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Investment Innovations Toward Achieving Net Zero: Voices of Influence

Brian Bruce, Editor

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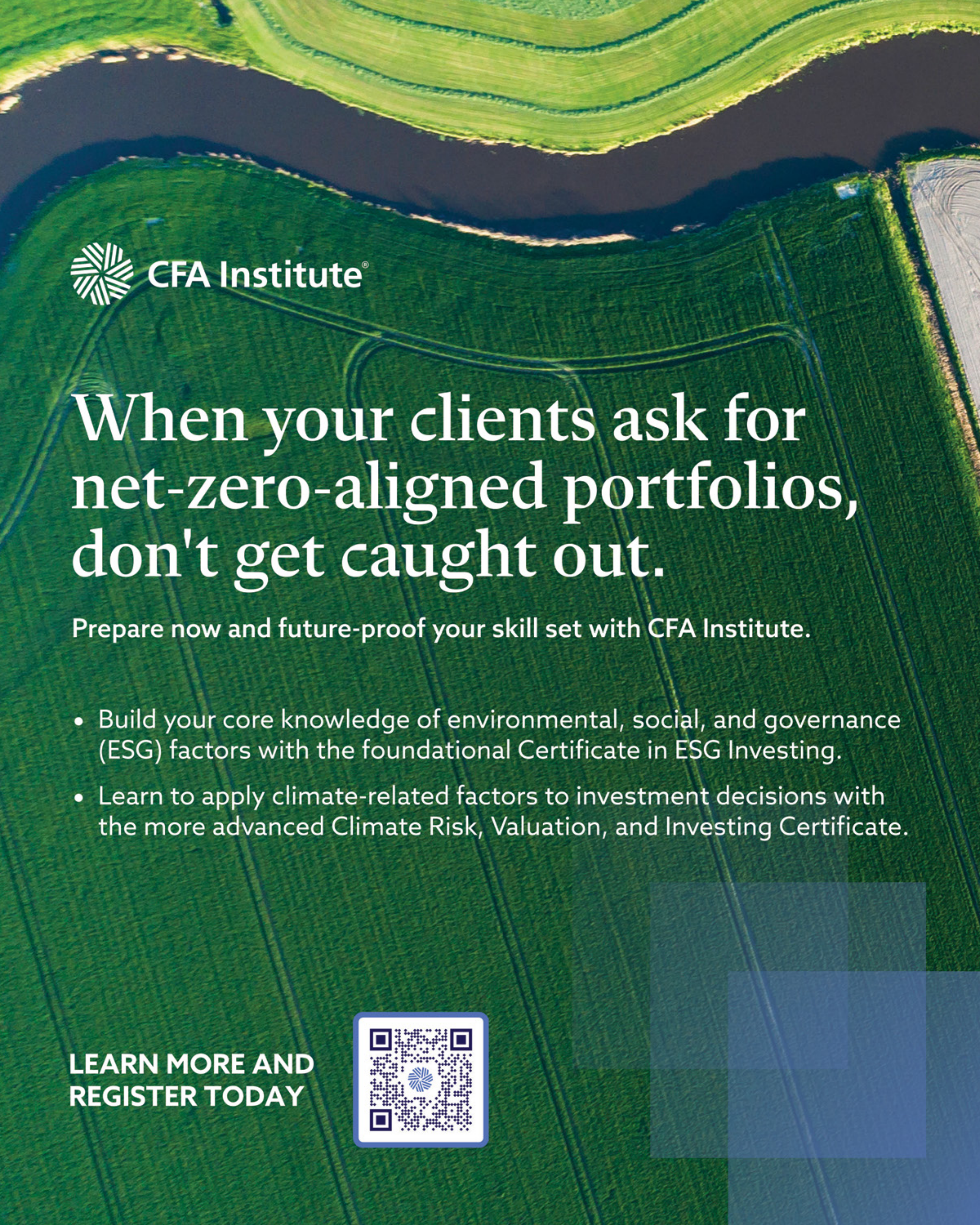
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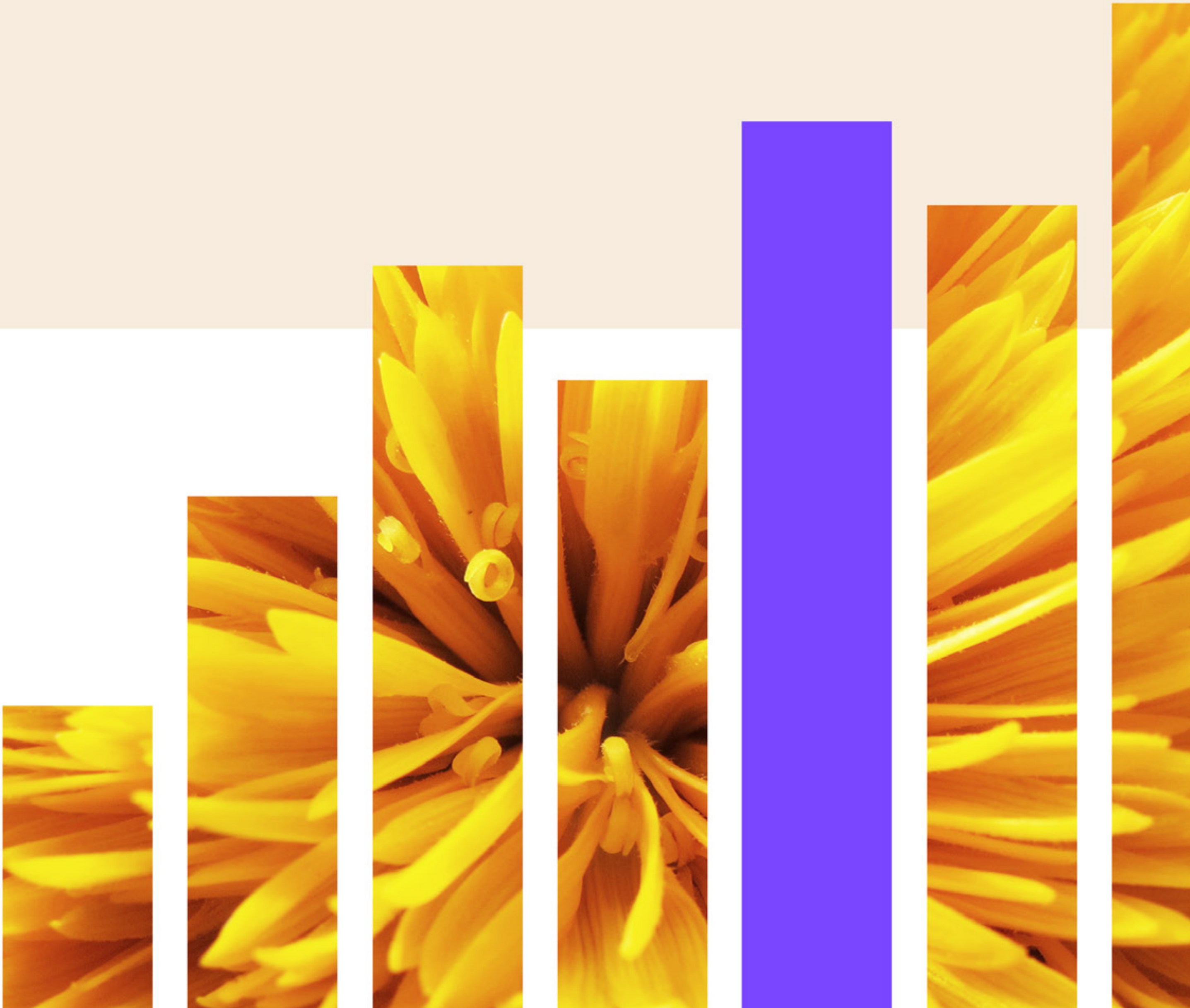

EDITOR'S LETTER

Brian Bruce
Chair of the Board of Directors, The Center for Investment Research,
Plano, Texas

The global journey toward achieving net zero by 2050 is one of the most significant challenges and opportunities of our time. This guide, *Investment Innovations Toward Achieving Net Zero: Voices of Influence*, brings together more than 50 thought leaders, researchers, and practitioners around the globe to explore the innovative strategies and tools shaping the financial industry's role in this critical transition. In three parts—Strategy, Tactics, and Case Studies—the collection offers a comprehensive roadmap for investors, asset managers, policymakers, and academics.

This guide reflects the financial industry's critical role in addressing climate change, presenting actionable insights and pioneering approaches for a net-zero future. We hope these contributions inspire collaboration and innovation across the investment community.

Brian Bruce, Editor

In collaboration with the authors in this guide, CFA Institute Research and Policy Center published a variety of tools to make the research more accessible. Through article landing pages on our research hub, CFA Institute members may access slides with key takeaways and *In Practice* companion features that present the research in digestible formats. Short author videos highlighting practical applications of the research are publicly available via the following QR Code.

Hear from Our Net-Zero Voices of Influence

PERSPECTIVE

NET ZERO: A FRAMEWORK FOR INVESTORS

Robert F. Engle
Professor Emeritus of Finance, Co-Director, Volatility and Risk Institute, Leonard N. Stern School of Business, New York University, New York City

The Essential Science of Climate Change

Science has shown us that if the energy coming to the earth is greater than the energy escaping from the earth, the planet's temperature will rise. The layer of greenhouse gases (GHGs) around the earth is now trapping heat that previously (in the last million years) would have been emitted back into space.

The rapid increase in CO_2 and other GHGs has resulted from the rate at which we humans burn fossil fuels. These fuels were created over countless millennia by plants, which converted the sun's energy into organic molecules that then were stored in the earth and sea. By burning these fuels, we release both the energy and the carbon that have been lying dormant.

As the planet warms, glaciers melt, sea levels rise, weather patterns change, and droughts and floods occur in different locations and intensities. These changes, unprecedented since humans first inhabited the earth, have occurred through other causes in the millions of years before. The fossil records show us that there were times when many species became extinct, water covered much of the land we now live on, and temperatures were much higher than today.

The planet will probably survive what we are doing to it. But we may not.

Long-Term Risk

A risk is a bad event that might occur, and a long-term risk is a bad event that might happen far in the future. Climate change is full of long-term risks—excessive heat, drought, storms, wildfires, floods, and sea-level rise. Clearly, uncertainty exists about the timing, location, and impact of these events—hence the term "climate risk"!

These are physical risks. We also face transition risks in response to policies that aim to mitigate climate change. Transition risks are even more uncertain than physical risks because they depend on the political process.

Suppose we decide to stop emitting carbon into the atmosphere. What would happen? Governments and companies would scramble to purchase solar panels, wind turbines, and maybe nuclear reactors to generate power. Fossil fuel–based energy companies would be forced to either adopt new technologies or cease operating. The winners would be deluged with capital from investors, while the losers would see their stock prices head toward zero. This outcome is an example of transition—clearly a risk for some companies and an opportunity for others.

Physical risk and transition risk often move together. With scientific evidence that the climate is warming faster than previously expected, both the physical risk of extreme weather and the transition risk of rapid decarbonization will rise. Other events, however, move these two risks in opposite directions. For instance, news that climate mitigation policies have been put in place will reduce physical risks but increase transition risk. Similarly, news that mitigation policies are canceled will increase physical risks.

How Can We Reduce Climate Risk?

Almost 10 years ago, most of the world's nations signed an agreement in Paris that committed them to make their economies emit no net emissions (net zero) by 2050. This commitment reflects a landmark shift from using the price of carbon as a target to using the quantity of emissions as a target. Countries can choose their own approach to reaching net zero.

Scientific research assures us that if the planet entirely achieves net zero by 2050, we will avoid the worst damages of global warming. Commitment to achieve net-zero emissions means that negative-emission strategies can potentially be used to offset positive emissions. The agreement is not binding, however, except as public pressure can enforce it or domestic legal actions can police performance.

Governments can choose among four broad types of policies to reach emission targets such as net zero:

- **Tax carbon emissions.** An example is cap-and-trade markets for emission certificates, such as the European Union Emissions Trading System (EU ETS).
- **Subsidize renewable energy and decarbonization.** Examples include electric vehicle subsidies and carbon capture and sequestration research in the United States, as part of the Inflation Reduction Act.
- **Regulate emissions.** Two examples of regulation are automobile emission standards and building code insulation requirements.
- **Hope.** Some would describe this approach as "do nothing." The hope, however, is that the private sector—including consumers, employees, investors, and corporations—will voluntarily adopt greener behavior. Although economists typically are pessimistic that hope will be sufficient to achieve net-zero targets, the idea surely has some promise.

A theoretical analysis of these policies by Acharya, Engle, and Wang (2025) finds justification for such a range of policies. The well-understood cause of climate change is the emission externality. A company that emits GHGs pays nothing for the emissions, but the whole world suffers damages. Conversely, if this company were to stop emitting, it would have to pay for some type of decarbonization but the rest of the world would receive the benefits. Whenever the beneficiaries of a project are not the ones paying for it, government intervention is needed to achieve the best outcome. An emission tax is the natural policy, as first pointed out by Pigou more than a century ago (see, e.g., Nicholson and Snyder 2016).

Acharya Johnson, Sundaresan, and Tomunen (2024) then propose that a second externality exists: green innovation. When one company reduces its emissions intensity by carrying out a green innovation, then the technology for doing so becomes cheaper for everyone else. Again, the company paying for the innovation is not getting all the benefit, and a government action would be needed to achieve the best outcome. In this case, a green innovation subsidy would be the natural policy.

When both of these externalities are put into the same model, it then becomes socially optimal to have both an emission tax and a green innovation subsidy. When countries for some reason cannot do both, the remaining policy can achieve only a second-best outcome. For example, a country that cannot subsidize green innovation will find that decarbonization is more expensive than in the optimal case and therefore will need to set a higher tax on emissions to get the same outcome.

Not only have countries committed to net-zero targets, but states, regions, cities, sectors, and firms also have voluntarily committed to net zero. Why do they do this? Presumably these entities and organizations believe that such commitments will encourage customers to buy their products, employees to work for them, and investors to own their stocks. This is the set of mechanisms that could make the "hope" strategy work. It requires good intentions by its members and suffers if too many are free riders (i.e., members who do not adopt greener behaviors but benefit from a better climate anyway).

Even if no one will voluntarily change their behavior toward green causes, however, incentives may exist for large firms, industries, states, or other coalitions to commit to net zero. Acharya et al. (2025) explore these as a game theory strategy called "Stackelberg leader." The idea is that a large firm may choose to decarbonize and commit to net-zero targets purely for profit and can succeed because of the externalities. By investing in green technology, the firm lowers the cost of decarbonizing for other firms and therefore reduces not only its own emissions but also emissions from others. In this way, the country can more easily reach its net-zero targets without imposing such a high carbon tax. If the benefit from lower carbon taxes is greater than the cost of decarbonization, then the Stackelberg leader will have raised its profitability and justified its strategy.

A similar argument can be suggested for states, regions, cities, and sectors, and many examples demonstrate the effect. The larger the coalition, the more likely that it will be a successful Stackelberg leader.

The Market Response to Climate Risks

Asset prices are influenced by long-run risks and rewards. An asset exposed to long-run risk is less desirable than one that is not, all else being equal. Stocks exposed to climate risk trade at lower prices and higher expected return than similar stocks without these risks. This dynamic is important because these asset prices guide investment today. The cost of capital is greater for firms exposed to climate risk. If you think long-run risks do not matter, compare the P/E of 59 for shares of Tesla Inc. with the P/E of 5 for shares of General Motors Company.

In a series of papers, Bolton and Kacperczyk (2021, 2023) have shown that returns on stocks with high or rising emissions are greater on average than returns on other stocks after controlling for firm characteristics. Engle, Giglio, Kelly, Lee, and Stroebel (2020) and De Nard, Engle, and Kelly (2024) point out that when there is news that the climate is getting worse than the market expects, these stocks will fall in value as their risk increases. This relationship between climate news and stock returns of high emission firms provides a basis for forming and testing climate-sensitive portfolios.

