Business accountability for climate change: carbon emissions contributions and future sectoral pathways for global carbon budgets

Maida Hadziosmanovic

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By: Maida Hadziosmanovic

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Signed by the final Examining Committee:

____ Chair

Dr. Norma M. Rantisi

____ Internal Examiner

Dr. Raymond Paquin

____ External Examiner

Dr. Shannon Lloyd

____ Supervisor

Dr. H. Damon Matthews

Approved by ____

Dr. Monica E. Mulrennan

Chair of Department

____

Dr. André Roy

Dean of Faculty of Arts and Science

Date ____

ABSTRACT

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Maida Hadziosmanovic

Discussions regarding climate change accountability, and accordingly, the effort-sharing of climate change mitigation, have focused predominantly on the role of nation-states as the most relevant actors. Yet, companies that are contributing greenhouse gas emissions to the atmosphere have not similarly been held accountable, nor have they been given clear mitigation guidelines that follow global climate targets. In this study, I aim to encourage business accountability by highlighting the emissions contributions of public companies and the need for reliable corporate reporting and mitigation efforts. I evaluate reported company emissions in 2015, and allocate sectoral carbon emissions budgets associated with the climate targets of remaining below a global mean temperature increase of 1.5°C, and 2°C. I then provide linear, exponential, and logistic functions as future sectoral emissions pathways that conform to these budgets. I also evaluate corporate reporting patterns in the context of company market value and location. Results show that only 7% of companies worldwide report direct emissions. These companies account for a fifth of global CO_2 emissions in 2015. Pathways constrained to the 1.5°C budget especially suggest that early and stringent mitigation is critical. Companies may favour the logistic pathway which accommodates an initial lag in emissions reductions, though it forecasts rigorous mitigation requirements in the near future. Weak but significant positive correlations between company market capitalization and emissions may indicate that larger companies are more likely to report greater emissions, and that market value may have potential to be used as a proxy for estimating company emissions. Sectoral level analyses would be improved if corporate emissions disclosure was widespread and verified for reliability. Achieving global climate goals requires accountability that goes beyond the nation-state boundary and that reaches businesses. Moreover, emissions disclosure paves the way for effective business mitigation efforts.

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LIST OF ABBREVIATIONS

CDP	(formerly) the Carbon Disclosure Program
CH_4	methane
CO_2	carbon dioxide
COP	Conference of the Parties
EBITDA	Earnings Before Interest, Depreciation, and Amortization
ETS	European Trading Scheme
EU	European Union
GHG	greenhouse gas
GtC	gigatonnes of carbon
$GtCO_2$	gigatonnes of carbon dioxide
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nations Framework Convention on Climate Change

Glossary

Accounting: In the context of 'carbon' or 'emissions' accounting: the methodology used to calculate greenhouse gas emissions.

Business: An entity in the practice of making, buying, or selling of goods and/or services. It can be used on its own or as a descriptor. It is also used in its abstract sense, as it relates to the realm of business.

Company: An entity formed to practice a business. May be used interchangeably with business.

Corporation: Carries a legal and formal meaning; it is a business that legally exists separately from its owners, and thus has its own distinct rights, privileges, and liabilities. Other theoretical applications of the term 'corporation,' namely its application to state governments, remains outside of the scope of this research.

Corporate: An adjective (as it *relates* to a corporation, but is *not limited* to a corporation) used to describe business activity, whether specific to an individual business, or more generally, the realm of business.

Country of domicile: The country location of a company's senior management (Bloomberg L.P. 2016).

Disclosure: Communication or reporting of environmental information, namely greenhouse gas emissions (with the assumption that the information becomes available to the public). The terms to 'disclose' or 'report' may be used interchangeably.

Market capitalization: The worth of a company calculated by multiplying the shares outstanding by the price share (Bloomberg L.P. 2016). Also considered the market value of company.

CHAPTER 1

INTRODUCTION

1.1 Climate change and relevant actors

The notion of responsibility for climate change and the effort-sharing of climate change mitigation has become pervasive in climate science and policy discussions. The working order and context in which the United Nations Framework Convention on Climate Change (UNFCCC) was adopted, as well as the reoccurrence of international state-led meetings such as the Conference of the Parties (COP), presumes nations to be principal actors in contributing to climate change. Though there is some merit to studying the responsibility or accountability of nations, there are other equally important actors that contribute substantial amounts of emissions to our atmosphere; namely, businesses. Businesses play a dual role in climate politics: they are principal players in the production of GHG emissions, but also carry the greatest potential for reducing future emissions through informed operational and financial decisions. On that account, interpretations of "common but differentiated responsibilities" (UNFCCC 1992), introduced by the Parties to the UNFCCC can and should extend to non-nation state actors.

1.1.1 Dimensions of blame for climate change: contributions, responsibility, and accountability

Before exploring the roles of business in climate change, it is important to identify and define different types of blame associated with these roles. Contributions, responsibility, and accountability, in the context of climate change must be differentiated when discussing climate change mitigation, as they are too often conflated. I adopt the definition of a 'contribution' in part from Müller *et al* (2009), who described it as a causal act, which in the context of climate change I understand to be the physical act of emitting GHGs to the atmosphere. Responsibility, on the other hand, is a concept of blame which carries more ambiguity. Aristotle considered moral responsibility as a blame assigned to agents carrying out voluntary actions, rather than involuntary ones (Ross 1954), while Müller *et al* (2009) suggested that it can also be assigned where action is involuntary and results in harmful effects[1]. Although science provides robust evidence of the harmful effects of climate change at grand scales (IPCC 2014a), it is nearly impossible to trace a single act of emitting GHGs to a specific event (Huber and Gulledge 2011). Accountability, on the other hand, is a type of blame which is action-oriented, or as Mulgan (2003) described it, must lead to some sort of rectification. In the context of climate change, examples of accountability could be emissions mitigation, or payments for adaptation. It is essential that accountability as a form of blame be accepted as it is the type of blame which incites climate change mitigation efforts. Yet, it carries elements from both the concepts of contribution and responsibility, and so it cannot easily succeed on its own.

1.1.2 Three conditions for establishing business accountability for climate change

Holding companies or more generally, the business world, accountable for their contributions to climate change in the form of GHGs emissions, is a difficult task. Legal authorities, both at the international and national levels, have yet to step in and enable accountability. So, in the general absence of legal authority, and with the climate change clock ticking, we must look towards other forms of non-government initiatives, namely those coming from companies and their stakeholders.

It follows that there are certain conditions necessary for these initiatives to take place. The first condition to establishing accountability is that companies recognize their roles as contributors to climate change, and so accept a degree of responsibility for the physical phenomena of climate change itself. (The obvious precursor being that climate change denial be relinquished). Companies' accommodating behaviours to the pressures of climate change since the 2000's (Jones and Levy 2007) may be evidence to support that companies are beginning to recognize their roles in contributing to climate change. Nevertheless, it is possible that these behaviours are simply pre-emptive to economic, competitive, or other pressures that climate change poses to business activity (Jones and Levy 2007). Openly acknowledging their roles as climate change contributors adds potential to establishing accountability, though it is not a pre-requisite for the

[1] Further discussion of the ambiguity and implications of assigning responsibility is continued in section 2.1: Exploring accountability.

next condition.

The next (second) condition for accountability is a commitment to transparency. One of the reasons why businesses have not been pressed to act on climate change is because there is no single agreed upon framework for the disclosure of environmental information. Furthermore, many national governments are either lax in regulation, or do not have regulation in place at all. But in recent years, an emerging corporate responsibility infrastructure has put pressure on companies to report more environmental information (Waddock 2008). As part of this infrastructure, there exist an abundance of emissions accounting methodologies and disclosure routes, although they are not necessarily streamlined with each other (Waddock 2008). Companies are nevertheless increasingly participating in the publishing of environmental information related to their business activities, sometimes in the form of sustainability reports, or submitted directly to disclosure programs. Despite this development, participation is not universal and accounting and reporting methodologies must be improved for consistency, reliability, and comparability. Without common and consistent emissions accounting methods, there is no point of comparison available for measuring efforts or improvements, and emissions mitigation becomes disincentivized. We should thus not anticipate that businesses will commit to long-term mitigation efforts in the absence of proper emissions accounting.

The third condition for accountability is an acceptance of the duty to take on emissions mitigation efforts. Beyond claiming support for climate change action, and beyond even accurate accounting and effective disclosure methods, GHG emissions must ultimately be reduced. It is important to note, as well, that disclosure does not necessitate mitigation (Sullivan 2009), but it does make it easier to achieve. Large, profit-making businesses are not restrained by lack of resources, expertise, technology, nor truthfully, capital, in order to take part in effectuating emissions reductions. In addition to patchy reporting frameworks, it is also due to the little guidance available on setting appropriate emissions targets in line with greater global climate goals, that companies are not engaging in mitigation action. The question that follows is, how might mitigation efforts in accordance with climate goals be distributed among businesses? Without an attempt at equitable allocation, actors are less likely to participate in climate action and reducing GHG emissions.

It is only once these three conditions - recognizing contributions, being transparent, and accepting the duty of mitigation - are assumed, that we might anticipate successful mitigation efforts. Yet, even when we recognize the paramount roles played by businesses, the question that remains is, how do we identify accountable actors, and subsequently distribute the efforts of mitigation? And how should these tasks be differentiated? It is evident that the earth's atmosphere as a commons only responds to GHG emissions reductions, and does not concern itself with who does it, or where or how it happens. That being so, it is essential to hold contributors to climate change accountable, by expecting not only transparency, but effective and timely mitigation efforts from them.

Until now, business accountability has remained largely on the periphery of scholarly discussions on anthropogenic climate change, as academic research has focused predominantly on the role of nation states as principal actors in contributing to climate change. So as to help facilitate business accountability, businesses, stakeholders, and policy-makers would benefit from more complete academic studies on the role of business in contributing to climate change. This includes further exploration of available emissions data provided by these businesses, as well as investigation into appropriate business emissions targets that are in line with global climate goals. It is important to acknowledge the potential of disclosed corporate emissions data in being informative and insightful, despite some of the uncertainty surrounding the accounting and reporting frameworks by and through which the data is provided. There is a need to synthesize this data, so as to understand both the extent of participation in reporting, and the quantity of GHG emissions being disclosed by these companies. Furthermore, other factors potentially influencing reported corporate emissions, such as company location and size, should also be considered relevant to this area of research.

1.2 Research goals and thesis structure

The main intent of this thesis is to address the importance of business accountability for climate change by:

1. Presenting emissions contributions from businesses sourced from voluntarily disclosed data;
2. Identifying patterns of reporting and factors influencing emissions disclosure; and
3. Providing guidance for creating business emissions reduction goals that are in line with the global climate targets of remaining below a 1.5°C and 2°C rise in global average temperature.

I provide a review of the literature in Chapter 2, which entails previous efforts at understanding and establishing climate change responsibilities, allocating future emissions shares, and corporate activities and responses to climate change.

In Chapter 3, I present the main analyses on emissions reporting, sectoral carbon budgets and future sectoral emissions pathways. Here, I provide my methodology, results, and discussion on the implications and limitations of the carbon budgets and emissions pathways. Chapter 3 is also supported with a short introduction and literature review.

I provide additional results in Chapter 4, examining the impact of company size and location as factors that may impact corporate emissions disclosure.

I conclude with Chapter 5, which reviews the research goals and implications of the results, while identifying future research avenues on the topic of business accountability for climate change.

CHAPTER 2

LITERATURE REVIEW

2.1 Exploring accountability

The question of who is accountable for climate change, and correspondingly, which agents should carry the effort of GHG emissions reductions, has been examined extensively. In this literature review I will summarize and evaluate the approaches that have been used to address the question of accountability, as well as identify which methods could further studied and justified.

Science has demonstrated, beyond a doubt, that current climate change is anthropogenic, and requires immediate and stringent GHG emissions mitigation action in order to avoid dangerous global repercussions (IPCC 2014b). Unfortunately, what science has not yet successfully produced, is a suitable method by which emissions mitigation should occur. This is in part due to differing perspectives and understandings of accountability; a topic which many authors have attempted to make sense of (Jamieson 2009, Müller *et al* 2009, Markowitz *et al* 2015).

First and foremost, accountability must be delineated as distinct from the concepts of *responsibility for* climate change, and *contributions to* climate change[2]. It is easy to conflate these concepts and employ them interchangeably, but I contend that they have important differences. A contribution may be viewed as a causal act (Müller *et al* 2009). In the context of climate change, it thus refers to the emission of GHGs. Thereby, anyone emitting GHGs is contributing to the resulting climate warming. Being responsible for climate change in the moral sense, however, is much more ambiguous. Müller *et al* (2009) well illustrated some issues of imparting responsibility in stating that, “It is one thing to say that this and that series of emissions have contributed a certain percentage to the increase in global mean temperature…, and quite another to say that the United States of America has done so.” While causal contributions of emissions from sovereign territory may be scientifically precise, moral responsibility is not so easily imparted. Responsibility, as judged by Aristotle (Ross 1954) is

[2] Where ‘responsibility’ encompasses ‘being responsible’, and ‘accountability’ encompasses ‘being accountable’ or ‘being held accountable’, but is different from the ‘accounting’ (calculating) of GHG emissions.

blame assigned to agents carrying out voluntary actions, rather than involuntary ones. On the other hand, Müller *et al* (2009) suggested that blame can also be assigned where action is involuntary, specifically where it results in harmful effects.

If we are to accept only Aristotle's definition of responsibility, in the context of climate change, this implies that every agent emitting GHGs voluntarily is morally responsible. Yet, it is challenging to determine the voluntary or involuntary nature of emitting GHGs, as this act is a physical phenomenon that requires some conscious human action (assuming that we are excluding non-human induced emissions from this discourse). Consequently, it could be argued that all emissions of GHGs are voluntary, in which case everyone emitting GHGs is found to be responsible. Yet if everyone is found to be responsible, then no one is responsible.

If we extend the definition to that given by Müller *et al* (2009), and if we are also able to identify involuntary emissions, then we would require proof of the resulting 'harmful effects'. Although GHGs emitted to the atmosphere, whether voluntary or involuntary, have harmful effects on the environment (i.e. the overall effect being anthropogenic climate change), it is extremely difficult to trace a single actor's emissions to a specific climate change impact. This also contributes to the ambiguity associated with responsibility.

Finally, an important distinction is the fact that simply carrying responsibility does not necessarily incite mitigation action, whereas, accountability does. Being accountable, or being held accountable goes beyond transparency, and must lead to some sort of rectification (Mulgan 2003). In this thesis my interpretation, therefore, is that in holding an actor accountable for their contributions to climate change, we anticipate mitigation action from them.

It is beyond the scope of this science based study to provide in-depth ethical or normative arguments to establish why businesses, in contributing to climate change, should also be morally responsible, and thus held accountable for climate change. Instead, to simplify and expedite the way towards climate change mitigation action, I allocate business emissions budgets in an effort to bring the viability and the importance of corporate action to the attention of climate mitigation discussions. Furthermore, I hope that this work helps render trivial any arguments which undermine the contributing role of business in climate change.

2.1.1 Nations

Recent literature on the topic of climate change mitigation has focused largely on nation states as the principal bearers of agency (Friedlingstein *et al* 2014, Höhne 2013, Matthews 2016, Müller *et al* 2009, Raupach *et al* 2014). Many authors, while de facto adopting an interpretation of accountability, have conducted qualitative (Ringius *et al* 2002) and quantitative (Baer *et al* 2009, Matthews 2016, Raupach *et al* 2014) analyses which allocate emissions mitigation efforts, often simultaneously addressing disparities in historical GHG emissions between nations. The concept of national historical accountability for climate change has prevailed in literature since the early 1990s (Grübler and Fujii 1991, Smith 1992). Since then, nations have proposed different types of effort or burden-sharing frameworks for distributing emissions rights or budgets (i.e. allowable emissions). These have been based on various fairness principles, such as cumulative historical emissions, convergence of per-capita emissions over time, and the ability to pay based on GDP per-capita, among others (Ringius *et al* 2002). Many researchers have used these proposals in their studies to determine the allocation of future emissions rights: some have quantified historical cumulative emissions of states (Botzen *et al* 2008), while others have reasoned the use of national per-capita emissions (Baer *et al* 2000, Matthews 2016, Neumayer 2000). In addition, the grandfathering approach, which allocates budgets proportionally according to emissions at a particular base year (Neumayer 2000), has been used under international regimes such as the Kyoto Protocol (UNFCCC 1998) and the early phase of the European Union Emissions Trading Scheme (EU ETS) (European Commission 2010).

Neumayer (2000) introduced the concept of a historical emissions 'debt', which is determined by assuming an equal per capita allocation of emissions across countries. Countries are given a lower share of emissions if they have historically emitted in excess of an equal per capita share, while those who have emitted less than the equal per capita share are given an emissions 'credit' (Matthews 2016). Matthews (2016) later applied this principle to national historical emissions data. He found that countries with large debts included industrialized nations such as the United States, Russia, and Germany. Others with small debts or credits, tended to be developing countries such as Indonesia, or countries in industrial transition, such as India and China. These results capture a general pattern recognized in the literature, and also recognized by the parties to the UNFCCC, which is that industrialized nations produce the greater share of global emissions (UNFCCC 1992, Shue 1999). Though reasons other than economic development or industrialization, namely geographic (Neumayer 2002, Neumayer 2004), have been proposed as factors influencing national emissions, the most prominent state emitters remain largely uncontested in the literature. Yet, developing policies that address these findings continue to be disputed, as there are various ethical issues arising from using a single effort-sharing framework. Accordingly, some authors have examined a multi-criteria approach, in which several fairness principals are employed in the solution (Müller *et al* 2009, Baer *et al* 2009).

While most research has focused on production-based accounting, where emissions are attributed to the territory in which they are produced, some authors have explored consumer responsibility instead (Davis and Caldeira 2010, Davis *et al* 2011, Peters 2008, Lenzen *et al* 2007). Davis and Caldeira (2010) took a consumption-based approach to emissions accounting and attributed CO_2 emissions to countries according to their consumption of finished goods. They highlighted the resulting differences in emissions allocations, showing that the primary net importers of emissions were overwhelmingly developed countries including the United States, Japan, the United Kingdom, and Germany. They also discussed ethical questions regarding the enabling of prosperity in developed countries by the emissions produced in other, often under-developed, countries.

In contrast to focusing on national contributions, whether directly through historical emissions accounting, or indirectly through national per-capita emissions accounting, some attention has been given to emissions accounting at the city-level (Dodman 2009, Duren and Miller 2012). Though cities evidently fall under the jurisdiction of sovereign territory, policy and authority at the municipal or local level have significant potential to catalyze urban GHG emissions mitigation (Dodman 2009).

2.1.2 Business

Though accountability at the national level prevails in the literature, examining the roles of other actors has surfaced as well. This includes businesses that directly or indirectly use, or produce, fossil fuels. Some researchers have examined the role of fossil fuel producers as prominent actors contributing to climate change (Frumhoff *et al* 2015, Heede 2014). Frumhoff *et al* (2015) focused on the responsibility of fossil fuel producers and underlined the fact that only a small number of companies have produced a large quantity of GHG emissions. Despite having been aware of the environmental consequences and the alternatives available to them, these companies continued to operate without sufficient efforts to change their behaviours (Frumhoff *et al* 2015). These companies had the knowledge to anticipate a transition to a low-carbon economy, and in spite of the viability of alternative low-carbon technologies, policies, and models, most have not pursued their implementation (Frumhoff *et al* 2015).

Heede (2014) completed a quantitative analysis of the embodied carbon emissions of fuels from the world's largest producers of coal, oil, natural gas and cement. The reasoning for this approach was to consider the function of those entities that extract, refine and market carbon fuels globally. He found that these fossil fuel producers were responsible for 63% of cumulative worldwide emissions of industrial CO_2 and methane (CH_4) from 1751 to 2010. Although Heede addressed the need to recognize the responsibility of corporate entities, he featured the roles of developing countries in supplying fossil fuels to the rest of the world, pressing that it may not be as simple as holding industrialized nations accountable for climate change. He found that a substantial amount of emissions embedded in fossil fuels have been extracted in Non-Annex 1 (mostly developing) countries and nations that are not necessarily large-scale emitters (Heede 2014). However, there is little discussion on the relationships existing between national-political and corporate structures, that perhaps influence the timing and location of fossil fuel production. He argued that Non-Annex 1 countries, that host much of fossil fuel production, also have an ethical obligation to help mitigate climate change because they have accrued 'considerable benefits'. Yet, there is no mention of where these benefits are directed. In the case of most Annex 1 countries, it is evident that wealth has trickled down to consumers in their societies, but for Non-Annex 1 countries, the orientation of these benefits is unclear. Furthermore, there is no discussion of the political or economic influences that industrialized nations have on business activities in other less-developed countries.

While Heede addressed one part of the supply chain, Davis *et al* (2011) examined all stages of the supply chain, incorporating trade and consumption as drivers of GHG emissions. They found that the number of entities extracting and refining fuels was relatively small, and that extraction points were concentrated geographically. In contrast, the burning of these fossil fuels for energy is widespread and generally occurs far from the points of extraction. Thereafter, goods and services produced by using this energy are often consumed at another, third, geographic point. Davis *et al* (2011) thus demonstrated the importance of accounting of carbon emissions at all stages of the supply chain, implicitly suggesting the allocation of mitigation efforts to any business with a function in the supply chain stating that they "…all benefit in some way from the current fossil fuel-driven economy, just as they are all are vulnerable in some way to the climate change that results."

Frumhoff *et al* (2015) also highlighted the concept of a "social license" to operate, as stakeholders and communities are increasingly demanding corporate disclosure and transparency from companies. These realities give merit to allocating emissions reductions to companies producing fossil fuels which are inevitably burned and result in GHG emissions to the atmosphere. This is further justified as some of these companies have actively lobbied against climate action, despite full awareness of scientific evidence for anthropogenic climate change (Frumhoff *et al* 2015). Indeed, some companies have voluntarily disclosed information on their operations and related GHG emissions, which has allowed academic researchers to complete various forms of emissions accounting for industries including the cement industry (Cagiao *et al* 2011), and the oil and gas industry (Heede 2014). Non-academic studies, such as those led by accounting firms, have also completed valuable studies on GHG accounting across sectors (Henderson and Trucost 2005, PricewaterhouseCoopers 2013). Though these studies address business accountability in some sense, they do not, however, take on the task of distinctly allocating mitigation efforts accordingly.

