. (2019). Green bonds for the Paris agreement and sustainable development goals. *Environmental Research Letters*, 14(6), 064009. <https://doi.org/10.1088/1748-9326/ab1118>
- Tomar, S. (2023). Greenhouse Gas Disclosure and Emissions Benchmarking. *Journal of Accounting Research*, 61(2), 451–492. <https://doi.org/10.1111/1475-679X.12473>
- Townsend, B. (2020). From SRI to ESG: The Origins of Socially Responsible and Sustainable Investing. *The Journal of Impact and ESG Investing*, 1(1), 10–25.
- TPI. (2021). *TPI sector data - CP Assessments*. <https://www.transitionpathwayinitiative.org/sectors>
- TPI. (2022). *FAQ: What is the TPI's data source / material?* <https://www.transitionpathwayinitiative.org/faq>
- Trelstad, B. (2016). Impact Investing: A Brief History. *Capitalism & Society*, 11(2).
- Tuncay, M., & Dorjnarant, B. (2023). HOW DO SOCIALLY RESPONSIBLE INVESTMENT AND MACROECONOMIC INDICATORS INTERACT WITH EACH OTHER? THE CASE OF SELECTED DEVELOPING COUNTRIES. *Journal of Economics, Finance and Accounting (JEFA)*, 10(1), 55–64. <https://doi.org/10.17261/Pressacademia.2023.1721>
- Turlach, B. A., Venables, W. N., & Wright, S. J. (2005). Simultaneous Variable Selection. *Technometrics*, 47(3). <https://doi.org/10.1198/004017005000000139>
- Uhlmann, D. M. (2016). The Pendulum Swings: Reconsidering Corporate Criminal Prosecution. *UCDL Rev.*, 49(4), 1235–1283.
- UN Global Compact. (2004). *Who Cares Wins: Connecting Financial Markets to a Changing World*. <https://documents1.worldbank.org/curated/en/280911488968799581/pdf/113237-WP-WhoCaresWins-2004.pdf>
- UN PRI. (2021). *Principles for responsible investment: An investor initiative in partnership with unep finance initiative and the un global compact*. <https://www.unpri.org/download?ac=10948>
- UN PRI. (2024a). *Data Portal: 2023 Public Reports*. <https://ctp.unpri.org/dataportalv2>

- UN PRI. (2024b). *Signatory Directory*. <https://www.unpri.org/signatories/signatory-resources/signatory-directory>
- UNEP. (2022). *Emissions Gap Report 2022*. <https://www.unep.org/emissions-gap-report-2022>
- UNEP. (2023a). *Emissions Gap Report 2023: Broken Record – Temperatures hit new highs, yet world fails to cut emissions (again)*. <https://doi.org/10.59117/20.500.11822/43922>
- UNEP. (2023b). *Global Climate Litigation Report: 2023 Status Review*. <https://doi.org/10.59117/20.500.11822/43008> This
- Van Atten, C., Saha, A., Hellgren, L., & Langlois, T. (2021). *Benchmarking Air Emissions of the 100 Largest Electric Power Producers in the United States* (Issue July).
- van Beurden, P., & Gössling, T. (2008). The Worth of Values: A Literature Review on the Relation Between Corporate Social and Financial Performance. *Journal of Business Ethics*, 82(2), 407–424. <https://doi.org/10.1007/s10551-008-9894-x>
- van der Ploeg, F., & Rezai, A. (2020). Stranded assets in the transition to a carbon-free economy. *Annual Review of Resource Economics*, 12, 281–298. <https://doi.org/10.1146/annurev-resource-110519-040938>
- Vicedo-Cabrera, A. M., Scovronick, N., Sera, F., Royé, D., Schneider, R., Tobias, A., Astrom, C., Guo, Y., Honda, Y., Hondula, D. M., Abrutzky, R., Tong, S., De Sousa Zanotti Stagliorio Coelho, M., Nascimento Saldiva, P. H., Lavigne, E., Matus Correa, P., Valdes Ortega, N., Kan, H., Osorio, S., ... Gasparrini, A. (2021). The burden of heat-related mortality attributable to recent human-induced climate change. *Nature Climate Change*, 11(6), 492–500. <https://www.nature.com/articles/s41558-021-01058-x>
- Visser, W. A. M., & McIntosh, A. (1998). A Short Review of the Historical Critique of Usury. *Accounting, Business & Financial History*, 8(2), 175–189.
- Viviers, S., & Eccles, N. S. (2012). 35 years of socially responsible investing (SRI) research – General trends over time. *South African Journal of Business Management*, 43(4). <https://doi.org/http://hdl.handle.net/10500/12853>
- von Wallis, M., & Klein, C. (2015). Ethical requirement and financial interest: a literature review on socially responsible investing. *Business Research*, 8(1), 61–98.

<https://doi.org/10.1007/s40685-014-0015-7>

- Vorosmarty, C. J., Osuna, D. A., Koehler, D. A., Klop, P., Spengler, J. D., Buonocore, J. . J., Cak, A. D., Tessler, Z. D., Corsi, F., Green, P. A., & Sanchez, R. (2018). Scientifically assess impacts of sustainable investments. *Science*, 359(6375), 523–526.
- Wagemans, F. A. J., Koppen, C. S. A. K. Van, & Mol, A. P. J. (2013). The effectiveness of socially responsible investment : a review. *Journal of Integrative Environmental Sciences*, 10(3–4), 235–252. <https://doi.org/10.1080/1943815X.2013.844169>
- Walenta, J. (2020). Climate risk assessments and science-based targets: A review of emerging private sector climate action tools. *Wiley Interdisciplinary Reviews: Climate Change*, 11(2), 1–12. <https://doi.org/10.1002/wcc.628>
- Wang, D. (2017). A comparative study of firm-level climate change mitigation targets in the European Union and the United States. *Sustainability*, 9(4). <https://doi.org/10.3390/su9040489>
- Wang, D. D., & Sueyoshi, T. (2018). Climate change mitigation targets set by global firms: Overview and implications for renewable energy. *Renewable and Sustainable Energy Reviews*, 94(October 2017), 386–398. <https://doi.org/10.1016/j.rser.2018.06.024>
- Weber, O. (2024). Climate stress testing in the financial industry. *Current Opinion in Environmental Sustainability*, 66, 101401. <https://doi.org/10.1016/j.cosust.2023.101401>
- Weber, O., & Felmate, B. (2016). The Business Case for Sustainability versus the Sustainability Case for Business. In *Sustainable Banking: Managing the Social and Environmental Impact of Financial Institutions*. University of Toronto Press.
- Weitzman, M. L. (2011). Fat-Tailed Uncertainty in the Economics of Catastrophic Climate Change. *Review of Environmental Economics and Policy*, 5(2), 275–292. <https://doi.org/10.1093/reep/rer006>
- Widyawati, L. (2019). A systematic literature review of socially responsible investment and environmental social governance metrics. *Business Strategy and the Environment*, 29, 619–637. <https://doi.org/10.1002/bse.2393>
- Wiedmann, T. O., Lenzen, M., & Barrett, J. R. (2009). Companies on the scale comparing and

- benchmarking the sustainability performance of businesses. *Journal of Industrial Ecology*, 13(3), 361–383. <https://doi.org/10.1111/j.1530-9290.2009.00125.x>
- World Bank. (2020). *State and Trends of Carbon Pricing 2020* (Issue May). <https://openknowledge.worldbank.org/bitstream/handle/10986/33809/9781464815867.pdf?sequence=4&isAllowed=y>
- World Bank. (2023). *State and Trends of Carbon Pricing 2023*. <https://doi.org/10.1596/978-1-4648-2006-9>
- WRI. (2015). *GHG Protocol Scope 2 Guidance*. <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>
- WRI, & WBCSD. (2004). *A Corporate Accounting and Reporting Standard*. <https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf>
- Xu, L., & Zhang, W. (2001). Comparison of different methods for variable selection. *Analytica Chimica Acta*, 446, 477–483.
- Yeo, Z. Y., Burley, K., French, I., Hsu, A., Roelfsema, M., Jones, C., Clapper, A., & Du, L. (2022). *Global Climate Action 2022: Progress and Ambition of Cities, Regions and Companies*. http://datadrivenlab.org/wp-content/uploads/2022/11/Global-Climate-Action_CitiesRegionsCompanies_Final.pdf
- Yin, H., Mo, F., & Wang, D. (2017). Determinants of Corporate Climate Change Mitigation Targets in Major United States Companies. *Journal of Sustainable Development*, 10(1), 71. <https://doi.org/10.5539/jsd.v10n1p71>
- Yu, P., Hoepner, A. G. F., & Adamsson, H. (2016). Towards a Carbon Data Science. In *SSRN Electronic Journal: Vol. ICMA Cente* (Issue March). <https://doi.org/10.2139/ssrn.2715101>
- Yu, Y., Wang, D. D., Li, S., & Shi, Q. (2016). Assessment of U.S. firm-level climate change performance and strategy. *Energy Policy*, 92, 432–443. <https://doi.org/10.1016/j.enpol.2016.02.004>
- Yu, Y., Zhou, S., & Shi, Y. (2020). Information sharing or not across the supply chain : The role of carbon emission reduction. *Transportation Research Part E*, 137(April), 101915. <https://doi.org/10.1016/j.tre.2020.101915>

- Zhang, Y., & Liu, J. (2020). Overview of research on carbon information disclosure. *Frontiers of Engineering Management*, 7(1), 47–62. <https://doi.org/https://doi.org/10.1007/s42524-019-0089-1>
- Zhou, S. (2022). Reporting and Assurance of Climate-Related and Other Sustainability Information : A Review of Research and Practice. *Australian Accounting Review*, 32(102), 315–333. <https://doi.org/10.1111/auar.12387>
- Zou, H., & Hastie, T. (2005). Regularization and variable selection via the elastic net. *Journal of the Royal Statistical Society Series B: Statistical Methodology*, 67(2), 301–320.

APPENDIX A ARTICLE 1: SUPPLEMENTARY MATERIAL

A.1 Methodological Fictious Examples

A.1.1 Absolute GHG Sectoral Benchmark

A fictious example describing the methodological steps for the absolute GHG emissions benchmark is presented in this section. Table A.1 provides two sets of target information for Company ‘A’.

Table A.1: Fictive example information of Company A for two targets

Company A information	Target 1	Target 2
BY	2010	2015
BY Scope 1 (tCO ₂ e)	900,000	800,000
BY Scope 2 (tCO ₂ e)	250,000	200,000
2017 Scope 1 (tCO ₂ e)	750,000	750,000
2017 Scope 2 (tCO ₂ e)	150,000	150,000
Target year	2025	2040
Target reduction from BY (%)	50%	50%
Target scope (Scope 1 and/or 2)	Scope 1	Scope 1 & 2
Scope covered (%)	75%	100%

For Target 1, a reduction of 50% applied to 75% of the scope 1 emissions are anticipated. For Target 2, a reduction of 50% on all of scope 1 and scope 2 emissions is targeted. As mentioned in the article, the uncovered emissions are assumed to remain constant when a target does not fully cover scope 1 and 2 emissions. Using Equation 4.1 of the main article, the target year emissions ($\mathcal{E}_{TY}$) for Target 1 is: $900,000 + 250,000 - 50\% \times 75\% \times 900,000 = 812,500$ tCO₂e. For Target 2, $\mathcal{E}_{TY} = 800,000 + 200,000 - 50\% \times 100\% \times (800,000 + 200,000) = 500,000$ tCO₂e.

For Step 4a, as the company have multiple targets, linear interpolation has been applied from common BY to first TY and from the first TY to the second as shown in Figure A.1. This allows the emissions reduction to be included into the sectoral consolidation in 2020 even if the TY is 2025.

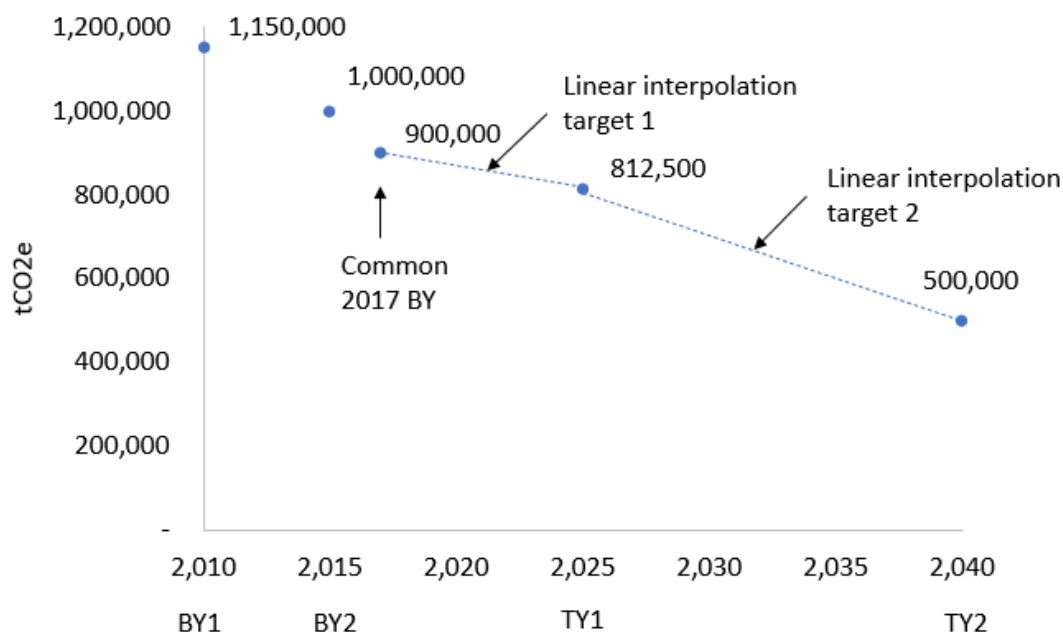


Figure A.1: Company A targets graphic representation

For Step 5, we will divide target metric results obtained for every year wanted by 2017 and subtract 1 so a negative result is a reduction, and a positive result, an increase. For example, the normalized reduction in 2025 is: $812,500 / 900,000 - 1 = -10\%$ which differs from the -25% announced in Table A.1.

Once the results for every target for companies in the same sector as Company A are calculated, the results are aggregated at the sectoral level.

A.1.2 Intensity Benchmark

A fictitious example describing the methodological steps specific to GHG intensity benchmark (Step 4b and 4c) is given in this section. The example presents the economic GHG intensity benchmark per revenue. The Step 4b and 4c would be similar for the other GHG intensity benchmark. Simply, a different unit would be used.

For economic GHG intensity sectoral benchmark per revenue, additional information is needed. For reminder, the target metric of that benchmark is tCO2e per million US dollars of revenue. Table A.2 provides the revenue information for Company 'A'. The target information of Company 'A' is the one of Section A.1.1.

Table A.2: Fictive example information of Company A revenue

Year	Revenue (\$M US)
1990	8,023
1991	8,926
1992	9,828
1993	10,731
1994	12,148
1995	13,460
1996	14,236
1997	15,070
1998	15,021
1999	15,748
2000	16,724
2001	16,054
2002	16,332
2003	18,232
2004	20,011
2005	21,167
2006	22,923
2007	24,462
2008	25,269
2009	23,123
2010	26,662
2011	29,611
2012	29,904
2013	30,871
2014	31,821
2015	30,274
2016	30,109
2017	31,657
2018	32,765
2019	32,136

From the historical revenue data in Table A.2, we can extrapolate the revenue data based on a linear regression model from 2019 until 2040 which is the year of the last target of Company A. Figure A.2 presents the linear regression model (Step 4b). The points and black line are the historical values. The blue line is the linear regression model.

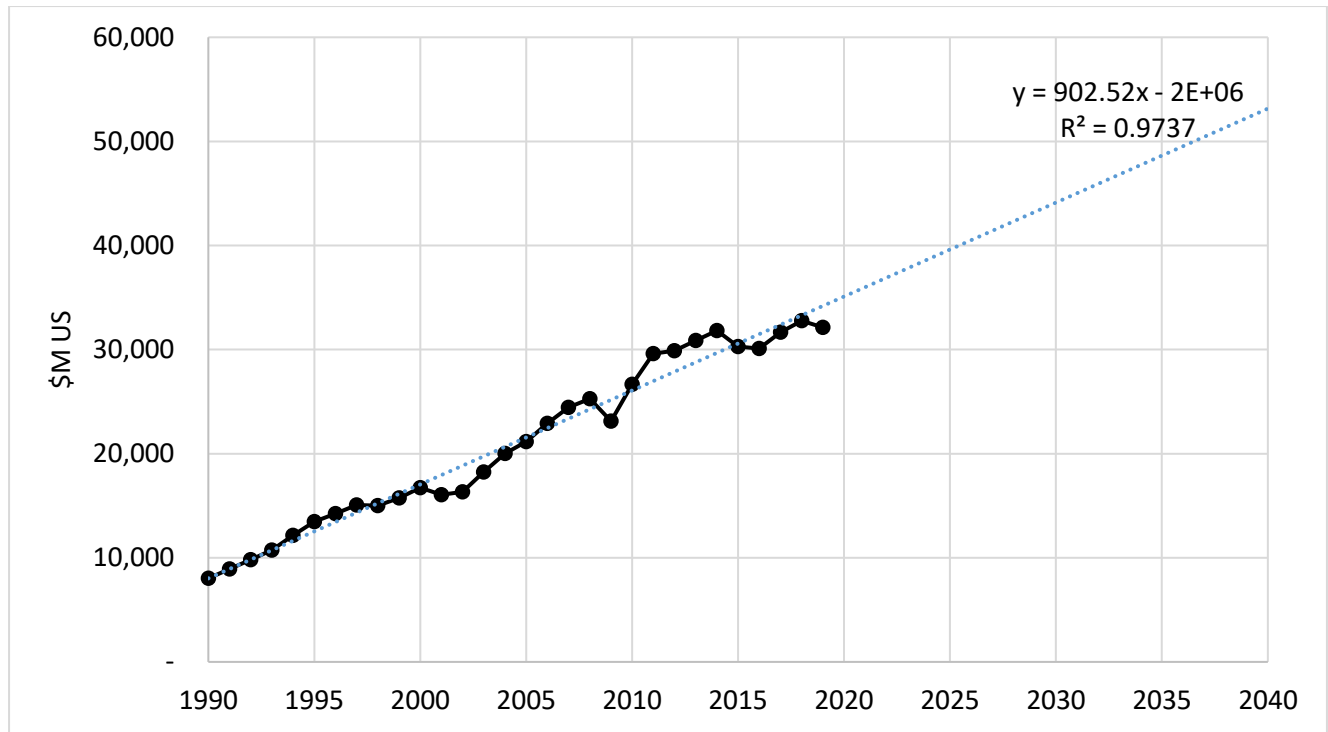


Figure A.2: Company A linear regression model

From the Step 4b, we can obtain the needed revenue value for every year needed until 2040. For example, the value in 2025 is 39,612 \$M US. The Step 4c consists of dividing the emissions for a specific year by the denominator of the same year which for this benchmark is million of US dollars of revenue as indicated in Equation 3 of the article. The emission intensity (ϵI_y) in 2025 is: $812,500 / 39,612 = 20.5 \text{ tCO}_2/\text{\$M US}$.