Climate hedge portfolios are designed to outperform conventional market portfolios if climate risk rises more than the market expects and to underperform otherwise. They typically are formed by identifying firms that are exposed to climate risk and underweighting them relative to firms that are prepared for climate risk and may even profit from it. Such a portfolio is called a hedge portfolio because it reduces the exposure to climate and should lower the long-run variance of any conventional portfolio to which it is added.

A climate hedge portfolio is thus a risk-reducing portfolio because rising risk will be associated with outperformance. Naturally, a risk-reducing portfolio should have negative expected returns and, just like an insurance policy, should cost something. This dynamic is a consequence of underweighting stocks highly exposed to climate risk, which are earning a risk premium, and overweighting assets with low climate risk premiums. As mentioned earlier, however, when there is news that climate risk is rising, these portfolios should outperform.

Climate hedge portfolios are useful investment vehicles for investors who want to reduce their climate risk or for investors who believe that the climate will ultimately be worse than the market expects. Climate risk portfolios are short climate hedge portfolios and consequently have positive expected returns, which are compensation for bearing climate risk. Climate change deniers might find such portfolios attractive.

Climate hedge portfolios can be constructed by performing either fundamental analysis or statistical analysis. Fundamental analysis is based on firm characteristics that are available from balance sheet data, ESG data, or other measures. This analysis often formulates the risk that is to be hedged and then creates both portfolios that are highly exposed and portfolios that are negatively exposed or at least unexposed. The hedge portfolio is short or underweight the former and long or overweight the latter. In contrast, the statistical approach focuses on evidence from climate news events. It takes a short or underweight position in assets that fall with adverse climate news and overweights or takes a long position in those that rise with such climate news.

Some Examples of Climate Hedge Portfolios

Suppose the risk being hedged is the demise of the coal industry. In this case, a hedge portfolio would naturally be short coal and related stocks and could be long a broad market index. The Volatility and Risk Institute (VRI) has used a specific version of this portfolio, proposed by Robert Litterman, for several years. The portfolio is short 70% of a coal exchange-traded fund (ETF) and 30% of the broad energy ETF called XLE, and it is long the S&P 500 ETF called SPY. This portfolio is labeled as the stranded asset portfolio in VRI research and on V-Lab.[1]

If the risk to be hedged is a carbon tax, however, then the biggest GHG emitters are likely to be most exposed. Thus a hedge portfolio can be short an emission-weighted collection of stocks hedged by SPY. Similar arguments can be made for policies that subsidize clean energy or that regulate emissions or emission intensities.

Similar approaches can be used for physical risk by recognizing that most physical risks are location specific. Heat is an exception, and Acharya et al. (2024) have a suggestion for how to measure this. Location-specific physical risk factors have been created from REITs and from property insurers, as described in Jung, Engle, Ge, and Zeng (2023).

The statistical approach to forming climate hedges can be implemented by looking at the behavior of individual stocks or by looking at publicly available funds with a sustainability mandate. De Nard, Engle, and Kelly (2024) document this strategy: They regress the daily return of each of about 200 funds on standard risk factors and a measure of climate news. The coefficient on the news is allowed to change over time, and the firms with the largest or most significant climate news betas are good candidates for hedges in the future. This implementation creates a long-only hedge portfolio, designed to have out-of-sample minimum variance and maximum correlation with climate news.

[1]https://vlab.stern.nyu.edu/climate.

How Investors and Risk Managers Can Use Hedge Portfolios

Climate hedge portfolios are constructed to be investable and can be useful additions to portfolios of investors who do not want to be overly exposed to climate risk or who believe that the climate will be worse than the market expects. These investors may similarly be interested in holding stocks or funds that are correlated with the climate hedge portfolios, because such investments should deliver the same benefits.

To measure these betas, V-Lab regresses the return on sustainable funds on standard risk factors and climate hedge portfolios. The betas on the hedge portfolios, posted on V-Lab, can be sorted to see which funds have the best response to hedge portfolios. To see the results for today, click on "Security Climate Betas"[2] and scroll down to the security tabulation.

Risk managers and regulators are particularly interested in whether financial institutions' returns are correlated with climate risks. If increases in climate risk portfolios (decreases in climate hedges) correlate with bank stocks, then the financial institution is likely exposed to climate risk. The bigger the beta, the bigger the exposure.

This relationship leads naturally to stress tests by considering extreme but plausible increases in climate risk. This approach measures the change in stock price under stress, which can be interpreted as a fall in market capitalization. The dollar value of this decline, called marginal CRISK, is a measure of how many dollars the assets of the institution will lose if climate risk rises. The capital adequacy of a firm under stress can also be estimated. Assuming a standard operating leverage, the capital shortfall of a financial institution after a climate event is now measurable, and this metric is posted on V-Lab with updates every week.[3] These measures—shown for the whole world, for countries, and for individual financial institutions—serve as monitors of climate exposure.

The analyses in this section focus on long-run climate risks. Over time, some of these risks may be realized. For example, when a carbon tax is implemented, the risk becomes a reality and markets reprice financial assets. In fact, often policies may be in place but not yet fully operational and can be considered as realizations for some purposes.

If transitional policies have been put in place and no further policies are contemplated, then there may no longer be any transition risk to price or hedge. Portfolio selection can then be conducted using standard analyses, such as Markowitz mean–variance analysis or other, more recent factor or risk budgeting approaches. The stock prices of companies that were facing transition risk

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[2]See https://vlab.stern.nyu.edu/climate.

[3]Go to https://vlab.stern.nyu.edu/climate/CLIM.WORLDFIN-MR.CMES.

will already have fallen and can now be held based on their expected future performance. Of course, there could still be further climate news and pressure for additional transition policies, so an argument to maintain climate hedges could be made.

Termination Risk

A particular form of long-run risk, relevant for analyzing climate risk, is called termination risk. It is the risk faced by a company that its business will be unable to continue at some uncertain point in the future. This is called a risk because it might happen or it might not. The following discussion first considers how a firm facing termination risk should be managed and then examines how it is relevant to climate risk.

To focus on the management issues, consider managing a luxury beachfront hotel that will likely be destroyed by sea-level rise at some point in the future. Although a natural strategy might be to sell the hotel, any potential buyers will also understand these risks. A second strategy is to reconsider any long-run investments, such as expanding or upgrading the hotel. If the payback period for such investments is long relative to the likely termination date, then these investments are unlikely to be wise. Even routine maintenance may not be appropriate from a financial standpoint. The net effect of this strategy will be reduced costs and higher net income for a shorter time. This policy will reduce the supply of luxury rooms, and if competitors follow the same logic, prices are likely to rise further, increasing income.

Will equity investors be willing to invest in the hotel? Yes, because it still has cash flow. Finance theory says the stock should be worth the present discounted value of the cash flow until termination minus a risk adjustment. Over time, the market cap will decline as termination approaches, and this decline will happen through big dividends and cash buybacks so that investors can receive a risk premium even as the market cap falls.

The relation between the stock price and cash flow is particularly significant. Because termination may come in the immediate future, the P/E is likely to be low. Further, the book value of the hotel is likely to be far below the market value, so P/B is typically low. Bond investors will also be willing to invest in the hotel but may require a big spread to lend beyond the expected termination date.

With large cash inflows, the manager may be tempted to develop other businesses that could continue after termination. Unless the new businesses have substantial synergies with the existing hotel business, however, such an approach would likely affect the stock price negatively. Investors would prefer to have the cash than have the manager invest it for them. In other words, the investors can diversify their own holdings without the manager doing it for them.

In this setting, we might expect to see consolidation of the hotels in a neighborhood. If some hotels independently lower prices to gain market share, then a price war may make all of them worse off, and they will still be facing termination. If one hotel buys another, then it can better manage the decline and access monopoly rents. This approach does not expand the business, and if the capital comes from equity, then it need not be diversified by the manager.

The features of the beachfront hotel are closely related to the features of a typical fossil energy company. If the Paris Agreement targets are met, such an energy company will be out of business by 2050 and possibly before. If they are not met, the business may continue but may still ultimately be terminated. We already have seen dramatic declines in the market cap and output of coal firms, static demand for oil, and rising demand for natural gas. Some of these dynamics, however, have been driven by the Ukraine war and may decline when it ends and as renewable energy continues to rise. We see low P/E and P/B ratios for fossil energy and higher bond spreads when the energy sector is under stress. Consolidation is active, with mergers of oil companies and frackers. Physical measures of investment such as drilling rigs are down.

Assuming that this description captures key features of the fossil energy markets, we should expect to see energy stocks rise when demand for energy rises and also when environmental regulations and laws are relaxed so that termination appears to be farther in the future. These same factors make climate hedge portfolios and sustainable funds underperform. Nevertheless, termination risk suggests that decarbonization is in the long-run plans of fossil energy firms. Higher energy prices, although bad for consumers and for inflation, are actually good for the environment. They encourage consumers to reduce consumption of fossil energy products and hence their GHG emissions.

Termination Risk for Countries

Countries also face termination risk when their largest industry is fossil energy. Many countries face this risk, and their solutions differ widely. For instance, Saudi Arabia and other Middle East Gulf Cooperation Council nations face the possibility that their most profitable business may terminate. In preparation, these countries are actively following strategies to diversify their economies by investing in tourism and luxury airlines, in sports franchises and events such as the FIFA World Cup, and in education. They are also saving massively in sovereign wealth funds. In light of these decisions, I believe the leaders in these countries could not possibly be denying the threat of climate change.

Two other prominent nations are facing termination risk. Both Russia and Iran are taking steps to improve their future that have led to wars. Iran is backing a wide range of disruptive groups in the Middle East. Its goal with this approach is unclear, but Iran is certainly hoping to strengthen its role and perhaps disable its competitors. This now appears to be a failed policy.

Russia chose to invade Ukraine, possibly to gain access to agricultural resources and products that Russia does not export. Russia could see that in a decade, its fossil energy business would be weaker while Europe would be more self-sufficient through renewable energy sources, so the invasion was urgent. Clearly, the costs greatly exceeded what Russia expected, but the outcome so far looks like the beachfront hotel. Oil prices are high, and supply is restricted. The ultimate outcome appears unsuccessful and surely has created massive human suffering and destruction.

Finally, one more example of termination risk must be discussed. The human species itself faces termination risk. There is a risk that we will make our planet uninhabitable for humans. Faced with this risk, our managers cannot simply reduce investment or diversify our economy. Rather, we must reduce the probability that this outcome will occur. How can we do this?

Conclusion

The Paris Agreement has a roadmap. Each country must meet its targets for decarbonization. We all must work together on this essential task. To succeed, we must solve the problem of countries that are free riders. The theory behind free riders is that from a self-interested point of view, each country is better off if it does not meet its targets while others do. This solution, however, is not the only solution. There are cooperative games in which by working together a better outcome can be achieved than from competition. Clearly this is such a case.

There is no global body that can force cooperation, so we must do it with policy. The starting point, in my view, is cooperation between the United States and China. The world's biggest emitter, China is also the world's biggest producer of electric vehicles, solar panels, wind turbines, and lots of other green technology. It has a young cap-and-trade system to tax carbon emissions. The United States must also strengthen its efforts to achieve its Paris targets. If these two nations can collaborate, they can be a model for the rest of the world. In this way, we can be confident that the worst outcomes will not occur and that we will peacefully reach a cleaner and greener world.

The views expressed herein are personal views of the author and do not represent the views of any organization or other third party, including CFA Institute.

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INTRODUCTION

Chris Fidler
Head, Global Industry Standards, CFA Institute, Charlottesville, Virginia

For those unfamiliar with the origins of net-zero investing, it is essentially a response to global warming. Geological records show that the Earth's climate is always changing and that it changes very slowly. The average global surface temperature had fallen approximately 0.8°C in a fairly steady trend that started about 5,000 years ago and ended about 200 years ago. And then suddenly, the trend reversed. During the last 200 years, the 30-year average global surface temperature has risen by more than 1°C.

Strong scientific evidence shows that the global warming of the last two centuries has resulted from an increase in atmospheric greenhouse gases (GHGs) caused by an increase in the industrialized production of goods and services to meet the demands of a growing global population with rising standards of living.

What are the implications of global warming for investors? Although it is impossible to answer this question with any precision, it is clear that global warming is a risk. Economic infrastructure around the world has been designed and built with the assumption of a stable climate. The more the climate moves away from historical baselines, the less likely economies will function at peak productivity and efficiency. Similar to other major global events, climate change will likely bring economic opportunities for some companies, but in aggregate, the opportunities are unlikely to offset the risks.

Many investors have begun to regularly assess the risks and opportunities of climate change. At a micro level, they are evaluating how climate change might impair a company's physical assets or affect its productivity, profitability, and cash flows. At a macro level, investors are considering how governments' efforts to mitigate and adapt to climate change through regulation, spending, taxes, and incentives might affect consumer demand and industry profitability.

A smaller but significant portion of investors has gone beyond risk assessment, asking how they might help mitigate the root cause of global warming. It was this question that gave birth to net-zero investing.

Net-zero investing is still in its infancy. The Institutional Investors Group on Climate Change published the first guidance on net-zero investing in 2020. Much has changed since then. Experience has yielded important insights, and practices continue to evolve.

Net-zero investing generally involves investing in projects and plans, engaging with investees, and supporting public policies to simultaneously earn a return on invested capital and help bring about a future global state where the net increase in GHG emissions from human activities is zero.

Risk management, portfolio alignment, and real-world decarbonization are important aspects of net-zero investing. Risk management focuses on the physical risks of climate change and the transition risks that may arise from efforts to mitigate or adapt to climate change. Portfolio alignment focuses on constructing a portfolio of assets that, in aggregate, aligns with a specified decarbonization pathway that leads to net zero. Real-world decarbonization focuses on deploying capital to finance specific projects, technologies, and initiatives and on persuading issuers and policymakers to take steps that are conducive to achieving net zero.

Although all net-zero investors share a common goal to contribute to global net zero, they put different amounts of emphasis on risk management, portfolio alignment, and real-world decarbonization. Furthermore, they pursue their different goals in different ways, on different timelines, and within different regulatory and cultural contexts. For these reasons, a variety of approaches and practices are followed under the moniker "net-zero investing." Climate benchmarks, climate bonds, value at risk, scenario analysis, system-level investing, stewardship, and blended finance are but a few of the many threads in the evolving conversation about how the financial sector can play a role in the reduction of global net GHG emissions.

Against this backdrop, we are pleased to present this net-zero guide—a compilation of ideas about net-zero investing from thought leaders in academia and industry. As the global association of investment professionals, with nearly 200,000 charterholders across 160 markets, it is our privilege to convene experts and practitioners to help advance both theory and practice.

Investment Innovations Toward Achieving Net Zero: Voices of Influence

I. Strategy

TOOLS USED BY SYSTEM-LEVEL INVESTORS IN THEIR NET-ZERO INITIATIVES

Jon Lukomnik
Sustainable Investing Research Initiative, School of International and Public Affairs, Columbia University, New York City

William Burckart
Sustainable Investing Research Initiative, School of International and Public Affairs, Columbia University, New York City

System-level investors believe that the vast majority (75%–94%) of their returns result from the general price level of the capital markets rather than which specific securities they own. They also believe that the health of the capital markets ultimately depends on a robust economy, which in turn relies on the health of the environmental, social, and financial systems. Many such investors identify climate change as a key systemic risk. Some have adopted net-zero goals. We find that these climate-focused and net-zero-aligned investors share certain common traits. First, they identify climate and the transition to net zero as a systemic risk with direct financial consequences and opportunities. Second, they cite a fiduciary responsibility to respond to that systemic risk and the related opportunities. Third, they use traditional tools of institutional investing to progress toward their net-zero goals, including setting investment beliefs and using security selection, proxy voting, and engagement. When asset owners use external managers, they also incorporate their net-zero goals into managerial due diligence and selection. Fourth, they use advanced tools of system-level investing, including those that stress collaborative action, building shared knowledge bases, setting industry standards, and engaging with policymakers in their net-zero efforts. Fifth, they have an individual who serves as a focal point and thought leader within the investing organization who drives their climate transition efforts. Sixth, they understand and accept that measuring the impact and influence of their net-zero efforts is difficult but try not to allow the impossibility of precision to deter them from being directionally correct. Lastly and perhaps most importantly, they try to have an impact not only in the capital markets but also in the wider world.