2.1.3 Allocating mitigation efforts among companies

If indeed businesses should be held accountable for their contributions to climate change, how would we effectively allocate emissions reduction efforts among them? It seems appropriate to begin with the various fairness principles established as methods for allocating emissions rights at the national level. Yet to date, there exist no comprehensive academic studies which account for corporate GHG emissions across all sectors globally, that would allow us to use these principles.

This step of aggregating corporate emissions data is absent from the literature, although some authors have attempted to create business metrics that could be applied to different fairness principles in the allocation of emissions reductions. For example, the works of Hoffmann and Busch (2008) established metrics that evaluate carbon [emissions] performance, otherwise recognized as indicators of the level of a business's carbon [emissions] efficiency. They presented the carbon intensity indicator, which measures the ratio of a company's carbon usage in absolute terms to a related business parameter (Hoffmann and Busch 2008). This is often represented as the ratio of a unit of emissions to a unit of production, either physical or monetary. Krabbe *et al* (2015) provided examples of indicators that could be used in different sectors, such as tons of CO_2 per tons of cement for the cement industry, or tons of CO_2 per US$ of value added (also, gross profit). Depending on the sector, either a physical or monetary parameters can be used. Krabbe (2015) stated that physical parameters, often in volume or weight of product, or other activity units such as MWh, are preferred for carbon intensity calculations because they can be better related to emissions and mitigation potential, as they represent a ratio between energy use and some physical quantity. Monetary parameters are used where physical parameters are not useful. This is the case for applications to more heterogeneous sectors, where there is either more than one product produced, or the sector is more service-oriented (Krabbe 2015). Some examples of these parameters include EBITDA, turnover, value added, revenue, and market capitalization.

Some non-academic publications use EBITDA as a denominator for carbon intensity (Henderson and Trucost, 2005, Societe Generale 2007), but do not thoroughly explain why it is preferable to other parameters, nor what the implications are of its use. EBITDA is considered a standard financial parameter which can be used to normalize data and provide a link between a measure of returns and carbon emissions (Henderson and Trucost, 2005), therefore allowing for comparison between company emissions contributions. Other financial parameters, such as turnover and market capitalization, have also been used when assessing corporate carbon performance, though are similarly poorly justified (Henderson and Trucost, 2005).

In comparison to employing absolute emissions when assessing business contributions, an industry-appropriate emissions intensity indicator allows for a different type of comparison. In some ways, it takes into account differences in business structure, operations, and finances. However, neither assessing emissions intensity nor absolute emissions as approaches to determining corporate accountability have been applied to company emissions data at the global level.

A parallel can be found between these approaches to establishing business accountability, and those principles used to assess national accountability. Considering absolute company emissions for the distribution of mitigation efforts is analogous to the grandfathering approach. This approach considers current or historical territorial emissions of a nation. Using carbon intensity indicators, on the other hand, represents a normalization of company emissions – similar to how equal per-capita emissions normalize nationally contributed emissions.

2.2 Carbon accounting and reporting

There is a broad set of literature entertaining corporate responses to climate change, however exploring these responses requires an understanding of existing accounting and reporting infrastructures in place. Waddock (2008) discussed the evolving institutional infrastructure related to corporate responsibility, by categorizing initiatives into state/government, market/economic, and civil society groups. In doing so, she revealed the largely non-compulsory nature of the infrastructure and the profusion of various standards, certification and monitoring programs, and accrediting agencies. Altogether, the infrastructure results in some confusion and a need for consolidation (Waddock 2008). Jones and Levy (2007) may have provided an explanation for this disorder by illuminating the paradox of companies opposing government regulation, while embracing carbon management initiatives. Because measures controlling GHGs directly threaten sectors relying on or producing fossil fuels, it became a trend to accommodate to the pressures of climate change. Yet at the same time, companies are acting to create, shape, and preserve a regime that is desirable to business (Jones and Levy 2007). By adhering to many, but no government-led, concentrated, or stream-lined expectations of climate change action, it remains difficult to evaluate accountability accurately.

Jones and Levy (2007), as well as Southworth (2009), brought to light the appeal and consequences of a voluntary infrastructure over a legislative one. Companies support voluntary approaches, as they have expressed concerns with federal regulation that would "stifle their ability to… tailor their industry's efforts to maximize economically and environmentally favourable action" (Southworth 2009). Jones and Levy (2007) determined that businesses seem willing to take on only limited measures towards climate change, ones consistent with an overall fragmented and weak policy regime. As such, business responses are directed more towards organizational changes rather than emissions mitigation (Jones and Levy 2007). Nevertheless, motivations for voluntary action are plenty, but overall seem to have little to do with contributing to social good. They include improvements through efficiency and alternate energy supply, reduced petroleum dependence, having a more reliable energy market, boosting shareholder and investor confidence, preventing or preparing for the physical effects of climate change, improving industry reputation, having access to new markets, lowering insurance costs, and preparing for restrictive carbon emissions legislation (Southworth 2009). As companies anticipated GHG control after the success of the Montreal Protocol in 1987, many voluntarily joined regional and/or local emissions trading groups with furtive aims of preventing the imposition of mandatory restrictions, shaping future trading systems, and acquiring a competitive advantage by gaining trading experience (Jones and Levy 2008).

Waddock (2008) identified that too many entities are influencing the corporate responsibility infrastructure. Different expectations about corporate behaviours and practices are put forward, contributing to the overall disorder of business responses to climate change. Accordingly, some authors have attempted to make sense of these responses by commenting on the strategies that businesses take to address climate change or the management of their GHG emissions (Jones and Levy 2007, Sullivan 2009, Weinhofer and Hoffmann 2010). Many others have more precisely studied business carbon accounting methodologies and different disclosure routes, while identifying some of their pitfalls (Kolk *et al* 2008, Southworth 2009, Andrew and Cortese 2011, Schaltegger and Csutora 2012, Dragomir 2012, Haslam et al 2014).

In analyzing the responses of 125 European companies to regulatory pressures reduce GHG emissions, Sullivan (2009) found that most have established management systems and processes necessary for them to manage their emissions, but the majority have yet to significantly reduce their emissions. He argued that uncertainties in climate change policy are the key barriers to companies taking a more proactive approach and actually reducing their emissions. Weinhofer and Hoffmann (2010) found complementing results while investigating the carbon strategies of 91 electricity producers around the world. They found that strategies are likely subject to regional climate policies, and that most companies take long-term management measures, while some still do not even mention measures to reduce CO_2 emissions. The trends show that there were significant differences between Japan, the US and the EU citing possible factors such as the lack of strong nation-wide regulations in the US, the ETS in the EU and the mandatory disclosure regulation in Japan.

A significant contribution to the literature, by Andrew and Cortese (2011), explored the general regulation of carbon disclosure and the influence that self-regulation has on reporting and climate change related decision making. They considered the Carbon Disclosure Project (CDP), an institutional investor group and disclosure program holding the largest global repository of self-reported environmental data, including GHG emissions (CDP 2017). They also considered the use of the GHG Protocol as a reporting model within the CDP. GHG Protocol Corporate Standard (WRI and WBCSD 2004) provides requirements and guidance for companies preparing a GHG emissions inventory, and is a standard that focuses on the accounting and reporting of emissions. Andrew and Cortese (2011) argued that as the CDP and GHG Protocol are voluntary regimes developed outside of the influence of democratically elected governments, and are largely the work of corporations, consultant accountants and non-governmental organizations, the reliability of the data produced is questionable. They claimed that the CDP is a capitalist driven approach to the climate crisis, which allows companies to dictate terms of new climate change strategies and policies. Furthermore, due to the absence of comparability as a requirement in the GHG Protocol standards, as well as the absence of a verification or audit, the usefulness of data from the CDP remains uncertain (Andrew and Cortese 2011). This is not helped by the fact that respondents of the CDP are not obligated to use the GHG Protocol as a guiding model, but are permitted to use other standards as well (Andrew and Cortese 2011).

These regime features have likely set the stage for observations made in other studies of the reliability of corporate disclosure. Dragomir (2012) completed an extensive study on the sustainability reports of the top five largest European oil and gas companies from 1998 to 2010, using the GHG Protocol as the benchmark for emissions reporting. By reviewing the sustainability reports from companies, he found that there was an overall poor comparability between data reported on a yearly basis, a lack of some basic information such as descriptions of data collection, calculation methodologies, and a frequent reformatting of these methodologies without regard to previous years' processes. He also evaluated some elements of the GHG Protocol including organizational versus operational boundary setting for emissions tracking. Dragomir (2012) identified a significant problem with the GHG Protocol's two approaches to determining organizational boundaries: the equity share approach and the control approach. The equity share approach, which accounts for emissions based on the share of equity the company has in an operation falsely "…eludes the notion of operational control," which is a prime measure for carrying out emissions reductions (Dragomir 2012). The control approach, which accounts for emissions the company has direct operational control over but not a financial interest in, "…neglects the responsibility accruing from an economic interest in the absence of full control." Thus, with the option of choosing either approach for reporting, a company can conceivably dodge the accounting of some emissions it is responsible for.

Haslam *et al* (2014) conducted a study in which they made similar conclusions about current company approaches to carbon disclosure. They indicated that accounting of emissions are adapted due to the discretionary decisions made regarding what is or what is not within the operational or financial control of the company. Emissions reporting therefore continues to be an unclear process that companies have the potential to manipulate. Haslam *et al* (2014) also provided general recommendations for more workable frameworks using conceptual business models, however the study's requirements for creating such models remain quite abstract and difficult to appreciate. Dragomir (2012) provided slightly more concrete suggestions, though his suggestions related specifically to changes in the GHG Protocol. This included adjusting the approaches to creating organizational boundaries for reporting, specifically expanding the reporting base under the notion of operational control by including branches in which the parent company has significant financial influence.

The literature highlights not only some of the issues of consistency and reliability of reported information, but addresses the immanent infrastructural problems of existing frameworks used to disclose information. For this reason, some authors have provided recommendations for improved frameworks and disclosure policies (Dragomir 2012, Haslam *et al* 2014), while others have implied that an effective way of obliging action on climate change and reducing GHG emissions is for political authorities to impose legal restrictions (Jones and Levy 2007, Southworth 2009). Nonetheless, voluntarily disclosed corporate emissions information could be valuable for political and scientific discussions on assessing whether mitigation efforts are sufficient and for stimulating more political commitment where it is needed (Schaltegger and Csutora 2012).

2.3 Future business emissions pathways

With a patchwork of reporting frameworks to work with, companies have little guidance on how to formulate emissions targets that adhere to greater global climate goals. Though there exist global and national carbon emissions budgets, which are allowable CO_2 emissions associated with a given global climate target (Matthews *et al* 2017), there are no clear carbon budgets provided for sectors, let alone companies. In light of this, Krabbe *et al* (2015) completed a study in which they provided a method for aligning business emissions targets with global climate goals. To allocate carbon budgets to sectors, they proposed the Sectoral Decarbonization Approach (SDA), for which they used a carbon budget associated with a 50% chance of keeping warming below 2°C, specifically following the 2DS scenario from the International Energy Agency (IEA). They calculated sectoral intensity pathways by dividing sectoral emissions pathways in units of CO_2, by the sector's activity projections, which were either physical or monetary business parameters depending on the sector. Though such measurements of intensity have been established by other authors (Hoffmann and Busch 2008, Busch 2010), sufficient justification for the indicator choices was not provided, except that physical parameters were preferred over monetary ones, and that monetary parameters were used in cases where sectors had more heterogeneous activity.

Based on the sectoral intensity pathways, individual company intensity pathways could be calculated (Krabbe *et al* 2015). The authors asserted that the SDA is a preferable approach for target setting because it attempts to account for structural differences across sectors, including mitigation potential, mitigation costs and expected activity growth. Growth and initial performance are accounted for by projected market share, and initial carbon intensity, respectively. The discord in this logic is that for companies with projected growing market shares, the quantity of absolute emissions is allowed to increase, while intensity is expected to improve. In light of the imminent and alarming consequences of climate change, along with the global political, economic, and social hurdles to mitigation, why should we be enabling companies to produce more GHG emissions? By considering corporate performance on the market before considering corporate performance in the environment, we are forgetting that the atmosphere does not respond to changes in company emissions intensity, but to changes in absolute emissions. Though the SDA methodology may adhere to set carbon budgets, companies should be aiming for long-term near-zero absolute emissions, as has been demonstrated to be requirement for stabilizing global mean temperatures (Matthews and Caldeira 2008).

The SDA methodology has been utilized by the Science Based Targets (SBT) initiative, a collaboration between several organizations, including the CDP, World Wildlife Fund (WWF), and World Resources Institute (WRI). The initiative's aim is "…that by 2020, science-based target setting will become standard business practice and corporations will play a major role in driving down global greenhouse gas emissions." (Science Based Targets 2017a) The SBT directs companies to the SDA as *one* of the tools possible to set a 'science-based target'. However, the SBT also provides other options, such as an absolute-based approach, and an economic-based approach. Without further explaining these approaches here, it is a blatant mis-step to offer entirely different approaches for determining company targets, as the final calculated targets will evidently vary depending on the approach taken. If company targets can vary, then total carbon budgets can vary as well. SBT even states on their website that, "The method a company chooses to use depends on its particular circumstances. Some methods are better suited for certain sectors, or for companies that are growing. There is not one 'best' method but there will be one that will work best for your company." (Science Based Targets 2017b) Indeed, there is no 'best' method, but in order to meet a global carbon budget, there should only be a single established method. Otherwise combined carbon budgets will not meet the global budget.

Arguments aside, it is clear that powerful companies have not taken any type of target-setting seriously. A recent report evaluated energy data provided by Fortune 500 companies and found that less than 20 (5%) had "science-based targets" (CDP *et al* 2017).

Altogether, it is apparent that in academic literature and beyond, more study into corporate target-setting and associated future emissions pathways is needed. With this, it is also essential to assess reported absolute emissions for their use in the allocation of mitigation responsibilities.

2.4 Conclusions

Literature pertaining to the concept of accountability for climate change and effort-sharing of mitigation is ample. Researchers have described the roles of various actors, including nations, and companies, in contributing to climate change. Though literature exploring business accountability, specifically, could be more developed, there are already compelling arguments that give merit to attributing climate change mitigation responsibilities to companies (Heede 2014, Frumhoff *et al* 2015). Moreover, the methodologies, or principles, that could be used to allocate emissions reductions are not well defined. However, they can be construed as analogous to those principles employed in analyses at the national level.

Heede's work contributed greatly to the literature in terms of historic emissions embodied in fossil fuels, though examining a small number of companies. But to date, there exist no comprehensive academic syntheses of global company GHG emissions, that reflect all sectors of business activity. As most GHG data is voluntarily self-reported and often adheres to non-government led reporting frameworks, it appears fragmented and may come across as unreliable. Nonetheless, it has not been readily experimented with in academic studies and the true extent of its range and reliability have not been confronted.

Although there is research which examines past and present carbon performances of companies using carbon performance indicators (Henderson and Trucost 2005, Societe Generale 2007, Weinhofer and Hoffmann 2010), these indicators are not, as of yet, fully instituted in business nor academia. Neither absolute emissions, nor emissions normalized by business parameters, have been put to use to calculate distributions of emissions mitigation efforts among companies. This appears to be in part a consequence of a lack of sound data, not simply because of the little information reported by companies, but also because of questions raised regarding reliability of existing reporting infrastructures. Business accountability is addressed somewhat by the SBT initiative, in that they provide methodologies for deriving emissions targets aligned with scientifically approved climate targets. However, because it issues more than one methodology for determining these targets, it raises the question of whether it properly promotes the achievement of a single global target. One of the approaches offered, the SDA, which relies on normalized emissions (that is, carbon intensity), allows for increases in absolute emissions. This sort of dispensation appears regressive when considering climate change action.

To effectuate business accountability for climate change, proper emissions accounting and disclosure are required. Thereafter, mitigation is possible, but only with the provision of consistent and accurate information guiding companies in creating targets aligned with global climate change objectives. The business world remains largely disoriented concerning emission reductions targets, and requires quantifiable objectives that rest within the global 1.5°C and 2°C carbon budgets. The literature does not provide an analysis or a synthesis of reported company emissions across sectors, and consequently does not explore the use of absolute emissions in the allocation of future emissions rights. This is a project that would contribute to our understanding of the effort-sharing of climate change mitigation among businesses, as well as contribute to our general knowledge of corporate commitments to battling climate change. It would also be informative to policy-makers aiming to institute future requirements or regulations of GHG emissions. This is an identifiable gap in the literature, one that should be promptly addressed in order to encourage business accountability.

CHAPTER 3

Manuscript

3.1 Introduction

It is now commonplace to recognize the ethical issues that come with assigning responsibility for climate change, and the effort-sharing of climate change mitigation (Shue 1999, Ringius *et al* 2002, Page 2008, Raupach *et al* 2014). These issues are concerned with determining who the responsible actors are and how accountability itself should be measured. The concept of "common but differentiated responsibilities" (UNFCCC 1992) has not successfully addressed these ethical questions, and has also been set exclusively in the context of national (state-level) responsibility. Yet, it is not national governments that physically emit large amounts of greenhouse gases (GHGs) to the atmosphere, but rather the business entities that operate within their borders. Businesses play a dual role in climate politics: they are the principal players in the production of major GHG emissions, and yet they carry the greatest potential for reducing future emissions through informed business decision-making. Nevertheless, statistics on corporate emissions within national borders have not been clearly established.

So, how do we hold companies accountable for their actions, specifically their contributions to climate change? A first important step is to understand what these contributions are, in terms of GHG emissions. Yet in the absence of legal authorities at both the international and national levels, businesses are not under great pressure to report their emissions, which makes their contributions difficult to measure. Some, however, are joining the trend of voluntary disclosure as a result of emerging corporate responsibility infrastructures and pressure from non-government stakeholders (Waddock 2008), by publicly disclosing an increasing amount of environmental information. This information, which often includes GHGs emitted directly by companies, has yet to be thoroughly explored for its potential and usefulness in climate change research. A second practical step could be to formulate future business mitigation objectives that fall in line with global climate change objectives. Presently, because the task has been largely left to national governments, neither companies, nor sectors on the whole are being instructed to mitigate emissions according to climate science recommendations.

Drawing on these objectives, I first collect available carbon emissions data provided by 43,756 companies from around the world, and evaluate the reporting activity occurring at the sectoral level. I also use financial market information to better understand emissions reporting patterns. With the emissions data, I allocate sectoral carbon emissions budgets aligned with targets of remaining below an increase of 1.5°C, and 2°C in global average temperatures. These goals have been defined as acceptable levels of climate change by the UNFCCC (UNFCCC 2009). Finally, I make use of the determined carbon budgets to suggest possible sectoral mitigation pathways that serve as preliminary guidelines for future business emissions activity.

3.1.1 Dimensions of accountability

3.1.1.1 Who plays a role in climate change?

In this section, roles are discussed, firstly, with the understanding that there are principal actors that contribute to climate change, and thus carry some blame. There are many actors at different levels of society who could therefore be held accountable.

Recent literature has largely focused on nation states as the principal bearers of responsibility (Friedlingstein *et al* 2014, Höhne 2013, Matthews 2016, Müller *et al* 2009, Raupach *et al* 2014). This approach uses the assumption that nations can be viewed as responsible for climate change because their respective governments should have (in theory) the authoritative structures in place to control the emissions of GHGs within their borders.

The role of individuals as contributing actors has also been studied, particularly how income inequality influences the impact of an individual on climate change (Roberts 2001, Baer *et al* 2009, Chakravarty *et al* 2009). Roberts (2001) examined income inequality and its link to GHG emissions, highlighting that the world's richest people cause emissions thousands of times higher than that of the world's poorest. Fahlquist (2008) illustrates the usefulness of examining inequality and individual responsibility together, arguing that individuals are blameworthy for acts that contribute to environmental [climate] problems, but only in circumstances where choosing a more climate-friendly decision is reasonable.

Business is another key actor contributing to climate change, because of the direct and indirect GHG emissions caused by using or producing fossil fuels. Some researchers have examined the role of fossil fuel producers (Frumhoff *et al* 2015, Heede 2014) as contributors to climate change due to the emissions embodied in extracted fuels. And while many authors have assessed GHG accounting methods and disclosure (Kolk *et al* 2008, Sullivan 2009, Southworth 2009, Andrew and Cortese 2011, Dragomir 2012, Haslam *et al* 2014), most GHG inventory studies have been completed by non-academic authors, such as those led by accounting firms (Henderson and Trucost 2005, PricewaterhouseCoopers 2013). On the other hand, a more objective attempt at accounting of corporate emissions is lacking in the literature.

3.1.1.2 Approaches to emissions accounting

Broadly, there are three presiding methods for emissions accounting, all of which identify steps in the supply chain of CO_2: extraction-based, production-based, and consumption-based emissions accounting. First, extraction-based accounting calculates the emissions embodied in fuels extracted and assigns the emissions to the entity responsible for the extraction (Davis *et al* 2011). Production-based accounting calculates the emissions from the combustion of fuels in the production of goods and services (Davis *et al* 2011) and assigns these emissions to the location where they are produced. By contrast, consumption-based accounting tracks the emissions that are embodied in trade, and assigns them to where the products or services are consumed rather than where they are manufactured (Davis and Caldeira 2010). The use of any of these approaches leads to varying results with respect to actors' climate contributions. These methods can be, and have typically been, applied to calculations of national contributions to climate change. However, they can also be analogously applied to companies, and in some manner, individuals.

At the national level, production-based accounting is the most widely used approach. Emissions produced within state borders are considered territorial or production-based, and many authors have made attempts to account for these emissions (Botzen *et al* 2008) and allocate mitigation responsibility according to this method (Matthews 2016, Raupach *et al* 2014). In contrast, Davis *et al* (2011) used extraction-based accounting as part of their evaluation of the distribution of emissions along the supply chain, tracing emissions back to the countries in which fuels were extracted. Taking a consumption-based approach, Davis and Caldeira (2010) attributed CO_2 emissions to countries according to their consumption of finished goods. They highlighted the resulting differences in emissions allocations, showing that the primary net importers of emissions were overwhelmingly developed countries.