A.2 Database Used

The two main sources of data used in the main article are Carbon Disclosure Project (CDP) and Bloomberg. Bloomberg have been used for the economic data while CDP have been used for all the other needed data (see Table 1 of the article). For the revenue value, the Bloomberg corresponding field used in the study is 'SALES_REV_TURN' and 'CURR_ENTP_VALUE' for the enterprise value information.

CDP exists for more than 20 years (CDP, 2021b). On the requests of investors representing US\$ 110 trillion in assets (CDP, 2021a), CDP sent annual survey to companies in order to collect information corporate climate risks, opportunities and performance (Walenta, 2020). Nevertheless,

CDP also collects information on water, forest, supply chain through other questionnaires sent to companies, cities or states and regions (CDP, 2021a).

Via all those questionnaires and years, more than 9,600 companies reported information to CDP (CDP, 2021a). However, not every company reports to every questionnaire or every part of the questionnaire. Through the climate change and supply chain 2018 questionnaires, 2,607 companies reported information on their climate mitigation target. In the last years, many academic studies related to corporate climate mitigation targets used CDP such as Ioannou et al. (2016), Kolk and Pinkse (2004), Wang (2017), Wang and Sueyoshi (2018), and Yin et al. (2017).

A.3 Further Results

A.3.1 Final Sample Description

A.3.1.1 GHG Emissions per Sector in 2017

For the final sample of 964 companies, scope 1 emissions in 2017 represent 2.6 GtCO₂e while scope 2 emissions are 0.6 GtCO₂e. The total emissions for scope 1 and 2 in 2017 are 3.2 GtCO₂e. Figure A.3 give the 2017 sector weight in the final sample. The number in brackets represent the numbers of companies included in that sector.

The scope 1 and 2 emissions within a given sector are not proportional to the number of companies in that sector. As shown in Figure A.3, 82% of scope 1 and 2 emissions were covered by 5 sectors for our final sample in 2017 (power generation, manufacturing, materials, fossil fuels, infrastructure). However, power generation for example, consists of only 28 companies, but represents 23% of 2017 scope 1 and 2 emissions. Furthermore, the ten most emitting companies of the power generation sector contribute to more than 6 sectors combined. Figure A.4 present 2017 scope 1 and 2 emissions in tCO₂e per sector.

Depending on the sector, the scope 1 and 2 distribution may vary widely from one company to another. In the manufacturing sector for example, the scope 1 emissions are near 0% of the total scope 1 and 2 emissions for one company while for another company, scope 1 emissions are close to 100%. Depending on the size of the company, scope 1 and 2 sectoral distribution is affected.

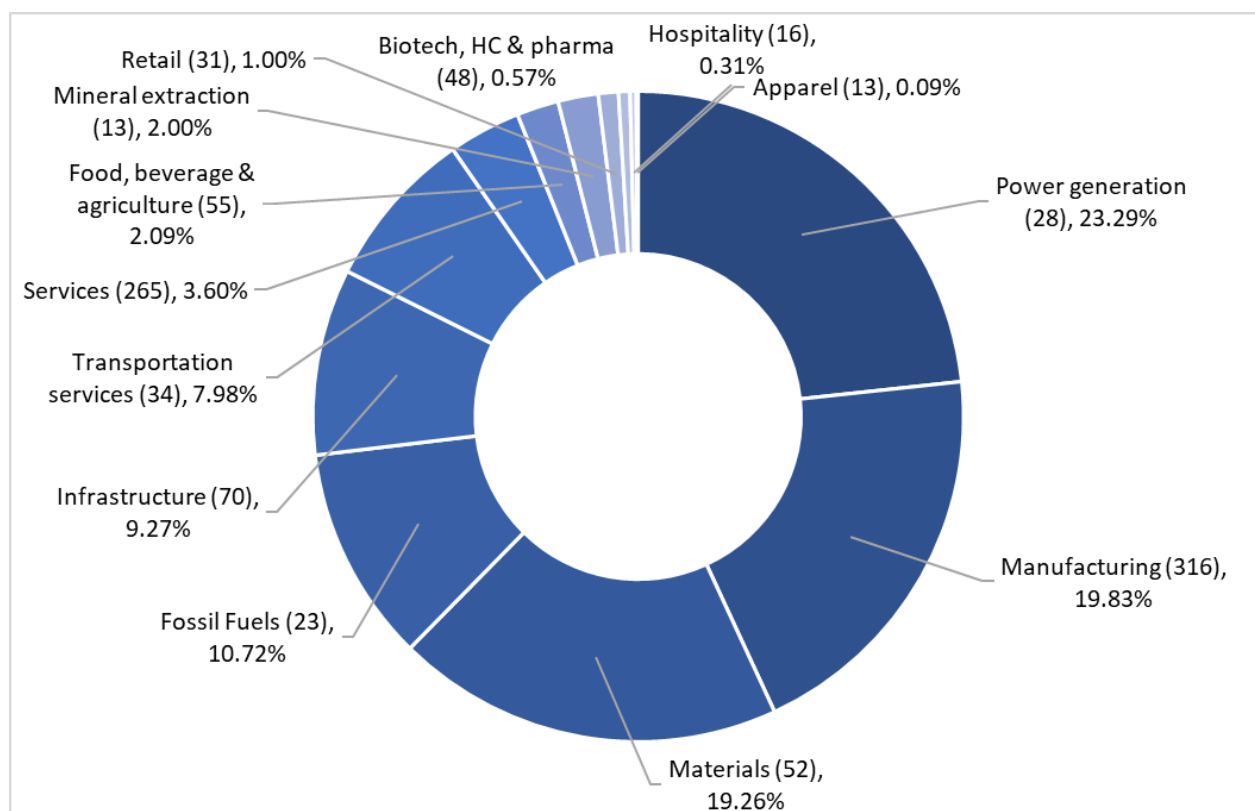


Figure A.3: Distribution of scope 1 and 2 2017 GHG emissions per sector

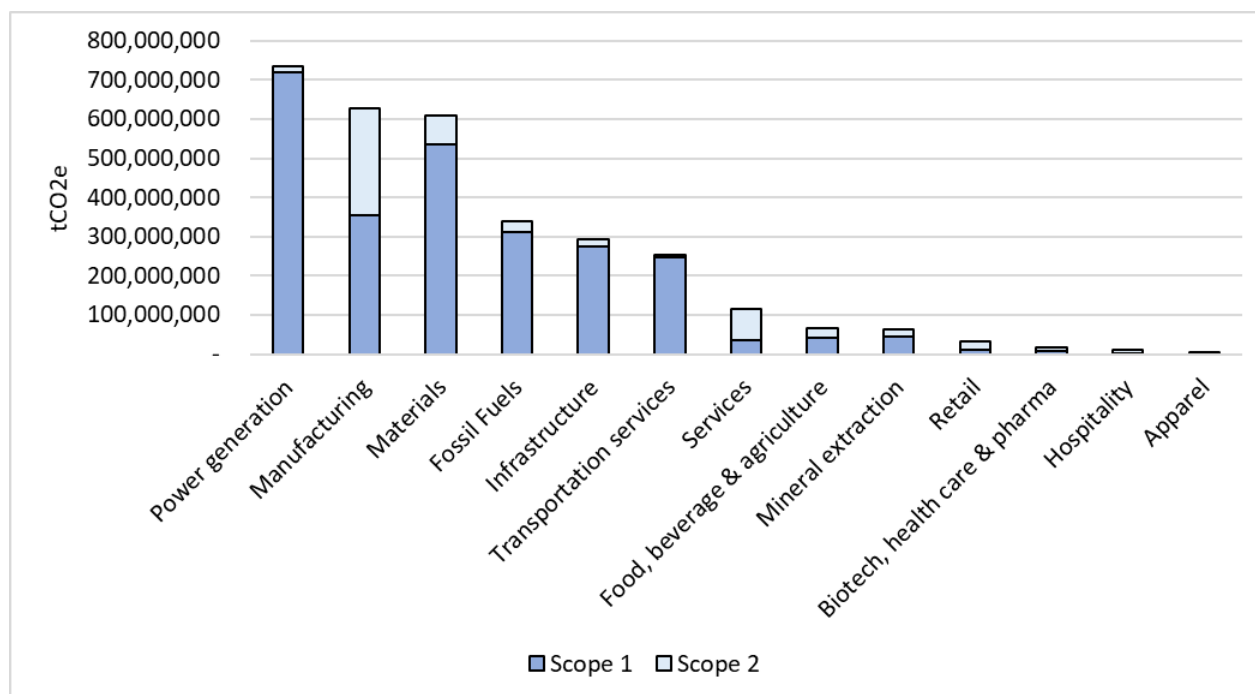


Figure A.4: Scope 1 and 2 GHG emissions in 2017 per sector

Figure A.5 represent the company scope 1 and 2 average distribution per sector. For the manufacturing sector, the scope 1 and 2 distribution at the sector level is 57% and 43% respectively while for the company scope 1 and 2 average distribution, the results are 62% and 38% as shown in Figure A.5.

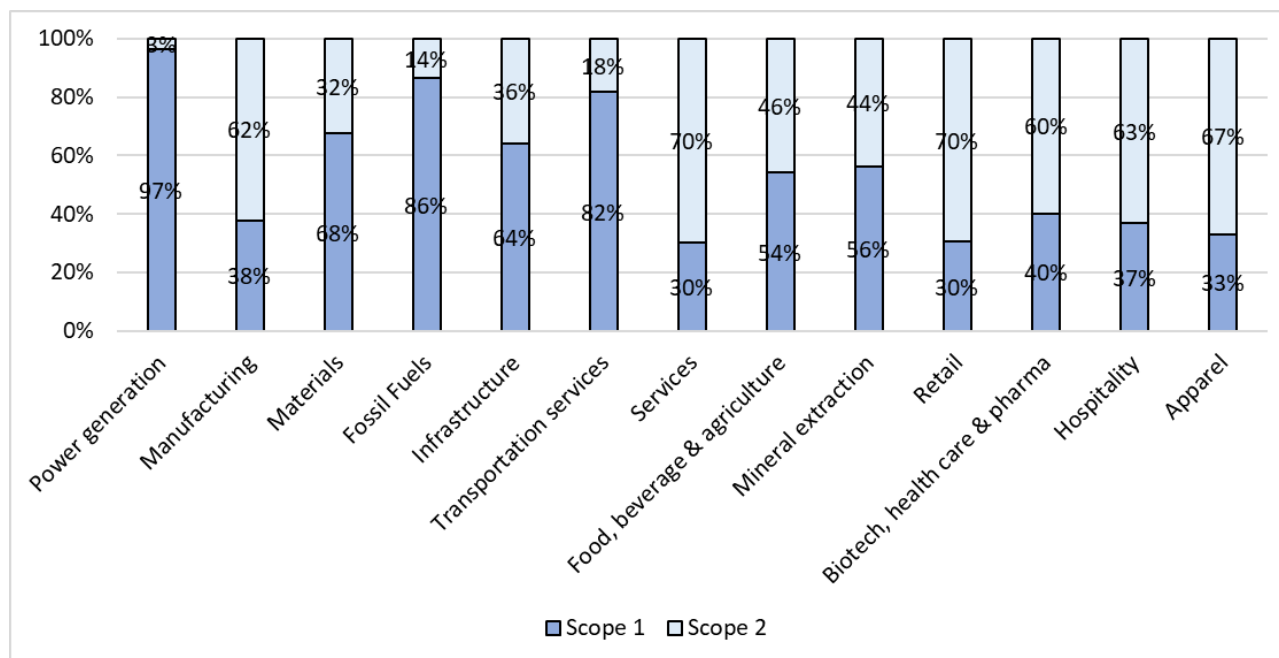


Figure A.5: Average company scope 1 and 2 distribution per sector in 2017

A.3.1.2 Number of Companies with a Science-Based Target.

In the ‘Targets and performance’ section of the CDP questionnaires, companies answered to the following question: ‘Is this a science-based target?’. The following answers are collected for every target: ‘Yes, this target has been approved as science-based by the Science-Based Targets initiative’, ‘Yes, we consider this a science-based target, but this target has not been approved as science-based by the Science Based Targets initiative’, ‘No, but we are reporting another target that is science-based’, ‘No, but we anticipate setting one in the next 2 years’, ‘No, and we do not anticipate setting one in the next 2 years’, and blank answers.

The collected answers have been aggregated at company level for every sector in our final sample and presented in Figure A.6. The blank answers have been regrouped with ‘No, and we do not anticipate setting one in the next 2 years’. We did not verify with the Science-based Targets Initiative database if the reported approved science-based targets information is accurate.

Our final sample include 114 companies with approved science-based target (SBT), 255 companies which consider their targets as science-based even if not approved, and 595 companies which does not consider their targets as science-based compliant. On those 595 companies, 383 said they anticipate setting a science-based targets in the two upcoming years.

Some sectors have more approved science-based targets than others. Mineral extraction sector has no approved science-based targets. Nevertheless, not every sector has a sector-specific guidance (Sectoral Decarbonization Approach) to set a science-based targets (SBTi, 2021b). However, other methods which don't use a sectoral perspective such as the absolute contraction approach are accepted to set a science-based targets (SBTi, 2021a).

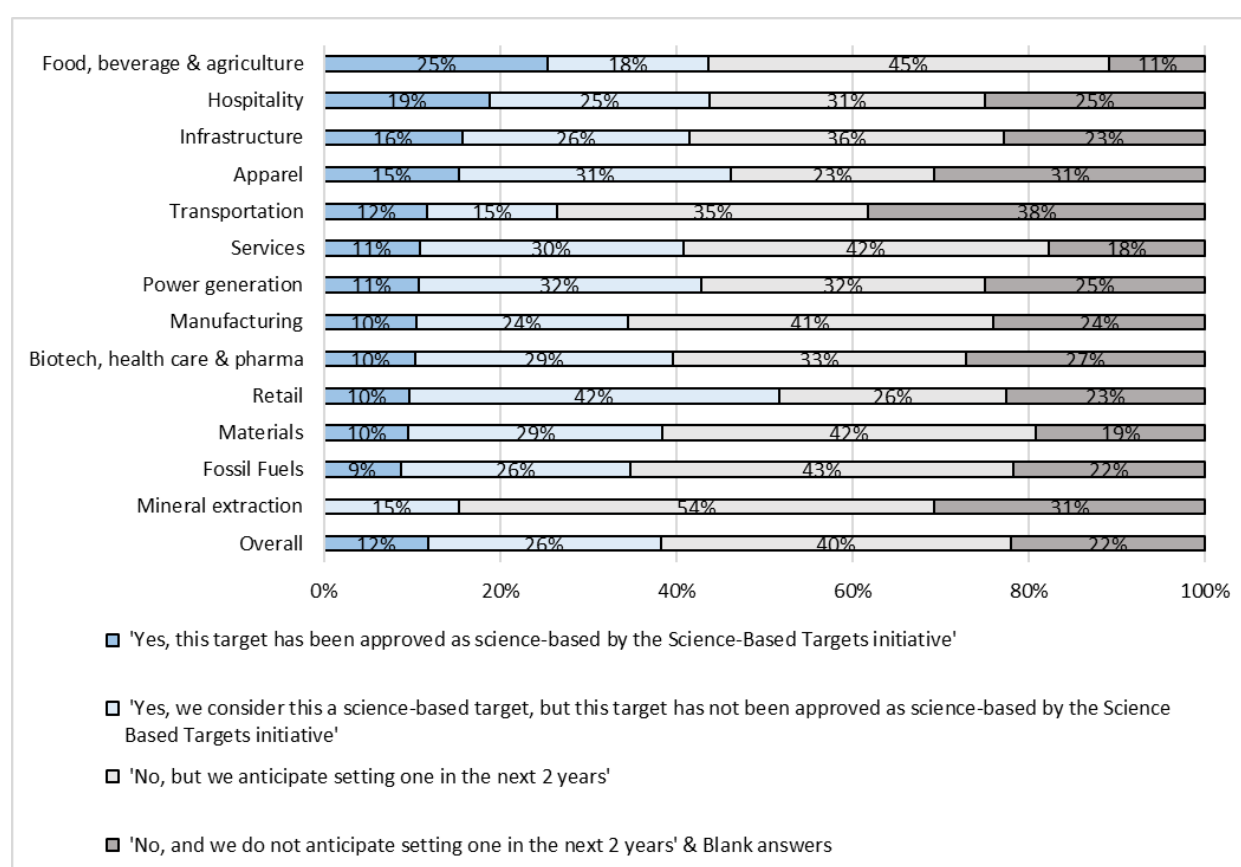


Figure A.6: Science-based targets distribution per sector

A.3.1.3 Number of Companies per Country or Region

To allow the results of our study to be compared with Wang and Sueyoshi (2018), an aggregation at the country or region level was necessary. The result per region of our study is presented in Table

A.8 of Section A.3.2.1. Figure A.7 present the number of companies included per region and countries of our final sample.

The same region and countries structure as Wang and Sueyoshi (2018) have been followed. Nevertheless, more countries are available in our sample. As them, we include UK in the European Union (EU) as at the time of their study and the data used by our study (2017), UK was still in the European Union. For information, in Wang and Sueyoshi (2018) study, the number of companies per region included also the companies that don't have a target. Our final sample only includes companies reporting a scope 1 and/or 2 target with the complete and accurate input data required for our study (Methodological Step 2).