Introduction

This chapter examines the tools used by system-level investors in their journey to net zero. System-level investing (SLI)[1] inherently focuses on the health of the environmental, social, and financial systems because they affect the capital markets, and so many system-level investors have adopted net-zero or other climate goals. This chapter examines some of the attributes of those investors and the tools they use.

[1]For more on the definition of system-level investing, see Burckart and Lydenberg (2021).

System-level investors tend to be either large investors with liabilities (e.g., asset owners such as pension funds)—and, therefore, more concerned with total return than with market-relative returns—or early adopters with long-term investment horizons (e.g., some major asset managers and foundations). The twin hallmarks of SLI are the beliefs that (1) the general price level of the capital markets is based on the health of the economy and the environmental, financial, and social systems on which it relies and (2) the general price level of capital markets determines 75%–94% of the variability in an investor's return, meaning that security selection and portfolio construction contribute only 25%, at most.[2]

For these total-return-focused investors, beta is salient, which is quite unlike those seeking relative return success (alpha), for whom beta is silent. Modern portfolio theory assumes that beta is exogenous, but system-level investors do not. They try to affect it. Because beta risk is universal and nondiversifiable, risk management is not limited to the capital market tools used to diversify or hedge idiosyncratic, security-specific risk. Focusing on systemic risks means these investors act both in the capital markets and in the wider world to mitigate risks to the financial, environmental, and social systems, with reducing climate risk atop many system-level investors' priorities list.

We find several commonalities in these investors' approaches.[3]

They Identify Climate and the Transition to Net Zero as a Systemic Risk with Direct Financial Consequences and Opportunities

System-level investors draw a direct connection between climate change, transition risk, and financial impact.

New York City Comptroller Brad Lander is responsible for overseeing USD253 billion invested by five city pension funds.[4] In a BNP Paribas Asset Management (BNPP AM) report, he argues, "As universal investors invested broadly across the global economy, we have nowhere to hide from the impacts of climate change. We have a clear and pressing responsibility to reduce emissions financed by our investments, and to underwrite improvements that address the systemic risk that climate change poses to our portfolios and our planet" (BNPP AM 2024, p. 3).

Nor is it only asset owners who make that connection—asset managers do as well. As BNPP AM, which has EUR562 billion in assets under management (AUM), explained, "We . . . believe a shift to a low-carbon, more sustainable economy is essential for the long-term sustainability of capital markets" (BNPP AM 2022, p. 3).

[2]Various studies show this. The key ones are by Roger Ibbotson (2010) and Gary P. Brinson (i.e., Brinson, Hood, and Beebower 1986). They are summarized in Lukomnik and Hawley (2021, pp. 32–33).

[3]For case studies on a number of the investors mentioned in this chapter, see TIIP (2024) and ongoing research from the High Meadows Institute.

[4]See www.top1000funds.com/asset_owner/nyc-office-of-the-comptroller/.

Cambridge Associates, a global investment firm with USD72 billion in AUM and USD568.9 billion in assets under advisement as of September 2023 (Cambridge Associates 2023), started discussing climate risk and opportunity as an economic factor in 2015, when it published "Risks and Opportunities from the Changing Climate: Playbook for the Truly Long-Term Investor" (Ma 2015). The report explained the imperative to consider climate factors as "an economic risk management and opportunity capitalization issue core to prudent investing for the long term." It articulated the interconnection between the management of climate as a systemic issue—which "has the potential to materially impact businesses, economic assets, and communities"—and their role as a fiduciary to their clients (Ma 2015).

Ma (2015) was early in distinguishing between "playing defense" and "playing offense." The report suggested four tactics for defense: (1) engagement through delegation (sensitizing external asset managers to climate risks and opportunities); (2) engagement through advocacy (demanding more climate reporting and transparency from portfolio companies and external managers, as well as using a "climate risk lens" in selecting and monitoring external managers and investments across asset classes); (3) proactive hedging (including both actual hedges and implicit hedges against market weights, such as low-carbon indexes); and (4) exclusion of investments tied to "assets at risk" (such as stranded fossil fuel assets).

To play "offense," the report suggested a few investible "themes": "Renewable infrastructure, clean transportation, smart energy, energy efficiency in buildings, and water and agricultural efficiency. . . . Our basic thesis is that *the more challenging the problem, the greater the opportunity set for innovation, solutions, and, ultimately, attractive investment returns*. Thus, investors seeking to incorporate climate risk in their long-term decision-making should focus not just on defending against climate risk but also on planning a strategy to invest (and/or be prepared to invest) in related solutions" (Ma 2015; italics in original).

They Cite a Fiduciary Responsibility to Respond to the Systemic Risk and the Related Opportunities

Although many investors view mitigating the impact of climate change as consistent with their fiduciary duty, system-level investors go further and consider addressing climate change as not only compatible *with fiduciary duty but* necessary *to take action to combat climate change to fulfill their fiduciary duty. This distinction is important: Simply trying to mitigate the impact of climate change on their portfolio to the extent possible is unacceptable. For system-level investors, there is an affirmative obligation to act to reduce the threat of climate change and its impact on capital markets.*

The Healthcare of Ontario Pension Plan (HOOPP), with CAD110 billion in AUM as of 31 December 2023 (HOOPP 2024), makes it clear that responding to climate change is tied to fiduciary duty: "We have a fiduciary duty to deliver on our pension promise and have a responsibility to do so in a way that takes ESG factors, such as climate change, into account in developing investment policy and making investment decisions as they impact financial risk and opportunity. We believe, as a large global investor operating in an increasingly interconnected world, our sustainability is linked to the health of the societies and environments we invest in. We believe that helping to shape sustainable communities, ecosystems and capital markets is part of being a prudent long-term investor."[5]

The refrain that the success of a large, long-term investment program is tied to the success of the financial, environmental, and social systems is one that is familiar to the California State Teachers' Retirement System (CalSTRS), with USD338 billion in AUM as of May 2024.[6] CalSTRS' policy explicitly notes that "short-term gains at the expense of long-term gains are not in the best interest of the Fund. Sustainable returns over long periods are in the economic interest of the Fund. Conversely, unsustainable practices that hurt long-term profits are risks to the System" (CalSTRS 2023, attachment "a"). Consistent with these views, CalSTRS aims to "be a catalyst in transforming the financial markets to focus on long-term value creation that fully integrates sustainability considerations and uses CalSTRS' influence as a significant global investor to promote sustainable business practices and public policies" (CalSTRS 2021, p. 3).

Piers Hugh Smith, head of stewardship, global, at Franklin Templeton (which has USD1.5 trillion in AUM), points out that the proliferation of diversified portfolios highlights the links between the risk–return dynamics of the market (a key SLI concept), climate change, and fiduciary obligation. As explained in a recent article Smith coauthored with Charles Elson, executive editor-at-large of *Directors & Boards*, "In managing risks that are financially relevant to the marketplace, the institution must consider the role that the overall market plays in the balance of portfolio return. Given changing investment product choices over the past 20 years, the proportion has grown. Fiduciary duty is a critical strength, as it permits the institution to consider system-level risks across all assets and steward them effectively" (Elson and Smith 2024).

They Use Traditional Tools of Institutional Investing to Progress Toward Their Net-Zero Goal

SLI adapts standard institutional investing tools and evolves them to be used in the transition to net zero, including statements of investment beliefs; asset allocation and security selection; manager selection; and stewardship, engagement, and proxy voting.

[5]See HOOPP's Sustainable Investing webpage: https://hoopp.com/investments/sustainable-investing.

[6]See www.calstrs.com/investments.

Investment Belief Statements

According to a paper by Professor Willem Schramade (forthcoming), 80 of the world's 300 largest pension funds publish a statement of investment beliefs on their websites. Of those, he found 64, or 80%, included statements related to societal issues, including 24 that mentioned the environment.

One of the pension funds that publishes its investment beliefs is HESTA, an Australian superannuation fund with AUD68 billion in AUM. The fund links its ability to mitigate climate change to its ability to fulfill its obligations to its members: "By managing systemic risks (such as climate change), integrating responsible investment factors, catalyzing innovative investments, and being a 'gutsy advocate' for a fair and healthy community, we can deliver strong, long-term returns for our members."[7]

CalSTRS is even more specific:

> Investment risks associated with climate change and the related economic transition—physical, policy and technology driven—materially impact the value of CalSTRS' investment portfolio.
>
> CalSTRS believes that public policies, technologies and physical impacts associated with climate change are driving a transition to a lower carbon economy. As a prudent fiduciary and diversified global investor, CalSTRS needs to understand the transition's impacts on companies, industries and countries and consider actions to mitigate risk and identify investment-related opportunities. CalSTRS recognizes the critical role that carbon pricing frameworks may play in integrating the costs of carbon emissions into the global economy to accelerate an orderly low-carbon transition and avoid exacerbating economic inequality and related geopolitical risks.[8]

Asset Allocation and Security Selection

PGGM, with EUR240 billion AUM, is making a robust set of changes to its portfolio as a result of taking an SLI approach. The Dutch pension specialist calls its approach "3D" for the three dimensions of risk, return, and impact.[9] That, in turn, has meant a root-and-branch rethinking of how to invest.

PGGM's 3D approach will affect all of its investments, even index funds, because PGGM wants to know each line item in its portfolio and have a rationale for

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[7]See HESTA's Investment Beliefs webpage: www.hesta.com.au/campaigns/investment-beliefs.

[8]See CalSTRS' Investment Beliefs webpage: www.calstrs.com/investment-beliefs.

[9]3D investing is semantically different from but substantively similar to SLI.

why it is there.[10] One result will be fewer holdings and an end to what Jaap van Dam (at the time the principal director of investment strategy for PGGM) calls "extreme benchmark orientation." After all, it is impossible to truly "know" every security in benchmark-replicating strategies that may invest in thousands of securities overall. Instead, PGGM will create "well-formed portfolios" with enough securities for PGGM's internal investment staff to know (with adequate diversification) each exposure to (and impact on) expected human activity that will be value generating and risk controlled. "These 'well-formed' portfolios will be very far away from what we now consider to be a good benchmark," van Dam explained (Hammond 2022).

Most of PGGM's portfolio companies already have climate targets and plans to reach them, and PGGM's own target is 100% alignment within the infrastructure portfolio by 2030. Its Climate and Energy Transition Solutions Mandate encourages direct investing in climate solution companies.[11]

Another example is the University Pension Plan Ontario (UPP), with CAD11 billion in AUM. It has set a target of investing CAD1.2 billion in climate solutions by 2030 (UPP 2023). Among the areas of focus are real estate and infrastructure. The first direct investment made under the framework was in Angel Trains, a railroad rolling-stock leasing company. The majority of Angel Trains' rolling stock is electric. As UPP wrote in announcing the investment, the direct investment aligns with the transition framework and "our desire to commit capital to climate solutions" (UPP 2024).

Manager Selection

Although UPP and PGGM have internal investment teams, many asset owners rely on external managers. For them, selecting, monitoring, and communicating with those managers is a tool to meet their net-zero and other climate pledges. Some SLI investors have taken the use of external managers to the next level by partnering with those managers to create new climate-oriented products, many of which then become publicly available. Climate-oriented impacts multiply as other asset owners invest in those products.

For example, Wespath, one of the largest faith-based pension funds in the world (with USD24 billion in AUM), partnered with BlackRock to create and seed the Transition Ready Portfolio (TRP).[12] The TRP features an enhanced passive investment approach that overweights carbon-efficient companies (investing in carbon technologies, reducing carbon emissions, using natural resources sustainably) and underweights companies that are poorly positioned for a low-carbon economy.

[10]Jon Lukomnik visit with PGGM CIO Geraldine Leegwater, Zeist, Netherlands, 3 July 2023.

[11]See www.pggm.nl/en/blogs/event-building-bridges-for-the-energy-transition/.

[12]Wespath Benefits and Investments, "Wespath Transition Ready Strategy: A Solution for Investing in the Low-Carbon Economy." www.wespath.org/assets/1/7/5405.pdf.

The TRP strategy focuses on real-world climate change mitigation investment opportunities, such as new technologies and emission reduction activities that actually reduce carbon emissions in the atmosphere. That approach differs from low-carbon investment strategies that tend to focus primarily on screening out carbon-intensive industries but that do not directly affect the actual emissions into the atmosphere (Wespath Benefits and Investments 2022). The strategy evaluates companies in five areas, or "pillars," to determine their readiness to transition to the low-carbon economy: energy generation/production, carbon-efficient technologies, energy management, water management, and waste management.[13] According to Wespath, the strategy results in a portfolio with a 50% reduction in carbon emission intensity and a 40% increase in climate technology exposure relative to performance benchmarks (the Russell Top 200 Index and the MSCI World ex USA IMI Value Index; see Wespath Benefits and Investments 2018). Wespath has more than doubled its investments into low-carbon-ready securities since its contribution to the initial commitment of USD750 million to the launch of the Transition Ready strategy in 2018. BlackRock has now expanded the investment strategy to other investors and grown the TRP strategy into a business line with USD18 billion in AUM (Wespath Benefits and Investments 2022).

Similarly, the McKnight Foundation is a family foundation with USD2.5 billion AUM[14] that leverages its position as a "customer of financial services" to try to mitigate climate change. In other words, it uses its due diligence of managers not only to identify those that operate in alignment with the foundation's mission but also to influence them to change existing strategies and build new ones. The foundation reports that its climate-focused due diligence led one of its fund managers, Mellon Capital Management, to develop the Carbon Efficiency Strategy, a fund that excludes coal-mining companies, overweights energy-efficient companies, and underweights inefficient producers. The McKnight Foundation provided USD100 million in seed funding for the fund, which it describes as a "win–win" because it "created new ESG capacity within Mellon and launched a new product for institutional investors."[15]

The McKnight Foundation notes that one of the most valuable aspects of its public commitment to net zero across the portfolio by 2050 is the clear signal it has delivered to fund managers that net zero is an area of prioritization and expectation. In 2022, the McKnight Foundation engaged with more than 75 fund managers regarding their net-zero ambitions, what it means to take tangible action in the transition to a sustainable low-carbon economy, and how the managers fit with the foundation's net-zero portfolio (McGeveran and Wade 2022). That year, 54% of their public equity managers had net-zero commitments in place; in 2024, more than 60% did.

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[13]Wespath Benefits and Investments, "Wespath Transition Ready Strategy: A Solution for Investing in the Low-Carbon Economy." www.wespath.org/assets/1/7/5405.pdf.

[14]As of 26 March 2024, according to the McKnight Foundation's Financials webpage: https://rb.gy/nbd1q0.

[15]See the McKnight Foundation's Customer of Financial Services webpage: www.mcknight.org/impact-investing/how-we-invest/customer-of-financial-services/.

Stewardship, Engagement, and Proxy Voting

For many institutional investors, systemic stewardship is the most important tool for combatting climate change and moving toward net zero. Whereas traditional stewardship's goal was maximization of an individual company's enterprise value (or at least stemming the diminution of enterprise value), systemic stewardship tries to protect or improve a system (such as by mitigating climate change).

Climate Action 100+ (CA100+) is an investor-led coalition designed to cooperatively engage with portfolio companies with troubling GHG profiles. Although some have criticized CA100+ for not having enough impact fast enough, its explosive growth from 25 investors when it started in December 2017 (Mitchell and Stewart 2022) to more than 700 investors with total AUM of USD68 trillion in 2023 (Gambetta 2023) demonstrates how widespread the belief is that engagement offers a key tool to reach net zero.