At the individual level, it is more difficult to map the three approaches of emissions accounting analogously, as the extraction of fuels is not specifically demanded or executed by single individuals. However, accounting for emissions from burning of fuel for transportation or other needs, can be likened to production-based emissions. Chakravarty *et al* (2009) considered high individual emitters and allocated responsibilities according to a universal individual emission cap. This approach treats high emitting individuals equally, no matter which country they reside in. Conversely, Baer *et al* (2009) focused on high individual incomes to determine climate burdens, which may be viewed as an indicator for consumption, and thus analogous to consumption-based accounting.

The national accounting approaches could be made applicable to corporate level emissions accounting as well. Extraction-based emissions can be calculated as those emissions embodied in fuels extracted by companies. Heede (2014) used this accounting method to attribute responsibility to the corporate entities that extract, refine and market carbon fuels globally. He also recognized the role of the countries in which the companies operate, drawing attention to the fact that a substantial amount of emissions embedded in fossil fuels have historically been extracted in developing countries, ones that are not necessarily large-scale emitters. The production and consumption-based approaches may be linked to what the GHG Protocol has established as Scope 1, and Scope 2 and 3 emissions, respectively. Scope 1 emissions, as defined by the WRI and WBCSD (2004) are those emissions coming from sources owned or controlled by the company, for example, from combustion in boilers, furnaces, or vehicles, or emissions from chemical production in process equipment. Scope 1 company accounting thus resembles production-based accounting in that it refers to the direct emission of GHGs from the burning of fuels. Scope 2 indirect emissions are those that result from the generation of purchased electricity consumed by the company, while Scope 3 emissions are a consequence of the activities of the company, but occur from sources not owned or controlled by the company[3] (WRI and WBCSD 2004). Both Scope 2 and Scope 3 emissions therefore resemble consumption-based emissions in that they represent emissions embodied in goods (material or electricity) or services that are consumed by individual companies. Some authors have investigated issues with accounting of the various scopes of emissions (Schaltegger and Csutora 2012, Haslam *et al* 2014), however the literature does not provide a comprehensive inventory of these emissions.

[3] Examples include production of purchased materials or use of products and services (WRI and WBCSD 2004).

3.1.1.3 How to hold actors accountable and distribute mitigation efforts

Once a method for emissions accounting is established, there remains the question of how to allocate climate change mitigation efforts. In the past, nations have proposed different types of effort-sharing frameworks based on various fairness principles (Ringius *et al* 2002). Broadly, these approaches include considering historical emissions, wealth (i.e. the ability to pay), per-capita emissions, or current (or other base year) shares of emissions to allocate future emissions rights. Botzen *et al* (2008) quantified cumulative historical emissions of nations, while others have argued for the use of national per-capita emissions (Baer *et al* 2000, Neumayer 2000, Matthews 2016) or included ability to pay based on GDP per capita in their analysis (Winkler *et al* 2002). Note that the grandfathering approach, which allocates future emissions proportionally according to emissions at a specified base year (Neumayer 2000), has been used under international regimes such as the Kyoto Protocol (UNFCCC 1998) and the early phase of the EU ETS (European Commission 2010). When applied to nations, however, the grandfathering allocation method only weakly reflects principles of international equity.

These burden-sharing frameworks were developed for nations, and it is not obvious how they may be applied or adapted in the business context. These difficulties, along with the lack of comprehensive data available on company emissions, might explain the lack of studies completed on the sharing of emissions budgets among companies.

To advance research in this field, I outline analogous approaches. Grandfathering appears as the most viable approach to allocating emissions responsibilities to business because we need only know the current share of emissions across companies or sectors. Cumulative historical emissions may prove difficult to determine, as companies emerge, merge, and disintegrate often and sporadically, thus emissions could be difficult to assign to one entity. If the per capita approach in some way normalizes historical or current shares of emissions, we may similarly find ways to normalize company emissions measured in absolute terms. The work of Hoffmann and Busch (2008) established metrics that evaluate company carbon performance, otherwise understood as indicators of the level of carbon efficiency of a businesses. Krabbe *et al* (2015) put these metrics to use, providing examples of indicators that could be used in different sectors, such as tons of CO_2 per tons of material produced for homogenous industries, or tons of CO_2 per US$ of value added [gross profit] for heterogeneous industries. Finally, it might be plausible to distribute emissions responsibilities according to ability to pay, which in the company's case may be determined by market value or another financial metric representing the worth of a company. However, many wealthy companies operate in sectors in which there are little to no direct emissions, welcoming arguments against this approach.

3.1.1.4 Pathways consistent with climate goals

Once emissions budgets are assigned to an actor, it is helpful to identify future pathways of emissions reductions that are aligned with the allocated budget. Though it has been shown that the emission pathway taken is independent of the associated cumulative emissions budget (Zickfield *et al* 2009), sustained high emissions in early years carry consequences later on, namely the need for more drastic and rapid reductions (Stern 2007). Similar consequences would of course apply to the business world, however the pathway opportunities in this context need further investigation. Krabbe *et al* (2015) attempted to fill this void by creating carbon intensity pathways for companies based on a scenario in line with a 2°C carbon budget. However, their results were based on hypothetical sectoral emissions and activity data, rather than accounted absolute emissions.

3.1.1.5 Purpose of the study

Overall, there has been little academic exploration of voluntarily disclosed emissions data from companies, and more broadly, not enough investigation into the role of business in climate change. Businesses are largely unguided when it comes to creating emissions targets and aligning their activities with global climate objectives. The main purpose of this study is to encourage business accountability for climate change by highlighting emissions contributions from companies using voluntarily disclosed data, and by providing sectoral emissions budgets and future pathways in accordance with the climate goals of remaining below a 1.5°C and 2°C average global temperature increase. I also aim to provide relevant information on reporting patterns and market values of contributing companies that may help us better understand the composition of these reporting companies.

3.2 Methodology

3.2.1 Data collection

I gathered GHG emissions data from The Bloomberg Professional Service (The Terminal), a software system and platform providing real-time data and analytics of financial markets and securities (Bloomberg Finance L.P. 2017). GHG emissions data are available in several variables in The Terminal, including different forms of Scope 1, Scope 2, and Scope 3 emissions. For the purposes of this research, I considered only Scope 1 emissions data, as including Scope 2 and Scope 3 emissions data would result in overlap or double-counting of emissions across sectors. Scope 1 variables in The Terminal are sourced either from data collected by Bloomberg analysts from company public reports, or from the CDP, an institutional investor group and disclosure program holding the largest global repository of self-reported environmental data (CDP 2017).

Using the data collected from The Terminal, I categorized all listed and active companies for the year 2015 according to the Global Industry Classification Standard (GICS) sectors. GICS is a four-tiered, hierarchical industry classification system, with 11 sectors, 24 industry groups, 68 industries and 157 sub-industries (MSCI Inc. 2017). Though there exist other classification systems, such as ICB (ICB 2017) and SICS (SASB 2017), GICS is a reputable system that has also been used in previous analyses of environmental performance and efficiency (Artiach *et al* 2010, Kumar 2014, Chang *et al* 2015) as well as analyses on disclosure (Blanco *et al* 2016). A table of the GICS sectors and their definitions may be found in Appendix A: Table A.1.

It should be noted that reporting of GHG emissions data often coincides with financial reporting, and so I collected GHG emissions data for the 2015 fiscal year[4], rather than the 2015 calendar year which begins January 1st and ends December 31st.

I collected data for three emissions variables that represent emissions of Scope 1 nature from The Terminal: 1) Direct CO_2 Emissions, 2) Scope 1/Direct GHG Emissions, and 3) Scope 1 Activity Emissions Globally, henceforth referred to as Direct 1B, Scope 1B, and Scope 1C, respectively. The definitions of these variables, which are sourced from The Terminal, can be found in Appendix A: Table A.2. It is important to note that Direct 1B accounts for CO_2-only emissions, while Scope 1B and Scope 1C may involve other GHGs. I also collected data on company

[4] Fiscal reporting dates may differ across companies, though in many cases the calendar year is the same as the fiscal year. GHG emissions data filtered for the fiscal year also return more data points than when filtered for the calendar year, as some companies do not report in accordance with the calendar year.

market capitalization[5] for the 2015 fiscal year, which I used as an indicator of company size.

3.2.2 Data aggregation: estimations and statistical testing

To facilitate the analysis, I merged the three variables, Direct 1B, Scope 1B and Scope 1C, into a single variable, Scope 1 Merged (henceforth Scope 1M). Merging the data renders the data more complete, whereby it accounts for various company emissions disclosure methods: e.g. some companies may disclose only to the CDP, while others may disclose in their annual public reports – both of which are picked up by The Terminal. Where companies reported emissions in more than one of the three variables (Direct 1B, Scope 1B or Scope 1C), I have taken the maximum reported emissions value.

It is important to recognize two limiting factors in the data. First, although Scope 1B and Scope 1C, by definition, should represent the same emissions, it is not always the case that companies report the same value for each. Second, Scope 1B and Scope 1C are reported in CO_2-equivalent (CO_2e), potentially representing GHGs other than CO_2, and differ from those of Direct 1B (CO_2-only). This distinction is important given that I will be using the CO_2-only derived carbon budgets provided by Matthews *et al* (2017) to generate sectoral future emissions pathways.

The first limiting factor is due to company oversight, but the difference between Scope 1B and Scope 1C data may not be so great that using them interchangeably would cause inaccuracy in the analysis. After confirming that the data on reported emissions were not normally distributed in any of the sectors, I used the Wilcoxen Signed Rank (Matched-Pairs) test at a 5% level of significance to verify whether these data were significantly different. This test assumes no normality in distribution, and assumes that the data are dependent[6]. The results for every sector (Appendix A: Table A.3), indicated that there was no difference between the data in Scope 1B and Scope 1C, thus justifying the use of Scope 1B and Scope 1C data interchangeably.

The second limiting factor is that the constituent emissions, and thus the units, for Scope 1B and Scope 1C (CO_2e) differ from those of Direct 1B (CO_2). This can be resolved by making some

[5] The company's worth calculated by multiplying the shares outstanding by the price share, in USD (Bloomberg L.P. 2016).

[6] The Scope 1B and Scope 1C data are dependent as they are from the same group of companies.

rudimentary estimations. To convert Scope 1B and Scope 1C to data represented in units of CO_2, it is necessary to estimate the proportion of CO_2-only emissions in Scope 1B and Scope 1C CO2-equivalent (CO_2e) emissions. I took the following steps to make these estimations for each sector:

1. Where companies reported both Direct 1B and Scope 1B emissions, I calculated the proportion of Direct 1B to Scope 1B.

2. Where companies did not report Scope 1B emissions, but reported both Scope 1C and Direct 1B, I calculated the proportion of Direct 1B to Scope 1C.

3. Where companies reported neither Scope 1B or Scope 1C, but reported Direct 1B, I assumed the proportion of CO_2 to be equal to 1. This indicates that 100 % of the company's emissions are assumed to be CO_2-only.

4. In the case where proportions were calculated to be greater than 1 (implying error on the part of the company's reporting), I adjusted the proportion to be equal to 1.

5. Where no emissions were reported, no estimation was made for the proportion of CO_2.

6. To calculate the CO_2-only emissions, *CE*, estimate for sector *S*, I used Equation 3.1,

$$CE_S = \sum_{IG_S} (\bar{p}_{IG} \times ME_{IG}) \tag{3.1}$$

where IG_S is the index for IG different industry groups in sector *S*, $\bar{p}_{IG}$ denotes the mean of all estimated proportions for an industry group IG, and ME_{IG} is the total Scope 1M emissions in an industry group IG. $\bar{p}_{IG}$ is thus applied as the proportion for all companies in industry group IG, and the sum of these values gives a CO_2-only emissions estimate for its corresponding sector, *S*. See Appendix A: Table A.4 for all sectoral and industry group Scope 1M emissions and CO_2-only estimates.

I determined the percentage of market capitalization represented by companies reporting Scope 1M emissions by dividing the sum of the market capitalization of reporting companies by the sum of the market capitalization of all companies in the chosen sector.

3.2.3 Allocating CO_2 emissions budgets to sectors

I used the grandfathering approach to calculate sectoral budgets according to the climate targets of remaining below global-mean warming of 1.5°C and 2°C. I used the model-based estimates for 'effective' global carbon budgets provided by Matthews *et al* (2017), and adjusted the estimates to a 67% level of confidence of remaining below a warming of 1.5°C and 2°C (i.e. 'likely' to occur). These estimates are 2565 $GtCO_2$ and 3427 $GtCO_2$, respectively. These effective carbon emissions budgets account for non-CO_2 warming, by assuming approximately 15% of total warming is caused by non-CO_2 GHGs and aerosols (Matthews *et al* 2017). I used the 2015 global estimate of CO_2 emissions presented by CDIAC, which is 9.90 GtC, converted to 36,262 $MtCO_2$ (Boden *et al* 2016), to determine the percentage share of global emissions constituted by Scope 1M reported emissions. I applied this share to the 1.5°C and 2°C emissions budgets to obtain the budget that would be allocated to companies sectorally. Sectoral budgets were calculated according to each sectors' share of total Scope 1M emissions.

3.2.4 Creating sectoral emissions pathways

Pathways can be described as trajectories, or long-term patterns of yearly emissions resulting from the usage of an allocated emissions budget. I created sectoral pathways with the intention of providing some guidance on future business emissions, while highlighting the consequences of different business futures in the context of global climate targets. It is important, however, to recognize that the sectoral budget allocations are only applicable to those companies that reported emissions in their respective sectors in 2015.

I created three emissions pathways per sector: a linear, exponential, and logistic pathway. Each sectoral pathway was derived in accordance with the emissions budget allocated and is thus only informative for the companies in the sector that reported emissions appearing in Scope 1M data.

Each pathway is represented by:

$$f(t) = \varepsilon_t \tag{3.2}$$

where *t* denotes time in years and ε denotes emissions in $MtCO_2$. ε_0 is established as the CE_S calculated in section 3.2.2, since $\varepsilon_0 = f(t_0) = f(2015)$, and

$$\int_{l}^{u} f(t) = Z$$

where Z is the corresponding emissions budget, represented by the area spanning from an upper limit, u, and lower limit, l.

The linear pathway equation is represented as:

$$f(t) = \varepsilon_t = at + b \tag{3.3}$$

where b is the y-intercept $f(2015)= t_0$, and a is the slope of the line.

The exponential pathway equation is represented as:

$$f(t) = \alpha\beta^t \tag{3.4}$$

where α is the y-intercept $f(2015)$, and β is solved using integration of $f(t)$ where

$$\int f(t)\,\alpha\beta^t dt = \frac{\alpha\beta^t}{\log(\beta)} \tag{3.5}$$

and the corresponding sectoral budget, Z, is equal to the area under $f(t)$ spanning t = 2015 as the lower limit and t = 2100 as the upper limit,

$$\int_{2015}^{2100} f(t)\ \alpha\beta^t dt = Z \tag{3.6}$$

The logistic pathway equation is represented as:

$$f(t) = \frac{A}{1 + Be^{-kt}} \tag{3.7}$$

where A is the upper asymptote (prescribed as $f(2015)$), e is Euler's constant, k is prescribed as - 0.24 for the 1.5°C budget, or - 0.1 for the 2°C budget (see Appendix B for justifications). B is solved using integration of $f(t)$ where

$$\int f(t) \frac{A}{1 + Be^{-kt}} dt = Aln(e^{kt} + B)/k \tag{3.8}$$

and the corresponding sectoral budget, Z, is equal to the area under $f(t)$ spanning t = 2015 as the lower limit and t = 2100 as the upper limit,

$$\int_{2015}^{2100} f(t)\frac{A}{1+Be^{-kt}}\,dt = -Z \tag{3.9}$$

Equation solutions for all sectoral pathways, along with their corresponding budgets, may be found in Appendix A: Table A.5.

3.3 Results

3.3.1 Corporate reporting and market capitalization

The Terminal listed 43,756 active public companies, from all over the world and across sectors (Bloomberg L.P. 2016). Of these companies, only 3,011, or 6.9%, reported emissions appearing in Scope 1M in 2015. The breakdown of reported emissions by sector shows that the Industrials, Materials, and Consumer Discretionary sectors make up almost 50% of the companies reporting in 2015, while Telecommunication Services, Real Estate, and Healthcare each make up under 5% of the total (Figure 3.1). These shares also depend on the size (number of companies) of the sector (see Appendix A: Table A.4). To consider differences in sector sizes, I calculated the percentage of reporting within each sector, as well as the percentage of market capitalization shared by reporting companies (Figure 3.2).

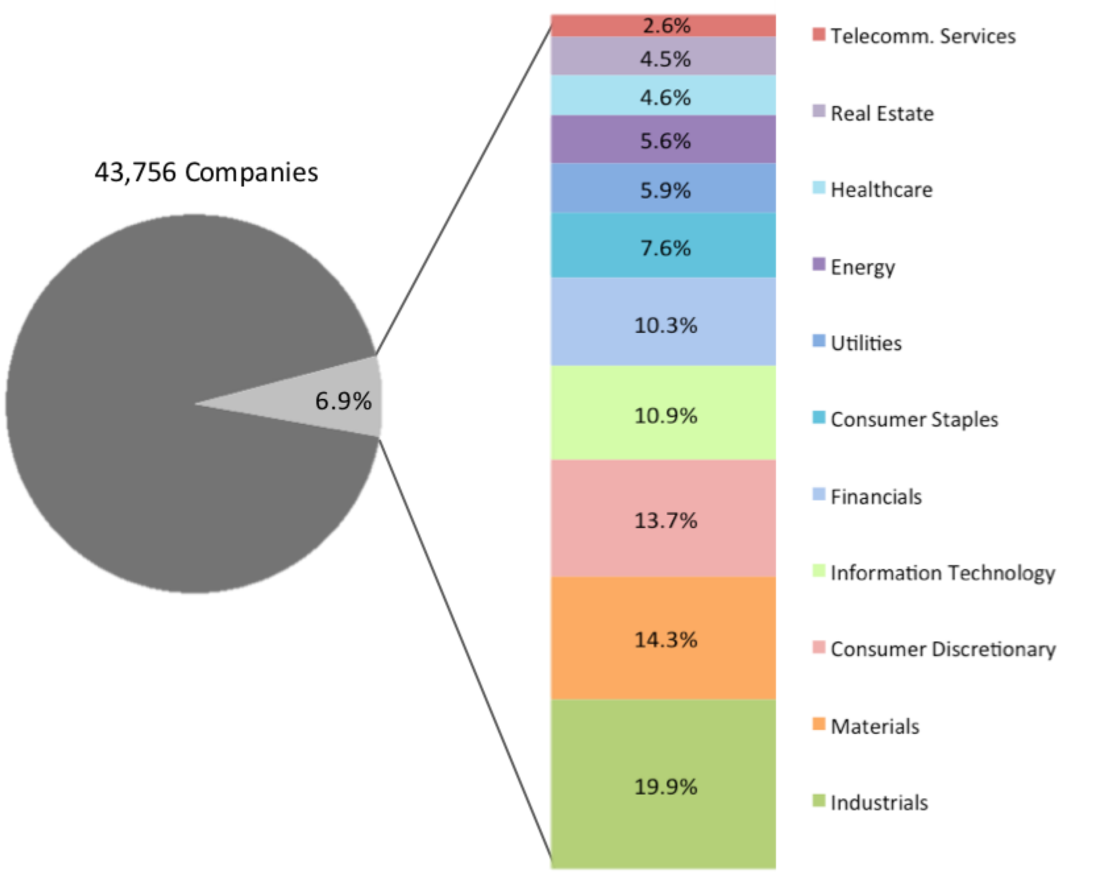

Figure 3.1 Breakdown of reported emissions by sector for 2015. Depicts reports from 3,011 companies across sectors. Sectoral composition depends highly on the size of the sector

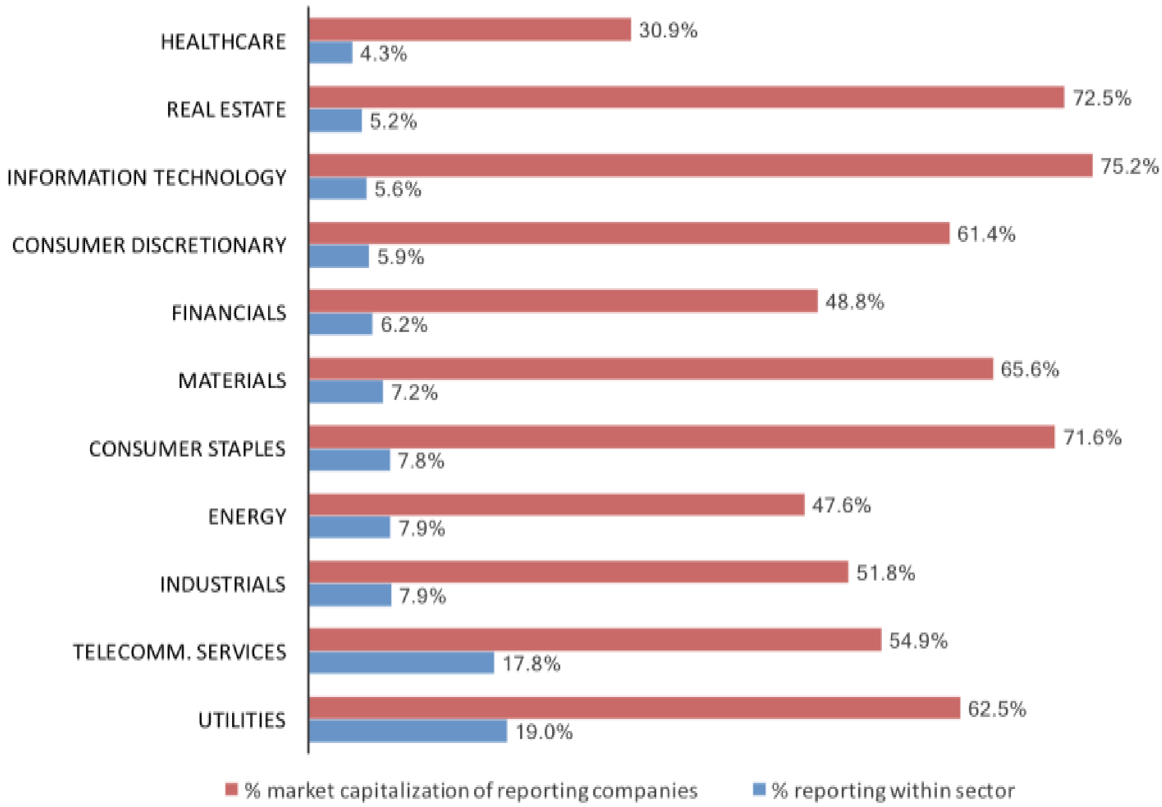

Figure 3.2: Percentage of market capitalization represented by reporting companies and percentage of reporting, within sectors, in 2015. Sector reporting represents Scope 1M emissions data

The sectors with the largest percentages of reporting were Utilities and Telecommunication Services, with close to 20%. This was well above the amount of the following sectors following: Industrials, Energy, and Consumer Staples, for which the reporting percentage was under 8%. The lowest percentages of reporting, of below 6%, included the Healthcare, Real Estate, Information Technology, and Consumer Discretionary sectors. Reporting companies make up the largest shares of sector market capitalization for the Information Technology sector (75.2%), followed by the Real Estate (72.5%) and Consumer Staples (71.6%) sectors. Interestingly, these sectors also have the greatest differences between reporting and market capitalization. The lowest percentage of market capitalization made up of reporting companies was in the Healthcare sector (30.9%), followed by the Energy (47.6%) and Financials (48.8%) sectors. Reporting companies make up 6.9% of public companies worldwide, and 56.8% of total global market capitalization of public companies in 2015. Total emissions reported across all sectors was 7828 $MtCO_2e$, where the CO_2-only estimate was 6881 $MtCO_2$. The sum of all CO_2-only emissions amounts to 19% of global CO_2 emissions in 2015 as reported by CDIAC (Boden *et al* 2016). Results in Figure 3.3 show that, starting with the greatest emissions, Utilities reported 2967 $MtCO_2e$, Materials 2098 $MtCO_2e$, Energy 1470 $MtCO_2e$, and Industrials reported 805 $MtCO_2e$. The remaining sectors reported less than 180 $MtCO_2e$. Notably, the Telecommunications Services sector reported the least (12 $MtCO_2e$), followed by the Healthcare (18 $MtCO_2e$) and Real Estate (21 $MtCO_2e$) sectors.