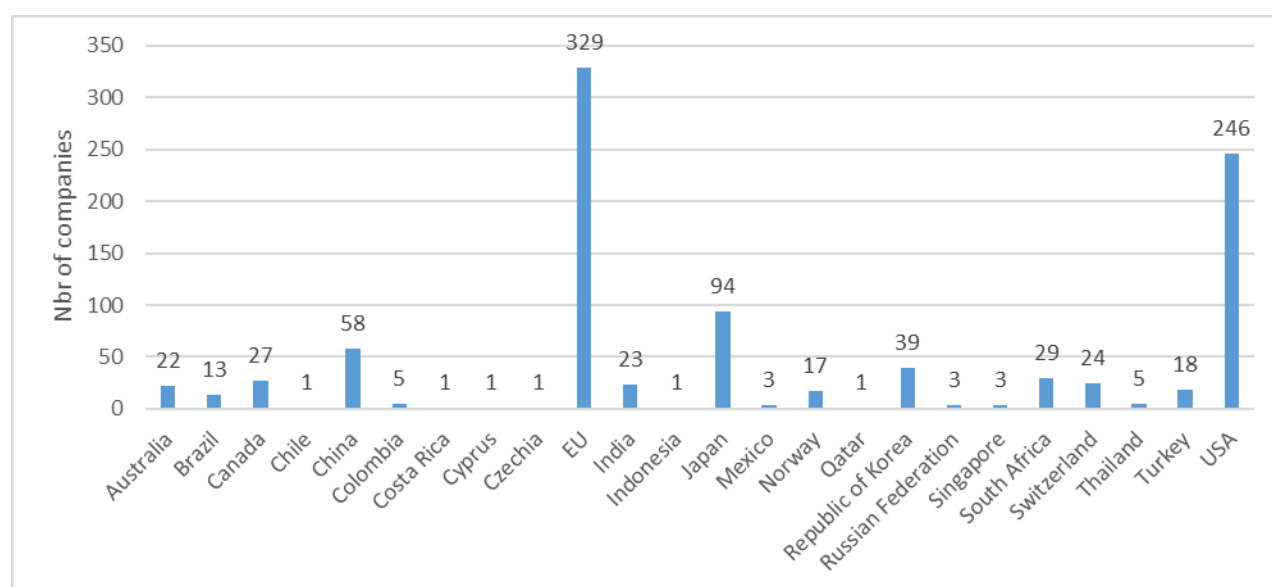


Figure A.7: Number of companies included in the final sample per country or region

A.3.1.4 Economic Intensity Sectoral Benchmarks

Complementary sensitivity analysis based on a data exclusion condition has been performed on financial extrapolation methods. The adjusted case (exclude companies with a R^2 value less than 0.4) and their corresponding case have been compared.

A.3.1.4.1 Revenue Adjusted Case Results

For the revenue benchmark, the default case (linear extrapolation of the financial value based on a linear regression) included 868 companies with an average R^2 of 0.64 and a median of 0.74. The default adjusted case included 679 companies with an average R^2 of 0.77 and a median of 0.81.

Figure A.3.6 presents the results for the default case and the default adjusted case with a 2017 common BY to 2020, 2025, and 2030. The corresponding percentage of change per sector for the median and Q1 are available in Table A.3.

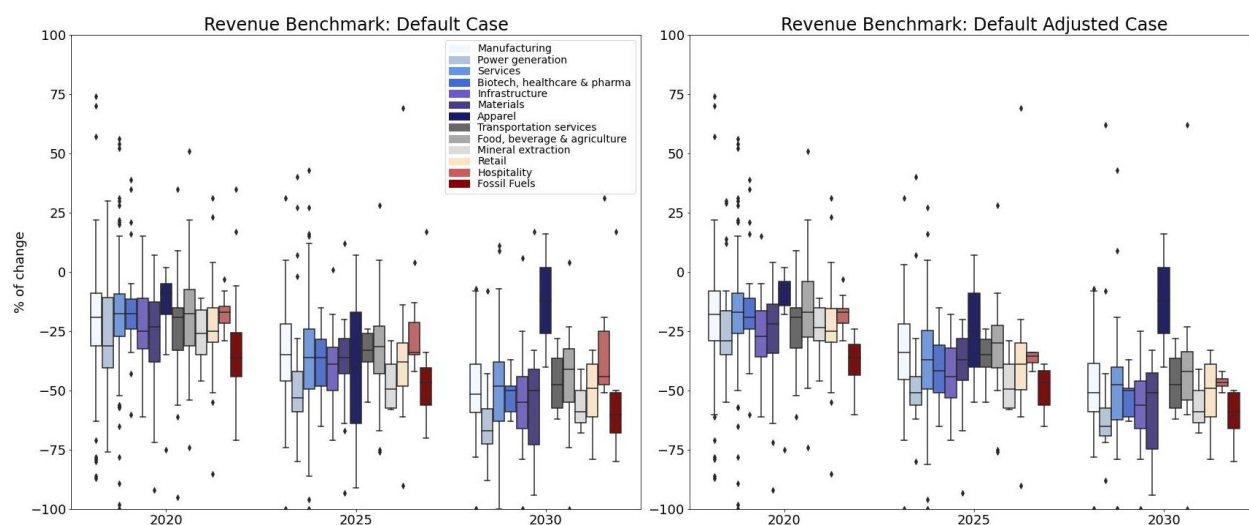


Figure A.8: Revenue-based intensity benchmarks result for default case and default adjusted case

As shown in Figure A.8, interquartile range variations between the default case and the adjusted case are not significant compared to the variations between financial extrapolation methods (see results in the main article). No sectors have an annualized variations of more than 3% between the default and adjusted case for their median and Q1 statistical indicators.

Variations between the default and adjusted case occur 72% on 39 observations for the median and 74% of the time for the Q1. However, the average annualized variation for the median is 0.24% while the Q1 average annualized variation is 0.43%.

The sensitivity analysis case (linear extrapolation based on the last segment of a discontinuous piecewise linear regression) included 865 companies with an average R^2 of 0.82 and a median of 0.87. The sensitivity analysis adjusted case has similar results to the sensitivity analysis case as the number of companies in the sample is 842 compared to 865. Only 23 companies in the sensitivity analysis case have an R^2 of less than 0.4. The sensitivity analysis adjusted case has an average R^2 of 0.84 and a median of 0.87. Figure A.9 presents the sensitivity analysis case and the corresponding adjusted case results with a 2017 common BY to 2020, 2025, and 2030. The percentage of change for the median and Q1 for those two cases are available in Table A.4.

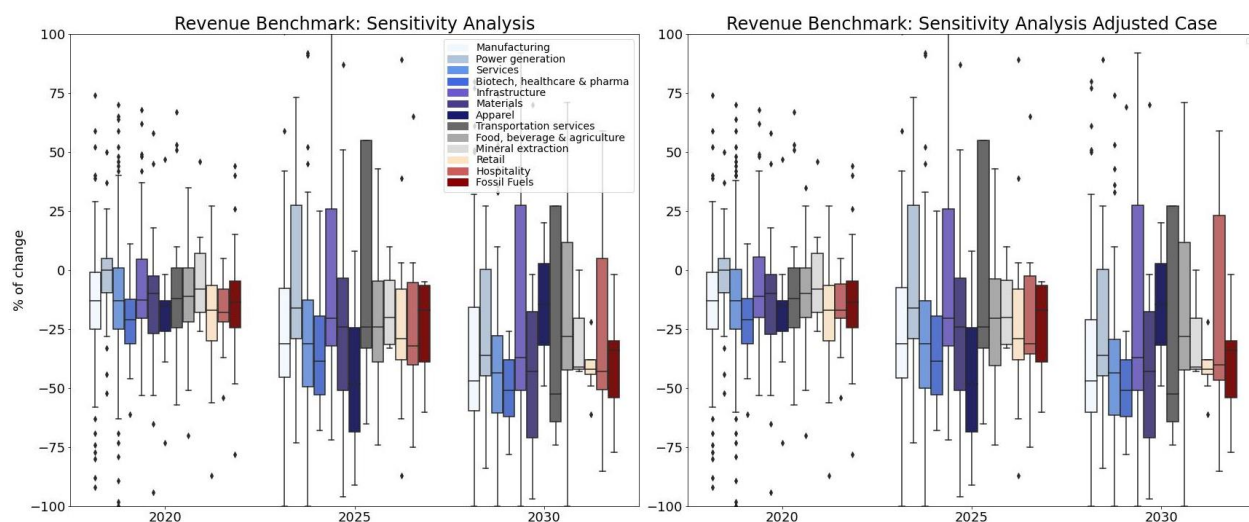


Figure A.9: Revenue-based intensity benchmarks result for sensitivity analysis and sensitivity analysis adjusted case

As the two cases only have 23 different companies on 868, the results are very similar as shown in Figure A.9. Variations between the two cases occur on 15% of the time (39 observations) for the median and 28% for Q1. The average annualized variation is 0.05% for the median and 0.07% for Q1.

Table A.3: Revenue-based intensity benchmarks result for default case and default adjusted case

	Default Case						Default Adjusted Case					
	2020		2025		2030		2020		2025		2030	
Sector/Metrics	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1
Apparel	-9	-18	-40	-64	-12	-26	-7	-14.25	-25	-40	-12	-26
Biotech, health care & pharma	-17.5	-24	-36	-48.25	-50	-59	-19	-24	-41.5	-51	-50	-61
Food, beverage & agriculture	-17.5	-31	-31.5	-42.75	-41	-55	-17	-27.5	-30	-40.5	-42	-54
Fossil Fuels	-36	-44	-46.5	-56.25	-60	-67.75	-36	-43.5	-46.5	-56.25	-59	-66
Hospitality	-17	-21.5	-34	-34.75	-44	-47.5	-17	-21.5	-35.5	-38.25	-46.5	-48
Infrastructure	-25	-32.5	-39	-50	-55	-66	-27	-35.75	-44	-53	-56	-66
Manufacturing	-19	-31	-35	-46	-51.5	-59.25	-18	-29	-34	-45.25	-51	-59
Materials	-23	-38	-36	-43	-50	-72.75	-22	-34.25	-37	-45.75	-51	-74.5
Mineral extraction	-26	-35	-49.5	-57.25	-59	-63.5	-23.5	-29	-49.5	-57.25	-59	-63.5
Power generation	-31	-40.5	-53	-59	-67	-72.5	-29	-35	-51	-56	-65	-69
Retail	-25	-29.5	-38	-48	-49	-61	-25	-29.75	-39	-49.75	-49	-61
Services	-17.5	-27	-36	-49.5	-48	-63	-17	-26	-37	-49.5	-47.5	-62.25
Transportation services	-19	-33	-33	-38	-47.5	-57.25	-19	-32	-35	-40.25	-47.5	-57.25

Table A.4: Revenue-based intensity benchmarks result for sensitivity analysis and sensitivity analysis adjusted case

	Sensitivity Analysis						Sensitivity Analysis Adjusted Case					
	2020		2025		2030		2020		2025		2030	
Sector/Metrics	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1
Apparel	-15	-26	-48	-68.5	-14.5	-31.75	-15	-26	-48	-68.5	-14.5	-31.75
Biotech, health care & pharma	-21	-31	-38.5	-52.75	-51	-62	-21	-31	-38.5	-52.75	-51	-62
Food, beverage & agriculture	-11	-22	-24	-39	-28	-42.25	-10	-20	-20.5	-40.5	-28	-42.25
Fossil Fuels	-13.5	-24.5	-17	-38.75	-34	-54	-13.5	-24.5	-17	-38.75	-34	-54
Hospitality	-18	-22	-32	-40.25	-43	-50.5	-17	-20.5	-31	-35.5	-40	-46.5
Infrastructure	-12.5	-20.25	-20.5	-32	-37	-51	-11	-20	-20.5	-32	-37	-51
Manufacturing	-13	-25	-31	-45.25	-47	-59.5	-13	-25	-31	-45.5	-47	-60
Materials	-10	-26.75	-24	-51	-43	-71	-10	-27	-24	-51	-43	-71
Mineral extraction	-8	-18	-20	-31.5	-41	-42	-8	-18	-20	-31.5	-41	-42
Power generation	0	-9.5	-16	-29	-36	-44.75	0	-9.5	-16	-29	-36	-44.75
Retail	-17	-30	-29	-38	-42	-44	-17	-30	-29	-38	-42	-44
Services	-13	-25	-31	-49.5	-43.5	-60.5	-13	-25	-31	-50	-43.5	-61.5
Transportation services	-12	-24.5	-24	-33	-52.5	-64.25	-12	-24.5	-24	-33	-52.5	-64.25

A.3.1.4.2 Enterprise Value Adjusted Case Results

For the enterprise value benchmark, the default case included 771 companies with an average R^2 of 0.52 and a median R^2 of 0.60. The default adjusted case included 505 companies with a R^2 over 0.4 with an average R^2 is 0.71 and median, 0.72. Figure A.10 presents the default case and the corresponding adjusted case results. The percentage of change per sector for the Q1 and median are available in Table A.5.

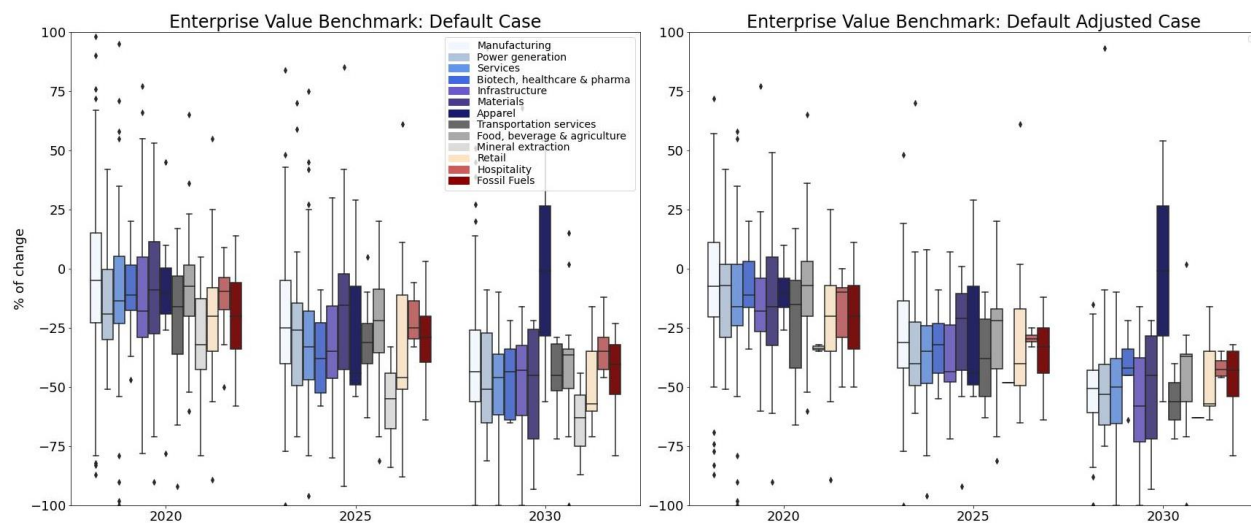


Figure A.10: Enterprise value-based intensity benchmarks result for default case and default adjusted case

Variations between the two cases occur 72% of the time for the median and 85% for Q1. The average annualized variation is 0.56% for the median and 0.71% for Q1. Nevertheless, no statistical indicators for any sector have annualized variations exceeding 3% between the two cases.

The sensitivity analysis case includes 760 companies with an average R^2 of 0.72 and median of 0.74. The sensitivity analysis adjusted case produces very similar results to the sensitivity analysis case. The two cases have a difference of 46 companies. The sensitivity analysis adjusted case (716 companies) has an average R^2 of 0.75 and a median of 0.77. Figure A.11 presents the sensitivity analysis and the adjusted case results in 2020, 2025, and 2030. The corresponding deterministic values for the median and Q1 are available in Table A.6.

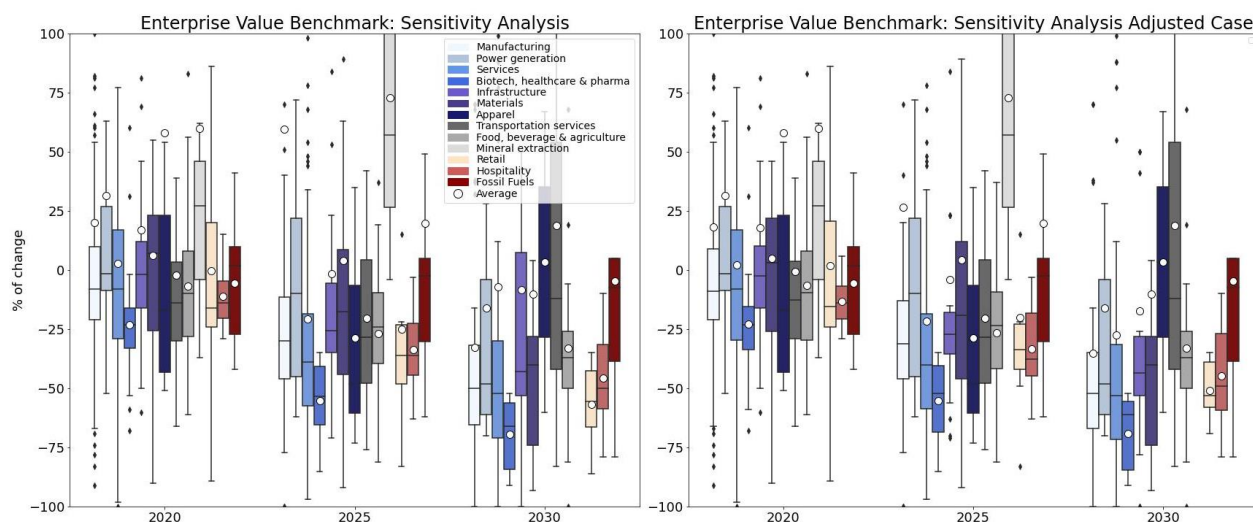


Figure A.11: Enterprise value-based intensity benchmarks result for sensitivity analysis and sensitivity analysis adjusted case

As shown in Figure A.11, the results of the sensitivity analysis case and the adjusted one are very similar. Variations between the two cases occur 51% for the median and 46% of the time for the Q1. However, the average annualized variation for the median is 0.12% and 0.11% for the Q1.