That engagement is part of the path to net zero is particularly true for system-level investors. For example, Wespath co-led CA100+ engagements that resulted in the publishing of climate risk reports by Occidental Petroleum and Chevron and a commitment by Cummins Inc. to become net zero by 2050 and align its lobbying activity with the Paris Agreement (Wespath Benefits and Investments 2022). Further, Occidental Petroleum recently stated its intentions to become the first US oil and gas major to achieve net-zero emissions from its operations by 2040 and reach net zero for all emissions, including those generated by suppliers and customers, by 2050 (Zellner 2022).

Wespath links its engagement work with its proxy voting activities and shareholder campaigns. Both the Chevron and Occidental Petroleum agreements came after Wespath filed shareholder proposals, and Jake Barnett, managing director of sustainable investment strategies at Wespath, has called for more shareowners to vote against board directors at companies that are not making adequate progress toward alignment with the Paris Agreement, "as a method of accountability" (Wilkes 2023).

BNP Paribas Asset Management has a similar posture. Its stated objective is "to make a substantive contribution to the low-carbon energy transition." Toward that end, it encourages its portfolio companies "to align their strategies with the goals of the Paris Agreement" (BNPP AM 2022, p. 4). An active member of CA100+, BNPP AM has served as the lead or co-lead investor for 10 corporate CA100+ dialogues and has actively supported 10 others. As with Wespath, BNPP AM uses proxy voting and engagement to reinforce one another.

BNPP AM supported 94% of shareowner climate proposals in 2020, 89% in 2021, and 92% in 2022. Perhaps more noteworthy is that the asset manager has increasingly voted against the election of board members and against approving the accounts of the company (in those jurisdictions where that issue is on the ballot) for environmental or social issues. It did so at 66 companies in 2020, 168 in 2021, and 216 in 2022. Like most system-level investors, both Wespath and BNPP AM focus more on stewardship and engagement than on divestiture or exclusions. But exclusions do play a role. For example, BNPP AM has said that it will exit thermal coal-mining companies and power generators that still use coal by 2030 for companies active in OECD countries and by 2040 for the rest of the world (BNPP AM 2022).

They Use Advanced Tools of System-Level Investing, Including Field Building, Thought Leadership, and Engagement with Policymakers, in Their Net-Zero Efforts

Because SLI recognizes the feedback loops between the environmental, social, and financial systems and the capital markets, SLI investors often use advanced tools that try to influence the wider world beyond the capital markets.

Field Building and Thought Leadership

Field building and thought leadership are tools designed to drive progress at scale by providing the logistical (field building) and intellectual (thought leadership) infrastructure to convince more investors to commit to net zero.

As previously noted in the "Stewardship, Engagement, and Proxy Voting" section, CA100+ is one of the key coalitions used by investors who are concerned with climate change. The prominent roles of SLI investors, such as Wespath and BNPP AM, reflect the emphasis that SLI puts on field building (and working in coalitions).

In terms of thought leadership, many of these investors have published papers on climate and investing, which are referenced throughout this chapter. These include the Cambridge Associates report "Risks and Opportunities from the Changing Climate" (Ma 2015) and the recent collaboration between New York City comptroller Brad Lander and BNPP AM titled "Accelerating Net Zero Ambition" (BNPP AM 2024), which also featured a foreword from Catherine McKenna, chair of the UN's High-Level Expert Group on the Net-Zero Emissions Commitments of Non-State Entities. SLI investors also collaborate with civil society institutions, with powerful effects.

Polity

As committed to net zero as they are, SLI investors recognize that institutional investors alone are unlikely to limit warming to 1.5°C without more government action. That is why virtually every investor mentioned in this chapter—and many who are not mentioned—engages with policymakers on climate, either directly or through intermediaries.

The McKnight Foundation is one of the key investor groups that attempt to influence climate policy. In 2015, it stood alongside hundreds of investors in advocating for an ambitious agreement ahead of COP21 in Paris. Since then, the foundation has expanded its impact investments and doubled its commitment to climate-related grantmaking (Thiede 2021). The McKnight Foundation also believes that as a market participant, it has "standing with policymakers and financial regulators . . . [and can] encourage action"[16] on its own and through investors collaborations, such as the Investor Network on Climate Risk, as described previously.

For example, in 2017 and in response to the United States' withdrawal from the Paris Agreement, the McKnight Foundation signed a letter, alongside 217 investors, urging G7 and G20 governments to develop plans to reduce greenhouse gas emissions. It also urged its asset managers to sign the letter. In 2016, the McKnight Foundation's then-president Kate Wolford wrote a letter to the SEC seeking to require publicly traded companies to disclose robust, standardized data on material environmental and social risks (Wolford 2016). Continuing this support, in 2022, the foundation's chief investment officer, Elizabeth McGeveran, wrote to the SEC in support of the proposed regulatory enhancements to mandate climate-related financial disclosures (McGeveran 2022).

Some funds, such as UPP, have the advantage of having a key policymaker as one of their executives. For example, Barbara Zvan, president and CEO of UPP, is a member of both the Canadian government's Expert Panel on Sustainable Finance and the Sustainable Finance Action Council, which launched in 2021. She was named one of 26 Climate Champions by British High Commission in Canada and the Canada Climate Law Initiative ahead of COP26 in 2021.

They Have an Individual Who Serves as a Focal Point and Thought Leader within the Investing Organization Who Drives Their Climate Transition Efforts

There is a saying in politics that "personnel is policy." That is true in investing as well. Institutional investors serious about climate and meeting their net-zero pledges tend to recruit serious talent—senior executives with climate experience and ability to drive change—to lead those efforts. These leaders are change agents with accountability.

Led by Barbara Zvan, UPP is a relatively new pension plan created during the COVID-19 pandemic, with a mandate to merge several smaller university pension plans. Zvan was previously the chief risk and strategy officer for the Ontario Teachers' Pension Plan, where she crafted the organization's climate

[16]See the McKnight Foundation's Market Participant webpage: www.mcknight.org/impact-investing/how-we-invest/market-participant/.

strategy (UPP 2020). Among her first hires was Brian Minns, CFA, who has a master's degree in environmental studies.

Minns would be the first to say that UPP's climate policies and actions are the product of intense work by many staff and board members. Nonetheless, Minns quickly became the chief architect of UPP's robust climate action plan, which features both a pledge to reach net-zero GHG emissions by 2040 and interim targets. The plan emphasizes "GHG emission reductions in the real economy" (UPP 2022, p. 8), a systemic risk mitigation focus consistent with UPP's self-identification as a system-level investor.

Minns also oversaw the creation of a climate transition framework, which both evaluates UPP's current portfolio and identifies new investment opportunities consistent with UPP's net-zero pledge. He is a major proponent of partnerships and alliances with other investors and civil society organizations, leading UPP's stewardship and engagement activities, both with portfolio companies and with other investors in such organizations as the Net-Zero Asset Owner Alliance, CA100+, Climate Engagement Canada, and the Institutional Investors Group on Climate Change.

Another leadership example is Jane Ambachtsheer, the global head of sustainability for BNPP AM.[17] Ambachtsheer was recruited to join the asset manager in 2018, following 18 years at Mercer Investments, where she became well-known as chair of the global consultant's Global Responsible Investment Business. Since being at BNPP AM, she has guided what the firm calls "an ambitious approach" to sustainability, including climate change and the firm's net-zero pledge. As evidence of her influence within the firm, Ambachtsheer is a member of both the Global Investment Committee and the Business Management Committee. In addition, she is responsible for BNP Paribas's CSR activities, helping align its actions with those the asset manager asks of its portfolio companies.

Ambachtsheer has a distinguished career in sustainable investing, with a focus on climate. She was a consultant to the United Nations when the Principles for Responsible Investment were being created, was named one of Canada's "Clean 50" leaders, has won a lifetime achievement award from the Canadian Social Investment Organization, and is a member of the Financial Stability Board's Task Force on Climate-related Financial Disclosures, a trustee of CDP, and a member of the PRI Academic Working Group. A practitioner who also has an academic skill set, Ambachtsheer is an honorary research associate at the Oxford Smith School and has authored and coauthored several important papers—most recently, "Aligning Investments with the Paris Agreement—Frameworks for a Net Zero Pathway" (de Carvalho, Ambachtsheer, Bernhardt, Clisson, Morgan, Kovarcik, and Soupé 2023).

[17]See https://mediaroom-en.bnpparibas-am.com/experts/jane-ambachtsheer.html.

They Understand and Accept That Measuring the Impact and Influence of Their Net-Zero Efforts Is Difficult but Try Not to Allow the Impossibility of Precision to Deter Them from Being Directionally Correct

John Maynard Keynes is often credited with saying that he desired "to be approximately correct rather than precisely wrong," although there is some doubt in that attribution (Joiner 2022). In the case of net zero, measurement difficulties create impossible barriers for those who want second-decimal-point precision ex ante. *System-level investors who have net-zero pledges do not let that challenge slow them down. For them, acting and being directionally correct are far superior to waiting for standardization of metrics, even if that means creating do-it-yourself solutions.*

As Ambachtsheer wrote recently, "Not finding any measurement solutions available [that] provided us with the tool we needed to track our progress holistically, we built the NZ:AAA methodology" (BNPP AM 2024, p. 2). BNPP AM then went a step further and compared the "Net Zero: Achieving, Aligned, Aligning" measurement approach with three other measurement frameworks: excluding fossil fuel companies from portfolios, a cleantech investing approach, and the Paris Aligned Benchmark framework. BNPP AM compared the portfolios resulting from each approach to more traditional benchmark-related portfolios to determine tracking error, as well as risk, return, and sustainability. The company then published the analysis, allowing other investors to examine the options and move ahead or create their own measurement regimes (de Carvalho et al. 2023).

Conclusion

Perhaps the overarching commonality for system-level investors concerned with climate is that they understand that capital markets may price risk but that risk, particularly systemic risk, is created in the wider world beyond the markets. They also know they cannot hedge or diversify away from climate change risk. Therefore, system-level investors consider, engage with, and try to impact the wider world to reduce GHG emissions and improve overall market price levels.

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A NEW FOCUS FOR INVESTOR CLIMATE COMMITMENTS

Tom Gosling
Senior Visiting Fellow, LSE Law School, London School of Economics, and Executive Fellow, Department of Finance, London Business School, London

Investors representing many trillions of dollars of client or beneficiary assets have signed on to net-zero targets to limit global warming to 1.5°C with limited or no overshoot. Sophisticated frameworks have been developed to help investors identify specific actions in support of these targets. In this chapter, I explore the concerns that many investors have about making 1.5°C-aligned commitments. These include concerns about fiduciary duty, the limited ability of investors to influence climate outcomes, and the legitimate role of investors versus government in addressing externalities. Analysis of these arguments suggests that they have some force, but they do not negate the case for certain investors to set targets and take action on climate change. Nonetheless, the analysis points to ways in which investor climate commitments can be made more robust in order to make them more effective and, perhaps, secure even wider support. In particular, given that the climate externality can be addressed only through a supportive government policy framework that changes economic incentives, I propose a new focus for net-zero frameworks that starts with this core premise. The result is two-fold. First, investors seeking to have material impact on climate change must, as a first-order matter, consider their relationship to the process of policy development, including corporate lobbying. Second, direct actions with investee companies should focus on objectives where investors realistically have influence and which companies can realistically deliver. This should lead to a more limited but also more focused, achievable, and therefore impactful set of objectives for investors who are concerned about climate change.

On 3 November 2021, the Glasgow Financial Alliance for Net Zero launched with much fanfare and no small amount of bravado (GFANZ 2021):

> Today, through the Glasgow Financial Alliance for Net Zero (GFANZ), over $130 trillion of private capital is committed to transforming the economy for net zero. These commitments, from over 450 firms across 45 countries, can deliver the estimated $100 trillion of finance needed for net zero over the next three decades.

GFANZ comprises a number of sector initiatives for asset owners, asset managers, banks, and, until recently, insurers.[1] Focusing on the investor initiatives, the Paris Aligned Asset Owners (PAAO) have 57 signatories with

[1]See www.gfanzero.com/membership/.

$3.3 trillion in assets under management (AUM). The Net-Zero Asset Owner Alliance (NZAOA) has 89 signatories with $9.5 trillion in AUM. And the Net Zero Asset Managers initiative (NZAM) has 315 signatories with $57 trillion in AUM.[2] Separate from GFANZ, another prominent initiative, Climate Action 100+, has approximately 700 signatories with approximately $68 trillion in AUM. It is an extraordinary phenomenon that so many asset owners and asset managers have signed up to commit to a target to achieve net-zero emissions by 2050 to limit global warming to 1.5°C.

Why have they made these commitments? For *asset owners*, the motivation appears to be largely driven by universal owner theory (see, e.g., Lukomnik and Hawley 2021). The idea is that broadly diversified investors own a slice of the whole economy. Therefore, it is in their interests to address any issue that adversely effects the economy. In this view, if climate change is considered to cause long-term economic damage, it can also be claimed to harm diversified portfolio values, thereby creating a *financial* argument for investor action. As stated by the PAAO (2024, p. 1),

> Most large asset owners are broadly exposed to whole national economies and given climate change presents economy-wide risks, they cannot entirely divest from these potential negative financial impacts for their beneficiaries. The economic science is clear that a rapid reduction in greenhouse gas emissions has the greatest net economic benefit, which benefits the financial returns of universal owners to their beneficiaries.

For *asset managers*, the motivations are more mixed. Some may have been influenced by the universal owner hypothesis. Others will have seen that a significant and vocal body of their clients have signed up for such commitments themselves and wanted their asset managers to show similar commitment.

The various investor coalitions have come under attack as part of the recent "anti-ESG backlash," particularly in the United States. Coalition members have been accused of violating antitrust laws by collaborating on climate action and of violating fiduciary duty by using other people's money to pursue political or nonfinancial goals. The Net-Zero Insurance Alliance was dissolved, and other initiatives have experienced a small number of high-profile signatory exits. Climate Action 100+ saw some investors withdraw as the initiative moved into a more assertive Phase 2, in which concrete demands are made of investee companies to reduce emissions as opposed to the earlier requests simply to provide improved disclosure. Although much of the criticism in the United States amounts to little more than political posturing, my experience is that many investors have genuine concerns about how best to reconcile ambitious climate goals with fiduciary duties and their role in society.

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[2]Details of the GFANZ-affiliated investor initiatives can be found at www.parisalignedassetowners.org, www.unepfi.org/net-zero-alliance/alliance-members/, and www.netzeroassetmanagers.org/signatories/.

At the same time, questions have arisen about the efficacy of investor coalitions seeking to deliver climate outcomes through voluntary commitments made by themselves and the companies they invest in. In a recent report, the Transition Pathway Initiative (2024) found that although 2050 net-zero commitments are becoming more prevalent, they are rarely backed up by concrete actions to meet the commitments. Only 5% of companies in the high-emitting sectors under review had quantified an emission reduction strategy, 2% had clarified the role of offsets in net-zero commitments, 2% had plans to phase out capital expenditure (capex) in carbon-intensive assets, 2% had aligned capex and decarbonization goals, and 1% had integrated net-zero goals into climate policy and trade association membership. The most recent review from Climate Action 100+ (2023) painted a similar picture. These wider trends are also reflected in specific high-profile cases of companies walking back ambitious climate goals in the name of reprioritizing shareholder returns.

In this chapter, I explore these concerns about current investor initiatives and consider the implications for the future direction of investor action on climate.[3] Reports of the death of investor climate coalitions are premature: They are very much still alive, especially (but not only) in Europe. However, now is a good time to re-evaluate what is and is not credible, as well as what is and is not working. I conclude that such a reevaluation leads to the conclusion that investor climate commitments should be refocused in a way that reflects achievable outcomes and the realistic role of investors in addressing climate change. This chapter is, therefore, addressed both to the governing bodies of the key existing investor initiatives and to investors who believe climate change is a critical issue and want to be part of the solution but feel unable to sign on to existing initiatives as they stand.