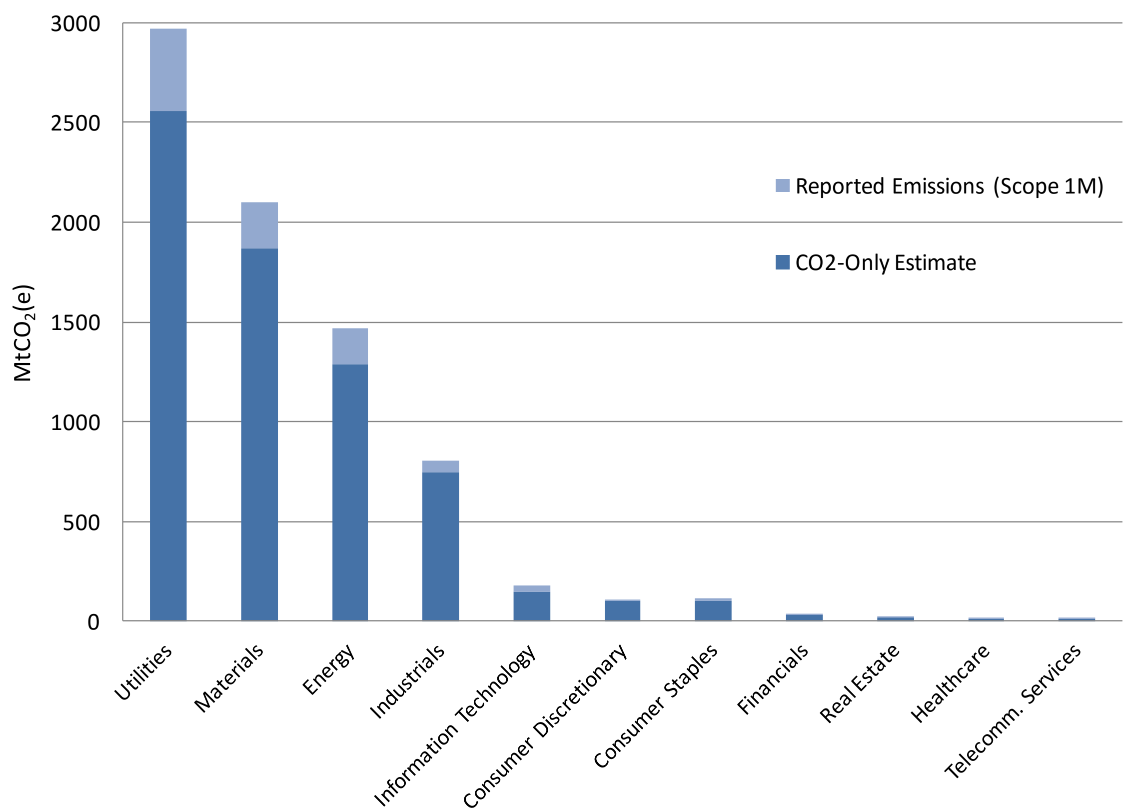

Figure 3.3: Scope 1M emissions for 2015 by sector, with estimates of CO_2-only emissions. The vertical (Y) axis depicts emissions in units of $MtCO_2$ for CO_2-only emissions, and $MtCO_2e$ for reported Scope 1M emissions

The CO_2-only estimate for Utilities is 2557 $MtCO_2e$, 409 $MtCO_2e$ less than the Scope 1M reported emissions, implying that this portion of reported emissions represents GHGs other than CO_2. Similarly, the difference between Scope 1M and CO_2-only for the Materials sector is 228 $MtCO_2e$, 180 $MtCO_2e$ for the Energy sector, and 59 $MtCO_2e$ for the Industrials sector. The greatest percentage differences[7] between Scope 1M and CO_2-only are 28% for Real Estate, followed by 26% for Healthcare, and 21% for Information Technology. The smallest percentage differences between Scope 1M and CO_2-only are 3% for Consumer Discretionary, followed by 8% for Industrials, and 9% for Telecommunication Services.

3.3.2 Sectoral emissions budgets

Using model-based estimates for effective global carbon budgets provided by Matthews *et al* (2017), and adjusted to a 67% confidence level, I determined the carbon emissions budget associated with a global mean warming of 1.5°C allocated to all reporting companies to be 100,905 $MtCO_2$, and for a warming of 2°C to be 264,429 $MtCO_2$. If regarded as budget boundaries, the sectoral allocations for the 1.5°C and 2°C emissions budgets also provide a range of possible budgets for each sector (Figure 3.4). The smaller 1.5°C budget is visible at the lowest

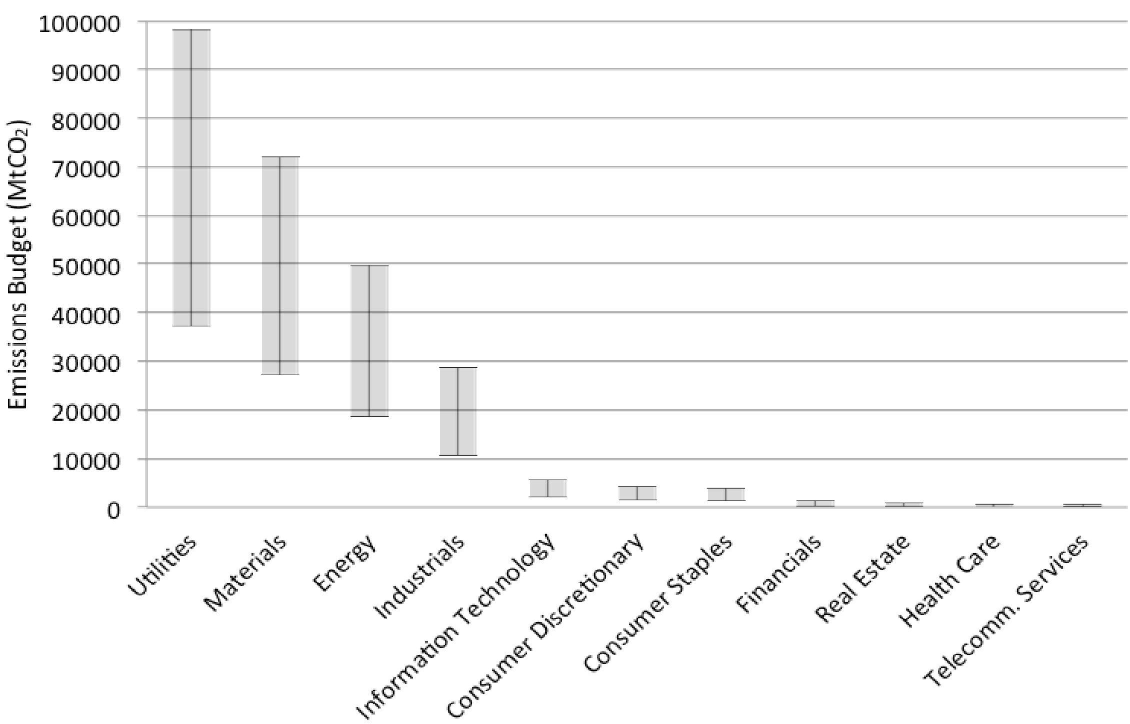

Figure 3.4: Ranges for allocated carbon budgets associated with the 1.5°C and 2°C climate targets. The budget associated with 1.5°C is depicted by the low-end of the range, and 2°C by the high-end of the range

[7] See Appendix B for calculation of percentage *difference*. It is not the same as percentage *change*, which compares an antecedent value to a new value and is divided by the antecedent value.

end of each range, while the 2°C budget is visible at the highest end of each range (Figure 3.4). The Utilities sector holds the largest budgets, 37,503 $MtCO_2$ (98,281 $MtCO_2$) for the 1.5°C (2°C) target, as well as the greatest range of 60,777 $MtCO_2$. Utilities are followed by the Materials and Energy sectors, with 1.5°C budgets of 25,421 $MtCO_2$ and 18,916 $MtCO_2$, and 2°C budgets of 71,860 $MtCO_2$, and 49,572 $MtCO_2$, respectively. The budget range for the Materials sector is 44,439 $MtCO_2$, and 30,655 $MtCO_2$ for the Energy sector. The smallest 1.5°C and 2°C carbon budgets are allocated to Telecommunication Services with 162 $MtCO_2$ and 426 $MtCO_2$, respectively. Likewise, this sector has the smallest budget range which is 263 $MtCO_2$. Sectors similarly low allocated budgets are Information Technology, Consumer Discretionary, and Consumer Staples.

3.3.3 *Sectoral emissions pathways*

I derived three emissions pathways for each sector according to the allocated budgets for the 1.5°C and 2°C scenarios (Figure 3.5). Only the pathways of sectors with the smallest (Telecommunications) and largest (Utilities) allocated carbon budgets are shown here, with pathways for the remaining sectors provided in Appendix C. The graphs in Figure 3.5 exhibit pathways from 2015 to 2100 for the Utilities sector (Figure 3.5a and c), which has the largest allocated budgets, and the Telecommunications sector (Figure 3.5b and d), which has the smallest allocated budgets. The three varying pathways, each represented as linear, exponential, and logistic trajectories, are relevant to each sector and budget scenario. The equations derived (Appendix A: Table A.5) for all pathways correspond to the allocated sectoral carbon budget, which is represented as the integral of the curves. It is noteworthy that each pathway carries different mitigation implications. While for the linear pathway the rate of change or the reduction in emissions stays constant, the exponential pathway implies a higher rate of emissions reduction in earlier years, which decreases with time. Due to the parametric restrictions of the exponential equation, the exponential pathway is asymptotic to the x-axis, and thus does not reach 0 $MtCO_2$[8].

[8]To adjust the exponential pathway so as it would reach near-zero values at 2100, two arithmetical approaches can be taken: reducing the sectoral budget, or extending the upper limit to a later date. I chose not to change the sectoral budget or extend the upper limit so as to remain true to the methodology. Moreover, extending the upper limit only allowed for small reductions in end of century emissions. In reality, a sector following an exponential pathway may adjust its pathway near 2100 to a linear pathway in order to reach true zero emissions.

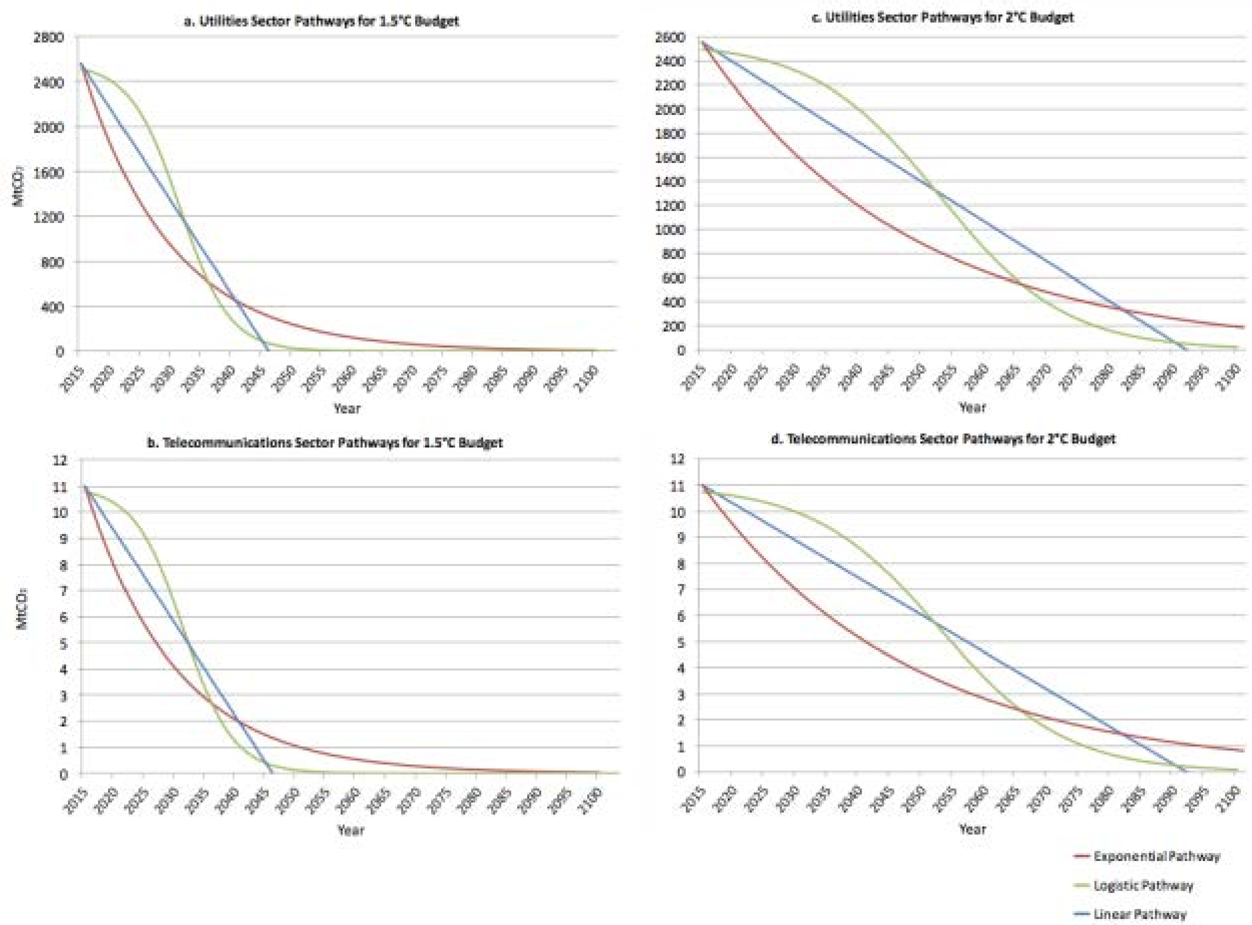

Figure 3.5: Sectoral emissions pathways for reporting companies in $MtCO_2$/year, a-d. Utilities sector pathways of the 1.5°C budget (a), Telecommunication Services sector pathways of the 1.5°C budget (b), Utilities pathways of the 2°C budget (c), and Telecommunication Services sector pathways of the 2°C budget (d)

This is especially apparent in the Figure 3.5c and d, where the larger sectoral budget for the 2°C scenario results in emissions slightly above zero at 2100 for the exponential pathways. The logistic pathway is characterized by an 'S' shape, where the decay rate of emissions is initially increasing, and changes to a decay rate that is decreasing at the point of inflection. Due to these characteristics, the logistic pathway allows for higher emissions than both the linear and exponential pathways in earlier years of mitigation, but eventually falls below the linear and exponential pathways in the later years. Due to the parametric limitations of the logistic function (see Equation 3.7), with $t_0 = 2015$, ε_0 is slightly below the emissions values reported in 2015[9].

Pathways derived for the Utilities and Telecommunications sectors for same 2°C budget appear identical in shape (Figure 3.5c and d), though the scale of emissions differs greatly. The linear pathway of the Utilities sector has a mitigation rate of approximately 33 $MtCO_2$/year, while for the Telecommunications sector it is approximately 0.14 $MtCO_2$/year. The linear pathways reach 0 $MtCO_2$/year in the year 2092. For the 2°C budget (Figure 3.5c and d), the annual emissions of the exponential pathway is less than that of the linear pathway until 2083, at which point the exponential pathway allows for higher residual yearly emissions than the linear pathway. For the smaller 1.5°C budget (Figure 3.5a and b), the exponential pathway will reach close to 0 $MtCO_2$/year, while for the larger 2°C budget, the parametrics of the equation will restrict the end of century rate to above 0 $MtCO_2$/year. The logistic pathway has a decay rate of emissions which is increasing until its inflection point, where the decay rate begins to decrease. The logistic pathways in Figure 3.5c and d allow for higher yearly emissions than the linear pathway until 2054, and until 2066 for the exponential pathway. The greatest difference in yearly emissions is between the logistic and exponential pathways in 2038. For the Utilities sector this difference is 684 $MtCO_2$, while for the Telecommunications sector it is 3 $MtCO_2$. In comparing the two sectors (Figure 3.5c and d), it is noteworthy that the vertical axes bounds between Utilities and Telecommunications are very different. Pathways were set according to the initial reported CO2-only estimate of emissions in 2015, so naturally, sectors like Utilities that reported higher emissions will have greater yearly emissions than those that reported less.

Similarly, the pathways for the 1.5°C budget (Figure 3.5a and b) of the Utilities and Telecommunications sectors mirror each other as well. However, these pathways appear notably different from those of the 2°C budget (Figure 3.5c and d). That is, they tend to approach near-zero emissions much earlier in the timeline than those pathways of the 2°C budget, and emissions mitigation is concentrated in the beginning of the timeline rather than spread out over the 85-year period. The linear pathway reaches 0 $MtCO_2$/year in the year 2046, which is 46 years

[9] In reality, the trajectory of the logistic curve in the first several years of the pathway may be adjusted so as to reach the correct starting emissions point in 2015.

before that of the 2°C budget. Likewise, the exponential and logistic pathways approach zero much earlier than for the 2°C budget; near 2080, and 2050, respectively. The greatest difference in yearly emissions is between the logistic and exponential pathways in 2023, though this window is significantly smaller than that of those in Figure 3.5c and d. For the Utilities sector this difference is 379 $MtCO_2$, while for the Telecommunications sector it is 1.7 $MtCO_2$. Recall again that the vertical axes bounds between the Utilities and Telecommunications sectors are different due to their distinct sectoral budgets.

3.4 Discussion

3.4.1 Emissions, reporting, and market capitalization

It is both meaningful and surprising that the small number of companies (3,011) that report their emissions accounted for almost a fifth of global CO_2 emissions in 2015. This disproportionate share of climate change contributions among businesses is not unlike those patterns observed in other studies. Though using an extraction-based accounting approach, Heede (2014) found complimentary results underlining that there is centralized control of fossil fuel extraction by a small group of businesses. Similarly, other authors that have focused on national contributions have also shown that a small number of countries are causing the majority of global GHG emissions (Botzen *et al* 2008, Matthews *et al* 2016).

It is remarkable that this small 6.9 % of all monitored companies in The Terminal already accounted for 19% of global CO_2 emissions, and moreover, that these reporting companies also made up more than half (56.8%) of the global market share in 2015. This is evidence showing that the reporting companies are some of the largest companies in the world (evaluated by market capitalization). It also provides us a better understanding of the composition of companies making up such a large portion of global emissions, and why they may be concentrated in the hands of a few thousand companies. Though a relationship between reported emissions and market capitalization has not been established, this research will show that some weak correlations can be observed (section 4.3.1). With further research and greater availability of data, the possibility of stronger correlations existing could help predict corporate accounted emissions, and even provide an element of external validation for accounting.

The low reporting rates across sectors are surprising as well. Despite many available avenues for corporate carbon disclosure, including the simple measure of reporting emissions in company annual reports, the majority of the world's businesses have chosen not to report their emissions. This highlights one major difficulty with business accountability for climate change, since accountability requires a certain degree of transparency. Without this transparency, the progress on climate change mitigation action is strongly impeded. For example, this is evident when placed in the context of international climate change agreements. Drafting such agreements with defined global climate targets, and associated national targets, is only plausible once nations are aware of each other's emissions contributions and development histories. Despite acknowledging that to reach the climate targets of remaining below an average global temperature increase of 1.5°C or even 2°C requires near-zero emissions in the future, we cannot assume that these goals can be reached in the absence of accounting. In order to facilitate emissions reductions, aside from having access to mitigation resources, accounting is necessary because it tracks progress. The benefits of tracking progress are twofold: first, it identifies problems and gaps in mitigation efforts, both at the company and sectoral levels, and second, it allows for comparability between companies. Identifying which mitigation efforts are not successful is important because reaching emissions reduction targets along the pathway to zero emissions carry different effort requirements, and become more difficult with each new target. Thus, perfecting, or at the least improving mitigation efforts in the early stages will help facilitate more difficult mitigation required in the long-term. Comparability is important for the accountability aspect of mitigation. While some companies may be reporting and actively reducing emissions, other companies reporting may not be doing the same. As Sullivan (2009) conveyed in his study, not all companies with established management of GHGs are significantly reducing emissions. Thus, through the accounting of emissions, we can identify those companies that need to carry out more or more effective mitigation efforts. Simply stated, emissions accounting is crucial to establishing business accountability.