Table A.5: Enterprise value-based intensity benchmarks result for default case and default adjusted case

	Default Case						Default Adjusted Case					
	2020		2025		2030		2020		2025		2030	
Sector/Metrics	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1
Apparel	-10.5	-19.25	-44	-49	-1	-28.5	-10.5	-16.25	-44	-49	-1	-28.5
Biotech, health care & pharma	-11	-17.5	-38	-52.5	-43.5	-64	-11	-16.25	-32	-44	-42	-45
Food, beverage & agriculture	-7.5	-20	-22	-35.5	-36.5	-50.5	-7	-20	-22	-42.25	-37	-56
Fossil Fuels	-20	-34	-29	-39.5	-40.5	-53	-20	-34	-33	-44	-43	-54
Hospitality	-9.5	-17.25	-25	-29.5	-35	-42.5	-10	-29	-29.5	-30.75	-42.5	-45.25
Infrastructure	-18	-29	-35	-46.25	-43	-62	-18	-26.5	-43.5	-47.75	-58	-73.25
Manufacturing	-5	-22.75	-25	-40	-43.5	-56	-7.5	-20.5	-31	-42	-50.5	-60.75
Materials	-9	-27.5	-15.5	-42.5	-45	-71.75	-16	-32.5	-21	-43	-45	-71.75
Mineral extraction	-32	-42.5	-55	-67.5	-63	-75	-33.5	-34.25	-48	-48	-63	-63
Power generation	-19	-30	-26	-49.5	-51	-65	-7	-29	-40	-49.5	-53	-66
Retail	-20	-34.75	-46	-51	-57	-60	-20	-35	-40	-49.5	-57	-58
Services	-13.5	-23	-33	-47	-46	-61.75	-16	-24	-35	-48.5	-50	-65.25
Transportation services	-16	-36	-31	-40	-45	-51.5	-15	-42	-38	-54	-56	-64

Table A.6: Enterprise value-based intensity benchmarks result for sensitivity analysis and sensitivity analysis adjusted case

	Sensitivity Analysis						Sensitivity Analysis Adjusted Case					
	2020		2025		2030		2020		2025		2030	
Sector/Metrics	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1	M.	Q1
Apparel	-17	-43.25	-48	-60.5	3.5	-28.25	-17	-43.25	-48	-60.5	3.5	-28.25
Biotech, health care & pharma	-23	-33	-53.5	-65.25	-66	-84.25	-23	-33.5	-52	-68.5	-61	-84.5
Food, beverage & agriculture	-10	-28	-24	-39.5	-37	-50	-9.5	-29.5	-23.5	-41.75	-37	-50
Fossil Fuels	2	-27	-2.5	-30.25	-7.5	-38.5	2	-27	-2.5	-30.25	-7.5	-38.5
Hospitality	-14	-20.25	-36	-44.5	-50	-58.5	-14	-20.75	-37.5	-44.75	-49	-59.25
Infrastructure	-2	-16	-25.5	-34.75	-43	-53	-2.5	-16	-27	-35.5	-43.5	-53
Manufacturing	-8	-21	-30	-46	-50	-65.25	-9	-21	-31	-46	-52	-67
Materials	7	-25.5	-17.5	-44	-40	-74	3	-26	-19	-46	-40	-74
Mineral extraction	27	-4	57	26.5	422	278	27	-4	57	26.5	422	278
Power generation	-1.5	-8.75	-10	-45	-48	-61	-1.5	-8.75	-10	-45	-48	-61
Retail	-16	-24	-36	-48	-55.5	-66.25	-15.5	-24	-33.5	-42	-53	-58
Services	-8	-29	-39	-57.5	-52	-71	-8	-29.5	-40	-58.5	-53	-71.5
Transportation services	-14	-30	-28.5	-47.75	-12	-42	-12.5	-29	-28.5	-47.75	-12	-42

A.3.2 Annualized reduction rate

To facilitate comparison with previous or upcoming studies, all the benchmark results have been annualized. For example, the annualized results in 2020 correspond to: percentage of change / (2020 – 2017). Also, some studies such as Dietz et al. (2021) and Wang and Sueyoshi (2018) uses only the average as statistical indicator. The median and Q1 are displayed in the main article tables as they are less subject to outlier and help determine if a company is positioned above 50% or 75% of their peers. The average results are only shown in the figures in the main article. Nevertheless, the average of the annualized sectoral percentage of change is available in this section.

A.3.2.1 Absolute GHG Sectoral Benchmark

The annualized sectoral reduction rate results for the absolute carbon emission benchmark are presented in Table A.7. The table included the average, median, and Q1 statistical indicators in 2020, 2025, and 2030.

To allow a comparison with Wang and Sueyoshi (2018) results, our results have been annualized per regions as Wang and Sueyoshi, 2018 presented no overall results per sector but overall results per regions. As explained in Section A.3.1.3, Wang and Sueyoshi (2018) structure for the regions and countries have been followed. Table A.8 presents those results and included the average, median and Q1 in 2020, 2025, and 2030.

A.3.2.2 Economic Intensity Sectoral Benchmark

The annualized reduction rate results per sector for the economic intensity benchmark per revenue benchmark are presented in Table A.9. Table A.9 include the average, median, and Q1 statistical indicators in 2020, 2025, and 2030.

For the economic intensity sectoral benchmark per enterprise value, the sectoral results for the annualized reduction rate are presented in Table A.10 and included the average, median and Q1 in 2020, 2025, and 2030.

Table A.7: Annualized reduction rate results per sector for the absolute GHG sectoral benchmark

	2020			2025			2030		
Sector/Metrics	Average	Median	Q1	Average	Median	Q1	Average	Median	Q1
Apparel	-4.0%	-1.3%	-3.8%	-4.6%	-3.5%	-7.2%	-0.7%	-0.7%	-1.0%
Biotech, health care & pharma	-2.6%	-1.0%	-5.2%	-2.6%	-2.3%	-3.7%	-2.2%	-2.1%	-2.7%
Food, beverage & agriculture	-3.5%	-1.8%	-4.9%	-2.5%	-2.0%	-3.0%	-2.2%	-1.6%	-2.5%
Fossil Fuels	-2.5%	-1.3%	-3.8%	-0.9%	-0.5%	-1.6%	-1.1%	-0.7%	-1.4%
Hospitality	-1.9%	-1.3%	-2.5%	-1.5%	-1.5%	-1.8%	-1.4%	-1.6%	-2.0%
Infrastructure	-3.2%	-2.0%	-4.3%	-2.5%	-1.9%	-2.9%	-2.5%	-2.2%	-2.8%
Manufacturing	-3.3%	-1.7%	-5.0%	-2.2%	-1.9%	-2.9%	-2.1%	-2.1%	-2.7%
Materials	-5.0%	-1.7%	-7.8%	-2.5%	-1.5%	-3.3%	-2.7%	-2.2%	-4.8%
Mineral extraction	-2.2%	-1.5%	-3.8%	-2.4%	-2.5%	-3.8%	-1.9%	-2.2%	-2.6%
Power generation	-2.6%	-2.3%	-3.5%	-2.3%	-2.7%	-3.7%	-2.2%	-2.8%	-3.4%
Retail	-4.2%	-3.7%	-6.3%	-2.7%	-1.8%	-4.3%	-2.2%	-1.9%	-3.2%
Services	-2.9%	-1.3%	-4.3%	-2.5%	-1.9%	-4.2%	-2.2%	-1.8%	-3.2%
Transportation services	-3.9%	-1.7%	-6.0%	-1.8%	-1.1%	-2.9%	-1.8%	-1.7%	-2.7%
Overall	-3.2%	-1.5%	-5.0%	-2.3%	-1.9%	-3.3%	-2.1%	-1.9%	-3.0%

Table A.8: Annualized reduction rate results per region for the absolute GHG benchmark

	2020			2025			2030		
Sector/Metrics	Average	Median	Q1	Average	Median	Q1	Average	Median	Q1
Australia	-2.9%	-2.5%	-4.4%	-5.1%	-3.8%	-7.8%	-4.2%	-3.3%	-6.6%
Brazil	-3.2%	0.0%	-5.0%	-1.1%	-1.1%	-1.6%			
Canada	-4.3%	0.0%	-3.8%	-0.7%	0.0%	-0.4%	-1.0%	-0.1%	-0.8%
Chile	-12.7%	-12.7%	-12.7%						
China	-2.4%	-0.7%	-4.3%	-1.7%	-1.5%	-2.1%	-1.6%	-1.5%	-2.2%
Colombia	-1.8%	-1.3%	-2.0%	-0.7%	0.0%	-1.1%	-1.1%	-1.1%	-1.6%
Cyprus	-4.3%	-4.3%	-4.3%						
Czechia	-9.3%	-9.3%	-9.3%						
EU	-3.9%	-2.0%	-5.7%	-2.7%	-2.1%	-3.9%	-2.6%	-2.3%	-3.3%
India	-4.5%	-3.0%	-7.3%	-4.0%	-2.9%	-5.4%	-3.9%	-3.0%	-6.4%
Indonesia	-10.7%	-10.7%	-10.7%						
Japan	-2.6%	-1.3%	-3.8%	-1.4%	-1.4%	-2.5%	-1.3%	-1.4%	-2.5%
Mexico	-3.1%	-1.0%	-4.7%	-5.2%	-5.2%	-6.3%	-4.6%	-4.6%	-4.6%
Norway	-6.1%	-4.3%	-7.5%	-2.9%	-2.5%	-5.6%	-2.3%	-1.7%	-4.3%
Qatar	-4.0%	-4.0%	-4.0%						
Republic of Korea	-3.9%	-1.7%	-4.5%	-1.2%	-1.3%	-2.0%	-1.3%	-1.4%	-1.9%
Russian Federation	-1.2%	-1.3%	-1.8%	-1.4%	-1.4%	-1.4%	-1.7%	-1.7%	-1.7%
Singapore	-7.9%	-10.7%	-11.2%	-3.0%	-3.0%	-3.9%	-2.3%	-2.3%	-2.8%
South Africa	-3.8%	-2.3%	-5.2%	-1.9%	-1.8%	-3.8%	-1.0%	0.0%	-1.5%
Switzerland	-2.1%	-0.3%	-4.7%	-1.7%	-1.9%	-3.3%	-2.0%	-2.4%	-2.5%
Thailand	-0.8%	-4.3%	-4.7%	-2.7%	-2.4%	-3.3%	-2.5%	-1.8%	-3.0%
Turkey	-0.7%	-0.7%	-1.7%	-1.0%	-0.9%	-1.8%	-0.8%	-0.8%	-1.3%
USA	-2.4%	-1.3%	-3.0%	-2.5%	-1.9%	-3.3%	-2.2%	-2.0%	-3.1%
Overall	-3.2%	-1.5%	-5.0%	-2.3%	-1.9%	-3.3%	-2.1%	-1.9%	-3.0%

Table A.9: Annualized reduction rate results per sector for the economic intensity benchmark per revenue

	2020			2025			2030		
Sector/Metrics	Average	Median	Q1	Average	Median	Q1	Average	Median	Q1
Apparel	-5.9%	-3.0%	-6.0%	-5.1%	-5.0%	-8.0%	-0.9%	-0.9%	-2.0%
Biotech, health care & pharma	-5.3%	-5.8%	-8.0%	-4.9%	-4.5%	-6.0%	-3.9%	-3.8%	-4.5%
Food, beverage & agriculture	-6.0%	-5.8%	-10.3%	-1.8%	-3.9%	-5.3%	-2.9%	-3.2%	-4.2%
Fossil Fuels	-10.9%	-12.0%	-14.7%	-5.6%	-5.8%	-7.0%	-4.1%	-4.6%	-5.2%
Hospitality	-5.7%	-5.7%	-7.2%	-3.3%	-4.3%	-4.3%	-2.4%	-3.4%	-3.7%
Infrastructure	-7.8%	-8.3%	-10.8%	-5.0%	-4.9%	-6.3%	-4.2%	-4.2%	-5.1%
Manufacturing	-6.2%	-6.3%	-10.3%	-4.1%	-4.4%	-5.8%	-3.8%	-4.0%	-4.6%
Materials	-4.8%	-7.7%	-12.7%	-4.8%	-4.5%	-5.4%	-4.1%	-3.8%	-5.6%
Mineral extraction	-8.6%	-8.7%	-11.7%	-5.8%	-6.2%	-7.2%	-4.3%	-4.5%	-4.9%
Power generation	-8.4%	-10.3%	-13.5%	-5.3%	-6.6%	-7.4%	-4.1%	-5.2%	-5.6%
Retail	-7.7%	-8.3%	-9.8%	-4.4%	-4.8%	-6.0%	-1.8%	-3.8%	-4.7%
Services	-6.2%	-5.8%	-9.0%	-3.0%	-4.5%	-6.2%	-3.8%	-3.7%	-4.8%
Transportation services	-8.1%	-6.3%	-11.0%	-4.3%	-4.1%	-4.8%	-3.6%	-3.7%	-4.4%
Overall	-6.5%	-6.7%	-10.3%	-3.9%	-4.6%	-6.1%	-3.7%	-3.8%	-4.8%

Table A.10: Annualized reduction rate results per sector for the economic intensity benchmark per enterprise value

	2020			2025			2030		
Sector/Metrics	Average	Median	Q1	Average	Median	Q1	Average	Median	Q1
Apparel	-3.8%	-3.5%	-6.4%	-2.9%	-5.5%	-6.1%	-0.1%	-0.1%	-2.2%
Biotech, health care & pharma	-3.1%	-3.7%	-5.8%	-4.5%	-4.8%	-6.6%	-3.6%	-3.3%	-4.9%
Food, beverage & agriculture	-2.4%	-2.5%	-6.7%	10.4%	-2.8%	-4.4%	-3.1%	-2.8%	-3.9%
Fossil Fuels	-6.6%	-6.7%	-11.3%	-3.7%	-3.6%	-4.9%	-3.4%	-3.1%	-4.1%
Hospitality	-4.3%	-3.2%	-5.8%	-2.7%	-3.1%	-3.7%	-2.6%	-2.7%	-3.3%
Infrastructure	-4.2%	-6.0%	-9.7%	-3.7%	-4.4%	-5.8%	-2.9%	-3.3%	-4.8%
Manufacturing	0.6%	-1.7%	-7.6%	-1.5%	-3.1%	-5.0%	-2.5%	-3.3%	-4.3%
Materials	-3.6%	-3.0%	-9.2%	1.1%	-1.9%	-5.3%	-2.8%	-3.5%	-5.5%
Mineral extraction	-10.1%	-10.7%	-14.2%	-7.1%	-6.9%	-8.4%	-5.0%	-4.8%	-5.8%
Power generation	-4.4%	-6.3%	-10.0%	-2.0%	-3.3%	-6.2%	-3.0%	-3.9%	-5.0%
Retail	-7.0%	-6.7%	-11.6%	-2.7%	-5.8%	-6.4%	83.4%	-4.4%	-4.6%
Services	-2.8%	-4.5%	-7.7%	-0.8%	-4.1%	-5.9%	-3.2%	-3.5%	-4.8%
Transportation services	-6.8%	-5.3%	-12.0%	-3.8%	-3.9%	-5.0%	0.6%	-3.5%	-4.0%
Overall	-2.5%	-4.0%	-8.7%	-1.1%	-3.6%	-5.8%	0.6%	-3.4%	-4.7%

A.3.2.3 Physical Intensity Sectoral Benchmark

Table A.11 presents the physical intensity benchmark annualized reduction rate results for the power generation sector including our study and TPI results. To allow a more coherent comparison, the TPI, 2021 database for the power generation companies assessed in 2019 have previously been normalised with a 2017 common BY as done with our results.

Table A.11: Comparison with TPI, 2021 results for the power generation physical intensity benchmark (annualized reduction rate and a 2017 common BY).

	2020			2025			2030		
Sector/ Metrics	Ave- rage	Median	Q1	Ave- rage	Median	Q1	Ave- rage	Median	Q1
Study result	-4.0%	-2.2%	-5.4%	-3.1%	-2.4%	-3.6%	-2.7%	-2.7%	-3.6%
TPI result	-3.7%	-3.0%	-7.1%	-3.3%	-2.4%	-4.7%	-3.3%	-2.7%	-4.5%

A.3.3 Paris Agreement Compliance

The results obtained in the article can be compared with decarbonisation trajectories needed to fulfill the Paris Agreement. For corporate climate mitigation target to be compliant with required temperature pathway (2 degrees, well-below 2 degrees, 1.5 degrees), many methods such as the Sectorial Decarbonisation Approach (SDA), the absolute contraction approach, and GEVA exists (SBTi, 2020). Some of the methods and temperature pathway are compared to the results of the article. Other methods and temperature pathway could be used. However, this subject was not the primary focus of the article. Further work is needed to complete this assessment.

A.3.3.1 Absolute GHG Sectoral Benchmark

With the absolute contraction approach, the minimum annual reduction rate to respect a well-below 2 degrees pathway must be 2.5% (SBTi, 2019). With a 2017 BY, the percentage of change should be -7.5% in 2020, -20% in 2025, and -32.5% in 2030. The median value of the retail sector respect such a reduction in 2020. In 2025, the apparel, mineral extraction, and power generation sectors

have a median reduction rate exceeding -20% while in 2030, only the power generation sector respects a median reduction rate better than -32.5%.

For a 1.5-degree pathway with the absolute contraction approach, the minimum annual reduction rate must be 4.2% (SBTi, 2019). With a 2017 BY, the corresponding percentage of change is -12.6% in 2020, -33.6% in 2025, and -54.6% in 2030. No sector respects such a reduction rate with their median values in 2020, 2025 or 2030.