The chapter starts by exploring the concerns that many investors have about setting a 1.5°C warming limit goal. Exploring these concerns with an open mind can provide insight into areas where investor climate commitments can be made more robust. It can also help inform how investor climate action can be framed to secure the widest possible support. The concerns fall into four categories. One concern is that pursuit of very ambitious climate mitigation goals may actually be bad for the economy in the medium term and for portfolio returns. A second is that, in any event, investors have little ability to affect climate outcomes and will be wasting resources and distracting from their core purpose in trying to do so. A third is that it is now unlikely that we will limit global warming to 1.5°C and investing based on an unlikely scenario is not in client and beneficiary interests. A fourth is that it is the role of governments not investors to address externalities like climate change through the democratic process. I conclude that all these concerns have some force, and the analysis gives rise to implications for how investor targets and action on climate change should be designed.

[3]This chapter focuses on action by investors to limit climate change in line with net-zero commitments. It is not concerned with the incorporation of climate risks and opportunities into stock selection and valuation.

In the second section of this chapter, I consider whether the concerns are so serious that investors should not be in the business of setting climate goals at all. I conclude that the concerns raised, although legitimate, do not negate the case for certain investors to set climate goals. However, a *directional goal* of supporting a *strengthening of current climate policies* may be easier to justify than a very ambitious goal based on a fixed warming target that is now, sadly, unlikely to be achieved.

In the subsequent section, I turn to the nature of suitable actions for investors who have concluded that a climate goal is appropriate. Given the foundational importance of government policy, investors who want to have an impact on climate change must consider their role in policy formation. This is a potentially controversial area, and I make suggestions for how investors can avoid being accused of overstepping the boundaries of political legitimacy. I then consider the actions investors can take when government policy is not yet supportive. These actions acknowledge that investors cannot substitute for effective policy and must instead be focused within the realistic scope of investor influence.

The chapter concludes by contrasting climate commitments of the type I propose with those arising from existing target-setting frameworks. Overall, the approach outlined should lead to a more limited but also more focused, achievable, and therefore impactful set of objectives for investors who are concerned about climate change.

Investor Concerns About Setting 1.5°C Targets

Many investors have made net-zero commitments, aligned with limiting global warming to 1.5°C.[4] But equally many have not. In addition to the small number of investors who have recently withdrawn from the various alliances, there are many who never signed up and some signatories who are grappling with genuine concerns about how to reconcile the commitments with their obligations to clients and beneficiaries. The reasons are not always rooted in skepticism about the negative impacts of climate change for society. Exploring these reasons can provide insight into ways in which existing climate initiatives can be made more robust. It can also help understanding of how support for climate action can be broadened and made more secure in the investor community. In my experience, where investors have concerns, they can be separated into four principal categories.

An Economy That Transitions to 1.5°C May Not Be the Best Outcome for Portfolio Returns

If climate change is bad for the economy, it must be bad for portfolio valuations. Therefore, diversified investors (and their clients and beneficiaries) will be better off if they take action on climate change. This simple and compelling logic

[4]In fact, most commitments are aligned with the yet more ambitious Race to Zero goal of limiting global warming to 1.5°C with limited or no overshoot.

underpins much investor action on climate. However, some investors believe that limiting warming to 1.5°C will be very costly and disruptive to the economy and companies and may be negative for market returns. This is reflected in nonacademic studies that often project that climate action will have a negative impact on portfolio returns.

When analyzing this concern, the first point to make is that, increasingly, economists who study climate change agree on the significant economic benefits of decisive action to limit global warming. A review of economic studies by the Intergovernmental Panel on Climate Change (IPCC) found substantial benefits in limiting global warming to the Paris Agreement goal of 2°C or less, compared with allowing 3°C or 4°C (see IPCC 2022, Chapter 3, Section 3.6.2, Cross-Working Group Box 1). Not only are expected economic losses reduced, but so are the losses in downside scenarios. The consensus that continuing with current policies will ultimately, at some point, be detrimental to economic growth and welfare has only strengthened since the IPCC released its report. Indeed, when summarizing points of consensus among economists studying climate change, the first observation highlighted by Pisani-Ferry and Posen (2024) is that "whatever the views on the economic consequences of climate action, the alternative of no action would be much worse."

However, while the economic case for climate action is strong, the *financial market* case for the specific, more ambitious goal of limiting warming to 1.5°C is less clear. First, no consensus has emerged as to whether the medium-term impacts of more assertive mitigation are positive or negative for GDP, with different economists holding different views (Pisani-Ferry and Posen 2024; Stern and Stiglitz 2023; Dietz, Bowen, Doda, Gambhir, and Warren 2018). Whether the medium-term GDP impact is positive or negative will depend on the extent of any "green growth" multiplier, the practical substitutability of energy sources, the pace of technology development, and the extent to which such assertive climate policy can be implemented efficiently and without political backlash.

Furthermore, conclusions based on GDP outcomes do not translate directly into conclusions for asset portfolios. Financial market valuations are skewed toward developed markets, which typically show lower negative GDP impacts of climate change. GDP projections mask the significant shift from consumption toward investment that would be required over the coming decades to achieve the net-zero transition. In addition, the high discount rates of financial markets mean that for 1.5°C scenarios, the additional upfront costs of mitigation can offset the discounted value of reduced future climate damages, resulting in a net negative for portfolio returns even if longer-term economic impacts are positive.

Some argue that the focus on comparing expected damages and mitigation costs for the 1.5°C and 2°C scenarios misses the point: At lower levels of warming, the most negative consequences of climate change are overwhelmingly in the tails of the probability distribution

(Trust, Bettis, Saye, Badenham, Lenton, Abrams, and Kemp 2024). Rather than considering central cases, market participants should instead consider downside risks in the presence of climate tipping points.

But even when considering tipping points, a financial fiduciary needs to bear in mind that some tipping points, once triggered, have consequences that play out over very long timescales—sometimes measured over many centuries (for example, sea level rises from melting ice sheets; see Armstrong McKay, Staal, Abrams, Winkelmann, Sakschewski, Loriani, Fetzer, Cornell, Rockström, and Lenton 2022). To affect portfolio values, tipping points need to be imminent, severe, relevant to corporate cash flows, and fast acting. The reality is that they are hugely uncertain, and views on the risk and the extent to which that risk should be taken into account by fiduciaries can reasonably differ.

For a financial fiduciary, the likely benefits for long-term portfolio returns of limiting warming from the current trajectory of approximately 3°C to meet the Paris goals of 2°C or less are compelling (Rebonato, Kainth, and Melin 2024), based on expected climate losses before allowance for tipping points. However, the pure *financial portfolio* benefits of limiting warming to 1.5°C are much less certain. This observation may seem cavalier in the context of long-term damage from global warming in excess of 1.5°C highlighted by the IPCC and the human suffering that will result in poor and vulnerable communities around the world. But when the case for investor climate action is made on financial terms based on the impact on portfolio values, as it usually is within investor commitments, then the case needs to be assessed on that basis. Belief in imminent, severe, financially relevant, and fast-acting tipping points appears necessary to make the *investor* case for the more stringent goal of 1.5°C. Some fiduciaries may in good faith conclude that the risk of such tipping points justifies the more stringent goal, but others may not. This matters because the real-world industrial and economic differences between 1.5°C and 2°C are significant, and net-zero frameworks require signatories to set targets in line with the more stringent goal. I will return later to the implications of these insights for setting overarching climate goals.

Investors Have Limited Ability to Affect Climate Outcomes

Some investors are concerned that setting very ambitious climate targets overstates the ability of investors to influence climate outcomes. Time and effort then could be wasted on a fruitless endeavor. This is a valid concern. Severe practical problems exist, which boil down to the *efficacy* of investor action and the *gap between company- and system-level effects*, as detailed elsewhere.[5]

Starting with the efficacy of investor action, there is little evidence that investing in or divesting from companies that are or are not aligned with the net-zero

[5]See Gosling (2024b); www.ecgi.global/projects/responsible-capitalism/does-sustainable-investing-work; and www.netzeroinvestor.net/news-and-views/why-universal-owners-need-modest-objectives.

transition can have enough effect on their cost of capital to change managers' investment decisions. First of all, academic estimates of the level of impact on cost of capital are generally small (on the order of 100 bps). Some research suggests that a change of this magnitude is too small for managers even to notice and is in any case far lower than necessary levels of carbon taxation to hit net-zero goals. Indeed, some researchers argue that constraining finance to carbon-intensive firms may cause them to double down on brown rather than green activities.

Engagement has more support as an impact mechanism, although it is important not to overstate the results of academic research in this area. Although collaborative engagements can be successful, what is counted as a success in many studies is rather limited: a disclosure commitment or a general commitment to reach net zero at some point in the future. There appears to be no evidence that investors can engage with companies sufficiently forcefully to make them undertake actions that are fundamentally against the financial interests of the company. This explains why the Transition Pathway Initiative (2024) finds that investor engagement on climate has been more successful at generating promises of action far in the future as opposed to tangible progress today to reduce emissions.

Even if investors succeed in bringing about changes in a given company, there needs to be a credible model of how this leads to system change. If one company is pressed into forgoing a profitable opportunity, what is the likelihood that no other company picks it up? Displacement of polluting activities from one form of ownership to another, less scrutinized form is also a real concern. Private, state-controlled, and family-controlled firms form a substantial part of the economy, largely beyond institutional investor influence.

The link between investor action and impact is therefore highly uncertain, and investor tools to bring about change are weak. In this area, the concerns about the influence some investors have seem legitimate. A conclusion is that investors should focus their actions where they can be most impactful while still meeting their fiduciary duties to clients and beneficiaries. This approach often means influencing the environment in which sustainable outcomes can emerge rather than trying to bring about those outcomes directly.

Investment Strategy Needs to Be Focused on Likely, Not Desired, Transition Pathways

The target of 1.5°C is now widely considered to be out of reach, if not technically then at least practically and politically (Matthews and Wynes 2022). Indeed, a poll of climate scientists for *Nature* found that fewer than 5% of respondents believed warming would be limited to 1.5°C by the end of the century (Tollefson 2021). Investors who believe they have limited ability to influence climate outcomes may find it difficult to justify having—let alone acting on—a goal that is so far removed from likely trajectories. This is because the disconnect between the 1.5°C target and reality can, if investors seek to meet the target, give rise to actions that actually increase costs and risks for investors (Gosling and MacNeil 2023). Investment allocations that seek to align with or create impact toward a 1.5°C world may underperform in a slower decarbonization scenario. Engagement demands for companies to align with unrealistic 1.5°C pathways may create a competitive disadvantage for those companies. Incurring such costs and risks is difficult to justify given the low efficacy of these actions.

This explains why truly 1.5°C-aligned strategies are so rare. When bold climate aspirations collide with commercial incentives, commercial incentives generally win. At this point, the commitments themselves can create a perverse consequence, through supporting a market for approaches that appear 1.5°C aligned but are nothing of the sort. Examples include the use of portfolio decarbonization indexes, carbon offsets, disclosure-based strategies, "science-based" targets not backed up by strategy choices, and selective targets excluding hard-to-abate sub-portfolios.

Of course, it is possible to advocate for a 1.5°C world while constructing investment and engagement strategies based on more likely scenarios. However, as currently constructed and implemented, investor net-zero frameworks are predicated on the alignment between investment and engagement objectives and the 1.5°C scenario. This tension is difficult for some investors to reconcile.

It Is the Role of Governments, Not Investors, to Address Climate Change

Climate change is a problem because something we believed was free (emitting carbon dioxide into the atmosphere), in fact, has a rather large long-term cost in terms of financial and nonfinancial economic welfare. That cost, however, only partially falls on the people benefiting from the emissions. Indeed, it falls disproportionately on those who do *not* benefit, which is the nature of an externality.

Importantly, this dynamic is not just a matter of time horizons. Those benefiting from free emission of carbon dioxide today will not proportionally bear the costs if we simply wait long enough. Moreover, it is also not yet plausibly the case that low-carbon technologies exist at the scale or cost required to decarbonize our economy through the normal market-based actions of capitalism.

Solutions to the climate crisis ultimately could be developed through private sector activity and innovation. But the externality is too great and too urgent for this approach by itself to suffice. Significant government action will, therefore, be necessary to support a decarbonization pathway at the pace we need to keep the risks of climate change acceptable. This action includes policy to reframe economic incentives, invest in national infrastructure, support research and development, and manage the social consequences of a major economic and industrial transformation. Investors cannot substitute for government action. Indeed, in attempting to achieve the 1.5°C target without supportive government policy, investors would almost certainly find it impossible to bring about the change in any coherent, economically efficient, or societally just way.

Most investors would, if asked, accept the importance of government action. Indeed, the necessity of government policy is built into the various investor commitments: All the NZAOA, PAAO, and NZAM commitments come with a caveat—the expectation that government will follow through with policies to achieve the more ambitious 1.5°C target within the Paris Agreement. Nevertheless, the portfolio decarbonization and engagement targets set under these initiatives are calibrated by references to a desired and ambitious 1.5°C-aligned climate pathway rather than one that is credibly backed by government policy strength. Yet it is unclear what it means for a company or a portfolio to be 1.5°C-aligned in a world that is not so aligned at a policy level. These challenges are evident in recent attempts to define "transition finance" by the UK's Transition Finance Market Review (2024). The Transition Pathway Initiative (2024) found that corporate action on climate change is associated with the policy environment of the host country, in terms of both aggregate net-zero commitments and detailed policies such as carbon pricing, again reinforcing that politically established economic incentives are critical.

Despite its weaknesses, government policy developed through the democratic process is the *only* credible mechanism to ensure that the societal trade-offs involved in decarbonization are addressed with legitimacy, leading to a just and accepted transition.

However, the primary importance of government policy does not mean that investors should have no role at all and leave everything to governments. Policy is not developed in a vacuum but instead emerges from a process of reconciling competing pressures. Given the efforts that adversely affected incumbents will always make to limit the damage to them of climate policies, beneficiaries of those same policies need to make their voice heard.

Some investors also have concerns about the political legitimacy of them taking a leading role in advocating for policy action. This is understandable, and I am not suggesting that every investor must engage on climate policy. Rather, I am saying that any investor who claims to act on climate change as a matter of major concern to them must, as a matter of first priority ahead of other actions, develop a plan for how they can influence the political process. The foundational primacy of government policy for a successful transition should not be a footnote to or a get-out-of-jail free card for investor commitments on climate. It should, instead, be a fundamental principle underpinning the actions that the investor prioritizes.

Should Investors Make Climate Commitments at All?

Given the challenges outlined in the previous section, one might question whether investors should be in the business of making climate commitments at all. And we have witnessed some pullback from commitments, particularly among US investors. I do believe, however, that climate commitments remain relevant for some investors.

First, the available evidence quite clearly shows that runaway global warming is likely to seriously harm both the economy and portfolio values over the long term. So, an asset owner with fiduciary obligations running several decades into the future (such as a pension fund) has a legitimate *financial* interest in seeing climate change being brought under control. Debates about what is the right target should not distract from this core fact.

However, what "under control" means will remain a highly contested matter, and for fiduciaries, the definition must always be founded on what is best for financial returns. Science and economics provide no single answer. Some argue, often based on the work of William Nordhaus (2019), that limiting global warming to 3°C or even higher strikes the right balance between costs and benefits. Others, typically focused on tail risks and tipping points, argue that conventional economic cost–benefit analysis makes little sense given the major risks and uncertainties of climate change and the limitations of economic models—and that anything above 1.5°C will be net damaging to portfolios, at least on a risk-adjusted basis (Trust et al. 2024; Stern, Stiglitz, and Taylor 2022).