Some sectors, including Industrials, Materials, and Consumer Discretionary, though comprising a greater portion of global reporting (Figure 3.1), did not also show high rates of reporting within their sectors in 2015 (Figure 3.2). These sectors represent the manufacture of various goods, many of which presumably produce substantial GHG emissions. Despite this, reporting of emissions in these sectors was highly unsatisfactory, considering that these sectors assume energy-intensive activities, and that there reported emissions were already much higher than those of other sectors. In contrast, the Telecommunications Services sector, made up of only 420 companies, has one of the highest reporting rates, along with one of the lowest reported emissions. This sector appears different from the others in the sense that it does not follow the same pattern of poor reporting relative to its size and emissions reported. The case of the Utilities sector also appears unique. Despite being a sector comprised of under a thousand global power producers, it had almost a fifth of its companies reporting emissions in 2015. It is the only energy-intensive sector with a relatively high reporting percentage, while it is also one of the smallest sectors consisting of only 936 companies. It is beyond the scope of this study to predict the sources of pressure for reporting, but it is clear that other energy-intensive sectors such as Industrials, Materials, and Energy, do not follow the same reporting pattern as the Utilities sector. Similarly, less energy-intensive sectors such as Healthcare and Real Estate do not follow the same reporting pattern as the Telecommunications Services sector.

A better understanding of the composition of companies reporting within sectors can be formulated with an assessment of market capitalization represented by these companies. If considering, in order, the sectoral reporting percentages, there is no clear pattern of associated market capitalization. However, some deductions can be made specifically from each sector's case. For example, the reporting companies in the Real Estate and Information Technology sectors represent over 70% of the sectors' market capitalization, while the reporting is below 6%. This reveals that the few companies reporting actually have an exceptional reach over the markets of their respective sectors and would thus be considered 'large' companies. On the other hand, the Financials sector, which has a similar reporting percentage, has a much lower represented market capitalization (48.8%). Yet, its results are still better than that of the Telecommunication Services, which has the second highest reporting percentage (17.8%), but a represented market capitalization of only 54.9%. Thus, judging by the results of Figure 3.2, it cannot be concluded that reporting percentages in sectors are reflective of their represented market capitalizations. Deductions made regarding the impact of market capitalization on reported emissions, however, requires further investigation (see Chapter 4).

Two key deductions can be made regarding the pathways displayed in Figure 3.3. First, if only considering the nature of the activities in the sectors themselves, the results are predictable. Sectors including Utilities, Materials, Energy, and Industrials, which are more energy-intensive, (see their definitions in Appendix A), reported the highest emissions. Second, when considering the reporting rates in each sector, the true pattern of emissions becomes unclear. Evidently, those sectors with more companies reporting emissions, are more likely to have higher reported emissions at the sectoral level. On that account, if the other energy-intensive sectors reported at rates closer to that of the Utilities sector, I would expect the data displayed in Figure 3.3 to change significantly.

While global estimates of CO_2 made up 76% of total GHG emissions in 2010 (IPCC 2014c), the CO_2-only estimates depicted in Figure 4.3 make up 88% of the total Scope 1M emissions reported in 2015. Given that most global non-CO_2 emissions are CH_4 (Montzka *et al* 2011), and that the main anthropogenic source of CH_4 is agriculture (Kirschke *et al* 2013), one explanation for this over-estimation is that companies in the agriculture business do not report emissions enough for an accurate estimation of a CO_2-only emissions proportion. The latter explanation is justifiable as only 89 of 1701 companies listed in the Food Products industry (which includes sub-industries of Agricultural Products, Meat, Poultry and Fish, and Packaged Foods and Meats) of the Consumer Staples Sector report emissions found in Scope 1M data. Yet, even if over-estimating, the sectoral results for CO_2-only emissions estimates would not change considerably if the sectoral proportions estimated in section 3.2.1 were adjusted to the IPCC global estimate for 2010.

Overall, the results suggest that if serious mitigation action was to be taken by a relatively small set of companies in the world, we might expect notable global emissions reductions.

3.4.2 Implications of the grandfathering approach

As an initial effort to distribute responsibility among companies, and in light of constraints on the availability of emissions data, the grandfathering approach is a reasonable option for several reasons. Firstly, this approach is defined by a simple calculation, and requires minimal data, allowing for the greatest transparency. Secondly, other allocation approaches are presently not as viable in the context of business. Approaches considering historical emissions are limited by the absence of company emissions accounting, year-to-year inconsistencies in emissions accounting, unascertained allocations after mergers and acquisitions, and historical emissions that would be unaccounted for due to company closures. Approaches considering current emissions normalized by physical or monetary business parameters are promising, but require data on company activity outputs, as well as established indicators that would be appropriate for different companies. Research has been conducted on such indicators (Hoffmann and Busch 2008, Busch 2010), and could be useful for future studies allocating business carbon budgets. A third, and more debatable reason for using the grandfathering approach, is its greater potential in getting high-emitters to cooperate (Knight 2013).

Though the grandfathering approach has been challenged in literature addressing emissions entitlements in the national context (Neumayer 2000, Caney 2009), many of these arguments have ethical foundations which I assert are not easily translated to the business context. For example, the argument for the right to develop in the national context indicates that individuals in every country have an equal right to the global resource atmosphere (Neumayer 2000). But, translating such an argument based in ethics to the business context is contentious. Business in itself is defined by profit achieved through the selling of goods and services, but ones not always necessarily beneficial to the public. Is business development meant to benefit society and individual livelihoods? Should small companies with low emissions that, nevertheless, aspire to expand, produce, and sell, be allowed to increase their GHG emissions in the anticipated low-carbon future? I argue that companies in these positions should embrace new business structures and initiatives that result in stringent emissions mitigation as soon as possible. I believe it is possible to grow business without also increasing contributions to climate change and if companies are meant to develop (and let us assume development in the economic sense), then they should do so without turning to arguments based in ethics meant for individuals and their nations. Creating targets that account for growth and initial performance (Krabbe *et al* 2014) is a risky approach, and ignores some of the very reasons for why global emissions remain so high: that companies, despite having knowledge of the environmental consequences of their activities, have continued to operate in a business-as-usual manner (Frumhoff *et al* 2015).

The grandfathering approach results in a proportional distribution of emissions budgets according to current emissions trends in the sectors, which is evident when comparing the mirroring patterns of Figures 3.3 and 3.4. Not only do the budgets increase with increased reported emissions, but the budget ranges (1.5°C to 2°C) increase as well. Consequently, companies with greater emissions have more opportunities (and would thus be more inclined) to mitigate emissions at different levels, while remaining in agreement with the 2°C budget. They also have the choice of assigning themselves targets within the budget ranges that are in line with their immediate capabilities. Despite the argument against allocating larger budgets to high-emitters, the grandfathering approach does indeed penalize high-emitting sectors in the sense that these sectors will need to reduce more emissions than others with lower emissions, in order to reach zero emissions by the end of the century. For example, it is conceivably more difficult to mitigate an allocated budget of 10,000 $MtCO_2$ than 1,000 $MtCO_2$. Allocating a greater carbon budget does not suggest that mitigating these emissions will be easier.

3.4.3 Implications of different emissions pathways

The pathways introduced in section 3.3.3 are idealistic trajectories, but each pathway presents differentiated and realistic challenges to emissions mitigation.

The linear pathways are uncomplicated trajectories, and are perhaps best suited as a point of comparison for the exponential and logistic pathways. Because the emissions reductions per year remain constant throughout the linear timeline, the implications of following this pathway lie in the assumption that every unit of emissions mitigated is equally difficult to mitigate. Following this mitigation pathway in the first few decades appears challenging, but feasible if compared to the stringent mitigation required for the first few years of the exponential pathways. Yet, emissions reduction at near-zero stages of the linear pathways will not be as easily and consistently mitigated. These emissions can be likened to those 'committed' emissions from existing infrastructure pointed out by Davis *et al* (2010). Though originally placed in the context of the national emissions, the idea that there are existing infrastructures that are anticipated to live out their regular lifetimes and that would otherwise be difficult to eradicate completely, is also relevant in the business context. A simple but effective example would be that a company producing energy by coal-burning is unlikely to replace its coal plants with wind turbines or solar panels as an initial attempt to reduce emissions. Rather, the company will look for more economic ways to do so in the first several years, such as reconfiguring plants to accommodate other lower carbon-emitting fuels. To reach near-zero emissions, some companies will need complete overhauls of their business structures and objectives. Given these insights, the linear pathway is a good point of comparison to other pathways carrying greater consequences either in the beginning, or the end of their timelines.

For companies that foresee having difficulties in mitigating emissions near-zero, the exponential pathway would be a more appealing option. This pathway, unlike the linear pathway, does not assume that every unit of emissions is equally difficult to mitigate, but accommodates for slower near-zero emissions reductions. The pathway begins with stringent emissions reductions as the rate of emissions per year begins higher than that of the linear and logistic pathways. The rate of reduction is highest at the start but continually decreases, resulting in lower year-to-year emissions reductions in the later years. The disadvantage to the exponential pathway is the need for immediate and rapid emissions mitigation.

In contrast, the logistic pathway accommodates companies that do not have the immediate capabilities to reduce emissions quickly and immediately. The rate of emissions reductions in early years is even less challenging than the linear pathway. The other advantage is the slower rate reduction when nearing zero emissions, also allowing for existing infrastructures to live out their lifetimes. However, the difficulty presented in the logistic trajectory is the large increase in emissions reductions per year required as the pathway approaches the inflection point. The inflection point is identified at the point where the emissions reduction rate is at its maximum. The reduction rate at the inflection point of the logistic pathway is greater than any point on either the linear or exponential pathways, and could present problems if companies are not ready to commit to stringent action at a point where emissions have already been reduced significantly.

One of the core assumptions in these trajectories is that companies within their respective sectors all have the same zero-emissions date. This is irrespective of company size, location, or other factor that may differentiate companies. Yet, these factors play relevant and important roles in determining company accountability, and in this context, setting zero-emissions deadlines. In parallel, discussions of national emissions allocations have recognized various factors and ethical considerations, such as historical contributions, per-capita contributions, ability to pay, and geography (Ringius *et al* 2002), that may differentiate national responsibilities. Though the sectoral pathways I have presented here are consistent in regards to the zero-emissions target dates, these restrictions can be adjusted in consideration of, for example, company location. It would be viable to extend a zero-emissions target date for companies located in developing countries and roll back the target date for those located in developed countries, if the justification for doing so is appropriate.

Each pathway provides companies with different opportunities, as well as drawbacks. The viability of a specific pathway can only be inferred when there has been thorough evaluation of the company's mitigation capabilities, and most importantly those capabilities in the short-term. With timely mitigation action, companies can avoid the risk of confronting future challenging mitigation requirements with which they might have difficulty coping. As a result, some of the drawbacks mentioned may even be diminished.

3.4.4 Implications of the 1.5°C and 2°C carbon budgets

It is evident from Figures 3.4 and 3.5 that adjusting the global climate target by only 0.5°C has significant consequences for business sectors. The allocated budget under the 1.5°C scenario, being almost a third of that of the 2°C budget, severely restricts the flexibility of future pathways. The differences between the linear, exponential, and logistic pathways under the 1.5°C budget are much less prominent than those of the 2°C budget. All three pathways follow similar trajectories up to about 2040, when they begin to approach near zero emissions, as opposed to years nearing the end of the century, as observed for the 2°C scenario. These results tell us that with constrained budgets such as that of the 1.5°C scenario, pathways become more difficult to differentiate, and the advantageous characteristics previously mentioned of choosing one pathway over another become more obsolete. Moreover, regardless of the pathway chosen, it is clear that stringent mitigation efforts are imperative in the first several years. This is a conclusion not unlike those presented in previous studies in the context of nations (O'Neill and Oppenheimer 2002, IPCC 2014a).

3.4.5 Limitations

3.4.5.1 Data from The Terminal

Though The Terminal contains information on publicly traded companies from all over the world, it is not exhaustive. Private companies or enterprises, by definition, are not traded on the market, and therefore do not appear in The Terminal. Given this, it may be interesting to examine private company voluntary disclosures and their estimated GHG emissions in future research. It is, however, critical to acknowledge that the company-level emissions data amassed in The Terminal are unlikely challenged by other known or accessible sources. The Terminal remains a critical, but not fully explored, source of environmental information and related data for academics.

3.4.5.2 Reporting methodologies and avenues

Given the lack of emissions disclosure at the global level, both the budgets and sectoral pathways provided are informative only in so much as they present viable options for business emissions mitigation and can only be inferred for those companies that have reported some form of Scope 1 emissions in 2015. It is without doubt that allocating sectoral budgets using the methods presented in this research is most constructive when accounting is properly verified and regulated for consistency and accuracy, and when most companies, or at the least all high-emitting companies, report their emissions. However, it is the largely non-compulsory nature of the existing corporate sustainability infrastructure (Waddock 2008) that has likely contributed to the lack of corporate emissions reporting, as well as the lack of assured authenticity.

This non-compulsory infrastructure is a product of what I perceive as a corporate paradox. Companies have outwardly opposed government regulation, yet at the same time have recognized the climate problem and supported voluntary approaches to disclosure (Jones and Levy 2008, Southworth 2009). The potential of GHG control by an authoritative infrastructure born in government legislation does not necessarily offer an ideal future for high-emitting companies. To resist such government-prescribed requirements, companies have accommodated to the pressures of climate change, all the while acting to design their own reporting infrastructure (Jones and Levy 2007). This included being heavily involved in developing the GHG Protocol, a recognized accounting tool and reporting model (Andrew and Cortese 2011). Yet, most companies in the world still do not have internal emissions accounting mechanisms in place to disclose information on their carbon emissions. It is evident that, regardless of the motives and design of carbon disclosure frameworks in the GHG Protocol and the CDP, without government interference and legislation of regulation and reporting, it will remain a difficult task to hold companies accountable for their contributions to climate change.

In addition, the issue of data authenticity is brought to light. Due to the absence of comparability as a requirement in the GHG Protocol standards, as well as the absence of verification or audit requirements, data from the CDP has been argued to be dubious (Andrew and Cortese 2011). Though comparability between companies, as well as accounting accuracy by the companies, are important qualities of data, we should not dismiss the data as unhelpful altogether. Certainly, the emissions reported by companies are not arbitrarily fabricated, and companies that are reporting have done so realizing the opportunities in proactive action. Advantages include having a more reliable energy market, boosting shareholder and investor confidence, lowering insurance costs, and preparing for eventual emissions legislation (Southworth 2009). Moreover, if little other company-level emissions data is available for use in academic research, I deem voluntarily disclosed data a good place to begin.

3.4.6 Prospects for mandatory and voluntary disclosure

At present, there are very few places in the world where companies are exposed to government legislation on GHG emissions. A few exceptions include the EU and Japan. The EU has in place the ETS, which follows a cap and trade system on emissions for companies with power plants, factories, or other installations (European Commission 2010). Japan, though it does not have a cap on emissions, requires companies emitting GHGs to follow national accounting guidelines and report their emissions (Ministry of the Environment 2012). These examples should, and can, be considered as models for legislation in other countries. Naturally, there is no one blanket solution for regulation that makes sense for every country. But, if we are to hold business accountable for their contributions to climate change, government becomes the only reliable institution – one without direct capital incentives - equipped to impose regulation of corporate emissions.

It is unclear whether the emergence of voluntary disclosure schemes is a consequence of the absence of federal legislation in most countries (Jones and Levy 2007), or whether is because of the influence that businesses may have on government authorities (Southworth 2009). If it is the former, then we might expect more swift action from governments in implementing emissions legislation. But unfortunately, if it is the latter, then we can expect more challenges in this process. Unfortunately, ties between government and business are not always transparent, and lobbying by corporate bodies might influence the stringency and effectiveness of regulation and reporting requirements. I will not delve further into vindicating such claims, but I do contend that government regulation of corporate GHG emissions reporting would bring about more reliability and consistency in company-level emissions data. It would lead to more streamlined and consistent accounting methods, verification and audits that would increase reliability and accuracy, and comparability between companies in similar industries. Implementing regulation and emissions quotas should be a principal goal for all current, if not, incoming, government parties. Yet, we must not in anticipation, delay research on company-level emissions. Rather, we must take advantage of increasing corporate transparency and for the present, rely largely on voluntarily disclosed information.

In light of absent government action and overall pressure on companies from various stakeholders to report environmental information, in the short term we can expect more widespread voluntary disclosure avenues and company emissions reporting. Despite some of the pitfalls of the current voluntary disclosure infrastructure, it is that which has increased corporate transparency, and not government-led initiatives.

3.4.7 Unlikely mitigation without accounting

Regardless of the state of disclosure avenues, it is of paramount importance that companies develop lasting capabilities of measuring their GHG emissions, and at the least, their Scope 1 emissions. Climate change mitigation is based on the premise of reducing GHG emissions in a timely manner, given that the environmental consequences of climate change are already catching up to us. Furthermore, science has determined what quantities of emissions in the atmosphere can result in disastrous climate effects, and what reductions are needed to prevent them. It follows that if companies are to be held accountable and contribute to mitigation efforts, and thus adhere to these stipulations, they must track their emissions going to the atmosphere. Without measuring GHGs emitted, companies will have nothing to compare to, and little to knowingly improve on. Then, there is even greater reason for accounting of CO_2 only emissions, rather than what many companies are doing which is aggregating different GHG emissions into one value represented in CO_2e. This was the case for companies reporting a Scope 1B or Scope 1C variable. All carbon budget estimations made in past studies can be applied to CO_2 emissions only (Rogelj *et al* 2016). If we expect companies to follow global climate goals, and thereby, global carbon budgets, then emissions accounting and reporting should give CO_2 emissions calculations priority. On the other hand, future research on emissions budgets for different GHGs would be advantageous as well.

3.5 Conclusion

In this work, I have approached climate change responsibility from a different perspective, including business in the climate change conversation and highlighting the need for corporate disclosure and guidance in a carbon constrained future. For successful global climate change mitigation, all levels of society must be included in the process. This especially means including those entities that directly contribute to climate change by emitting large quantities of GHGs, particularly CO_2, into the atmosphere. Recognizing that these actors are predominantly businesses, many of which carry out energy-intensive operations, some degree of responsibility for climate change must be accepted. With this responsibility, comes transparency and mitigation efforts; transparency in the form of consistent and accurate accounting and reporting of GHG emissions, and mitigation in the form of emissions reductions in accordance with specific global climate targets.

Broadly, I have assessed three elements of business in this work: reported company emissions, sectoral reporting patterns, and market capitalization of reporting companies, by sector. I found that sectoral reporting percentages were overall not representative of reported Scope 1M emissions and that they were also not reflective of their represented market values. I have amassed company-level GHG emissions data that has not been previously evaluated for its potential in informing us of business emissions contributions at the global scale. The results showed that a small 6.9% of the world's public companies were reporting some form of Scope 1 emissions, and that they accounted for 19% of global CO_2 emissions in 2015. I have also attempted to apply established methods for accounting emissions and allocating emissions budgets to business, using them to determine sectoral emissions budgets and future emissions pathways. In light of recent climate discussions, I have included budgets associated with both 1.5°C and 2°C global mean warming scenarios. I allocated sectoral budgets according to absolute reported emissions, a task not yet attempted in the literature. I provided three principal future emissions pathways in line with these budgets for each sector, each carrying different implications for businesses. Pathways constrained to the 1.5°C budget particularly suggest that early and stringent mitigation is preferable as near-zero emissions reductions are significantly more challenging than initial reductions. For companies that cannot afford immediate action, the logistic pathways provide flexibility in early years for reaching budget targets, but forecast rigorous emissions reductions in years approaching mid-century.

In an effort to anticipate challenges to using voluntarily disclosed company emissions data in academic research, I have identified some of limitations which stand in the way of appreciating this data. Alongside these limitations, I reassert that with time ticking on the climate clock, and unconfirmed action to come from government authorities, this type of data should be used to the greatest possible potential – not simply to track business contributions to climate change, but also to show companies that their accounting and mitigation efforts are not unrecognized, and that they do indeed have impacts on climate change.

If academics and society at large expect successful climate change mitigation in the near future, businesses must also be held accountable alongside other important actors. Moreover, if companies are looking to reap any benefits in a carbon-constricted business world, they will need to be prepared with the tools and knowledge required for accurate emissions accounting, reporting, and mitigation.

CHAPTER 4

ADDITIONAL RESULTS

4.1 Other factors contributing to company-level emissions

Just as there is a need to consider historical, political, or geographic factors when assessing national accountability for climate change, there also exist various factors for evaluating business responses to climate change beyond considering only absolute emissions. These may include, but are not limited to, location of the company – be it the headquarters or location(s) of operations –, size in regard to market value, profit, or other financial indicator representing the state of business activities, and the nature of business activities – determined by industry classification. The impact of these factors may be linked to company exposure to different social, government, industry, or economic pressures, authorities, and infrastructures (Christmann 2004, Reid and Toffel 2009, Liu and Anbumozhi 2009). Consequently, these varying exposures can impact company strategies and actions towards carbon accounting, disclosure, and mitigation action.

Though it is challenging to understand the impact of the aforementioned factors in a manner that would allow for an equitable evaluation of company commitments to battling climate change, I provide a glimpse into the potential significance of two of them: company location and size. In this chapter, I specifically aim to get a better understanding of whether the country location provides insight into the disclosure of emissions, and whether company size evaluated by market value has an impact on reported company emissions.

To represent company location, I used company country of domicile, defined as the company location of senior management (Bloomberg L.P. 2016). This is different from location of company operations, which can represent more than one location. To represent company size, I used market capitalization, defined as the market value [in USD] of a company's outstanding shares, in 2015 (Bloomberg L.P. 2016). I collected these data from The Terminal.