A.3.3.2 Economic Intensity Sectoral Benchmark

To the knowledge of the authors, no methods allow a comparison with GHG intensity per revenue indicator. The economical method for science-based compliant target such as GEVA use tCO₂ per value-added (SBTi, 2020). However, in order to respect a 1.5-degree pathway, the EU Technical Expert Group on Sustainable Finance has defined a 7% geometric annual average reduction using tCO₂e per enterprise value (EU Technical Expert Group on Sustainable Finance, 2019). With a 2017 BY, the corresponding percentage of change is -19.6% in 2020, -44% in 2025, and -61.1% in 2030. The median value of the fossil fuel and the mineral extraction sector respect such a reduction in 2020. In 2025, the apparel, mineral extraction, and retail sectors have a median reduction better than the required -44%. In 2030, only the mineral extraction sector surpasses the reduction requirement of 61.1%. However, the economical intensity results of our study are very sensitive to the methods used to extrapolate the financial value. In order to be compared with more confidence to decarbonization trajectories, those results need to be further investigated.

A.3.3.3 Physical Intensity Sectoral Benchmark

The sustainable development scenario of the IEA World Energy Outlook 2020 which corresponds to a well-below 2 degrees pathway stated the physical GHG intensity for the power generation sector (IEA, 2020). The physical GHG intensity in 2025 should be less than 0.33 tCO₂e/MWh and 0.22 tCO₂e/MWh in 2030 (IEA, 2020). No intensity is given for 2020.

Our final sample for the power generation physical GHG intensity benchmark includes 32 companies in 2017 of which 24 have a target until 2025 and 22 until 2030. In 2025, 10 companies have a target with an intensity under 0.33 tCO₂e/MWh while 7 companies have an intensity under 0.22 tCO₂e/MWh in 2030.

A.3.4 Higher Current Emitters Reduction Rate

Higher current emitting companies have the potential to reduce more than lower current emitting companies. To test this hypothesis, the power generation companies in the physical GHG intensity benchmark have been divided into two groups. Group 1 represents companies with an intensity higher than the global intensity in 2017 and Group 2, under. The global 2017 intensity for the power sector is 0.482 tCO₂e/MWh (IEA, 2019). In total, Group 1 included 14 companies while Group 2 included 18. Table A.12 presents the percentage of change for those two groups including the median and Q1 values from 2017 to 2020, 2025, and 2030. Groups 1 & 2 combined correspond to the results of the power generation sector presented in Table 5.5 of the article.

From the values displayed in Table A.12, Group 1 is reducing more than Group 2 in terms of median value. The average annualized reduction rate between the two groups is 0.6% for the median and 0.5% for Q1. Accordingly, the higher current emitting companies are planning to reduce more on average than the lower current emitting companies.

Table A.12: Higher Current Emitters Reduction Rate

	2020		2025		2030	
Group/Metrics	Median	Q1	Median	Q1	Median	Q1
Group 1 (Over)	-8%	-22%	-20%	-26%	-35%	-47%
Group 2 (Under)	-6%	-15%	-15%	-30%	-27%	-47%
Group 1 & 2 combined	-7%	-16%	-19%	-29%	-35%	-47%

This hypothesis could only be tested on the physical intensity benchmarks as the economical intensity benchmarks results are very sensitive to the financial forecasting method used. Further research on the topic is necessary to confirm with more certainty those results.

A.4 Companies Included in Benchmarks

The absolute GHG benchmark includes 964 companies. The economical intensity benchmarks per revenue counts 868 companies and the one per enterprise value, 760 companies. The physical intensity benchmark includes 32 companies.

Table A.13 presents the companies included in each benchmark. For each company, the sector and CDP account number is also available. The acronym A. is for absolute GHG benchmark, R. for the economical intensity benchmarks per revenue, EV. for economical intensity benchmarks per enterprise value, and P. for physical intensity benchmarks. Table A.13 is sorted by company name alphabetic order.

Table A.13: Companies included in each benchmark

*** Due to the length of Table A.13 (around 30 pages), this table is not provided here but is available online with the supplementary information of the main article at <https://doi.org/10.1016/j.jclepro.2022.134220>.

APPENDIX B ARTICLE 2: SUPPLEMENTARY MATERIAL

B.1 Literature review

B.1.1 Target progress indicators

As mentioned in the main article, the following progress indicators are used by existing studies: percentage of the target achieved (Dragomir, 2023; Ioannou et al., 2016; SBTi, 2022a; Yeo et al., 2022), progress ratio (A. Hsu et al., 2020), and categorical variables using terminology such as on track, behind, or achieved (Callery & Kim, 2021; Gieseckam et al., 2021a; Kuramochi et al., 2021; D. Wang, 2017; Yeo et al., 2022).

The percentage of target achieved (Equation 5.2 in the main article) has been used by Ioannou et al. (2016) and Dragomir (2023), with an adaptation by Yeo et al. (2022) that divides it by the number of years passed since the base year. Indeed, if a company has started its target last year, a 20% achievement of the targeted reduction does not represent the same attainment if there is 1 year remaining to the target or 9 years. To contravene to a certain extent to the lack of integration of the remaining time left to achieve a target, Ioannou et al. (2016) used the percentage of time elapsed (Equation 3 in the main article) as a control variable. This was also presented separately by SBTi (2022b), with Dragomir (2023) and Yeo et al. (2022) visually presenting it with the remaining years left to the target.

Progress ratio, as defined by Hsu et al. (2020), consists of the reduction achieved on the reduction required at the year assessed, which measures the speed of the target progression. This assumes a linear reduction trajectory between the base year and target year (constant reduction rate per year), i.e., different equations, but equivalent to Equation 2 (main article) divided by Equation 3 (main article). The progress ratio has often been transformed into categorical variables where a value of 1 or over corresponds to on track, a value under 1, not on track (Callery & Kim, 2021; Kuramochi et al., 2021; D. Wang, 2017; Yeo et al., 2022) and achieved when the year assessed has lower emissions than the target year (Gieseckam et al., 2021a). Both the progress ratio and categorical variables integrate a time perspective; however, targets will be judged not on track by categorical variables regardless of whether they are slightly or highly behind their linear reduction trajectory, leading to a lack of comparability.

To the authors knowledge, only the Hsu et al. (2020) study has used the progress ratio as dependent variable, and its use in this study is limited by the specificity of our sample. Hsu et al. (2020) assessed city targets with a 2020 target year (homogeneous sample), which differs from the specificity of corporate targets (Yeo et al., 2022). As shown by Yeo et al. (2022), corporate targets have substantial progress variation near their base year, implying some targets have a high percentage achieved with a low percentage of time elapsed (extreme values with the progress ratio indicator; outliers).

On the other hand, the studies by Dahlmann et al. (2019) and Aldy et al. (2023) used a different approach by measuring the change in corporate carbon performance over time, with Dahlmann et al. (2019) measuring the percentage of corporate carbon performance change over one year and Aldy et al. (2023) measuring the annualized change over 10 years. These approaches are similar to using the percentage of target achieved (not integrating the remaining time left to achieve the target) when it corresponds to the scope covered by companies' targets, which does not appear to be the case for all the targets assessed by these studies, thus lacking comparability with the progression measure used).

B.2 Methodology

B.2.1 List of determinants

Table B.1: List of all the determinants with their corresponding category, preprocessing and unit, and the corresponding CDP question. Abbreviations: SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based, SC12LB; scope 1 and scope 2 location-based, SC12MB; scope 1 and scope 2 market-based, SC3; scope 3, SBTi = Science-Based Target Initiative; ETS = Emissions Trading System.

#	Category	Determinant name	Explanation	Unit	CDP question
1	Target parameters	Annualized target ambition	Target ambition harmonized at scope 1 and 2 divided by the timeframe of the target	Percentage	C4.1a, C4.1b
2	Target parameters	Percentage of the target achieved at the year the target was set	Percentage of the target achieved when the target is launched (start year) which corresponds to the percentage of the target	Percentage	C4.1a, C4.1b

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
			achieved due to the choice of the baseline year.		
3	Target parameters	Absolute target (not intensity target)	The value is 1 for an absolute target and 0 for an intensity target	1 or 0	C4.1a, C4.1b
4	Target parameters	Number of years between the base year and the target year	Difference between the target year and the base year	Year	C4.1a_C5, C4.1a_C8, C4.1b_C6, C4.1b_C9
5	Target parameters	Number of years between the base year and the year the target was set	Difference between the start year and the base year	Year	C4.1a_C5, C4.1a_C2, C4.1b_C6, C4.1b_C2
6	Target parameters	Remaining numbers of years until the target year	Difference between the target year and the reporting year	Year	C0.2_C2, C4.1a_C8, C0.2_C2, C4.1b_C9
7	Target parameters	Baseline year	Reference year of the target	Calendar year	C4.1a_C5, C4.1b_C6
8	Target parameters	Baseline year emissions total	Total of scope 1 and 2 emissions for the baseline year. The scope 2 market-based is used only when the target covers the scope 2 market-based.	TCO2 eq	C5.1_C3
9	Target parameters	Start year	Launching year of the target	Calendar year	C4.1a_C2, C4.1b_C2
10	Target parameters	Last year	Reporting year	Calendar year	C0.2_C2
11	Target parameters	Last year emissions total	Total of scope 1 and 2 emissions for the reporting year. The scope 2 market-based is used only when the target covers the scope 2 market-based.	TCO2 eq	C6.1_C1, C6.3_C1, C6.3_C2
12	Target parameters	Target year	Target year of the target	Calendar year	C4.1a_C8, C4.1b_C9
13	Target parameters	Expected reduced emissions	Correspond to the base year emissions covered by	TCO2 eq	C4.1a_C6, C4.1a_C9, C4.1b_C12

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
			the target multiplied by the target ambition		
14	Target parameters	SC12LB covered by target	If the target covers the scope 1 and 2 location-based, the value is 1, else, 0.	1 or 0	C4.1a_C4, C4.1b_C4
15	Target parameters	SC12MB covered by target	If the target covers the scope 1 and 2 market-based, the value is 1, else, 0.	1 or 0	C4.1a_C4, C4.1b_C4
16	Target parameters	SC1 covered by target	If the target covers the scope 1, the value is 1, else, 0.	1 or 0	C4.1a_C4, C4.1b_C4
17	Target parameters	SC2LB only covered by target	If the target covers the scope 2 location-based, the value is 1, else, 0.	1 or 0	C4.1a_C4, C4.1b_C4
18	Target parameters	SC2MB only covered by target	If the target covers the scope 2 market-based, the value is 1, else, 0.	1 or 0	C4.1a_C4, C4.1b_C4
19	Target parameters	Percentage scope covered by the target	Percentage scope covered by the target as reported by the company	Percentage	C4.1a_C7, C4.1b_C8
20	Target parameters	Approved by the SBTi	If the company reports that the target is approved by the SBTi, the value is 1. If not the case, the value is 0.	1 or 0	C4.1a_C14, C4.1b_C17
21	Emissions reporting and other targets	Disclose 100% of emissions for scope 1 and 2	If all sources of scope 1 and 2 are included in the reporting boundaries, the value is 1 and 0 otherwise.	1 or 0	C6.4
22	Emissions reporting and other targets	SC1 emissions breakdown by gas type	If the company reports the breakdown by GHG type for their scope 1 emissions, the value is 1 and otherwise, 0.	1 or 0	C7.1
23	Emissions reporting and other targets	SC1 emissions breakdown by country	If the company reports the breakdown by countries for their scope 1 emissions, the value is 1 and otherwise, 0.	1 or 0	C7.2_C2
24	Emissions reporting and other targets	SC1 emissions breakdown by	If the company reports the breakdown by business division for their scope 1	1 or 0	C7.3a_C2

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
		business division	emissions, the value is 1 and otherwise, 0.		
25	Emissions reporting and other targets	SC1 emissions breakdown by business facility	If the company reports the breakdown by business facility for their scope 1 emissions, the value is 1 and otherwise, 0.	1 or 0	C7.3b_C2
26	Emissions reporting and other targets	Carbon intensity figure per revenue	If the company reports a carbon intensity result per revenue, the value is 1 and otherwise, 0.	1 or 0	C6.10_C1
27	Emissions reporting and other targets	SC2 LB emissions	If the company reports their scope 2 location-based emissions for the reporting year, the value is 1 and otherwise, 0.	1 or 0	C6.3_C2
28	Emissions reporting and other targets	SC2 MB emissions	If the company reports their scope 2 market-based emissions for the reporting year, the value is 1 and otherwise, 0.	1 or 0	C6.3_C2
29	Emissions reporting and other targets	Use renewable energy certificate in their scope 2 market-based accounting	If the company mentions using renewable energy certificates in their scope 2 market-based emissions reporting, the value is 1 and otherwise, 0.	1 or 0	C8.2e_C1
30	Emissions reporting and other targets	More than one target	The value is 1 when the company reports more than one target including short-term and long-term target, absolute or intensity targets, or target covering the scope 3 and 0 when they report only one target.	1 or 0	C4.1a, C4.1b
31	Emissions reporting and other targets	Renewable energy consumption	If the company reports their renewable energy consumption, the value is 1 and otherwise, 0.	1 or 0	C8.2a_C2
32	Emissions reporting and other targets	Energy target	If the company reports an energy target, the value is 1 and otherwise, 0.	1 or 0	C4.2a_C1

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
33	Emissions reporting and other targets	SC3 target	If the company reports an absolute or an intensity target covering the scope 3, the value is 1 and otherwise, 0.	1 or 0	C4.1a_C4, C4.1b_C4
34	Emissions reporting and other targets	SC3 emissions for at least one category	If the company reports scope 3 emissions, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
35	Emissions reporting and other targets	SC3 emissions for the category 1 Purchased goods and services	If the company reports scope 3 emissions for the category 1, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
36	Emissions reporting and other targets	SC3 emissions for the category 2 Capital goods	If the company reports scope 3 emissions for the category 2, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
37	Emissions reporting and other targets	SC3 emissions for the category 3 Fuel-and-energy-related activities not included in SC 1 or 2	If the company reports scope 3 emissions for the category 3, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
38	Emissions reporting and other targets	SC3 emissions for the category 4 Upstream transportation and distribution	If the company reports scope 3 emissions for the category 4, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
39	Emissions reporting and other targets	SC3 emissions for the category 5 Waste generated in operations	If the company reports scope 3 emissions for the category 5, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
40	Emissions reporting and other targets	SC3 emissions for the	If the company reports scope 3 emissions for the	1 or 0	C6.5_C2

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
		category 6 Business travel	category 6, the value is 1 and otherwise, 0.		
41	Emissions reporting and other targets	SC3 emissions for the category 7 Employee commuting	If the company reports scope 3 emissions for the category 7, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
42	Emissions reporting and other targets	SC3 emissions for the category 8 Upstream leased assets	If the company reports scope 3 emissions for the category 8, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
43	Emissions reporting and other targets	SC3 emissions for the category 9 Downstream transportation and distribution	If the company reports scope 3 emissions for the category 9, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
44	Emissions reporting and other targets	SC3 emissions for the category 10 Processing of sold products	If the company reports scope 3 emissions for the category 10, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
45	Emissions reporting and other targets	SC3 emissions for the category 11 Use of sold products	If the company reports scope 3 emissions for the category 11, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
46	Emissions reporting and other targets	SC3 emissions for the category 12 End of life treatment of sold products	If the company reports scope 3 emissions for the category 12, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
47	Emissions reporting and other targets	SC3 emissions for the category 13 Downstream leased assets	If the company reports scope 3 emissions for the category 13, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
48	Emissions reporting and other targets	SC3 emissions for the	If the company reports scope 3 emissions for the	1 or 0	C6.5_C2

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
		category 14 Franchises	category 14, the value is 1 and otherwise, 0.		
49	Emissions reporting and other targets	SC3 emissions for the category 15 Investments	If the company reports scope 3 emissions for the category 15, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
50	Emissions reporting and other targets	SC3 emissions for the category 16 Other upstream	If the company reports scope 3 emissions for the category 16, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
51	Emissions reporting and other targets	SC3 emissions for the category 17 Other downstream	If the company reports scope 3 emissions for the category 17, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
52	Emissions reporting and other targets	Number SC3 categories reported	The number of scope 3 categories reported by the company	Number of categories	C6.5_C2
53	Emissions reporting and other targets	More than fifteen SC3 categories reported	If the company reports to 15 or more scope 3 categories, the value is 1 and otherwise, 0.	1 or 0	C6.5_C2
54	Governance	Board oversight climate-related issues	If the board oversight climate-related issues, the value is 1 and otherwise, 0.	1 or 0	C1.1
55	Governance	CEO oversight climate-related issues	If the CEO oversight climate-related issues, the value is 1 and otherwise, 0.	1 or 0	C1.2_C1
56	Governance	Board oversight on target scheduled at every meeting	If the board monitors the climate change target at every board meeting, the value is 1 and otherwise, 0.	1 or 0	C1.1b_C2
57	Governance	Management remuneration link to climate-related issues	If the management remuneration is linked to climate-related issues, the value is 1 and otherwise, 0.	1 or 0	C1.3_C1
58	Governance	CEO remuneration	If the CEO remuneration is linked to climate-related	1 or 0	C1.3_C1

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
		link to climate-related issues	issues, the value is 1 and otherwise, 0.		
59	Governance	Board chair remuneration link to climate-related issues	If the board remuneration is linked to climate-related issues, the value is 1 and otherwise, 0.	1 or 0	C1.3_C1
60	Carbon price	ETS or carbon taxes regulation	If the totality or part of the operations are regulated by ETS, cap and trade or carbon taxes, the value is 1 and otherwise, 0.	1 or 0	C11.1
61	Carbon price	ETS or carbon taxes regulation next three years	If no operations are regulated by ETS, cap and trade or carbon taxes, but the company anticipate it will be in the next three years, the value is 1 and otherwise, 0.	1 or 0	C11.1
62	Carbon price	Voluntary offsetting	If the company generate or purchase voluntary offsetting carbon credit, the value is 1 and otherwise, 0.	1 or 0	C11.2a_C8
63	Carbon price	Internal carbon price	If the company use an internal carbon price into their decision process, the value is 1 and otherwise, 0.	1 or 0	C11.3
64	Risks and opportunities	Physical risks considered relevant	If the company report that physical acute and/or chronic risks is relevant or sometimes relevant, the value is 1 and otherwise, 0.	1 or 0	C2.2a_C1
65	Risks and opportunities	Transition risks considered relevant	If the company report at least one of the transition risks (current regulation, emerging regulation, legal, market, reputation, technological) is relevant or sometimes relevant, the value is 1 and otherwise, 0.	1 or 0	C2.2a_C1