Fiduciaries will need to come to their own view in good faith and based on considered reasoning, evidence, and advice. However, the investor case for strengthening climate mitigation policies compared with the current trajectory appears strong. The trajectory implied by current policies is typically considered to be around 3°C of warming (IPCC 2023). There is a growing weight of evidence that this level of warming would be materially negative for the economy and portfolio values over the long term, even in central scenarios before taking into account tail risks. It therefore seems entirely reasonable for a financial fiduciary to be in favor of more climate mitigation than we are seeing in a current policy framework.

As discussed previously, however, the evidence in favor of limiting warming to 1.5°C *for financial portfolio* reasons relies strongly on the perceived potential for imminent, fast-acting, severe, and cashflow-relevant tipping points. Although such tipping points cannot be ruled out, they are highly uncertain. The existence of low-probability but severe downside risks of course creates the case at the societal level for adoption of the precautionary principle, with democratic consent, to mitigate the risk even if costs are involved. However, given the deep uncertainty involved, this is a very difficult judgement for financial fiduciaries to make. At the same time, given the low likelihood of society achieving the 1.5°C goal, some fiduciaries may question how much sense it makes for them to adopt this goal and act on it, regardless.

Using these positions as bookends, it seems reasonable for a long-term fiduciary to at least (1) take a *directional* position of favoring significantly more stringent mitigation compared with the current policy trajectory, in line with the Paris Agreement goal of limiting warming to well below 2°C, and

(2) support progressive tightening of policy as a result, to the greatest extent that is politically feasible. Such a positioning for climate goals has a number of advantages. First, it is unambiguously aligned with the minimum ambition level in the Paris Agreement and so has democratic legitimacy as a goal in signatory countries. By contrast, the political status of the 1.5°C target (especially with limited or no overshoot) has always been less clear.[6] Second, limiting warming to well below 2°C is consistent with credible policy pathways.[7] Third, the purely financial case for this target is stronger for fiduciaries to rely on.

Undoubtedly the 1.5°C target has become a point of difficulty for some investors for all of the reasons outlined in this chapter so far. A reframing of the overarching climate goal to one that is biased toward a strengthening of climate policy while respecting the primacy of the political process could potentially draw in wider investor support. This reframing also lessens the force of arguments that investors are over-reaching what has been politically endorsed and in practical terms, given realistic pathways, may lead to no less ambitious outcomes. There is understandable resistance in some quarters to any perceived softening of overarching climate goals given the increasing, and potentially non-linear, nature of climate risks with every small mean temperature increase. But there is a risk that the goal ceases to be a useful basis for determining actions and targets for which investors can credibly be held accountable.

The discussion so far supports the case for investors, particularly long-term asset owners, to have some kind of position or commitment on climate. But it will not be relevant for all investors. Some asset owners will have time horizons that are too short for climate change to be among the most material factors. Some will not believe they have the expertise to take a position on climate targets or on what policies will be effective but will instead wish to focus on managing risks and opportunities for beneficiaries across a range of climate outcomes. Others will consider the tools at their disposal to influence change to be relatively weak and unable to justify specific focus on the issue. For asset managers, the materiality of climate change as an issue will depend strongly on the nature of the mandates they fulfill, their investment style, and the wishes of their asset owner clients. Some investors may believe that climate change, although important, is not their issue to address.

For investors who consider it appropriate to have an overall climate goal, the question then turns to how to translate that goal into specific objectives. The discussion of prevalent investor concerns about current target-setting frameworks provides the following insights.

First, government policy is of foundational importance to addressing climate change. Therefore, channels for investor influence on policy formation must be

[6]It should be recognized that the 1.5°C target has increased in prominence as climate scientists have become more pessimistic about the negative implications of any given level of warming, but this has only in rare cases been reflected in updated political commitments.

[7]See, for example, the Inevitable Policy Response at https://ipr.transitionmonitor.com.

of first-order importance. Second, direct investor influence on climate outcomes is limited, and investors need to protect the interests of beneficiaries in likely—not just desired—climate scenarios. Therefore, investors should focus on areas where they can influence company activity at the margin but in a manner consistent with the commercial incentives those companies face.

In the next two sections, I develop these themes, starting with policy influence and then turning to other forms of objective.

Influencing Policy

Given the foundational nature of government policy, it is hard to avoid the conclusion that climate-concerned investors who are serious about having an impact should first consider their influence on the policymaking process. Such influence can take a number of forms, direct and indirect.

Direct Policy Engagement

The Institutional Investors Group on Climate Change (IIGCC)[8] started out with a major focus on creating an investor voice on policy. IIGCC can be credited with stiffening the resolve of both EU and global policymakers in the run-up to the signing of the Paris Agreement.[9] Despite its importance, however, policy engagement receives relatively little attention in existing target-setting protocols, and of 127 investors that have published targets under the NZAOA framework and the Net Zero Investment Framework (NZIF), only 5 make any reference to public policy engagement.[10] The Transition Pathway Initiative (2024) found that companies struggle to manage the interface between their activities and public policy formation.

Perhaps the key role for investors is to show strong and visible support for ambitious climate policy, particularly around key points of government policy development, such as climate finance negotiations ahead of COP 29 in Baku or the current revisions to Nationally Determined Contributions in the run-up to COP 30 in Belém. Climate policies frequently face organized and well-resourced resistance from affected business and labor interests that can be extremely influential politically. Investors are well placed to give governments assurance that the aggregate impacts of climate policies are manageable and that costs in one area are balanced by opportunities in another.

Second, investors can support specific policies that may have costs, but manageable costs, for some businesses but carry significant environmental benefits. Here, strong support from the investment industry can embolden governments to take action and can dilute resistance from affected sectors.

[8]IIGCC acts as one of the convenors for PAAO and NZAM.

[9]See www.iigcc.org/our-history.

[10]For initial targets set under the NZAOA framework and NZIF, see www.unepfi.org/net-zero-alliance/alliance-members/ and PAAO (2022).

As an example, a group of major investors pressed the US government to adopt more-stringent methane regulations (Climate Action 100+ 2021). In such circumstances, investors have the opportunity to play the role of "honest brokers," supporting reasonable regulation but pushing back on rules that are poorly designed or excessively burdensome.

Third, for investors to influence detailed policy development, they will need to bring insight into the critical government policies required to enable the institutional investment flows needed to support the transition to net zero in the sectors in which they invest. As an example, ahead of the recent UK general election, the UK Sustainable Investment and Finance Association (2024) developed a series of focused policy requests based on policies that would support private sector investment into the energy transition. However, involvement needs to go beyond issuing high-level concept statements on policy to detailed engagement plans with government officials at critical stages of policy development (for example, development of Nationally Determined Contributions or national transition plans). Chapters 2, 3, and 6 of the UK's Transition Finance Market Review (2024) set out what this might look like in practice.

Different investors will have different contributions that they can make where policy is inadequate. Some may be willing to engage in policy advocacy directly, either themselves or through industry associations. But to be impactful, such advocacy must be appropriately resourced, conducted at senior levels (e.g., the CEO to minister level), and carried out with appropriate vigor. Much current policy engagement is quite high level and appears to lack determined intent and resourcing, especially when compared with the very well-resourced efforts that incumbent industries deploy to defend against climate action. The UN Principles for Responsible Investment (PRI) has established a pilot project on collaborative sovereign engagement in Australia (PRI 2024). This is an initiative that deserves investor support, but its embryonic nature demonstrates how far this area has still to develop.

A problem for asset owners is that their asset managers do not have the same incentives to address the very long-term risks of climate change for portfolios. Indeed, there appears to be a large gap between the vigour with which the financial industry lobbies on climate change and the vigour with which it lobbies on regulation that it sees as harming its direct economic interests. So engagement with asset managers on their policy lobbying will be an important but challenging part of asset owner activity (NZAOA 2022).

Indirect Influence on Policy Engagement

An area that has recently gained prominence is the role that investors can play in influencing the lobbying practices of investee companies and membership of representative trade associations. Lobbying by incumbent industries against climate regulation clearly presents a significant impediment to development of rational climate policy. Investors can provide an important counterbalance to this, although it is a complex area where investors could easily be accused of interfering in directors' area of responsibility. The NZAOA developed guidelines on policy engagement by investors directly and engagement with asset managers on lobbying alignment (NZAOA 2023). These guidelines rightly focus on governance, transparency, and alignment of policies with stated positions on climate change. The PRI has developed guidelines for responsible political engagement (PRI 2022).

Lobbying has also recently been the focus of specific corporate engagements, showing that action is possible. Climate Action 100+ (2024) has successfully engaged with a number of high-emitting companies to ensure improved governance and greater transparency in relation to climate lobbying positions of firms themselves and their trade associations.

Nonetheless, action on corporate lobbying also has limits. Investors cannot order directors to lobby in a particular direction. Directors will always see some engagement with lobbying as being part of their duty to act in the best interests of the company. Policy engagement and action on policy lobbying should not be seen as the new silver bullets in the fight against climate change. As with other aspects of investor influence, they are inherently limited.

Maintaining Legitimacy in the Policy Debate

Investors are understandably concerned about becoming involved in any way with politics or political advocacy. A lesson many have taken from the anti-ESG backlash in the United States is simply to keep their heads down. Dangers clearly exist for investors wading into what many now see as a highly politicized swamp. Nonetheless, investors should not shy away from engagement on policy matters where they perceive that to be in the interests of their beneficiaries. Or if they do, they should accept that they have forsworn their single most material channel for climate impact and moderate their claims accordingly. Investors should, however, bear in mind several factors to help maintain the perceived legitimacy of their voice on climate policy:

- First, policy advocacy should be based on a very clearly articulated and robust case founded on the investor's financial interests. Investors should avoid speculative cases or implying too much certainty on highly uncertain conjecture.
- Second, to the extent possible, policy advocacy should be based on positions of fact that cannot be interpreted as taking a partisan political stance.

These first two conditions provide further support for the idea that a directional position of seeking to strengthen climate policy compared with current policies as rapidly as politically feasible may be preferrable to lobbying for the more ambitious absolute goal of limiting warming to 1.5°C.

- Third, active policy engagement should focus on matters in which investors have expertise and that are directly material to them and should avoid areas that are readily characterized as political in nature.

As an example of this third point, an energy and utilities investor may have detailed knowledge about the requirements for government subsidy, planning, permitting and grid connections, and wholesale market reform in order to enable acceleration of investment in renewables, storage, and grid services. These policy requirements are also material to the investor's strategy. By contrast, investors are unlikely to have particular expertise or agency in relation to policies for a just transition for workers[11] (notwithstanding the importance of this issue), nor are such policies likely to be directly material to their investment strategy. Investors broadening policy engagement beyond their direct areas of interest and expertise can easily be perceived as acting from political motives or imposing their values on the rest of society.

- Fourth, when addressing corporate lobbying (or for asset owners, when addressing asset managers' lobbying), the focus should be on governance, transparency, and alignment between public positions and lobbying activity rather than trying to enforce particular lobbying positions.

Trying to mandate corporations to engage in a particular way on policy will likely be met with accusations of micromanagement and overreach into areas that are the preserve of company boards. Such efforts also may infringe on activities that boards consider to be part of their fiduciary duty to support the long-term interests of the company. Demanding transparency and alignment of lobbying activities, however, is simply a question of business ethics and plain dealing and so is less likely to be controversial, while still offering hope of modest change.

Exerting Influence at the Margin in Favor of Climate Action

I have devoted some time to the question of government policy given its foundational importance to and currently underemphasized role in investor climate targets. But what can investors do when government policy is not yet supportive of the desired change? Investors can influence climate action in other ways. Because these have been extensively covered elsewhere, I refer to them only briefly here. It should be emphasized, however, that in many cases, the practical influence of these actions is likely to be much lower than that of effective policy engagement.

[11]Some aspects of just transition policies may be highly relevant for investors—in particular, the necessary finance structures to secure private sector financial flows to developing markets.

Corporate Engagement

Previously, I highlighted the fact that investor engagement, although well evidenced as a channel of investor influence on companies, has limited power. For this reason, engagement needs to be "limitations-aware" to be effective.

For example, engagement to try to force oil and gas companies to set production-cut targets, which these companies' boards view as fundamentally against company interests, has largely failed. Engagement to encourage these companies to take methane emissions more seriously, however, has arguably been more successful. The latter issue, despite its high environmental impact, is low cost for the company to address and does not challenge the company's core business model. Limitations-aware engagement involves investors focusing on low-cost adjustments companies can make that are consistent with long-term value creation but that have positive environmental impacts.

On the positive side, engagement can also create a supportive environment for directors who are seeking to innovate with strategies that create long-term value with lower environmental impact. Private sector investment in innovation will play a crucial role in addressing climate change. Directors have a significant zone of discretion in how they seek to create value, and investor support and challenge can encourage directors to seek value-creating pathways that are consistent with decarbonization. In other cases, investors may spread best practice gained from other investments they hold—for example, in relation to potential decarbonization within supply chains.

However, it is questionable how credible it is for investors to engage with companies in order to press them to become "aligned to 1.5°C." Absent government policy designed to meet that outcome, it remains unclear whether such alignment is even a meaningful concept. This challenge is emerging within transition plans being published by companies and the complexities of defining "transition finance." Such engagement has tended to focus on extracting corporate net-zero commitments and emission reduction targets. To date, however, there is little evidence that these efforts are leading to sustained emission reductions or business transformations, especially of a systemic nature.

Instead, I believe investors can make a greater impact in the climate arena by focusing on understanding and engaging with industry participants on key blockages in decarbonization pathways, helping understand and support the technology and policy developments needed to remove these impediments, and pressing companies to accelerate where there are transition opportunities that are at or close to cost parity. It is therefore encouraging that in its Phase 2 program, Climate Action 100+ (2024) chose to place greater emphasis on sector and thematic engagements. Ultimately, to be successful, investor engagement should focus on matters that enhance long-term value in portfolio companies and make decarbonization commercially viable. Investor action cannot substitute for government regulation in the matter of addressing externalities.

Climate Solutions

Investment in "climate solutions" is a key part of target-setting frameworks under the various investor initiatives. Depending on how it is implemented, however, such investment may or may not have impact. At one extreme, investment in a fund of listed clean energy providers probably has little or no impact on climate change because the investment is not contributing to the provision of additional capital. At the other extreme, the provision of concessionary capital to finance-constrained and pre-economic climate solutions—a pure impact investment—will, almost by definition, have impact.

For most fiduciaries, impact investment in its purest sense will likely be off limits, although I have argued elsewhere that, perhaps, it need not be (Gosling 2024a). Climate-concerned investors, however, can focus on aspects of climate solutions investment that are likely to be more rather than less impactful. Examples include the following:

- **Investments in private rather than public markets.** Investors who use their risk capacity and expertise to invest in private markets are more likely to provide genuinely impactful and catalytic capital. However, investors should guard against the assumption that private market investment automatically qualifies as impact.
- **Investments in climate bottlenecks.** Investors with an industry focus may be able to identify key technologies requiring development in order to unlock decarbonization in key industries. Examples might include regenerative agriculture, lab-grown meat, low-carbon cement, or green steel. Here, investors use their expertise to enable capital flows toward the technologies most likely to be successful.
- **Investments based on the provision of resources and expertise to develop new investment products.** This example might include development of blended finance structures, in which the ultimate investment provides a market rate of risk-adjusted return but the investor has used their time and expertise to help create an investible project.

This list is not comprehensive, but it illustrates how investors who want to have impact should pick their targets carefully, focusing on those dimensions where they can apply their expertise for greatest leverage and where their interventions are genuinely additional in some way.

Climate Integration

The final area where I believe investors can influence positively for change at the margin is through integrating climate considerations into the investment process. Investors who take account of climate risks and opportunities help markets correctly price these factors and thereby ensure efficiency of economic signals. Although it is easy to lament slow progress on climate change, at the same time, the world is on a powerful and inevitable decarbonization trajectory, driven by improving technology and economics. Investors actively participating in these opportunities can also help with the efficient propagation of signals from policy or where there are economic tipping points.