4.2 Additional methods

4.2.1 Is market capitalization an indicator of emissions?

To develop an understanding of the relationship between emissions and company size, I focused on four key sectors: Utilities, Energy, Materials, and Industrials. I chose to analyze these four sectors because they reported the highest emissions in 2015 compared to other sectors, and as described in their definitions, are the most energy intensive sectors.

Using R Statistical Software, I first plotted Scope 1M emissions data against market capitalization for each sector to visualize the relationship. I then used Spearman's rank and Kendall's tau correlations to measure monotonicity and test the association between market capitalization and Scope 1M emissions, at a significance level of 0.05. Both statistics are used on non-parametric data, and do not assume normality in the data. Though Kendall's tau is preferred because it is less sensitive to ties in the data as well as other discrepancies, complimentary (differentiated) results from conducting both tests could strengthen (weaken) the conclusions.

4.2.1 Is corporate reporting and company location associated?

The data on company country of domicile, as represented by the location of senior management, spans 119 different countries. The main challenge in using this data is first determining what type of country may or may not impact a company's decision to report emissions. This would require insight into, for example, a country's political and legal structures, history, or social or corporate norms. As an initial, but not conclusive step, I categorize countries into two groups: Annex 1, and Non-Annex 1 countries, as designated by the UNFCCC (2014). Annex 1 countries consist of generally developed or industrialized countries, while Non-Annex 1 countries consist of generally developing countries (UNFCCC 2014). I thereby aim to develop a better understanding of the relationship between disclosure of emissions and geographic location based on whether the company is located in a developed or developing country.

Recognizing that the dataset of public companies and their locations is a population, rather than a sample of data, I have chosen to represent the data as is, avoiding statistical manipulations. I separated the data into groups of companies located in Annex 1 and Non-Annex 1 countries, and also into groups of companies reporting and not reporting emissions. I employed the raw counts of observations in each of the categories to create contingency tables which I visualized as mosaic plots (Figure 4.3). The sizes of the mosaic tiles are proportional to the observations counted for each category.

4.3 Results

4.3.1 Descriptive findings

Table 4.1 provides a glimpse of company data in the Utilities, Energy, Materials, and Industrials sectors, showing the top 10 highest reported Scope 1M emissions, along with market capitalization and country of domicile. No single country of domicile stands out as dominating the top 10 emitting companies, save the Utilities sector where the United States is the country of domicile for 5 out of the top 10 companies. What is more evident is that Annex 1 countries dominate the top 10 of every sector. The few countries of the Non-Annex 1 group appearing Table 4.1 include Brazil, Argentina, and South Africa in the Energy sector, Mexico and India in the Materials sector, and Special Administrative Region of Hong Kong (Hong Kong) in the Industrials sector.

Non-reporting companies of high market value over $10 billion, are not predominantly in either Non-Annex 1 or Annex 1 countries (Table 4.2). This is because the two countries that appear most frequently on the lists in Table 4.2 are the United States (Annex 1) and China, including Hong Kong (Non-Annex 1). China dominates the Utilities and Industrials sector lists, while the United States dominates the Energy sector list. The few other companies from Non-Annex 1 countries in Table 4.2, each appearing only once, include Côte D'Ivoire, Malaysia, and Nigeria in the Materials sector, and India and Saudi Arabia in the Utilities sector.

Table 4.1: Top 10 companies in the Utilities, Energy, Materials, and Industrials sectors by reported Scope 1M emissions

Utilities Companies	Scope 1M Emissions ($MtCO_2e$)	Country of Domicile	Market Capitalization (USD)
RWE AG	182	Germany	$7,822,068,122
ENGIE	133	France	$42,499,857,604
AMERICAN ELECTRIC	130	United States	$28,613,634,048
DUKE ENERGY CORP	126	United States	$49,116,319,744
SOUTHERN CO	121	United States	$42,653,765,632
ENEL SPA	120	Italy	$39,767,239,759
TOKYO ELECTRIC P	108	Japan	$8,816,293,023
NRG ENERGY	106	United States	$3,698,016,768
E.ON SE	98	Germany	$18,946,884,911
AES CORP	77	United States	$6,381,360,128
Energy Companies			
GAZPROM	124	Russia	$42,878,844,656
EXXON MOBIL	121	United States	$323,960,209,408
PETROBRAS-PREF	79	Brazil	$22,065,777,407
ROYAL DUTCH SH-A	76	Netherlands	$144,116,924,416
PETROBRAS ARGT-B	72	Argentina	$1,233,048,611
SASOL LTD	62	South Africa	$17,612,061,251
CHEVRON	58	United States	$169,377,939,456
BP PLC	49	Great Britain	$95,872,319,488
TOTAL SA	44	France	$109,408,657,408
ENI SPA	43	Italy	$53,999,383,846
Materials Companies			
ARCELORMITTAL	176	Luxembourg	$7,015,733,760
LAFARGEHOLCIM-RE	165	Switzerland	$30,469,341,463
NSSMC	95	Japan	$17,339,554,493
POSCO	83	South Korea	$11,327,166,779
JFE HOLDINGS INC	59	Japan	$7,771,662,582
HEIDELBERGCEMENT	55	Germany	$15,440,849,911
US STEEL	45	United States	$1,167,322,752
CEMEX SAB-CPO	44	Mexico	$7,358,291,086
VEDANTA LTD	40	India	$4,027,461,264
SABIC	38	Saudi Arabia	$61,146,190,572
Industrials Companies			
AMERICAN AIRLINE	42	United States	$26,452,758,528
AP MOLLER-B	37	Denmark	$27,709,052,928
DELTA AIR	35	United States	$39,476,559,872
UNITED CONTINENTAL	31	United States	$20,892,102,656
DEUTSCHE LUFT-RG	28	Germany	$7,351,942,606
AIR FRANCE-KLM	28	France	$2,290,052,120
INTL CONS AIRLINE	26	Great Britain	$18,218,500,075
NIPPON YUSEN KK	26	Japan	$3,271,162,156
WASTE MANAGEMENT	19	United States	$23,865,843,712
MITSUI OSK LINES	19	Hong Kong	$2,434,652,642

Table 4.2: Companies with market value over $10 billion in 2015 not reporting Scope 1M emissions in the Utilities, Energy, and Materials sectors

Company	Country of Domicile	Market Capitalization (USD)
Utilities		
CHINA YANGTZE-A	China	$34,487,860,613
CKI HOLDINGS	Hong Kong	$23,342,674,494
PPL CORP	United States	$22,998,738,944
CHINA NATIONAL-A	China	$22,889,279,470
HONG KG CHINA GS	Hong Kong	$22,674,080,633
HUANENG POWER-H	China	$18,186,918,817
SAUDI ELECTRICIT	Saudi Arabia	$17,439,903,474
CGN POWER-H	China	$17,006,407,141
NTPC LTD	India	$16,061,548,553
ZHEJIANG ZHENE-A	China	$15,702,375,892
GD POWER DEVEL-A	China	$11,903,824,840
Energy		
PETROCHINA-H	China	$222,238,181,065
SINOPEC CORP-H	China	$88,465,051,202
ENTERPRISE PRODU	United States	$51,481,104,384
CHINA SHENHUA-H	China	$43,394,493,180
KINDER MORGAN IN	United States	$33,260,019,712
COAL INDIA LTD	India	$27,878,122,988
ENERGY TRANSF PA	United States	$19,787,595,776
PIONEER NATURAL	United States	$18,729,265,152
WILLIAMS PARTNER	United States	$16,802,741,248
SINOPEC OILFIE-A	China	$15,697,357,778
MAGELLAN MIDSTREAM	United States	$15,446,841,344
ENERGY TRANSFER	United States	$14,384,727,040
TENARIS SA	Luxembourg	$14,091,631,616
NATIONAL OILWELL VAR	United States	$12,584,363,008
CONCHO RESOURCES	United States	$11,991,752,704
MPLX LP	United States	$11,956,320,256
Materials		
CROWN SIEM	Côte d'Ivoire	$46,458,667,995
LYONDELLBASELL-A	United States	$38,249,041,920
NORILSK NICKEL	Russia	$19,718,131,712
INNER MONGOLIA-AA	China	$18,118,575,757
DANGOTE CEMENT	Nigeria	$14,535,304,519
BAOSHAN IRON	China	$14,126,778,114
ANHUI CONCH-H	China	$14,038,866,434
PCHEM	Malaysia	$13,512,070,093
NUCOR	United States	$12,813,869,056
VULCAN MATERIALS	United States	$12,647,345,152
TRANSFAR-A	China	$11,826,055,455
Industrials*		
CKH HOLDINGS	Hong Kong	$52,092,536,096
CITIC	Hong Kong	$51,498,483,186
CRRC CORP LTD	China	$50,796,939,479
GENERAL DYNAMICS	United States	$42,991,931,392
CHINA RAIL GR-H	China	$34,567,913,024
CHINA STATE-A	China	$29,317,918,923
CHINA COM CONS-H	China	$28,806,707,833
CHINA SHIPBUIL-A	China	$26,604,955,896
CHINA RAIL CN-H	China	$26,476,497,763
SH INTL PORT	China	$23,146,882,664
RYANAIR HOLDINGS	Ireland	$20,800,197,851

* Shows companies valued over $20 billion USD only.

4.3.1 Correlations between market capitalization and emissions

A commonality found among the four sectors (Figure 4.1) is the clustering of points near low market capitalization and low Scope 1M emissions, followed by a dispersal of data points with increasing market capitalization and Scope 1M emissions. A linear relationship cannot be visually inferred from any of the sectors, but a weakly positive monotonic relationship in each is plausible. The Utilities sector (Figure 4.1a) appears to have the greatest dispersal of data points and the least discernable pattern, while the data points in the Energy sector (Figure 4.1c) show a more confined pattern.

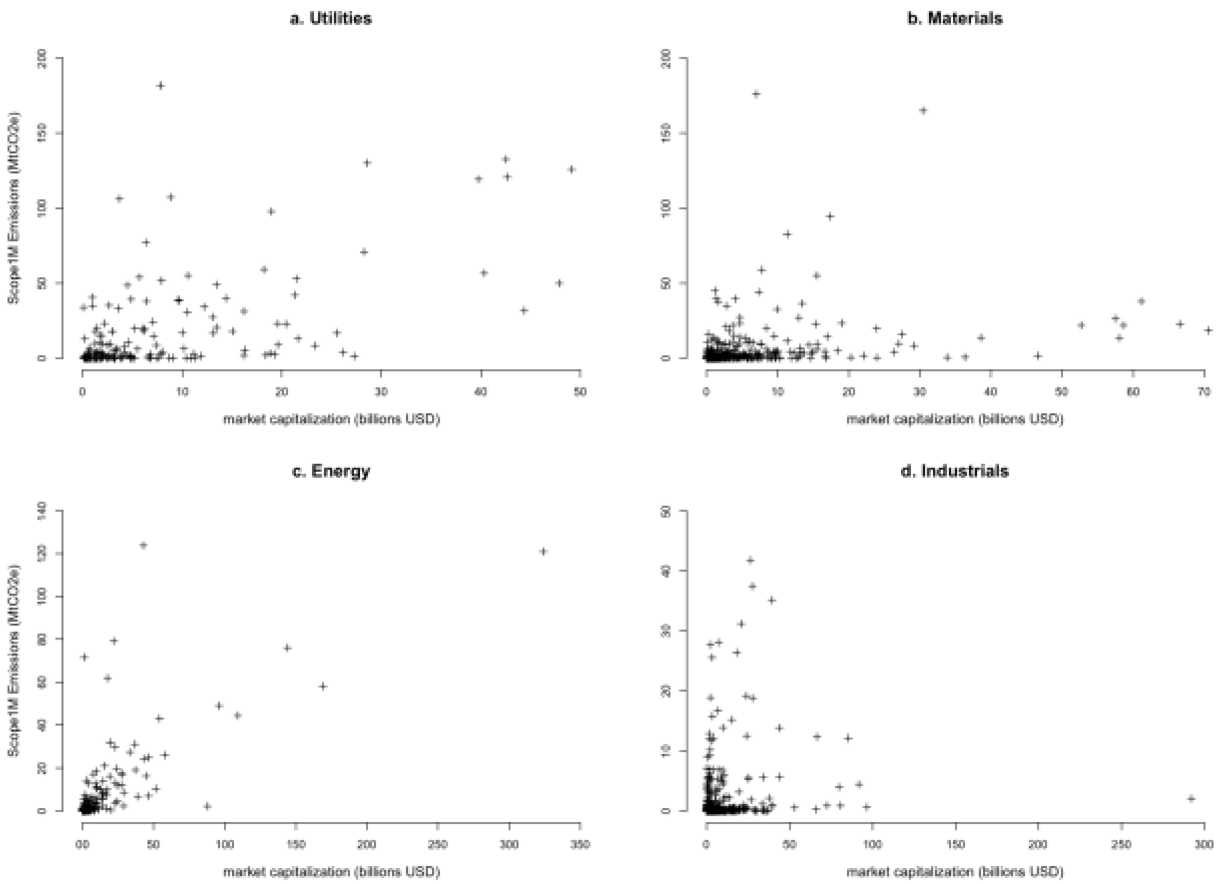

Figure 4.1 Market capitalization (billions USD) vs. Scope 1M emissions of companies in the Utilities (a), Materials (b), Energy (c), and Industrials (d) sectors in 2015

The results of calculating two correlation coefficients, Spearman's rho (ρ) and Kendall's tau (τ), confirm positive monotonicity in the data in all four sectors (Table 4.3) Spearman's ρ indicates a strong correlation between market capitalization and Scope 1M emissions in the Energy sector, followed by the Utilities and Materials sectors with moderate correlations, and the Industrials sector with a weak correlation. All correlations were found to be statistically significant ($p<0.05$).

The Kendall τ coefficients follow a similar order of correlation strengths to those results of the Spearman ρ coefficients: the Industrials sector has the weakest correlation, and the Energy sector has the strongest correlation. However, the $\tau < \rho$ for each sector and thus the correlations calculated using τ indicate overall weaker correlations than those interpreted from the Spearman ρ coefficients.

Sector	Spearman Rank p-value	Spearman Rho Coefficient (ρ)	Kendall Tau p-value	Kendall Tau Coefficient (τ)
Utilities	1.87E-13	0.5189815	1.45E-12	0.3603402
Materials	2.20E-16	0.5110109	2.20E-16	0.3652102
Energy	2.20E-16	0.7411598	2.20E-16	0.5401918
Industrials	2.20E-16	0.3924914	2.20E-16	0.270871

Table 4.3: Spearman Rank and Kendall Tau testing results for market capitalization vs. emissions

Due to the large number of data points, it is difficult to discern patterns, especially at the clustering occurring at the lower end of the Scope 1M emissions and market capitalization ranges (Figure 4.1) To better discern the data in this area, I have presented the same plots as in Figure 4.1, but magnified to display the data at these lower ranges (Figure 4.2). The results show even greater dispersal of data points in all four sectors. A positive monotonic pattern becomes even less discernable for the Utilities, Materials, and Industrials sector, while the Energy sector holds some of this pattern.

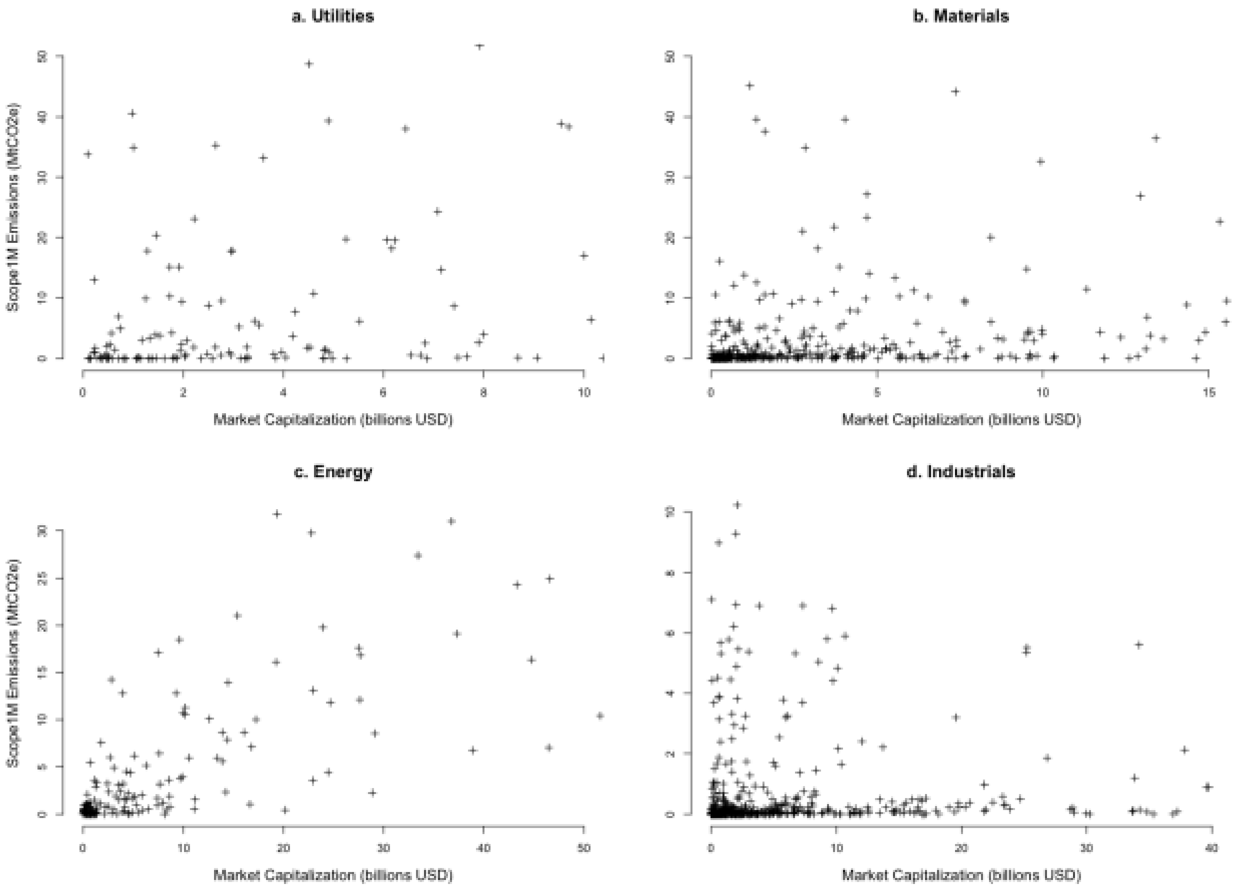

Figure 4.2: Low-end of market capitalization (billions USD) vs. low-end of Scope 1M emissions of companies in the Utilities (a), Materials (b), Energy (c), and Industrials (d) sectors in 2015

4.3.2 Company reporting in Annex 1 and Non-Annex 1 countries

Figure 4.3 shows mosaic plots depicting the frequencies of companies either reporting emissions (green tiles) or not reporting emissions (blue tiles) in Annex 1 and Non-Annex 1 countries. What is immediately evident are the very small proportions of companies reporting Scope 1M emissions across sectors. Common among the sectors is that the majority of reporting companies are located in Annex 1 countries. However, the majority of non-reporting companies in the Industrials, Materials, and Utilities sectors are located in Non-Annex 1 countries. The exception is the Energy sector, with the only case of a majority of non-reporting companies located in Annex 1 countries. It is important to note, however, that the Energy sector has an overwhelming majority of companies located in Annex 1 countries, whereas the split between Annex 1 and Non-Annex 1 countries in the other sectors is approximately equal. As a result, we also see a large difference between the number of non-reporting companies in Annex 1 versus Non-Annex 1 countries in the Energy sector.

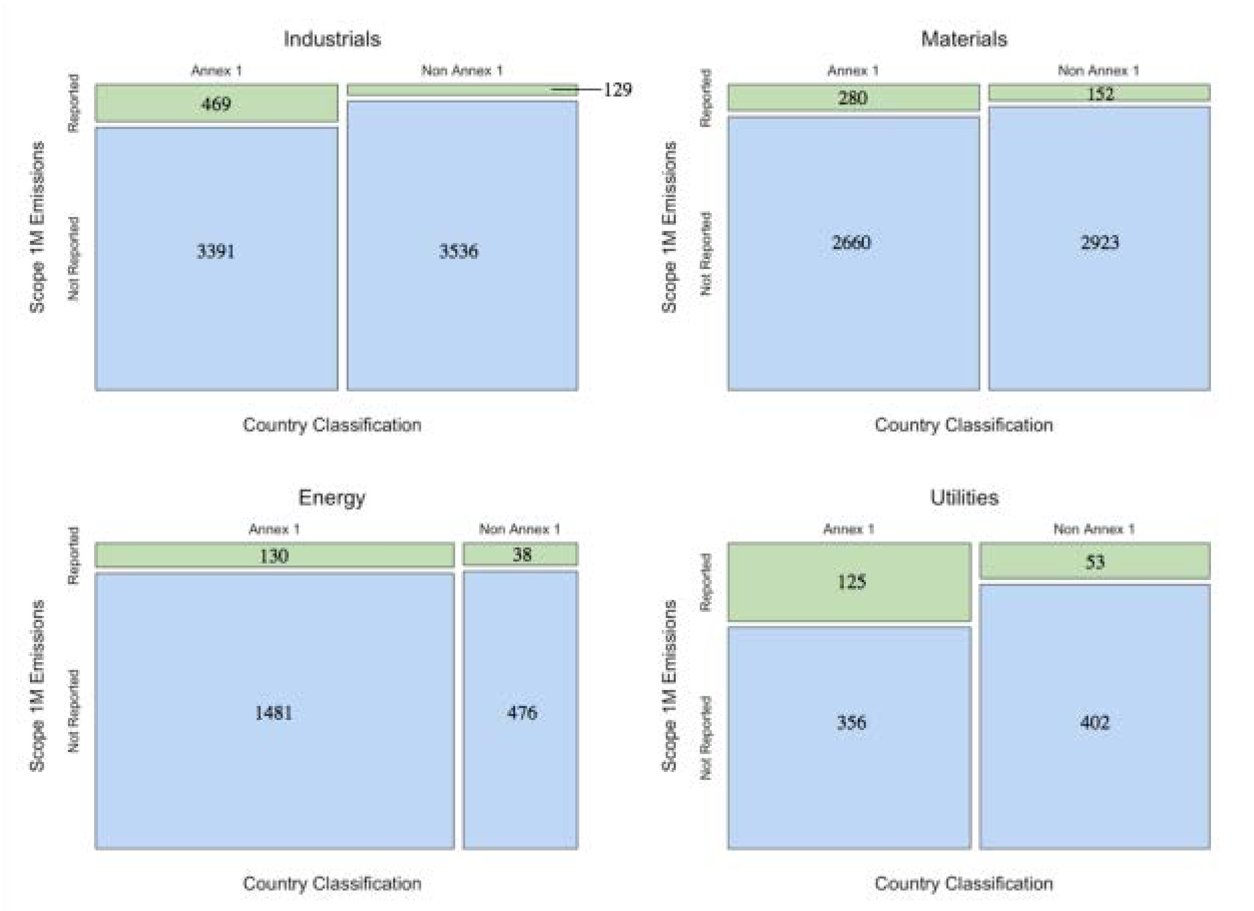

Figure 4.3: Mosaic plots showing the relationship between the status of emissions reporting and Annex 1 or Non-Annex 1 country classification of companies in the Industrials, Materials, Energy and Utilities sectors

4.4 Discussion

4.4.1 Emissions uncertainty with varied market value at the sectoral level

Although only conclusions of correlation, not causation, can be made of the relationship between market capitalization and Scope 1M emissions, there are notable differences when comparing the data between sectors. The higher density of data points in all four plots (Figure 4.1) near the low end of the ranges in market capitalization and Scope 1M emissions may indicate that companies that have low market value (relative to the range of market values of other companies in their associated sectors), are more likely to report lower emissions. This appears more true for the Energy sector, than the Utilities, Materials, or Industrials sectors. Furthermore, it appears as company market capitalization increases, companies are more likely to differ widely in reported emissions. This brings up other important questions regarding the influence of market capitalization on reported emissions: Do companies with similar high[10] market values encounter less limitations to reducing their emissions? And if so, are some companies doing significantly more to reduce their emissions than others? It would not be irrational to suppose that some companies with the capabilities to mitigate emissions, have simply chosen not to do so (Frumhoff *et al* 2015).