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
66	Risks and opportunities	Financial impact estimate for climate risks	If the company identifies risks with a substantive financial or strategic impact on the direct operations, upstream operations and/or downstream operations, the value is 1 and otherwise, 0.	1 or 0	C2.3a_C2, C2.3a_C10
67	Risks and opportunities	Financial impact estimate for climate opportunities	If the company identifies opportunities with a substantive financial or strategic impact on the direct operations, upstream operations and/or downstream operations, the value is 1 and otherwise, 0.	1 or 0	C2.4a_C2
68	Strategy	Low-carbon transition plan	If the company report having develop a low-carbon transition plan, the value is 1 and otherwise, 0.	1 or 0	C3.1
69	Strategy	Influenced by climate-related risks or opportunities	If one the following area is influenced by climate-related risks, the value is 1 and otherwise, 0. The areas are products and services, supply chain and/or value chain, investments in R&D, and operations.	1 or 0	C3.1d_C1
70	Strategy	Climate-related scenario analysis (quantitative and qualitative)	If the company have developed a quantitative and a qualitative scenario analysis, the value is 1 and otherwise, 0.	1 or 0	C3.1a
71	Strategy	Climate-related scenario analysis	If the company have developed a quantitative or a qualitative scenario	1 or 0	C3.1a

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
		(quantitative or qualitative)	analysis, the value is 1 and otherwise, 0.		
72	Strategy	Low-carbon products	If the company have low-carbon products, the value is 1. If not, the value is 0.	1 or 0	C4.5
73	Strategy	Revenue for low-carbon products	Percentage of low-carbon products in the reporting year	Percentage	C4.5a_C5, C4.5a_C3
74	Strategy	CO2 savings for implemented, commenced, or to be implemented initiatives	If the company reports an estimated CO2 savings for implemented, commenced, or to be implemented initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3a_C2
75	Strategy	CO2 savings for voluntary initiatives	If the company reports an estimated CO2 savings for implemented, commenced, or to be implemented voluntary initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3b_C2, C4.3b_C4
76	Strategy	CO2 savings for mandatory initiatives	If the company reports an estimated CO2 savings for implemented, commenced, or to be implemented mandatory initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3b_C2, C4.3b_C4
77	Strategy	Annual savings for voluntary initiatives	If the company reports financial annual savings for their voluntary initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3b_C5, C4.3b_C4
78	Strategy	Annual savings for mandatory initiatives	If the company reports financial annual savings for their mandatory initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3b_C5, C4.3b_C4
79	Strategy	Investment required for voluntary initiatives	If the company reports the investment required for their voluntary initiatives,	1 or 0	C4.3b_C6, C4.3b_C4

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
			the value is 1 and otherwise, 0.		
80	Strategy	Investment required for mandatory initiatives	If the company reports the investment required for their mandatory initiatives, the value is 1 and otherwise, 0.	1 or 0	C4.3b_C6, C4.3b_C4
81	Engagement	Engage with value chain actors	If the company reports they engage on climate-related issues with the value-chain actors, the value is 1 and otherwise, 0.	1 or 0	C12.1
82	Engagement	Engage with scope 3 suppliers	Percentage of the supplier related to scope 3 emissions with whom the company engage with	Percentage	C12.1a_C5
83	Engagement	Engagement with customers	If the company reports they engage on climate-related issues with their customers, the value is 1 and otherwise, 0.	1 or 0	C12.1b_C1
84	Engagement	Direct influence on policymakers	If the company engage in activities directly influencing policymakers, the value is 1 and otherwise, 0.	1 or 0	C12.3
85	Engagement	Indirectly influence policymakers	If the company engage in activities indirectly influencing policymakers, the value is 1 and otherwise, 0.	1 or 0	C12.3
86	Engagement	Process in place to ensure direct or indirect activities influencing policy are consistent with climate change strategy	If the company have process in place to ensure direct or indirect activities influencing policy are consistent with their climate change strategy, the value is 1 and otherwise, 0.	1 or 0	C12.3f

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
87	Engagement	Position consistent with trade associations where are members	If the position of trade associations is consistent with the company strategy, the value is 1 and otherwise, 0.	1 or 0	C12.3c_C2
88	Engagement	Position mixed with trade associations where are members	If the position of trade associations is mixed (not totally consistent) with the company strategy, the value is 1 and otherwise, 0.	1 or 0	C12.3c_C2
89	Engagement	Disclose list of all funded research organisations	If the company disclose publicly the list of all research organizations, they are funding, the value is 1 and otherwise, 0.	1 or 0	C12.3d
90	Verification	Third-party verification	If the company verifies by a third-party at least one of their scopes, the value is 1 and otherwise, 0.	1 or 0	C10.1_C1
91	Additional reporting	Report for five years in CDP	If the company has reported in at least five CDP questionnaires between 2010 to 2020, the value is 1 and otherwise, 0.	1 or 0	CDP questionnaire from 2010 to 2020
92	Additional reporting	Report for ten years in CDP	If the company has reported in at least ten CDP questionnaires between 2010 to 2020, the value is 1 and otherwise, 0.	1 or 0	CDP questionnaire from 2010 to 2020
93	Additional reporting	Report in another place than CDP	If the company reports climate change information in another communication channels such as CSR report, the value is 1 and otherwise, 0.	1 or 0	C12.4_C1
94	Additional reporting	Report in financial statement	If the company reports climate change information in their	1 or 0	C12.4_C1

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
			financial statement, the value is 1 and otherwise, 0.		
95	Sector	Apparel	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
96	Sector	Biotech, health care & pharma	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
97	Sector	Food, beverage & agriculture	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
98	Sector	Fossil Fuels	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
99	Sector	Hospitality	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
100	Sector	Infrastructure	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
101	Sector	International bodies	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
102	Sector	Manufacturing	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
103	Sector	Materials	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
104	Sector	Power generation	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
105	Sector	Retail	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
106	Sector	Services	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2
107	Sector	Transportation services	CDP sector classification. Value of 1 if correspond to that sector and 0 if not.	1 or 0	C0.2

Table B.1: Continued

#	Category	Determinant name	Explanation	Unit	CDP question
108	Region	Australia and New Zealand	Based on the country of the company headquarter location. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
109	Region	Central America	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
110	Region	Eastern Asia	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
111	Region	Eastern Europe	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
112	Region	Northern America	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
113	Region	Northern Europe	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
114	Region	South America	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
115	Region	South-Eastern Asia	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
116	Region	Southern Africa	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
117	Region	Southern Asia	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
118	Region	Southern Europe	Based on the country of the company headquarter.	1 or 0	C0.2

Table B.1: Continued and end.

#	Category	Determinant name	Explanation	Unit	CDP question
			Value of 1 if the country is in that region and 0 if not.		
119	Region	Western Asia	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2
120	Region	Western Europe	Based on the country of the company headquarter. Value of 1 if the country is in that region and 0 if not.	1 or 0	C0.2

B.3 Further results

B.3.1 Final sample description per country

Table B.2: Number of companies and targets by country included in the final sample. The scopes covered by the targets are represented in the last five columns. Abbreviations: SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based.

Country	Number companies	Number targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Argentina	1	2	0	0	0	2	0
Australia	15	26	13	6	5	2	0
Austria	7	8	4	3	1	0	0
Belgium	7	14	5	3	2	2	2
Brazil	18	36	14	4	13	4	1
Canada	32	42	29	8	5	0	0
Chile	1	1	0	0	1	0	0
China	83	100	58	6	14	20	2
China, Hong Kong Special Administrative Region	13	19	9	3	5	1	1
China, Macao Special Administrative Region	1	1	1	0	0	0	0
Colombia	4	5	0	2	2	1	0
Costa Rica	1	1	0	1	0	0	0

Table B.2: Continued

Country	Number companies	Number targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Czechia	2	2	0	1	1	0	0
Denmark	11	15	4	10	0	1	0
Finland	16	24	10	12	1	0	1
France	44	63	24	29	4	3	3
Germany	34	57	14	25	10	4	4
Greece	2	4	0	0	3	1	0
India	28	42	22	5	10	3	2
Indonesia	3	4	2	0	1	1	0
Ireland	9	15	7	5	2	1	0
Japan	73	112	39	65	4	1	3
Kuwait	1	1	1	0	0	0	0
Malaysia	2	4	1	0	3	0	0
Mexico	7	11	6	3	1	1	0
Netherlands	8	9	3	6	0	0	0
New Zealand	2	2	2	0	0	0	0
Norway	13	20	14	0	3	3	0
Poland	2	2	0	0	2	0	0
Portugal	8	9	1	7	0	0	1
Republic of Korea	36	60	57	1	1	1	0
Russian Federation	4	8	6	0	2	0	0
Singapore	3	4	2	2	0	0	0
Slovakia	2	6	1	2	1	1	1
South Africa	21	27	18	3	0	6	0
Spain	30	68	11	32	12	5	8
Sweden	25	31	9	19	2	0	1
Switzerland	23	31	7	13	6	2	3
Taiwan, Greater China	57	91	47	5	17	22	0
Thailand	8	11	6	4	1	0	0

Table B.2: Continued and end.

Country	Number companies	Number targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Turkey	25	47	33	6	5	3	0
United Kingdom of Great Britain and Northern Ireland	75	119	54	47	11	5	2
United States of America	249	331	146	132	31	19	3
Total	1030	1528	692	480	194	121	41

B.3.2 Final sample description per region

Table B.3: Number of companies and targets by region included in the final sample. The scopes covered by the targets are represented in the last five columns. Abbreviations: SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based.

Region	Number companies	Number targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Australia and New Zealand	17	28	15	6	5	2	0
Central America	8	12	6	4	1	1	0
Eastern Asia	263	383	211	80	41	45	6
Eastern Europe	10	18	7	3	6	1	1
Northern America	281	373	175	140	36	19	3
Northern Europe	149	224	98	93	19	10	4
South America	24	44	14	6	16	7	1
South-Eastern Asia	16	23	11	6	5	1	0
Southern Africa	21	27	18	3	0	6	0
Southern Asia	28	42	22	5	10	3	2
Southern Europe	64	124	24	49	27	12	12

Table B.3: Continued and end.

Region	Number companies	Number targets	SC1 & 2 LB	SC1 & 2 MB	SC1	SC2 LB	SC2 MB
Western Asia	26	48	34	6	5	3	0
Western Europe	123	182	57	79	23	11	12
Total	1030	1528	692	480	194	121	41

B.3.3 Target progress per sector

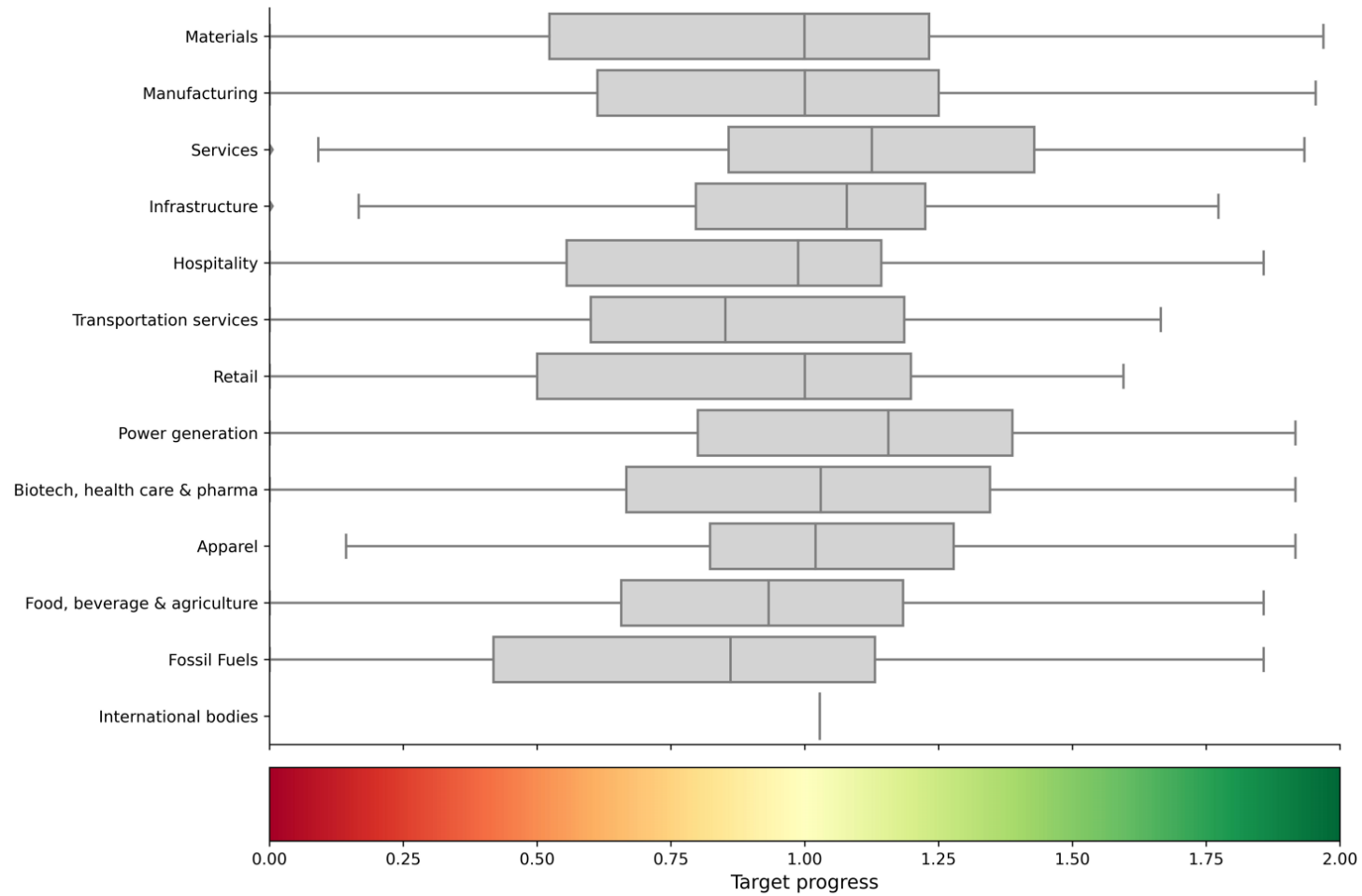


Figure B.1: Distribution per sector of target progress indicator $P_{k,t}$. The color bar ranging from orange to red indicates targets behind linear reduction trajectory, while the range from yellow to green indicates targets ahead of that trajectory (see Figure 1 in the main article).

B.3.4 Target progress per region

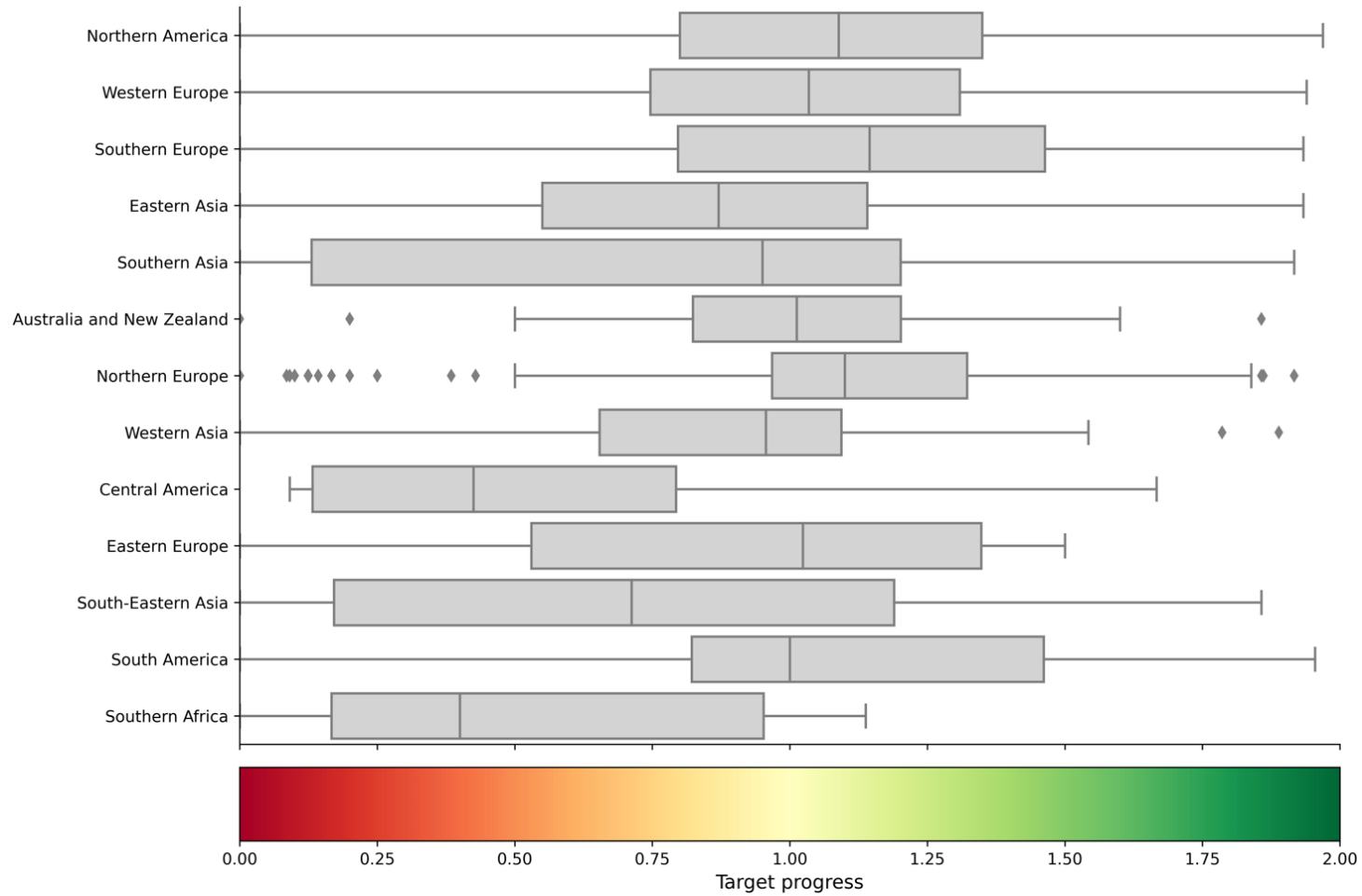


Figure B.2: Distribution per region of target progress indicator $P_{k,t}$. The color bar ranging from orange to red indicates targets behind linear reduction trajectory, while the range from yellow to green indicates targets ahead of that trajectory (see Figure 1 in the main article).