Conclusion

For valid reasons, even climate-concerned investors may have reservations about signing on to the major investor initiatives on climate. There are legitimate fiduciary concerns about adopting 1.5°C-aligned targets, based on reasonable views of the impact of climate change on the economy and financial markets. There are also legitimate concerns about whether the primary focus of those initiatives, in terms of portfolio and asset alignment to 1.5°C pathways, is either credible or effective.

In this chapter, I have laid out these concerns, which I believe demand a fair hearing and which could influence how climate-concerned investors think about where to focus their efforts. Investors who hold these views should not automatically be seen as climate deniers; the concerns are often reasonable given the available climate and economic science and investor duties. However, analysis has also identified the limits of these concerns. For example, they do not negate the case for some investors to set climate targets. However, the analysis has provided insights into how climate commitments and targets could be made more robust and effective and, potentially, how support for them could be broadened.

I have argued that two particularly relevant factors are the foundational primacy of government policy to a successful transition and the inherently marginal nature of investor impact. These factors imply that a *directional* goal of supporting accelerated climate action to meet the Paris goal of 2°C or less may be both more realistic and more appropriate than the *absolute* goal of 1.5°C, which is a long way from the trajectory of likely policy. They also imply a different focus for specific climate targets for those investors who choose to take a position on the issue.

First and most importantly, influence on policy would be at the heart of investor activities, given its foundational role in securing an efficient and fair transition to a low-carbon economy. Investors cannot claim they are making a material direct contribution to climate action without a robust and well-resourced plan for influencing public policy development. Such influence can include both direct policy advocacy and indirect influence on the policy lobbying activity of investee firms or, for asset owners, their delegated asset managers. Although this area is important, it is also extremely sensitive, so I have made suggestions for how firms can maintain legitimacy in the policy arena.

Second, under this model, investors would not set portfolio decarbonization targets (or equivalent targets, such as implied temperature increase). Currently, these are the single most common type of target. Portfolio-level targets, however, bear no relation either to real-world decarbonization or to the channels by which investors can realistically influence decarbonization. Such targets involve significant data gathering, manipulation, and adjustment (for example, for portfolio growth and acquisitions) but ultimately are not very meaningful. Institutional portfolio emissions have fallen during recent years, yet global emissions have grown (Atta-Darkua, Glossner, Krueger, and Matos 2023). The portfolio decarbonization approach perpetuates a false narrative whereby "investors-as-central-planners" can squeeze the economy down on a decarbonization path to net zero. Moreover, the ability to manage portfolio coverage, start dates, methodologies (absolute versus intensity), emission scopes, and portfolio allocations makes such targets ripe for obfuscation and gaming. This can create a perception of investor action on climate that is not reflected in reality.

Third, engagement targets would no longer be based on the concept of asset alignment. Asset alignment is the idea that it is possible to identify companies as either net-zero aligned or not (for example, through adoption of "science-based" targets) and then to credit investors for the portion of their portfolio that is net-zero aligned. Net-zero alignment is inherently a society-wide phenomenon, which cannot be decomposed into company-level net-zero targets.

Reliance on forward-looking corporate targets is particularly problematic given the oft-demonstrated reality that commercial considerations trump carbon targets, when push comes to shove. Instead, engagement targets would be extremely focused and based on specific outcomes that an investor is trying to achieve (for example, exact real-time renewable energy matching for tech firms running data centers or methane reduction for oil and gas firms) according to the investor's specific sector focus and expertise. Engagement targets would be "limitations-aware," recognizing the marginal nature of investor influence and the impracticality of pushing for engagement outcomes that are against firms' fundamental financial interests.

Fourth, generic targets relating to investment in climate solutions would not play an important role. Such targets enable extremely varied definitions of climate solutions and often involve investment in solutions that face no serious funding deficit. They therefore have no assurance of additionality. Instead, investors would adopt very specific targets where they can make a difference based on their expertise or influence. Such targets might include, for example, support for development or scaling of technologies to address key decarbonization blockages (e.g., low-carbon cement, carbon capture and storage, meat substitutes) or demonstration projects, such as project development in critical areas in developing markets. Climate solutions investment, to be impactful, will usually occur in private markets.

The resulting targets would likely be few in number and specific to each investor based on the investor's potential for maximum impact and points of leverage, recognizing the marginal nature of investor influence. Some may criticize such an approach for lack of comparability or lack of connection to economy-wide decarbonization trajectories. But the comparability and connection to economy-wide decarbonization trajectories of existing target-setting norms are an illusion. They create a false sense of accountability but with little connection to the real-world task of decarbonization.

The good news is that the areas of focus I recommend are far from new. Some members of the existing climate initiatives are already engaging on policy and on lobbying, although the intensity and resourcing are often wanting. Thematic and industry groups exist that focus on specific industry blockages and seek to find a way to remove these impediments. Investors are encouraging innovation in companies that will be crucial to the climate crisis. But there is also a significant volume of investor activity relating to portfolio and asset alignment with 1.5°C pathways that is time-consuming, expensive, not very impactful, and increasingly difficult for some investors to endorse. A focus on specific objectives related to investors' marginal ability to influence and on key blockages to decarbonization could enable larger and more impactful coalitions while avoiding some of the accusations of political overreach.

The approach set out in this chapter aims to contribute to the debate about the most appropriate form of investor action on climate. If adopted, it would be the basis for development of more focused and modest—but also, in my view, more effective—commitments. Such focus and modesty are simply appropriate recognition of the sphere of investor influence. Targets and objectives can still be ambitious, but they should be ambitious along realistic dimensions.

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CARBONOMICS: THE ECONOMICS OF REACHING NET ZERO

Michele Della Vigna, CFA
Managing Director and Head of Natural Resources Research in EMEA, Goldman Sachs Bank Europe SE, Milan

Yulia Bocharnikova
Associate, Goldman Sachs International, Dubai

Anastasia Shalaeva
Analyst, Goldman Sachs International, Dubai

Quentin Marbach
Analyst, Goldman Sachs International, London

In the last few years, many challenges have emerged on the path to net-zero carbon. Three of them are (1) direct hydrocarbon subsidies reaching $1 trillion in 2022, 4× the six-year average; (2) coal consumption resuming an upward trend; and (3) the nationally determined contributions (NDCs) still needing an extra 54% reduction of estimated 2030 CO_2 equivalent emissions to remain on track for 1.5°C. The impact of technological innovation, however, leaves room for optimism. By analysing more than 100 different applications of decarbonization technologies across all key emitting sectors globally, we arrive at five key conclusions. (1) We identify a re-emergence of cost deflation and improved affordability in some key technologies, such as solar panels and batteries. (2) The decarbonization of transport becomes 30% cheaper as batteries resume their deflationary trend. (3) The impact of higher interest rates on the overall cost curve is actually limited, although it is material for the carbon abatement cost in the renewable power sector. (4) Policy remains supportive, and we identify $500 billion of project announcements driven by the Inflation Reduction Act, which has reduced the decarbonization cost curve in the United States by 75% according to our estimates. (5) Bio-energy continues to grow its role, with renewable natural gas and sustainable aviation fuel gaining momentum in heavy transport, industry, and buildings.

Carbonomics Cost Curve

The Carbonomics cost curve—or carbon abatement cost curve—models the cost of achieving net-zero carbon emissions across more than 100 decarbonization technologies. The Carbonomics cost curve serves as a critical tool in the global effort to mitigate climate change by indicating the carbon price associated with a low-carbon technology that would make this technology affordable and in the money. Today, the lower part of the cost curve is still dominated by power generation or nature-based solutions, while industry and transport remain more expensive to decarbonize. For instance, electric vehicle incentives typically have an implied CO_2 cost of around $500/ton, while shifting from gas to solar in power generation has a CO_2 cost of –$50/ton to $50/ton depending on the region.

Overall, our Carbonomics cost curve shows a consistent flattening since its 2019 inception, with technologies dominated by China moving lower and technologies that compete with natural gas moving higher. China has been leading the technology upgrade for clean tech innovations and continues to drive costs down, as it currently produces approximately 60% of electric vehicles, 86% of batteries, and 85%–97% of solar products. In 2023, we saw significant deflation in the prices of batteries and solar panels, which has moved the cost curve lower. On the other hand, lower conventional energy prices, higher interest rates, and clean tech inflation in areas such as offshore wind have moved the cost curve higher.

Carbonomics Cost Curve Shifts, 2022–23

Our 2023 Carbonomics cost curve shows a mix of technologies moving lower and higher relative to 2022. Overall, the cost curve has become more affordable—encouraging individuals and corporates to implement decarbonization technologies—thanks to the higher end moving lower despite the lower end of the curve moving higher. Movements in the cost curve were driven by contributions from (1) lower long-term energy prices (natural gas, coal, power, oil products) following 2022 peaks, increasing the implied cost of the switch to cleaner alternative technologies; (2) clean tech cost inflation for existing technologies (such as equipment costs in renewable power generation, especially in offshore wind); and (3) higher interest rates increasing the cost of capital for existing clean technologies (primarily in power generation); while (4) battery cost deflation and electric vehicle (EV) economies of scale have driven down EV costs and decreased the implied cost of switching to EVs from internal combustion engines (ICEs).

The net impact is that clean technologies at the low-cost end of decarbonization, dominated by renewable power, have become more expensive year over year (reflecting lower energy prices, higher interest rates, and cost inflation), while those at the high-cost end, dominated by transportation, have become cheaper as batteries resumed their deflationary trend. Further, lower raw material costs and simpler cell-to-vehicle integration have brought the target three-year payback in sight by mid-decade. According to our estimates, the evolution of the Carbonomics cost curve results in higher costs to reach 75% decarbonization but a decrease in the cost of achieving the remaining 25%.

The transformation of the cost curve brings with it a change in the global annual cost to achieve decarbonization from existing, large-scale, commercially available technologies. A combination of lower energy prices and higher clean tech costs (inflation) has had an unfavorable impact on the Carbonomics cost curve, while lower battery prices in EVs have had a favorable impact on overall cost.

We estimate that the initial ~50% of global anthropogenic greenhouse gas (GHG) emissions—what we classify as "low-cost decarbonization"—can now be abated at an annual cost of ~$1.0 trillion based on the 2023 cost curve ($0.3 trillion per annum higher than in 2022), largely driven by lower energy prices (~50%), cost inflation (~30%), and higher interest rates (~20%) primarily impacting sectors such as power generation.

The cost of achieving 75% abatement of global anthropogenic GHG emissions is approximately $3.2 trillion annually, based on our 2023 cost curve (~$0.1 trillion per annum higher than in 2022), with lower battery prices being offset by clean tech inflation, higher interest rates, and lower energy prices. At the same time, as we move toward 100% decarbonization, we enter into the "high-cost decarbonization" end of the spectrum, with the 2023 Carbonomics cost curve indicating that the cost to abate the last 25% of emissions is down ~$0.6 trillion per annum from 2022. At this end of the curve, lower battery prices in EVs are driving savings for the transportation sector.

Power Generation

Renewable power has transformed the landscape of the global energy industry and represents one of the most economically attractive opportunities in our decarbonization cost curve. We estimate that approximately 35% of the decarbonization of global anthropogenic GHG emissions is reliant on access to clean power generation, including electrification of transport and various industrial processes, electricity used for heating, and more. In 2023, the power generation switch from natural gas to renewables (and storage) became more expensive as cost inflation and higher funding costs in renewable power increased the cost of generating electricity for solar and wind year over year, while European and Asian gas prices decreased, making renewables relatively more expensive. Specifically, we highlight the following:

- The weighted average cost of capital (WACC) for new renewable power projects increased to 6.0%–6.5% in 2023 from 4.0%–4.5% in 2022, driven by the increase in risk-free rates in Europe and the United States.
- Equipment costs rose overall in renewable energy, although cost inflation has been most prominent in offshore wind, while solar module prices have been decreasing. Overall, higher interest rates and cost inflation raised the cost of generating electricity from renewable power (solar and wind) in Europe by ~11% year over year and by ~42% compared with the trough observed in 2020.
- Costs also increased in other forms of renewable generation, primarily hydro (largely owing to the development of more challenging and remote sites) and nuclear power.
- Gas prices eased from 2022 peaks as supply concerns receded, leading to roughly a 30% decline in the back end of the European gas forward curve, increasing the competitiveness of gas versus renewables.

We estimate that last year, the weighted average carbon abatement cost in power generation increased by ~3× year over year—from $20/ton in 2022 to $66/ton in 2023—with about 35% of this increase driven by cost inflation, 40% by lower gas prices, and 25% by higher interest rates. At the same time, the CO_2 cost for power generation remains the lowest on the Carbonomics cost curve in comparison with other sectors.

Offshore Wind and Solar

Solar power generation has been relatively less prone to cost inflation, with prices for solar modules—mostly produced in China—declining significantly since August 2023. The ongoing decline in equipment costs and somewhat stickier long-term clean energy prices suggest better economics for solar generation, which we estimate to be two times cheaper than offshore wind. Solar's competitiveness against other renewable technologies and its high deflationary impact in the context of current power prices (especially in Europe) suggest that it could gain incremental market share from other technologies.

Meanwhile, the steep cost inflation in offshore wind (especially in the United States, owing to an underdeveloped supply chain) could signal a setback in growth and a slowdown in future developments. Since its inception in the late 1990s, the offshore wind industry has benefited from a major improvement in economics. In Europe, we estimate that between 2008 and 2020, the electricity cost for offshore wind dropped by 65%. Yet, following a steep 20-year decline in costs, the more recent cost inflation in raw materials and an unprecedented spike in funding costs led to a marked increase in offshore costs of approximately 10% in 2023 year over year.

Transportation

Transportation, in contrast to power generation, mostly sits in the "high cost" area of the decarbonization cost curve, with the sector responsible for about 30% of global final energy consumption and about 15% of net GHG emissions. In 2023, we saw the transportation decarbonization cost curve shift downward significantly, driven by cost deflation and the technological innovation observed in EV batteries leading to a decrease in the carbon price of technologies dependent on EVs. At the same time, because of lower gasoline and jet fuel prices, some technologies, such as sustainable aviation fuel (SAF), have become relatively more expensive.

Overall, we estimate that these factors drove an approximate 30% year-over-year decrease in the weighted average carbon abatement cost in transport in 2023—to $422/ton CO_2 equivalent—because the material deflation in battery costs was partly offset by lower jet fuel and gasoline prices.

Electric Batteries and EVs

Battery technology and its evolution play a key role in the decarbonization of both transport and power generation. The high focus on electric batteries over the past decade has helped to reduce battery costs by more than about 30% in the past five years alone, owing to the rapid scale-up of battery manufacturing for passenger electric vehicles. Nonetheless, the technology is currently not readily available at large, commercial scale for long-haul transport trucks, shipping, or aviation, and it remains in the early stages for long-term battery storage for renewable energy.

Looking ahead, we expect declining battery prices, as well as EV economies of scale, to help narrow the cost gap between EVs and ICEs by 2030. As a rule of thumb, we see an EV premium payback period of around three years (i.e., the number of years needed for fuel savings from cheaper electricity vs. gasoline to cover the EV cost premium over a fossil fuel car) as a threshold for a new powertrain to be widely accepted by consumers, given the case of Toyota Prius. We expect this three-year target could be reached around mid-decade for EV makers in China, as well as in ex-China markets such as the United States. In our view, the main drivers for a decline in battery prices from here include lower lithium and other raw material costs and simpler cell-to-vehicle integration (e.g., cell-to-pack, cell-to-chassis).

Clean Tech Innovations

The ongoing product innovation and technology upgrade continues to drive cost reduction and expand the demand outlook for key decarbonization technologies, such as clean hydrogen, sustainable aviation fuel, renewable diesel, and carbon capture and storage, which are gaining momentum.