Though an overall positive relationship may be judged for each sector when considering Figure 4.1, Figure 4.2 does not easily allow for any statements to be made about the relationships. The dispersal of data points in the Utilities, Materials, and Industrials sectors are widespread, and while the data points for the Energy sector are also scattered, there is a clearer sustained positive monotonic relationship. The uncertainty in the patterns may be attributed to the industry classification level chosen for the analysis. Analyzing company data at the sectoral level may be too broad to allow for the identification of any patterns. Instead, analysis at lower classification levels, such as sub-industry, may provide different results. In lower classifications, greater similarities can be found among companies in regards to business activities and structures. For example, the Utilities sector includes companies producing electricity using fossil fuels, nuclear, and renewable sources. Clearly, the emissions reported by a renewable electricity producer

[10] Relative to the market capitalization of other companies in its respective sector.

would be conceivably much less than that of a non-renewable electricity producer. This company distinctions are made only at the sub-industry level. Therefore, using lower industry classifications in the analysis may allow for determining more precise relationships between market capitalization and reported emissions.

The statistical results confirming that relatively weak correlations exist between market capitalization and emissions (Table 4.3) could be helped if more companies were reporting their emissions, especially those with high market values. Though Spearman's rank shows stronger correlations than those of Kendall's tau, τ is the preferable measurement as it deals with ties more appropriately than ρ (Gilpin 1993). It is otherwise unsurprising that $\tau < \rho$ since ρ is typically about 1.5 times larger than τ (Gilpin 1993). However, conducting non-parametric statistics on distribution-free data remains a less powerful tool than using parametric statistics. Spearman's rank and Kendall's tau correlations are computed by ranking the data, so inevitably some information about the differences between values are lost. To improve the statistical results in this thesis, it would thus be of high value in the future to investigate methods for using parametric statistics on presently available company emissions data in the future.

Yet, if the correlation statistics presented in Table 4.3 reflect reality, then it can be estimated that companies with large market value, that are not currently reporting, are also emitting at larger quantities than those with smaller market value. This reasoning should be further explored in future research, with more comprehensive company-level emissions data where possible. Moreover, it would be of interest to conduct similar evaluations of the data (i.e. producing scatter plots, conducting tests for correlations) on lower GICS industry classifications, such as industry group or sub-industry.

4.4.2 Majority of reporting companies in Annex 1 countries in three sectors

I chose to use country of domicile as an independent variable because the location of senior management is where important corporate decisions are made, including those decisions having to do with where business operations, and consequently emissions, will occur (if not already in the country of domicile). The location of senior management is important in the context of emissions reporting practices, as some countries may be exposed to different reporting practices (i.e. whether or not reporting of emissions is a norm or regulation). Furthermore, though company emissions are also influenced by the stringency of rules or laws in the countries where the company is operating, the decision to operate in these countries is presumably made in the country of domicile.

A major finding was that out of the four sectors analyzed, three showed an approximately equal distribution of companies located in Annex 1 and Non-annex 1 countries: the Utilities, Materials, and Industrials sectors (Figure 4.3). This is important because it allows for a more reliable analysis of the proportions of companies reporting and not reporting. In these three sectors, the majority of reporting companies were located in Annex 1 countries. This finding may shed light on the corporate practices and norms present in developed countries versus developing countries. If reporting is more common in developed countries, we can infer that businesses are exposed to different, perhaps stronger, pressures to account for and disclose emissions information. This also highlights the greater acceptance of climate change accountability at the business level in developed countries. Though the results do not provide information about mitigation efforts, the fact that companies are engaging in emissions disclosure is a sign that there is a recognition of their climate change contributions, and is thus a step towards mitigation.

The Energy sector yields interesting results in that it is the only sector with a majority of companies located in Annex 1 countries. Moreover, the majority of these companies in Annex 1 countries are not reporting emissions. Recalling the definition of the Energy sector (Appendix A: Table A.1), this sector includes companies engaged in exploration, production, refining, marketing, storage and transportation of fossil fuels. Thus, it is conceivable that operations of a company in the Energy sector are likely carried out in more than one country. In fact, Heede (2014) found that a substantial amount of emissions embedded in fossil fuels have been extracted in Non-Annex 1 countries. In addition, my results show that a majority of companies engaging in the extraction of fossil fuels (i.e. those in the Energy sector) have senior management located in Annex 1 countries. Though emissions accounting does not take an extraction-based approach as Heede (2014) as done, but rather a production-based approach, direct emissions resulting from the exploration, extraction, and production of fossil fuels should be accounted for. On the whole, these findings question the motives and activities of those Energy companies with senior management in Annex 1 countries who are also not reporting their emissions.

While Heede (2014) argued that Non-Annex 1 countries, which host much of fossil fuel production, should carry an obligation to mitigate, I argue that companies that are carrying out these operations should also carry this obligation. With that, comes the recognition that most of these fossil fuel production companies are headquartered in developed countries.

The emissions reporting practices of the Energy sector are controlled primarily by companies in developed nations, and I encourage further analyses of the peculiarities of this sector's accounting and reporting activities.

CHAPTER 5

CONCLUSIONS

We are at a time when climate change action is essential, and focusing and debating for too long on where to place blame may thwart mitigation itself. What is clear is that GHG emissions are a direct cause of anthropogenic climate change, and there is an immediate need to decrease these emissions. I have shown that past efforts to identify climate change contributors, discuss responsibility, and allocate mitigation efforts have largely focused on nations as the relevant actors. In an effort to open conversations on an alternative, but also relevant, actor in climate change, I have identified the business world as a dominant contributor of direct GHG emissions. Businesses must be included in future discussions and research on climate change mitigation. They must be held accountable by way of not only committing to transparency and accounting of emissions, but also carrying out emissions reductions. Though accepting a sense of responsibility for their contributions to climate change is a constructive step, remaining accountable is even more essential. This is why I have attempted, in this research, to align global climate targets with what should be associated business targets.

Plenty of research has been conducted on the existence and effectiveness of corporate disclosure avenues, accounting methods, and management of GHG emissions (Sullivan 2009, Waddock 2008, Southworth 2009, Andrew and Cortese 2011, Haslam *et al* 2014), but a straightforward application of company emissions data to climate change mitigation research is yet to be carried out. I have attempted to fill this void by studying company-level absolute emissions at a global scale, and I have incorporated global climate targets into business futures.

In using this voluntarily disclosed company-level data, I have uncovered interesting results about business reporting patterns and about reported emissions quantities themselves. An alarming finding was the overall low rate of emissions reporting across the globe, wherein 9 of 11 sectors were reporting percentages of under 8%. Recognizing the necessity of accounting for emissions in the process of long-term mitigation, it is striking that this condition is not even close to being fulfilled. Furthermore, it was remarkable to find that only a few thousand of the world's public companies (7%) already accounted for almost a fifth of global CO_2 emissions in 2015. This was explained in part by the finding that these companies made up over 50% of global market share, indicating that some of the largest companies in the world are responsible for 19% of global emissions. This fifth of global emissions was found to be composed mostly of emissions reported from four energy-intensive sectors: Utilities, Materials, Energy, and Industrials.

I have used established methods for allocating emissions mitigation efforts among nations to explain analogous methods that have, or can, be used for businesses and sectors. Using one of these methods, the grandfathering approach, I allocated 1.5°C and 2°C global carbon budgets to business sectors, which resulted in larger budgets for sectors that reported larger emissions. This may present an unfair advantage to certain companies, but I believe that it is the most realistic approach strictly in terms of reaching mitigation targets. Though the grandfathering approach has been criticized for its lack of ethical considerations (Neumayer 2000, Caney 2009), I have pointed to the fact that these arguments were founded in the national context, and not the business context. It would, however, be beneficial for future studies to further examine the applicability of past ethical or normative arguments against the grandfathering approach in the business context.

I provided three distinct emissions pathways for each sector, and described their different implications: a constant and simple mitigation pathway (linear), an initially stringent but eventually accommodating pathway (exponential), and an initially accommodating but potentially risky pathway for reaching near-zero emissions (logistic). These pathways were more constrained when adjusted for a smaller 1.5°C budget, than when adjusted for a larger 2°C budget. In the case of the linear pathway, reaching zero emissions according to the 1.5°C budget occur 46 years before that of the 2°C budget. This reiterates the importance of urgent and rigorous emissions reductions, for any sector, especially if we are aiming to remain *below* a rise of 2°C in global average temperature. The 1.5°C to 2°C budget ranges are meant to show other, more climate-ideal business emissions scenarios, rather than simply targeting the highest possible emissions in the range. As previously stipulated, these budgets and pathways are informative only in so much as they are relevant to the 7% of public companies reporting globally. Despite this limitation, the effort to create corporate emissions budgets in line with global climate goals, along with the initiative to provide business emissions pathways according to voluntarily reported data, has not been attempted in the literature.

I have supported my findings with considerations of other factors that potentially influence company emissions, and emissions disclosure. I explored the associations between emissions and company size, to find that there were overall weak positive correlations between market capitalization and reported emissions. It is somewhat unsurprising that the larger a company's value is, the greater it's emissions may be. However, more clear correlations might be found with analysis of company data at lower industry classifications. Emissions data from more companies, as well as higher quality data, would also help to produce more confident conclusions.

I also investigated the potential impact of company location on reported emissions. Non-reporting companies were located predominantly in developing countries (Non-Annex 1), suggesting that reporting norms or pressures may be different than those in developed countries. The exception of the Energy sector also suggests that analyses at lower industry classifications may be helpful for discerning clearer associations between company location and reporting. Other research avenues may also include investigating the effects of other variables representing company size and location, or other variables altogether.

The approach I took to allocating carbon budgets and providing future mitigation pathways to sectors is applicable down to the company level. The sectoral level analyses are insightful, but in reality, would be most beneficial if company emissions reporting was: 1) widespread, and 2) verified for reliability. Unfortunately, governments are unlikely to demand emissions reporting, nor impose auditing measures for accounting, which could otherwise assure that emissions reporting becomes widespread and reliable. This is why corporate voluntary disclosure, as our only choice of source information on company-level emissions, must be improved upon.

Overall, I hope that my research has called attention to the role of business in contributing to climate change, as well as the importance of business accountability. This work highlighted the need for corporate transparency in the form of emissions accounting and disclosure. The capacity to account for and disclose environmental information on a yearly basis appears minimal when compared to the long-term planning required to implement mitigation initiatives. It comes down to a simple deduction: that without proper emissions accounting, there can be no effective and long-lasting mitigation. Accordingly, it also stressed the need for mitigation commitments specifically associated with greater global climate targets – targets that must trickle down further than the organizational boundaries of national governments if we are to expect effective and urgent mitigation measures.

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APPENDIX A

TABLES

Table A.1: GICS Sector definitions (MSCI Inc. 2017)

Sector	Definition
Energy	Comprises companies engaged in exploration and production, refining and marketing, and storage and transportation of oil and gas and coal and consumable fuels. It also includes companies that offer oil and gas equipment and services.
Materials	Includes companies that manufacture chemicals, construction materials, glass, paper, forest products and related packaging products, and metals, minerals and mining companies, including producers of steel.
Industrials	Includes manufacturers and distributors of capital goods such as aerospace and defense, building products, electrical equipment and machinery and companies that offer construction and engineering services. It also includes providers of commercial and professional services including printing, environmental and facilities services, office services and supplies, security and alarm services, human resource and employment services, research and consulting services. It also includes companies that provide transportation services.
Consumer Discretionary	Encompasses those businesses that tend to be the most sensitive to economic cycles. Its manufacturing segment includes automotive, household durable goods, leisure equipment and textiles and apparel. The services segment includes hotels, restaurants and other leisure facilities, media production and services, and consumer retailing and services.
Consumer Staples	Comprises companies whose businesses are less sensitive to economic cycles. It includes manufacturers and distributors of food, beverages and tobacco and producers of non-durable household goods and personal products. It also includes food and drug retailing companies as well as hypermarkets and consumer super centers.
Health Care	Includes health care providers and services, companies that manufacture and distribute health care equipment and supplies and health care technology companies. It also includes companies involved in the research, development, production and marketing of pharmaceuticals and biotechnology products.
Financials	Contains companies involved in banking, thrifts and mortgage finance, specialized finance, consumer finance, asset management and custody banks, investment banking and brokerage and insurance. This Sector also includes real estate companies and REITs.
Information Technology	Comprises companies that offer software and information technology services, manufacturers and distributors of technology hardware and equipment such as communications equipment, cellular phones, computers and peripherals, electronic equipment and related instruments and semiconductors.
Telecommunication Services	Contains companies that provide communications services primarily through a fixed-line, cellular or wireless, high bandwidth and/or fiber optic cable network.
Utilities	Comprises utility companies such as electric, gas and water utilities. It also includes independent power producers and energy traders and companies that engage in generation and distribution of electricity using renewable sources.

Table A.2: Definitions for emissions variables, sourced from The Terminal (Bloomberg L.P. 2016)

Emissions Variable	**Definition**
Scope 1 Activity Emissions Globally	Scope 1 Activity Emissions Globally Total global amount of scope 1 emissions emitted by the company, measured in millions of metric tons of carbon dioxide equivalent ($mtCO_2e$). Scope 1 emissions are direct GHG (greenhouse gas) emissions from sources that are owned or operated by the company. Sources include combustion facilities, company owned or operated transportation, and physical or chemical processes. This field is sourced directly from the company's response to the Carbon Disclosure Project (CDP) questionnaire.
Scope 1/Direct GHG Emissions	Scope 1/Direct Greenhouse Gas (GHG) Emissions of the company, in thousands of metric tons. GHG are defined as those gases which contribute to the trapping of heat in the Earth's atmosphere and they include Carbon Dioxide (CO_2), Methane, and Nitrous Oxide. Scope 1 Emissions are those emitted from sources that are owned or controlled by the reporting entity. Examples of Direct Emissions include emissions from combustion in owned or controlled boilers, furnaces, vehicles, emissions from chemical production in owned or controlled process equipment. Emissions reported as CO_2 only will NOT be captured in this field. Emissions reported as generic GHG emissions or CO_2- equivalents (CO_2e) will be captured in this field. Field is part of the Environmental, Social and Governance (ESG) group of fields.
Direct CO_2 Emissions	Direct Carbon Dioxide (CO_2) Emissions of the company, in thousands of metric tons. Direct Emissions are those emitted from sources that are owned or controlled by the reporting entity. Examples of Direct Emissions include emissions from combustion in owned or controlled boilers, furnaces, vehicles, and emissions from chemical production in owned or controlled process equipment. Emissions expressed as generic Greenhouse Gas emissions or CO_2-equivalents (CO_2e) will not be captured in this field. Field is part of the Environmental, Social and Governance (ESG) group of fields.

Table A.3: Sector Shapiro-Wilks and Anderson-Darling tests for normality and Wilcoxon Signed Rank test results

Sector	Dataset	Appears normally distributed?	Shapiro-Wilks Test	Anderson-Darling Test	Wilcoxon Signed Rank Test
Consumer Discretionary	Scope 1B (Bloomberg)	No	W = 0.2254, p-value < 2.2e-16	A = 76.5056, p-value < 2.2e-16	V = 9903 p-value = 0.1330
	Scope 1C (CDP)	No	W = 0.2637, p-value < 2.2e-16	A = 86.7312, p-value < 2.2e-16	
Consumer Staples	Scope 1B (Bloomberg)	No	W = 0.5243, p-value < 2.2e-16	A = 22.5787, p-value < 2.2e-16	V = 2609 p-value = 0.1864
	Scope 1C (CDP)	No	W = 0.3867, p-value < 2.2e-16	A = 31.8747, p-value < 2.2e-16	
Energy	Scope 1B (Bloomberg)	No	W = 0.5773, p-value < 2.2e-16	A = 17.6846, p-value < 2.2e-16	V = 2210 p-value = 0.6447
	Scope 1C (CDP)	No	W = 0.4799, p-value < 2.2e-16	A = 24.2478, p-value < 2.2e-16	
Financials	Scope 1B (Bloomberg)	No	W = 0.0604, p-value < 2.2e-16	A = 83.145, p-value < 2.2e-16	V = 8223 p-value = 0.8093
	Scope 1C (CDP)	No	W = 0.0458, p-value < 2.2e-16	A = 117.2326, p-value < 2.2e-16	
Health Care	Scope 1B (Bloomberg)	No	W = 0.3172, p-value < 2.2e-16	A = 18.5646, p-value < 2.2e-16	V = 974 p-value = 0.9888
	Scope 1C (CDP)	No	W = 0.3249, p-value < 2.2e-16	A = 24.1521, p-value < 2.2e-16	
Industrials	Scope 1B (Bloomberg)	No	W = 0.3534, p-value < 2.2e-16	A = 89.6163, p-value < 2.2e-16	V = 15972.5 p-value = 0.8037
	Scope 1C (CDP)	No	W = 0.3388, p-value < 2.2e-16	A = 121.8799, p-value < 2.2e-16	
Information Technology	Scope 1B (Bloomberg)	No	W = 0.076, p-value < 2.2e-16	A = 75.3568, p-value < 2.2e-16	V = 6262 p-value = 0.2611
	Scope 1C (CDP)	No	W = 0.0481, p-value < 2.2e-16	A = 91.9876, p-value < 2.2e-16	
Materials	Scope 1B (Bloomberg)	No	W = 0.3039, p-value < 2.2e-16	A = 61.8195, p-value < 2.2e-16	V = 7772 p-value = 0.2261
	Scope 1C (CDP)	No	W = 0.3791, p-value < 2.2e-16	A = 59.3748, p-value < 2.2e-16	
Real Estate	Scope 1B (Bloomberg)	No	W = 0.0901, p-value < 2.2e-16	A = 37.3995, p-value < 2.2e-16	V = 1068 p-value = 0.6838
	Scope 1C (CDP)	No	W = 0.0927, p-value < 2.2e-16	A = 35.9819, p-value < 2.2e-16	
Telecommunication Services	Scope 1B (Bloomberg)	No	W = 0.5357, p-value < 2.2e-16	A = 9.6061, p-value < 2.2e-16	V = 548 p-value = 0.5437
	Scope 1C (CDP)	No	W = 0.2557, p-value < 2.2e-16	A = 15.6509, p-value < 2.2e-16	
Utilities	Scope 1B (Bloomberg)	No	W = 0.5899, p-value < 2.2e-16	A = 17.3683, p-value < 2.2e-16	V = 1737 p-value = 0.4551
	Scope 1C (CDP)	No	W = 0.6374, p-value < 2.2e-16	A = 18.3892, p-value < 2.2e-16	

Table A.4: Sector and Industry Group statistics: number of companies, Scope 1M Emissions, estimated CO_2 proportions, and CO_2-only estimates

Sector	Industry Group	Number of Companies	Total Scope 1M Emissions ($mtCO_2e$)	Estimated CO_2 Proportion	Estimated CO2-only emissions ($mtCO_2$)
Energy		2125	1469.79	0.878	1289.93
	Energy	2125	1469.79	0.878	1289.93
Materials		6015	2098.09	0.891	1869.91
	Materials	6015	2098.09	0.891	1869.91
Industrials		7523	804.85	0.925	745.49
	Capital Goods	5252	150.09	0.889	133.37
	Commercial & Professional Services	1242	67.84	0.954	64.69
	Transportation	1029	586.92	0.933	547.43
Consumer Discretionary		7052	104.64	0.945	101.60
	Automobiles & Components	869	46.43	0.979	45.46
	Consumer Durables & Apparel	2272	7.87	0.927	7.30
	Consumer Services	1491	43.46	0.985	42.80
	Media	1066	1.67	0.994	1.66
	Retailing	1354	5.23	0.840	4.39
Consumer Staples		2920	118.16	0.843	100.12
	Food & Staples Retailing	405	30.23	0.753	22.77
	Food, Beverage & Tobacco	2108	75.42	0.876	66.08
	Household & Personal Products	407	12.51	0.901	11.26
Health Care		3263	18.24	0.793	14.05
	Health Care Equipment & Services	1317	2.33	0.822	1.91
	Pharmaceuticals, Biotechnology & Life Sciences	1946	15.91	0.763	12.14
Financials		4989	35.20	0.862	29.95
	Banks	1785	20.46	0.872	17.84
	Diversified Financials	2547	13.20	0.813	10.73
	Insurance	657	1.54	0.900	1.39
Information Technology		5883	178.81	0.816	145.10
	Software & Services	2739	2.30	0.861	1.98
	Technology Hardware & Equipment	2329	136.60	0.825	112.75
	Semiconductors & Semiconductor Equipment	815	39.91	0.761	30.37
Telecommunic-ation Services		420	12.08	0.917	11.08
	Telecommunication Services	420	12.08	0.917	11.08
Utilities		936	2967.05	0.862	2557.41
	Utilities	936	2967.05	0.862	2557.41
Real Estate		2630	21.48	0.754	16.20
	Real Estate	2630	21.48	0.754	16.20
Sector Total		43756	7828.40	0.873	6880.84