B.3.5 Determinants with multicollinearity

Table B.4: List of determinants excluded with their corresponding number (see Table 1) and category due to multicollinearity with other determinants. Abbreviations: SC12LB; scope 1 and scope 2 location-based, SC3; scope 3.

#	Category	Determinant name
6	Target parameters	Remaining numbers of years until the target year
7	Target parameters	Baseline year
8	Target parameters	Baseline year emissions total
9	Target parameters	Start year
10	Target parameters	Last year
11	Target parameters	Last year emissions total
12	Target parameters	Target year
13	Target parameters	Expected reduced emissions
14	Target parameters	SC12LB covered by target
19	Target parameters	Percentage scope covered by the target
34	Emissions reporting and other targets	SC3 emissions for at least one category
35	Emissions reporting and other targets	SC3 emissions for the category 1 Purchased goods and services
36	Emissions reporting and other targets	SC3 emissions for the category 2 Capital goods
37	Emissions reporting and other targets	SC3 emissions for the category 3 Fuel-and-energy-related activities not included in SC 1 or 2
38	Emissions reporting and other targets	SC3 emissions for the category 4 Upstream transportation and distribution
39	Emissions reporting and other targets	SC3 emissions for the category 5 Waste generated in operations
40	Emissions reporting and other targets	SC3 emissions for the category 6 Business travel
41	Emissions reporting and other targets	SC3 emissions for the category 7 Employee commuting
42	Emissions reporting and other targets	SC3 emissions for the category 8 Upstream leased assets
43	Emissions reporting and other targets	SC3 emissions for the category 9 Downstream transportation and distribution

Table B.4: Continued and end.

#	Category	Determinant name
44	Emissions reporting and other targets	SC3 emissions for the category 10 Processing of sold products
45	Emissions reporting and other targets	SC3 emissions for the category 11 Use of sold products
46	Emissions reporting and other targets	SC3 emissions for the category 12 End of life treatment of sold products
47	Emissions reporting and other targets	SC3 emissions for the category 13 Downstream leased assets
48	Emissions reporting and other targets	SC3 emissions for the category 14 Franchises
49	Emissions reporting and other targets	SC3 emissions for the category 15 Investments
50	Emissions reporting and other targets	SC3 emissions for the category 16 Other upstream
51	Emissions reporting and other targets	SC3 emissions for the category 17 Other downstream
69	Strategy	Influenced by climate-related risks or opportunities
74	Strategy	CO2 savings for implemented, commenced, or to be implemented initiatives
77	Strategy	Annual savings for voluntary initiatives
79	Strategy	Investment required for voluntary initiatives
95	Sector	Apparel
107	Region	Australia and New Zealand

B.3.6 Stepwise backward OLS regression results

Table B.5: Coefficient and p-values for the 19 key determinants selected with the backward stepwise OLS regression model. Abbreviations: SBTi = Science-Based Target Initiative; SC1 = scope 1; ETS = Emissions Trading System.

Determinant	Category	P-value	Coefficient
Percentage of the target achieved at the year the target was set	Target parameters	3.12E-63	0.195483
Number of years between the base year and the target year	Target parameters	1.87E-31	0.159601
Number of years between the base year and the year the target was set	Target parameters	1.91E-23	-0.13019
Northern Europe	Region	4.13E-08	0.064155
Absolute target (not intensity target)	Target parameters	2.8E-07	0.062537
Annualized target ambition	Target parameters	2.17E-06	-0.05184
Northern America	Region	0.000163	0.045635
Central America	Region	0.00111	-0.03451
Western Europe	Region	0.002137	0.035983
Financial impact estimate for climate opportunities	Risks and Opportunities	0.002793	0.033424
Board chair remuneration link to climate-related issues	Governance	0.002821	0.031936
Southern Europe	Region	0.008377	0.030111
More than one target	Emissions reporting and other targets	0.00859	0.031653
Approved by the SBTi	Target parameters	0.013247	0.026945
SC1 emissions breakdown by country	Emissions reporting and other targets	0.020036	-0.0259
Southern Africa	Region	0.022194	-0.02465
South-Eastern Asia	Region	0.025471	-0.02377
ETS or carbon taxes regulation	Carbon price	0.030225	-0.02447
South America	Region	0.040719	0.022141

APPENDIX C ARTICLE 3: SUPPLEMENTARY MATERIAL

C.1 Methodology

C.1.1 Sample: Companies and targets covered with corresponding CDP questions assessed

Table C.1: Comparisons included in the inconsistency assessment of companies' disclosures, with corresponding CDP question numbers. Abbreviations: SC1 = Scope 1; SC2 LB = Scope 2 location-based; SC2 MB = Scope 2 market-based; BY = base year.

Comparison number	Global emissions per scope (aggregated carbon data)	Corresponding breakdown (usually unaggregated carbon data)	CDP question number
1	SC1 for reporting year	SC1 per GHG	C6.1_C1, C7.1a_C2
2		SC1 per country	C6.1_C1, C7.2_C2
3		SC1 per business division	C6.1_C1, C7.3a_C2
4		SC1 per business facility	C6.1_C1, C7.3b_C2
5		SC1 per business activity	C6.1_C1, C7.3c_C2
6	SC2 LB for reporting year	SC2 LB per country	C6.3_C1, C7.5_C2
7		SC2 LB per business division	C6.3_C1, C7.6a_C2
8		SC2 LB per business facility	C6.3_C1, C7.6b_C2
9		SC2 LB per business activity	C6.3_C1, C7.6c_C2
10	SC2 MB for reporting year	SC2 MB per country	C6.3_C2, C7.5_C3
11		SC2 MB per business division	C6.3_C2, C7.6a_C3
12		SC2 MB per business facility	C6.3_C2, C7.6b_C3
13		SC2 MB per business activity	C6.3_C2, C7.6c_C3
14	SC1 and corresponding SC2 (LB or MB as stated in intensity figure) for reporting year	SC1 and SC2 (LB or MB), with combined disclosure from intensity figure for the reporting year, such as emissions per revenue (disclosed separately).	C6.1_C1, C6.3_C1, C6.3_C2, C6.10_C2, C6.10_C5
15	SC1 for base year	SC1 for reporting year or previous years	C5.1_C3, C5.1_C2, C6.1_C1, C6.1_C3
16	SC2 LB for base year	SC2 LB for reporting year or previous years	C5.1_C3, C5.1_C2, C6.3_C1, C6.3_C4

Table C.1: Continued and end.

Comparison number	Global emissions per scope (aggregated carbon data)	Corresponding breakdown (usually unaggregated carbon data)	CDP question number
17	SC2 MB for base year	SC2 MB for reporting year or previous years	C5.1_C3, C5.1_C2, C6.3_C2, C6.3_C4
18	SC1 and/or corresponding SC2 for base year, reporting year or previous years	SC1 and/or SC2 covered by an absolute emissions reduction target for the base year, corresponding to the percentage of scope covered by the target.	C5.1_C3, C5.1_C2, C6.1_C1, C6.1_C3, C6.3_C1, C6.3_C2, C6.3_C4, C4.1a_C6, C4.1a_C5, C4.1a_C4, C4.1a_C7

Table C.2: Companies' characteristics for each hypothesis, with corresponding CDP question numbers

Hypothesis	Group name	Company characteristics	CDP question number
H1	Approved SBTi targets vs No targets	Report an intensity or an absolute target with the following: "Yes, this target has been approved as science-based by the Science-Based Targets initiative"	C4.1a_C14, C4.1b_C17, C4.1a_C1, C4.1b_C1
H2	Net-zero targets vs No targets	Report an intensity or an absolute target with an ambition of 100% covering at least 95% of Scope 1 and 2 emissions without being in the group Approved SBTi targets.	C4.1a_C4, C4.1a_C7, C4.1a_C9, C4.1b_C4, C4.1b_C8, C4.1b_C10, C4.1a_C1, C4.1b_C1
H3	Targets (not approved SBTi or net-zero) vs No targets	Report an intensity or an absolute target without being in the group Approved SBTi targets or Net-zero targets	C4.1a_C1, C4.1b_C1

In addition to the CDP question numbers presented in Table 6.1 and in Table 6.2, the implications of inconsistent disclosures on the assessment of emissions reduction targets (RQ3) required CDP

information on the reporting years (C0.2_C2), target years (C4.1a_C8) and target ambitions (C4.1a_C9).

C.1.2 Inconsistency indicator

To calculate the inconsistency indicator described in Section 6.2.2 of the main article, the following equation was used. Note that the functional relationship for a given comparison (presented in Table 6.1 in Section 6.2.1 of the main article), which defines how global emissions per scope are assessed with their corresponding breakdowns, is represented as a function in the equation explanation below.

Equation 1: Inconsistency indicator

$$\begin{aligned} -\varepsilon_{j,k} &\leq e_{j,k} \leq \varepsilon_{j,k} \rightarrow E_{j,k} = 0 : \text{consistent} \\ e_{j,k} &> \varepsilon_{j,k} \rightarrow E_{j,k} = 1 : \text{inconsistent, overstated} \\ e_{j,k} &< -\varepsilon_{j,k} \rightarrow E_{j,k} = 1 : \text{inconsistent, understated} \end{aligned}$$

Where:

- j : a specific comparison
- k : a specific company
- $e_{j,k}$: the difference for comparison j of company k , calculated as:

$$e_{j,k} = f_{j,k}^y(y_{1,k}; \dots y_{i,k}; \dots y_{m,k}) - f_{j,k}^x(x_{1,k}; \dots x_{i,k}; \dots x_{n,k})$$

- $f_{j,k}^y$ and $f_{j,k}^x$: functions for company k , connected to overarching functions f_j^y and f_j^x , which links y_i (global emissions per scope) and x_i (corresponding breakdown) for comparison j .
 - f_j^y : often involves a single value of y elements.
 - f_j^x : often a sum of x elements.
- m and n : the number of $y_{i,k}$ and $x_{i,k}$ elements for company k , respectively.
- $\varepsilon_{j,k}$: The accepted tolerance for comparison j of company k , calculated as:

$$\varepsilon_{j,k} = \max(\varepsilon_{relative\ j,k}; \varepsilon_{rounding\ j,k})$$

- $\varepsilon_{relative\ j,k}$: the relative tolerance for comparison j of company k based on ε_{level} , which is the percentage of tolerance allowed:

$$\varepsilon_{relative\ j,k} = \varepsilon_{level} \times f_{j,k}^y$$

- $\varepsilon_{rounding\ j,k}$: the rounding tolerance for comparison j of company k

$$\varepsilon_{rounding\ j,k} = f_{j,k}^x(x_{1,k} + 1; \dots x_{i,k} + 1; \dots x_{n,k} + 1) - f_{j,k}^x(x_{1,k}; \dots x_{i,k}; \dots x_{n,k})$$
 - $\varepsilon_{rounding\ j,k}$: corresponds to the number n of $x_{i,k}$ elements for company k when f_j^x is a sum of x elements.
- $E_{j,k}$: The inconsistency indicator for comparison j of company k
 - Consistent (0): when the difference $e_{j,k}$ is within the accepted tolerance interval $[-\varepsilon_{j,k}, \varepsilon_{j,k}]$.
 - Inconsistent, overstated (1): when the difference $e_{j,k}$ is greater than the positive accepted tolerance $\varepsilon_{j,k}$.
 - Inconsistent, understated (1): when the difference $e_{j,k}$ is lower than the negative accepted tolerance $\varepsilon_{j,k}$.

C.1.3 Inconsistency index: Frequency and Presence

To calculate the frequency inconsistency index described in Section 2.3 of the main article, the following equation was used.

Equation 2: Frequency inconsistency index

$$I_k^{frequency} = \frac{\sum_j E_{j,k}}{\sum_j j}$$

Where:

- j : a specific comparison
- k : a specific company
- $E_{j,k}$: the inconsistency indicator for comparison j of company k
- $I_k^{frequency}$: the frequency inconsistency index for company k

To calculate the presence inconsistency index described in Section 2.4 of the main article, the following equation was used.

Equation 3: Presence inconsistency index

$$I_k^{frequency} = 0 \rightarrow I_k^{presence} = 0: \text{company consistent}$$

$$I_k^{frequency} > 0 \rightarrow I_k^{presence} = 1 : \text{company inconsistent}$$

Where:

- j : a specific comparison
- k : a specific company
- $I_k^{frequency}$: the frequency inconsistency index for company k
- $I_k^{presence}$: the presence inconsistency index for company k

As mentioned in Section 6.2.6 of the main article, the target progress indicator results for the two scenarios developed using a min-max approach were calculated according to Bolay et al. (2024). This calculation involves the (in)consistent disclosure of base year emissions (parameter 1) and reporting year emissions (parameter 2).

The target progress indicator is determined by subtracting the percentage of time elapsed (limited from 0 to 100%) from the percentage of the target achieved (limited from 0 to 100%) and adding 1. The percentage of the target achieved is the reduction that occurred between the base year and reporting year, while considering the targeted emissions reduction between the base year and the target year. The percentage of time elapsed corresponds to the period between the base year and reporting year, while accounting for the target timeframe (base year to target year).

The following example illustrates this calculation for the two scenarios:

- A company announces a 50% emissions reduction target by 2025 from a 2015 base year.
- The base year emissions are reported as 100,000 tCO₂e in one instance and 80,000 tCO₂e elsewhere (parameter 1).
- The company disclosed 60,000 tCO₂e and 70,000 tCO₂e for the reporting year, which correspond to the year 2020 (parameter 2).

Parameters for scenario 1:

- Base year emissions: 100,000 tCO₂e (maximum value)
- Reporting year emissions: 60,000 tCO₂e (minimum value)
- Base year: 2015

- Reporting year: 2020
- Target year: 2025

Calculations for scenario 1:

- Targeted emissions reduced: 50,000 tCO₂e ($100,000 * 50\%$)
- Percentage of target achieved: 80% ($((100,000 - 60,000) / 50,000)$)
- Percentage of time elapsed: 50% ($((2020 - 2015) / (2025 - 2015))$)
- Target progress: 1.3 ($80\% - 50\% + 1$)

Parameters for scenario 2:

- Base year emissions: 80,000 tCO₂e (minimum value)
- Reporting year emissions: 60,000 tCO₂e (maximum value)
- Base year: 2015
- Reporting year: 2020
- Target year: 2025

Calculations for scenario 2:

- Targeted emissions reduced: 40,000 tCO₂e ($80,000 * 50\%$)
- Percentage of target achieved: 25% ($((80,000 - 70,000) / 40,000)$)
- Percentage of time elapsed: 50% ($((2020 - 2015) / (2025 - 2015))$)
- Target progress: 0.75 ($25\% - 50\% + 1$)

This example demonstrates how inconsistent disclosures can reverse the progress conclusion from 'on track' (Scenario 1, progress result above 1) to 'not on track' (Scenario 2, progress result below 1). The variation between the target progress results of the scenarios is solely due to the variation in the percentage of the target achieved, as the percentage of time elapsed remains constant between scenarios. This suggests that the company's target could appear to have achieved 55% of its target reduction due to inconsistent disclosure (difference between Scenario 1 and 2 results: $1.3 - 0.75$).

C.2 Further Results

C.2.1 Companies carbon data reporting

C.2.1.1 Companies carbon data reporting by sector

Table C.3: Percentage of companies per sector reporting in the 2020 CDP investor questionnaire for each scope and year. Abbreviations: Nbr Cie = number of companies; SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based, BY = base year.

Sector	Nbr Cie	Reporting year			Previous year			Base year		
		SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB
Apparel	27	100%	100%	56%	56%	56%	33%	93%	81%	63%
Biotech, health care & pharma	107	94%	89%	70%	31%	29%	14%	94%	90%	67%
Food, beverage & agriculture	123	99%	89%	72%	26%	20%	16%	97%	86%	72%
Fossil Fuels	86	100%	93%	38%	48%	43%	15%	94%	88%	33%
Hospitality	36	100%	97%	78%	31%	28%	19%	100%	89%	61%
Infrastructure	183	98%	92%	56%	35%	32%	19%	96%	86%	60%
International bodies	1	0%	0%	0%	100%	100%	0%	100%	100%	0%
Manufacturing	457	98%	93%	64%	29%	26%	18%	97%	88%	60%
Materials	255	100%	94%	57%	43%	38%	23%	98%	89%	57%
Power generation	74	100%	93%	49%	42%	38%	11%	96%	78%	51%
Retail	175	99%	92%	67%	30%	25%	19%	94%	88%	64%
Services	633	98%	94%	64%	36%	34%	20%	95%	88%	61%
Transportation services	84	100%	90%	67%	39%	37%	23%	95%	85%	54%
Total	2,241	98%	93%	62%	35%	32%	19%	96%	88%	60%

C.2.1.2 Companies carbon data reporting by country

The headquarters of the 2,241 companies responding to the 2020 CDP questionnaire were located in 61 countries. Table C.4 describes the 28 countries with more than 15 companies.

Table C.4: Percentage of companies per country reporting in the 2020 CDP investor questionnaire for each scope and year. Abbreviations: Nbr Cie = number of companies; SC1 = scope 1; SC2 LB = scope 2 location-based; SC2 MB = scope 2 market-based, BY = base year.

Country	Nbr Cie	Reporting year			Previous year			Base year		
		SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB
USA	480	98%	95%	70%	25%	23%	14%	96%	89%	61%
Japan	324	99%	85%	84%	42%	35%	34%	97%	78%	79%
UK	201	100%	98%	72%	38%	37%	20%	99%	95%	58%
Canada	98	98%	97%	42%	29%	27%	10%	96%	92%	43%
France	95	98%	97%	57%	32%	29%	13%	96%	92%	52%
Germany	74	97%	92%	80%	46%	45%	34%	96%	85%	70%
Sweden	68	97%	82%	84%	21%	15%	18%	93%	76%	71%
Brazil	62	98%	94%	37%	39%	35%	13%	95%	94%	42%
South Africa	60	98%	97%	40%	22%	22%	3%	98%	95%	57%
India	57	98%	95%	19%	60%	58%	11%	93%	91%	35%
Korea	54	100%	100%	15%	28%	28%	4%	96%	96%	35%
Australia	51	98%	100%	24%	25%	27%	4%	90%	94%	33%
Switzerland	51	100%	96%	80%	31%	31%	20%	98%	88%	76%
Spain	48	100%	94%	79%	46%	40%	33%	94%	83%	69%
Italy	47	100%	96%	89%	49%	43%	40%	98%	85%	81%
Taiwan	43	100%	100%	35%	40%	40%	9%	95%	95%	44%
Norway	42	100%	100%	67%	26%	26%	12%	100%	100%	69%
Finland	40	98%	98%	88%	40%	40%	35%	93%	78%	70%
Turkey	40	100%	98%	18%	28%	28%	5%	98%	95%	65%
China	32	91%	75%	16%	19%	13%	3%	84%	69%	34%
Netherlands	31	100%	94%	68%	61%	52%	39%	100%	90%	65%
Ireland	29	100%	86%	72%	31%	21%	17%	97%	90%	62%
Denmark	24	100%	88%	67%	29%	25%	13%	92%	83%	67%

Table C.4: Continued and end.

Country	Nbr Cie	SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB	SC1	SC2 LB	SC2 MB
Belgium	18	89%	83%	72%	22%	22%	17%	89%	89%	61%
China	18	100%	94%	28%	67%	67%	17%	94%	78%	33%
New Zealand	17	88%	88%	18%	35%	35%	12%	88%	82%	18%
Russia	17	100%	88%	6%	76%	71%	6%	100%	82%	18%
Mexico	15	100%	80%	53%	47%	40%	27%	80%	73%	67%
Total	2,241	98%	93%	62%	35%	32%	19%	96%	88%	60%

C.2.2 Inconsistency per comparison

Table C.5: Percentage of inconsistent companies for each comparison with tolerance level of 0%, 1%, 2.5%, 5%, and 10% (n = number of companies reporting sufficient information per comparison, j = comparison number). Numbers in the column 'Under.' represent Understated (where global emissions per scope are lower than the total of a corresponding breakdown), while numbers in the column 'Inc.' represent Inconsistent (combining Overstated and Understated). Abbreviations: SC1 = Scope 1; SC2 LB = Scope 2 location-based; SC2 MB = Scope 2 market-based; BY = base year.

Relative tolerance level	0%		1%		2.5%		5%		10%	
Comparisons	Inc.	Under	Inc.	Under	Inc.	Under	Inc.	Under	Inc.	Under
j: 1, SC1 for reporting year: SC1 per GHG (n = 1290)	21.63%	7.36%	9.15%	2.02%	6.67%	1.32%	4.81%	0.70%	3.72%	0.39%
j: 2, SC1 for reporting year: SC1 per country (n = 1868)	11.46%	3.85%	4.93%	1.39%	3.48%	0.86%	2.19%	0.64%	1.87%	0.54%
j: 3, SC1 for reporting year: SC1 per business division (n = 1041)	12.97%	4.90%	4.80%	1.73%	3.17%	1.25%	2.31%	1.06%	1.44%	0.58%
j: 4, SC1 for reporting year: SC1 per business facility (n = 540)	20.19%	5.19%	11.48%	2.04%	9.44%	1.85%	6.30%	1.11%	4.81%	0.74%
j: 5, SC1 for reporting year: SC1 per business activity (n = 798)	11.15%	3.88%	4.01%	1.75%	2.88%	1.00%	2.63%	0.88%	2.13%	0.63%
j: 6, SC2 LB for reporting year: SC2 LB per country (n = 1677)	14.85%	5.90%	7.04%	2.74%	5.19%	1.67%	4.23%	1.31%	2.86%	0.95%
j: 7, SC2 LB for reporting year: SC2 LB per business division (n = 936)	13.78%	5.88%	5.77%	2.46%	4.06%	1.60%	2.99%	1.07%	2.14%	0.75%
j: 8, SC2 LB for reporting year: SC2 LB per business facility (n = 514)	20.82%	7.39%	11.87%	3.70%	7.98%	1.95%	5.45%	1.75%	3.70%	0.97%
j: 9, SC2 LB for reporting year: SC2 LB per business activity (n = 623)	9.47%	3.21%	4.17%	1.12%	3.21%	0.48%	2.73%	0.32%	1.93%	0.32%

Table C.5: Continued and end.

Relative tolerance level	0%		1%		2.5%		5%		10%	
Comparisons	Inc.	Under	Inc.	Under	Inc.	Under	Inc.	Under	Inc.	Under
j: 10, SC2 MB for reporting year: SC2 MB per country (n = 1143)	15.05%	5.42%	7.09%	2.19%	5.07%	1.40%	4.20%	1.22%	3.06%	0.96%
j: 11, SC2 MB for reporting year: SC2 MB per business division (n = 672)	12.80%	4.46%	6.25%	1.49%	4.61%	0.89%	3.72%	0.60%	2.53%	0.30%
j: 12, SC2 MB for reporting year: SC2 MB per business facility (n = 301)	20.60%	7.31%	11.30%	2.99%	7.64%	1.33%	5.65%	0.66%	5.32%	0.66%
j: 13, SC2 MB for reporting year: SC2 MB per business activity (n = 470)	8.09%	3.19%	3.83%	1.06%	3.19%	1.06%	2.55%	0.64%	1.28%	0.21%
j: 14, SC1 & 2 for reporting year: SC1 & 2 from numerator of intensity indicator (n = 2116)	15.45%	7.04%	7.80%	3.40%	6.43%	2.93%	5.48%	2.41%	4.30%	1.80%
j: 15, SC1 for BY: SC1 for reporting or previous years (n = 495)	8.08%	3.64%	6.26%	2.83%	5.66%	2.42%	5.05%	2.02%	4.24%	1.62%
j: 16, SC2 LB for BY: SC2 LB for reporting or previous years (n = 450)	8.89%	3.78%	7.11%	3.11%	7.11%	3.11%	6.22%	2.44%	4.67%	1.56%
j: 17, SC2 MB for BY: SC2 MB for reporting or previous years (n = 270)	11.85%	3.33%	8.89%	2.59%	7.04%	1.48%	6.30%	1.11%	5.56%	0.74%
j: 18, SC1 &/or 2 for BY, reporting, or previous years: SC1 &/or 2 for BY covered by target at 100% (n = 718)	33.15%	20.19%	32.87%	20.17%	27.44%	16.43%	23.12%	13.79%	17.83%	10.58%

C.2.3 Inconsistency per comparison

Table C.6: Share of inconsistent disclosures among companies with inconsistencies at different tolerance levels. Inconsistent: combining Overstated and Understated categories. Understated: where global emissions per scope are lower than the total of a corresponding breakdown. Nbr Cie: number of companies.

Tolerance level	Category	Nbr Cie	Descriptive statistics						
			mean	std	min	25%	50%	75%	max
0%	Inconsistent	1041	33%	24%	6%	14%	25%	44%	100%
	Understated	579	24%	18%	6%	13%	17%	30%	100%
1%	Inconsistent	729	26%	21%	6%	13%	17%	33%	100%
	Understated	367	21%	18%	6%	11%	14%	25%	100%
2.5%	Inconsistent	588	26%	21%	6%	13%	17%	33%	100%
	Understated	279	22%	19%	6%	11%	14%	25%	100%
5%	Inconsistent	494	24%	21%	7%	13%	17%	29%	100%
	Understated	224	22%	20%	6%	11%	14%	25%	100%
10%	Inconsistent	387	25%	22%	6%	13%	17%	29%	100%
	Understated	161	23%	22%	6%	11%	14%	25%	100%
15%	Inconsistent	336	25%	22%	7%	13%	17%	29%	100%
	Understated	138	24%	23%	6%	11%	14%	25%	100%
25%	Inconsistent	281	24%	22%	7%	11%	14%	25%	100%
	Understated	115	22%	21%	6%	11%	14%	25%	100%
50%	Inconsistent	197	24%	21%	6%	11%	17%	29%	100%
	Understated	77	25%	23%	6%	11%	17%	25%	100%
75%	Inconsistent	140	24%	20%	6%	13%	17%	29%	100%
	Understated	59	23%	21%	6%	12%	17%	25%	100%

C.2.4 Inconsistency index: Presence

C.2.4.1 Presence inconsistency index per sector

Table C.7: Percentage of companies being inconsistent in one or more of the 18 comparisons per sector, considering different tolerance levels (0%, 1%, 2.5%, 5%, and 10%). Numbers in the column ‘Under.’ represent Understated (where global emissions per scope are lower than the total of a corresponding breakdown), while numbers in the column ‘Inc.’ represent Inconsistent (combining Overstated and Understated). Nbr Cie: number of companies.

Tolerance level		0%				1%		2.5%		5%		10%	
Sector	Nbr Cie	Insufficient data	Consistent	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.
Apparel	27	3.70%	44.44%	51.85%	33.33%	33.33%	25.93%	25.93%	18.52%	18.52%	14.81%	14.81%	11.11%
Biotech, health care & pharma	107	7.48%	42.99%	49.53%	28.97%	38.32%	23.36%	29.91%	16.82%	25.23%	15.89%	22.43%	13.08%
Food, beverage & agriculture	123	1.63%	47.97%	50.41%	30.08%	34.15%	20.33%	26.83%	15.45%	19.51%	8.94%	13.01%	4.07%
Fossil Fuels	86	2.33%	31.40%	66.28%	37.21%	40.70%	18.60%	32.56%	11.63%	31.40%	11.63%	26.74%	8.14%
Hospitality	36	0.00%	66.67%	33.33%	19.44%	25.00%	11.11%	16.67%	8.33%	11.11%	5.56%	5.56%	2.78%
Infrastructure	183	2.19%	51.37%	46.45%	21.86%	28.96%	13.66%	25.14%	12.02%	20.77%	9.84%	15.30%	6.56%
International bodies	1	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Manufacturing	457	1.75%	44.86%	53.39%	30.42%	35.89%	17.94%	28.23%	13.13%	24.73%	11.16%	18.82%	8.10%
Materials	255	0.78%	42.35%	56.86%	36.47%	36.47%	19.61%	27.84%	14.51%	21.18%	10.98%	16.47%	7.45%
Power generation	74	1.35%	43.24%	55.41%	20.27%	24.32%	6.76%	18.92%	4.05%	9.46%	0.00%	8.11%	0.00%
Retail	175	1.14%	62.86%	36.00%	18.86%	28.00%	11.43%	22.86%	8.00%	20.57%	6.29%	17.71%	4.00%
Services	633	2.69%	62.56%	34.76%	18.17%	28.75%	14.38%	24.64%	12.01%	21.80%	9.79%	17.06%	7.42%
Transportation services	84	0.00%	46.43%	53.57%	33.33%	40.48%	20.24%	30.95%	14.29%	25.00%	11.90%	20.24%	10.71%
Total	2241	2.14%	51.41%	46.45%	25.84%	32.53%	16.38%	26.24%	12.45%	22.04%	10.00%	17.27%	7.18%

C.2.4.2 Presence inconsistency index per country

As for Table C.4, Table C.8 only includes the 28 countries with more than 15 companies.

Table C.8: Percentage of companies being inconsistent in one or more of the 18 comparisons per country, considering different tolerance levels (0%, 1%, 2.5%, 5%, and 10%). Numbers in the column ‘Under.’ represent Understated (where global emissions per scope are lower than the total of a corresponding breakdown), while numbers in the column ‘Inc.’ represent Inconsistent (combining Overstated and Understated). Nbr Cie: number of companies.

Tolerance level		0%				1%		2.5%		5%		10%	
Country	Nbr Cie	Insufficient data	Consistent	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.
USA	480	2.71%	53.33%	43.96%	25.42%	27.92%	13.75%	22.71%	22.71%	9.79%	18.75%	7.08%	14.17%
Japan	324	2.16%	52.16%	45.68%	28.09%	29.63%	13.89%	22.53%	22.53%	10.49%	16.98%	7.41%	11.73%
UK	201	0.50%	51.24%	48.26%	25.37%	38.31%	19.40%	30.35%	30.35%	12.44%	25.87%	10.45%	20.90%
Canada	98	1.02%	46.94%	52.04%	19.39%	29.59%	9.18%	25.51%	25.51%	6.12%	24.49%	6.12%	20.41%
France	95	2.11%	45.26%	52.63%	35.79%	44.21%	28.42%	32.63%	32.63%	20.00%	28.42%	17.89%	23.16%
Germany	74	4.05%	44.59%	51.35%	35.14%	37.84%	24.32%	31.08%	31.08%	16.22%	18.92%	12.16%	16.22%
Sweden	68	2.94%	50.00%	47.06%	25.00%	29.41%	13.24%	23.53%	23.53%	10.29%	22.06%	7.35%	22.06%
Brazil	62	3.23%	41.94%	54.84%	27.42%	43.55%	17.74%	37.10%	37.10%	14.52%	35.48%	12.90%	29.03%
South Africa	60	1.67%	61.67%	36.67%	20.00%	31.67%	13.33%	23.33%	23.33%	11.67%	18.33%	10.00%	16.67%
India	57	3.51%	61.40%	35.09%	8.77%	15.79%	5.26%	10.53%	10.53%	3.51%	8.77%	3.51%	8.77%
Korea	54	0.00%	40.74%	59.26%	25.93%	31.48%	18.52%	24.07%	24.07%	12.96%	16.67%	9.26%	9.26%
Australia	51	0.00%	64.71%	35.29%	19.61%	21.57%	13.73%	19.61%	19.61%	13.73%	17.65%	13.73%	15.69%
Switzerland	51	0.00%	52.94%	47.06%	23.53%	35.29%	17.65%	27.45%	27.45%	13.73%	23.53%	11.76%	21.57%

Table C.8: Continued and end.

Tolerance level				0%		1%		2.5%		5%		10%	
Country	Nbr Cie	Insufficient data	Consistent	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.	Inc.	Under.
Spain	48	0.00%	60.42%	39.58%	20.83%	27.08%	14.58%	22.92%	22.92%	14.58%	22.92%	12.50%	16.67%
Italy	47	0.00%	48.94%	51.06%	29.79%	42.55%	23.40%	40.43%	40.43%	23.40%	29.79%	19.15%	27.66%
Taiwan	43	0.00%	72.09%	27.91%	18.60%	20.93%	13.95%	13.95%	13.95%	9.30%	13.95%	9.30%	11.63%
Norway	42	0.00%	64.29%	35.71%	19.05%	28.57%	16.67%	23.81%	23.81%	11.90%	16.67%	4.76%	9.52%
Finland	40	0.00%	37.50%	62.50%	47.50%	45.00%	27.50%	35.00%	35.00%	22.50%	30.00%	20.00%	12.50%
Turkey	40	0.00%	70.00%	30.00%	10.00%	25.00%	7.50%	25.00%	25.00%	7.50%	22.50%	5.00%	12.50%
China	32	15.63%	34.38%	50.00%	34.38%	50.00%	28.13%	40.63%	40.63%	21.88%	40.63%	21.88%	40.63%
Netherlands	31	0.00%	35.48%	64.52%	38.71%	51.61%	25.81%	45.16%	45.16%	19.35%	41.94%	19.35%	38.71%
Ireland	29	0.00%	51.72%	48.28%	31.03%	41.38%	27.59%	31.03%	31.03%	27.59%	24.14%	17.24%	20.69%
Denmark	24	8.33%	37.50%	54.17%	25.00%	45.83%	12.50%	33.33%	33.33%	12.50%	33.33%	8.33%	29.17%
Belgium	18	11.11%	27.78%	61.11%	22.22%	44.44%	11.11%	38.89%	38.89%	11.11%	16.67%	0.00%	5.56%
China	18	0.00%	38.89%	61.11%	38.89%	44.44%	27.78%	38.89%	38.89%	22.22%	27.78%	11.11%	16.67%
New Zealand	17	11.76%	64.71%	23.53%	11.76%	17.65%	11.76%	17.65%	17.65%	11.76%	17.65%	11.76%	11.76%

C.2.5 Are companies with carbon data verified by a third-party less inconsistent?

To gain credibility for their carbon data, an increasing number of companies use independent third-party assurance (Datt et al., 2021; Zhou, 2022). Indeed, externally verified data is perceived as reliable and valued by investors (PCAF, 2022; Reimsbach et al., 2018; Sánchez-García et al., 2019). However, some authors have shown that third-party verification does not guarantee reliable data (Garcia-Vega et al., 2023; Talbot & Boiral, 2018). Thus, the following hypothesis will be tested as more consistent carbon data can reasonably be expected from companies with this characteristic:

H4 Companies with carbon data verified by a third party disclose more consistent carbon data.

To answer to H4, the statistical analysis used to address RQ2, and its three hypotheses (H1 to H3) was applied (see Section 6.2.5 of the main article). In addition to the CDP question numbers presented in Table C.1 and in Table C.2, Table C.9 describes the additional input data needed to test the relationship between (in)consistency and carbon data verified by a third party.

Table C.9: Companies' characteristics for hypothesis, with corresponding CDP questions

Hypothesis	Name	Company characteristics	Corresponding CDP questions
H4	Third-party verification vs Without verification	Report a third-party verification that is complete with limited, moderate, or high assurance on 100% of their scope 1 and 2 emissions.	C10.1a_C1, C10.1.a_C3, C10.1.a_C7, C10.1b_C1, C10.1b_C3, C10.1b_C8

Of the 2,193 companies with an inconsistency assessment, 1,544 reported having a third-party verification, whereas 649 did not. Based on the share of inconsistent individual companies' disclosures with 1% tolerance level, companies in the third-party verification group are not different from companies without third-party verification (p-value > 0.05), indicating they are neither more nor less consistent. Therefore, the result does not corroborate H4.

This result supports the findings of Garcia-Vega et al. (2023) and Talbot et al. (2018), suggesting that third-party assurance does not reduce the presence of inconsistencies in corporate carbon

disclosures. This reveals that investors cannot assume verified carbon data are more reliable than unverified carbon data. In addition to demonstrating the need for stricter regulations of corporate carbon disclosure, this result shows that investors need to engage with third-party verifiers to enforce a better verification process.