Table A.5: Sectoral allocated budgets and pathway equations for the 2°C and 1.5°C scenarios

Sector	Allocated budget ($MtCO_2$)	Linear pathway *f(t)*	Exponential pathway *f(t)*	Logistic Pathway *f(t)*
		2°C Scenario		
Consumer Discretionary	3905	-102/77t+102	$102(0.97)^t$	$102/(1+0.023e^{0.1t})$
Consumer Staples	3848	-100/77t+100	$100(0.97)^t$	$100/(1+0.023e^{0.1t})$
Energy	49572	-1290/77t+1290	$1290(0.97)^t$	$1290/(1+0.023e^{0.1t})$
Financials	1151	-30/77t+30	$30(0.97)^t$	$30/(1+0.023e^{0.1t})$
Healthcare	540	-14/77t+14	$14(0.97)^t$	$14/(1+0.023e^{0.1t})$
Industrials	28649	-745/77t+745	$745(0.97)^t$	$745/(1+0.023e^{0.1t})$
Information Technology	5576	-145/77t+145	$145(0.97)^t$	$145/(1+0.023e^{0.1t})$
Materials	71860	-1870/77t+1870	$1870(0.97)^t$	$1870/(1+0.023e^{0.1t})$
Real Estate	622	-16/77t+16	$16(0.97)^t$	$16/(1+0.023e^{0.1t})$
Telecommunication Services	426	-11/77t+11	$11(0.97)^t$	$11/(1+0.023e^{0.1t})$
Utilities	98281	-2557/77t+2557	$2557(0.97)^t$	$2557/(1+0.023e^{0.1t})$
		1.5°C Scenario		
Consumer Discretionary	1490	-102/31t+102	$102(0.934)^t$	$102/(1+0.031e^{0.24t})$
Consumer Staples	1468	-100/31t+100	$100(0.934)^t$	$100/(1+0.031e^{0.24t})$
Energy	18916	-1290/31t+1290	$1290(0.934)^t$	$1290/(1+0.031e^{0.24t})$
Financials	439	-30/31t+30	$30(0.934)^t$	$30/(1+0.031e^{0.24t})$
Healthcare	206	-14/31t+14	$14(0.934)^t$	$14/(1+0.031e^{0.24t})$
Industrials	10932	-745/31t+745	$745(0.934)^t$	$745/(1+0.031e^{0.24t})$
Information Technology	2128	-145/31t+145	$145(0.934)^t$	$145/(1+0.031e^{0.24t})$
Materials	27421	-1870/31t+1870	$1870(0.934)^t$	$1870/(1+0.031e^{0.24t})$
Real Estate	237	-16/31t+16	$16(0.934)^t$	$16/(1+0.031e^{0.24t})$
Telecommunication Services	162	-11/31t+11	$11(0.934)^t$	$11/(1+0.031e^{0.24t})$
Utilities	37503	-2557/31t+2557	$2557(0.934)^t$	$2557/(1+0.031e^{0.24t})$

APPENDIX B

EQUATIONS

For calculating percentage differences between reported Scope 1M emissions and CO2-only estimates I used Equation B.1:

$$\% \, difference = \frac{ME_S - CE_S}{(ME_S - CE_S)/2} \times 100\% \tag{B.1}$$

where ME_S is the total Scope 1M emissions in a sector, and CE_S is the CO2-only emissions estimate in a sector.

In the logistic equation (3.7),

$$f(t) = \frac{A}{1 + Be^{-kt}}$$

k must be prescribed in order to determine *B,* and thus find a suitable equation to represent the logistic pathway. As indicated by Goshu and Koya (2013), the inflection point, *a*, is at the point where $f''(t) < 0$ and $f''(t) > 0$ on either side of the point. Goshu and Koya (2013) showed that,

$$f'(t) = kf(t)[1 - \frac{f(t)}{A}] \tag{B.2}$$

and,

$$f(a) = A/2 \tag{B.3}$$

So substituting Equation B.2 into Equation B.3 I found that,

$$\frac{f'(a)}{f(a)} = \frac{k}{2} \tag{B.4}$$

Recall that $f(t)$ is presented in $MtCO_2$/year and represents an annual rate of emissions, while $f'(t)$ is $MtCO_2$/year^2, and represents the change in the rate of annual emissions. As the inflection point is defined as the point of maximum growth/decay of the function, $\frac{f\prime(a)}{f(a)}$ will thus give a maximum proportion of the rate of change (annual emissions) of the function. This can be translated to a percentage change in annual emissions. To demonstrate the use of Equation B.4, I will provide the example of a prescribing a maximum percentage decrease in emissions [at the inflection point] of 5%:

$$-\frac{5\%}{100\%} = \frac{k}{2} \tag{B.5}$$

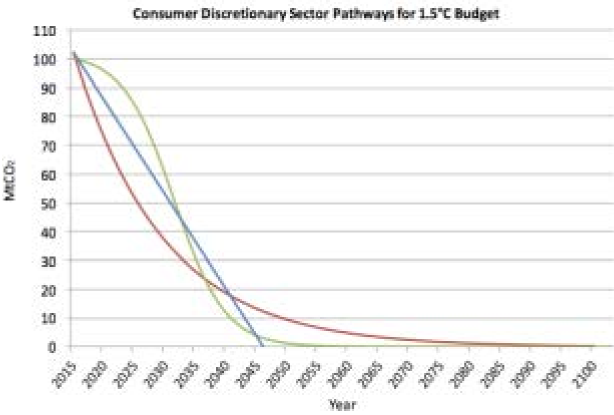
and solving for *k* in Equation B.5 gives us 0.1.

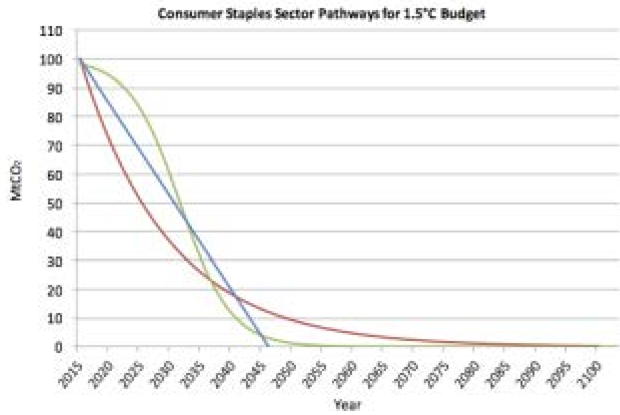
For the 2°C budget, the logistic pathways for all sectors were prescribed a maximum percentage decrease in emissions to be 5%, while for the 1.5°C budget, the prescribed amount was 12% (resulting in a *k* value of 0.24). As the 2°C budget is larger, the prescribed maximum percentage decrease in emissions is much lower than that of the 1.5°C budget. Though presented in a broader context of emissions mitigation going beyond just businesses, reduction rates above 5% already appear to be considered high, and are accompanied by fundamental and rapid structural changes (Riahi *et al* 2015). A reduction of 12% in one year, I deduct, would be nearly unattainable without major infrastructural changes. Yet, the constricting budget of the 1.5°C scenario does not allow for leisurely mitigation efforts.

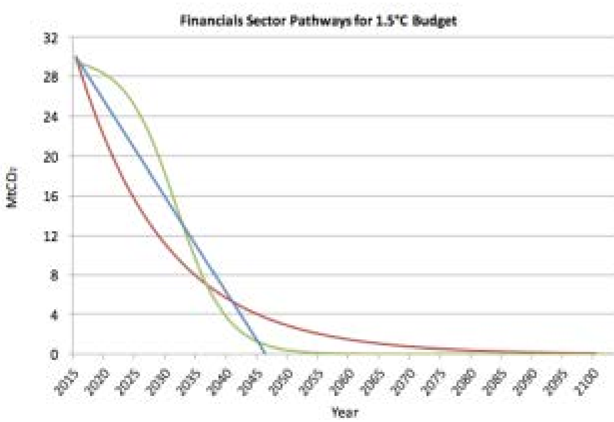
APPENDIX C

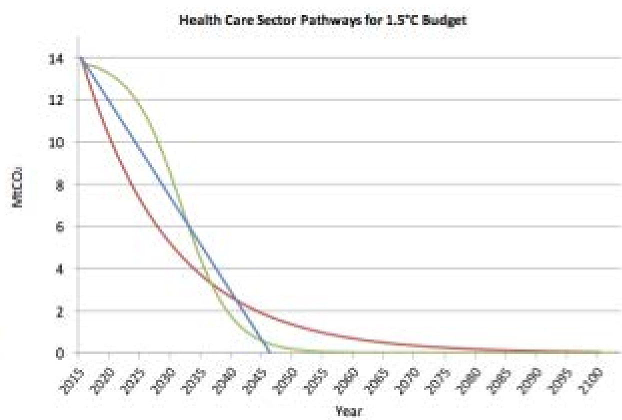
SECTORAL EMISSIONS PATHWAYS

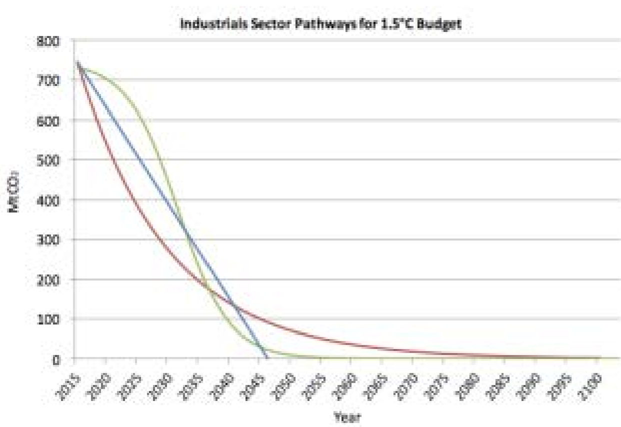
Figures C.1-C.9: Sectoral emissions pathways for the 1.5°C budget

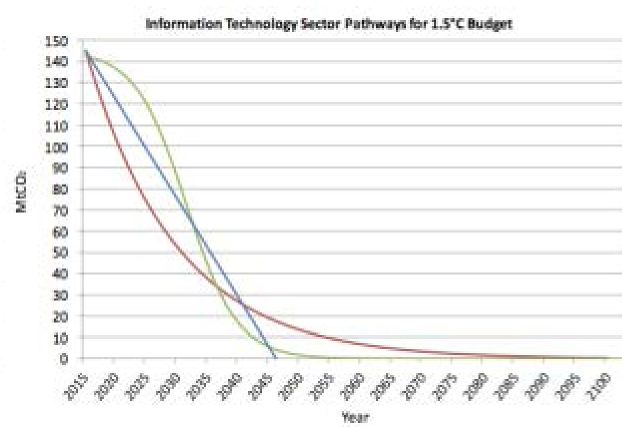


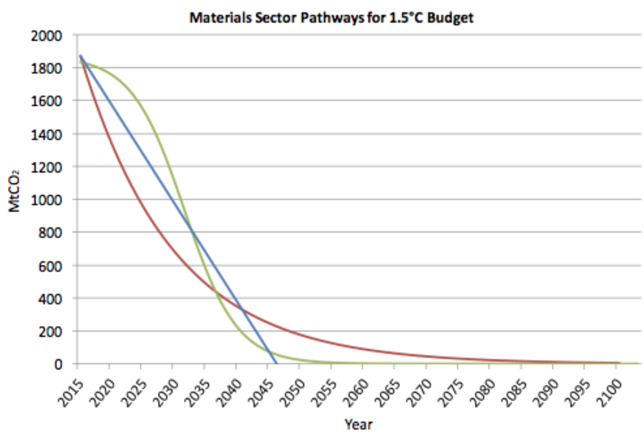


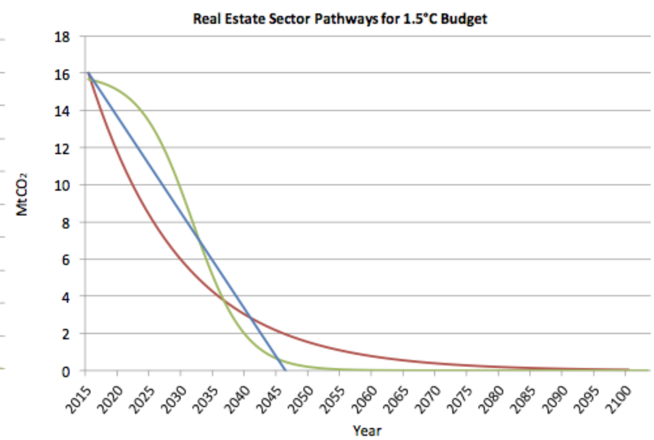


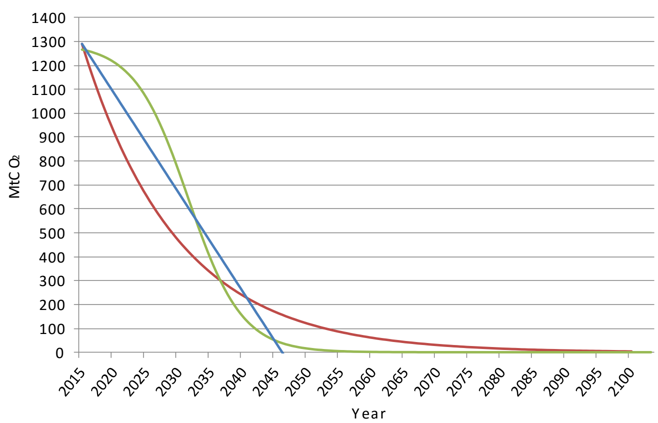




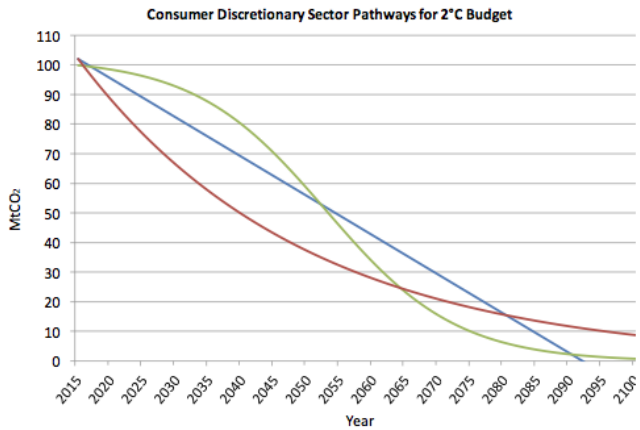


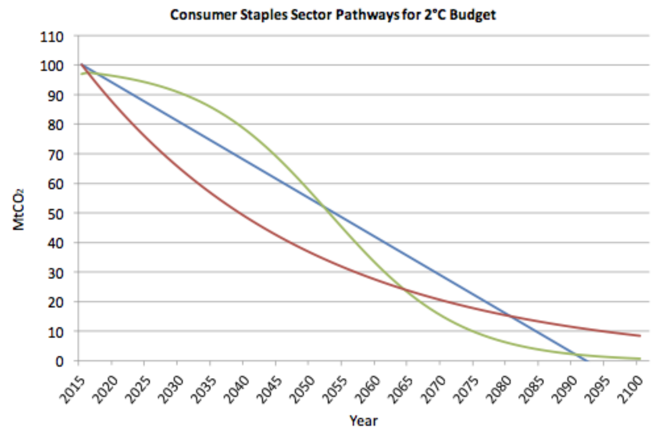

Materials Sector Pathways for 1.5°C Budget
MtCO2
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Year

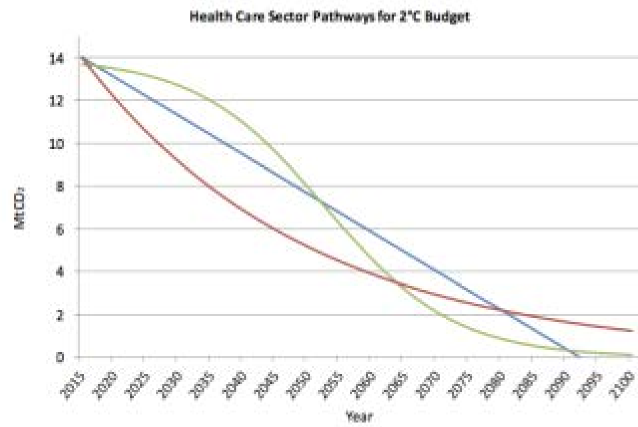

Real Estate Sector Pathways for 1.5°C Budget
MtCO2
18
16
14
12
10
8
6
4
2
0
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Year

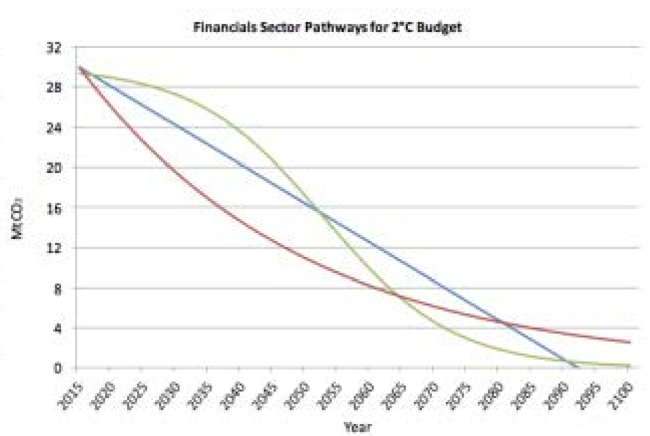

MtC O2
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
Year

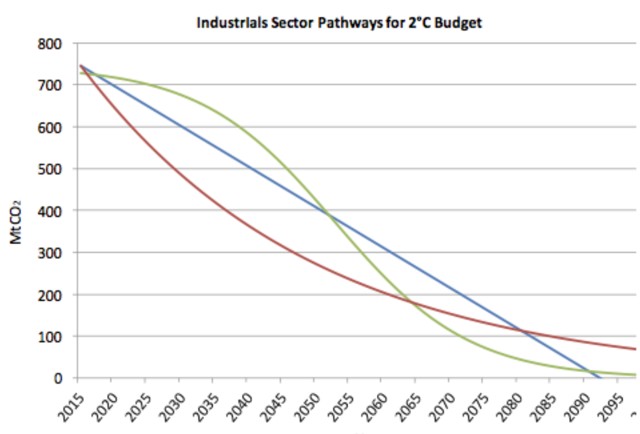
Figures C.2-C.18: Sectoral emissions pathways for the 2°C budget

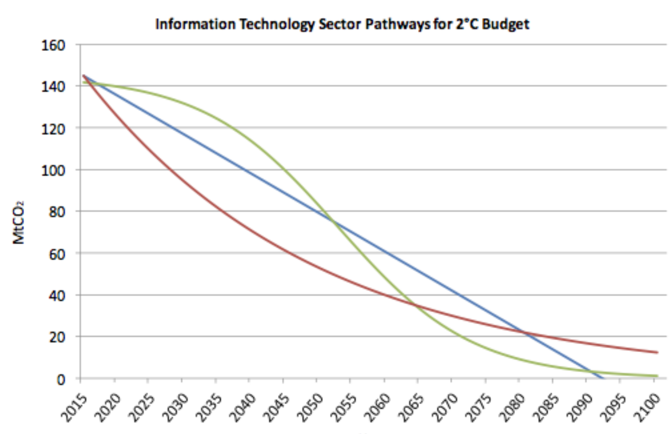


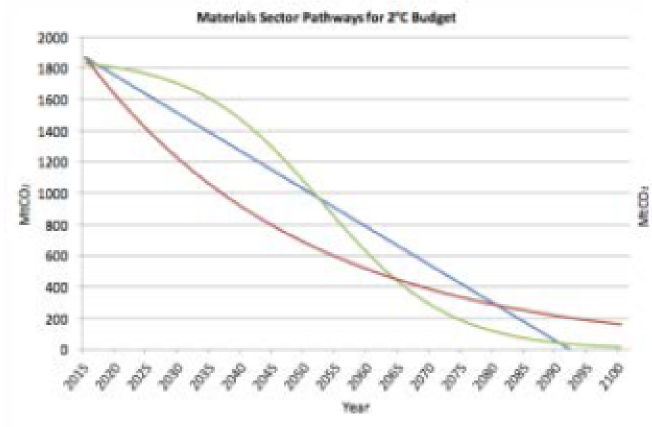


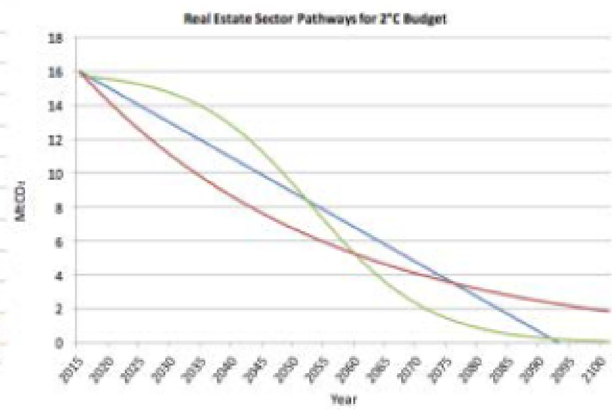









Materials Sector Pathways for 2°C Budget
MtCO₂
Year


Real Estate Sector Pathways for 2°C Budget
MtCO₂
Year