Bioenergy

Bioenergy is already the largest source of renewable energy in the world and has the potential to decarbonize road, marine, and air travel, as well as heating, industry, and power generation. In renewable diesel (RD), we forecast strong capacity growth of more than 3 million tons in 2024, as well as a tightening feedstock market. However, we also see potential upside from the implementation of the Renewable Energy Directive (RED) III regulation in the EU from 2026, which could generate 5 million to 6 million tons of additional RD demand by 2030 (see European Commission 2024).

SAF is emerging as the leading technology to decarbonize air transport, with blending becoming mandatory from 2025 in several countries. We expect a tight market dominated by a few players in 2025–27 and see an opportunity for healthy margins.

Renewable Diesel

On 4 September 2023, the Dutch government proposed an upward revision in its 2024 target for renewable use in transport from 19.9% currently to 28.4%, which could result in up to 500 kilotons of additional RD demand in the Dutch market. Also, on 13 September 2023, the EU adopted amendments to RED II that increased the binding share of renewables within final energy consumption in transport to at least 29% by 2030, up from 14% previously (see European Commission 2024).

Although a number of countries in the EU with the highest RD consumption already have higher or similar renewables target ambitions (e.g., Sweden, Finland, Germany, the Netherlands), we believe there is potential for an upward revision to country mandates. This is after the adoption of RED III in countries with lower targets (e.g., Italy and France), given that member states are required to implement EU-wide regulations within 12–18 months of RED adoption, which we think could benefit the supply–demand balance in the RD market from 2026. Unlike regulations, which are binding in their entirety and directly applicable in all EU countries, directives require integration into national law by a specified deadline. EU member states are required to incorporate RED III into their national legislation over the coming months.

Beyond that, amendments to the Low Carbon Fuel Standard (LCFS) program have been proposed that would increase the stringency of carbon intensity (CI) targets through 2030 and extend emissions targets through 2045. The California Air Resources Board (CARB) has proposed tightening the CI reduction target to 30% (compared with the 2010 baseline) by 2030 from the current target of 20%, with a 5% proposed step-up in the reduction by 2025 compared with the level targeted under the current regulation. The CARB expects the proposed tightening of the CI reduction target to support LCFS prices: Preliminary CARB estimates show that LCFS prices could increase from $60/ton currently to more than $100/ton in 2025 and as high as $200/ton in 2026.

Sustainable Aviation Fuel

Following adoption of RED III in October 2023 (see European Commission 2024), the European Parliament adopted the ReFuelEU Aviation Regulation (European Council 2023). After ratification by the European Council, most of the new aviation rules came into force on 1 January 2024. New rules require aviation fuel suppliers to supply a minimum share of SAF at EU airports, starting from 2% of overall fuel supplied from 2025 (volume-based), then rising to 6% by 2030, 20% by 2035, and 34% by 2040, before reaching 70% by 2050.

Looking at voluntary demand, a number of European airlines have already set more ambitious targets than the ReFuelEU target for 2030 of 6%: Air France/KLM Royal Dutch Airlines (10% by 2030), Ryanair (12.5% by 2030), Iberia (10% by 2030), and International Consolidated Airlines Group (10% by 2030).

Clean Hydrogen

Clean hydrogen is a key rising technology in the path toward net-zero carbon, providing decarbonization solutions in the most challenging parts of the Carbonomics cost curve, including long-haul transport, steel, chemicals, heating, and long-term power storage. Clean hydrogen is a fuel, but as an energy vector it can also be produced by technologies that are increasingly widespread and scaling up, such as renewables and carbon capture. Although the basic scientific principles behind clean hydrogen are well understood, most of these technologies applied in their respective industrial sectors are still at the demonstration or pilot stage.

In the long term, we think hydrogen has a critical role to play in any aspiring path targeting carbon neutrality by 2050. We see a wide range of applications across sectors, including its potential use as an energy storage (seasonal) solution that can extend renewable electricity's reach, an industrial energy source, and an industrial process feedstock. Such uses could include replacing coal in steel mills, serving as a building block for some primary chemicals, and providing an additional clean fuel option for high-temperature heat. We also see potential applications for hydrogen in long-haul heavy transport.

Hydrogen has had an eventful couple of years, benefiting from strong policy support in the United States from the Inflation Reduction Act (IRA) and in Europe from REPowerEU. The year 2023 was also not without challenges, however: The hydrogen industry experienced pressure from high interest rates, and the US Treasury Department finally released its long-delayed proposed regulations for how hydrogen producers can secure tax incentives in the IRA. The proposed regulations are still being debated by the industry and overall appear burdensome, in our view, especially with requirements for longer-term hourly matching of renewable energy used for hydrogen production. These requirements, together with uncertainty associated with the upcoming presidential elections, continue to hurt backlog and near-term growth in the United States. We believe that this uncertainty is holding back major new US projects, despite the tax credits, while in Europe we continue to see medium-scale projects going ahead—especially for refineries and bio-refineries.

Carbon Capture and Storage

Carbon sequestration efforts can be broadly classified into three main categories, outlined in Goldman Sachs Research (2020):

1. natural sinks, encompassing natural carbon reservoirs that can remove carbon dioxide from the air (efforts include reforestation, afforestation, and agro-forestry practices);
2. carbon capture, utilization, and storage technologies (CCUS) covering the whole spectrum of carbon capture technologies applicable to the concentrated CO_2 stream coming out of industrial plants, carbon utilization, and carbon storage; and

3. direct air carbon capture and storage (DACCS), the pilot carbon capture technology that could recoup CO_2 from the air, unlocking almost infinite decarbonization potential, irrespective of the CO_2 source.

We envisage two complementary paths to enable the world to reach net-zero emissions: conservation and sequestration. The former refers to all technologies enabling the reduction of gross GHGs emitted. The latter refers to natural sinks and carbon capture, usage, and storage technologies that reduce net emissions by subtracting carbon from the atmosphere.

The need for technological breakthroughs to tackle emissions that cannot currently be abated through existing conservation technologies makes sequestration a critical piece of the puzzle in leading the world to net zero at the lowest possible cost. Carbon sequestration efforts are critical for a global carbon neutrality path, as they can (1) unlock emissions abatement across the hardest-to-abate sectors, where technological net-zero alternatives have not yet been developed or remain highly inefficient and expensive—a prominent example is heavy, highly energy-intense industrial processes; (2) avoid the early retirement of young plant fleets and assets, thereby easing concerns around stranded assets in the age of decarbonization; and (3) reduce the total load of GHGs in the atmosphere to the required carbon budget, thus correcting for any overshoot. In this context, direct air carbon capture is the key technology to abate accumulated emissions directly from the atmosphere.

Clean Tech Policy Support

The global ecosystem of clean tech innovators has benefited significantly from policy support and the capex opportunities available for renewables, driving technological innovation throughout our Carbonomics cost curve.

Inflation Reduction Act (IRA)

The IRA became law in August 2022, and its impact has been striking. As of October 2023, we estimate that about $500 billion in large-scale clean tech projects have been announced in new private clean energy investments thanks to the IRA, and we expect more announcements in the coming years. Some of these projects, however, have not yet started construction and are waiting for the US Treasury to issue key clarifications, especially in green hydrogen and carbon capture.

We estimate that CO_2 savings from IRA incentives and induced investments to 2032 will amount to 22 gigatons, implying a $52/ton cost of CO_2 abated to the US government. This abatement CO_2 price varies by technology: For solar and onshore wind, the CO_2 price is less than $25/ton given their 25+-year longevity and the mature nature of the technologies. For hydrogen, EVs, and biofuels, however, the price exceeds $100/ton given the shorter project life (the average car life is 15 years) and the relative immaturity of many of these technologies.

We also consider how the IRA changes the cost curve of decarbonization for the United States. Incorporating US IRA tax credits and other incentives, the Carbonomics cost curve for the United States moves 75% lower.

Carbon Pricing

We believe that carbon pricing will be a critical part of any effort to move to net-zero emissions, while incentivizing technological innovation and progress in decarbonization technologies. The still-steep carbon abatement cost curve highlights a growing need for technological innovation, deployment of sequestration technologies, and effective carbon pricing. At present, 73 carbon pricing initiatives are underway, covering 39 national and 33 regional governments worldwide, mostly through cap-and-trade systems. These initiatives are now gaining momentum beyond developed markets, with Indonesia launching the initial phase of its own national carbon pricing scheme in February 2023. The carbon pricing systems have, however, shown varying degrees of success in reducing carbon emissions so far. According to the World Bank Group, these initiatives together cover 13 gigatons of CO_2 equivalent, representing approximately 24% of the world's total GHG emissions.

European Carbon Market Policy

In Europe, we argue that the carbon market is at a crossroads, growing from a successful but narrow instrument that facilitates the move away from coal power generation to a driver of decarbonization across much of the European economy. We also argue that the lower natural gas prices we expect in the second half of the decade—driven by a 50% increase in the global liquefied natural gas (LNG) market—provide an opportunity for EU policymakers to push the EU Emissions Trading System (ETS) to the price level required for the decarbonization of heavy industry (€100–€130/ton on our Carbonomics cost curve) without energy cost inflation to industry and consumers. The introduction of the Carbon Border Adjustment Mechanism (CBAM) and the potential for a parallel ETS for transport and heating complement this transformation. We envisage three key catalysts for this shift: (1) the introduction of CBAM in 2026, (2) a likely deficit in the permit market after the market stability reserve (MSR) in 2026 and before the MSR in 2030, and (3) auctioned emissions in industry and transport exceeding those in power generation by 2030.

Stress-testing key assumptions on industrial production, coal retirement, and renewable ramp-up in our supply–demand model for credits, we conclude that by 2028 we should see a structural breakthrough in the market toward a CO_2 price of €100–€130/ton—the level we estimate would incentivize CCUS on a large scale. For 2026–27, our negative view on natural gas pricing, driven by an acceleration in LNG supply growth, implies some downside risk to prices in the EU ETS market. But it also suggests an opportunity for EU regulators to tighten the carbon market and achieve their "Fit for 55" commitment, leveraging lower energy prices to accelerate the energy transition. This dynamic should prevent an excessive decline in power prices from potentially derailing the buildup of renewables. We estimate that EU ETS auctions could generate €62 billion annually in tax revenue for the EU member states by the end of the decade.

EU CBAM: Near-Term Beneficiaries

The EU CBAM will impose a direct carbon tariff on the embedded emissions from 2026 of selected imported products—iron and steel, aluminium, cement, fertilizers, electricity, and hydrogen—with potential implications for product prices, margins, and volumes. In our view, the EU CBAM may (1) be a potential catalyst for global carbon pricing; (2) create margin risks for high-carbon products (if charges are absorbed) or declines in sales (if passed through, depending on demand elasticity), with potential "green" premium benefits for low-carbon products; (3) lead to goods being rerouted based on embedded emissions; and (4) accelerate green capex investment.

We believe that explicit carbon schemes (such as the EU ETS) have scope to be a more efficient, technology-agnostic instrument of decarbonization and clean tech innovation. Carbon leakage and unfair competition can, however, be an issue in the absence of a globally coordinated carbon pricing mechanism, prompting a focus on a border adjustment to ensure a level playing field. The CBAM approved by the EU could help remedy the issue of carbon leakage by placing a tariff-like cost on emission-intensive imports and exports to attempt to reconcile the difference in carbon pricing between the EU and its trading partners.

Although the EU CBAM is ultimately an incremental charge, we see a number of potential near-term relative beneficiaries:

- **Producers of low-carbon solutions:** Arguably the most obvious to benefit, companies that have a lower carbon intensity EU CBAM-covered product offering relative to global peers may see increased demand from European customers. An implicit "green premium" could result from this increase, despite any margin implications being driven by lower CBAM-related costs for such products as opposed to an increase in product pricing.
- **European low-carbon-facility operators:** We estimate that European producers with more sustainable products could benefit from a temporary early mover advantage, even in highly carbon-intensive industries, such as cement.
- **Steel value chain—scrap steel and EAF steel production:** The EU CBAM will incentivize a more rapid transition toward electric arc furnace (EAF) use from blast furnace (BF) use. (About 70% of the world's steel is currently produced via BF, which has a carbon intensity 75% higher than an EAF.) Because scrap steel is a key feedstock into an EAF, we see its producers as likely beneficiaries.

- **Audit and assurance:** One of the biggest near-term challenges for companies is meeting the compliance and reporting obligations of their customers. This challenge has multiple layers, including adjusting monitoring and reporting to meet the EU definition of direct versus indirect emissions. Companies we have spoken with have commented that doing so will likely require in-house or outsourced engineers to work alongside sustainability teams. Receiving assurance on EU CBAM disclosures will be a mandatory requirement under the regulation once the Definitive (payment) Period begins in 2026.

European Natural Gas Prices

The European energy crisis started in 2021, with a tight gas market exacerbated by the Russia–Ukraine conflict. Gas and power outlays rose approximately €2 trillion in 2022 (of which €0.8 trillion was imported), creating an affordability crisis and fears of deindustrialization. The LNG supply response—with a customary four to five years' time to market—is now under construction, with LNG supply set to accelerate from the beginning of 2025, we estimate. It will bring a total 204 million tons per annum (mtpa) of LNG onto the market by 2028, according to our estimates, almost 2× the 115 mtpa of curtailed Russian supplies to Europe. The increase will bring the global gas market back into material oversupply, especially in 2026–28. Sectors that benefit the most from lower gas prices are industrials and European cyclicals. The deindustrialization theme has become a growing concern over the past few years, mainly because of a challenging cost environment driven by high energy prices and regulatory hurdles. Lower energy prices could ease such concerns and have material benefits to the European consumer, reducing the average bill for a European household by about €218/month according to our estimates.

European Carbon Market and Carbon Capture Economics

Changes in the EU ETS system will likely mean changes in carbon pricing. Historically, the European carbon price has been correlated with the coal-to-gas pricing ratio, given that power generators have been buying more than 90% of total carbon allowances since 2016, while such sectors as industry and aviation have been receiving more than 90% of carbon allowances as free allocations. We argue that the upcoming changes in the ETS system suggest the European carbon market will no longer be correlated with the economics of coal-to-gas switching (effectively, the decarbonization of power generation) and will converge to the economics of industrial carbon capture (effectively, the decarbonization of industry)—mainly because of the phase-out of free allocations for industry in 2026–34 coupled with the introduction of the CBAM in 2026.

Carbon capture cost varies for different industrial applications. CCUS encompasses a range of technologies and processes that are designed to capture the majority of CO_2 emissions from large industrial point sources and then provide long-term storage solutions or utilization. The CCUS chain consists of processes that can be broadly categorised into three major parts: (1) the separation and capture of CO_2 from gaseous emissions; (2) the subsequent transport of this captured CO_2, typically through pipelines, to suitable geological formations; and (3) the storage of CO_2—primarily in deep geological formations, such as former oil and gas fields, saline formations, or depleting oil fields—or the utilization of captured CO_2 for alternative uses and applications (e.g., to help produce synthetic hydrogen based fuels). The cost of capturing CO_2 is the key contributor to the total cost and can vary significantly between different processes, mainly according to the concentration of CO_2 in the gas stream from which it is being captured, the plant's energy and steam supply, and integration with the original facility. For some processes, such as ethanol production and natural gas processing or after oxy-fuel combustion in power generation, CO_2 can be already highly concentrated, leading to costs below $50/trillion CO_2eq (as in natural gas processing, ethanol, and ammonia). For more diluted CO_2 streams, including the flue gas from power plants (where the CO_2 concentration is typically below 20%) or a blast furnace in a steel plant (20%–30%), the cost of CO_2 capture is much higher. The average industrial carbon sequestration cost used in our European cost curve is approximately $120/ton.

Conclusion

Achieving the goals set by the Paris Agreement is one of the most significant challenges of our time, requiring policy coordination, efficient financing, and technological innovation.

In this chapter, we examine the progress of some key low-carbon technologies and present the Carbonomics cost curve, an important tool for investors and corporates to assess the cost of decarbonization across different sectors. In 2023, we saw significant deflation in technologies dominated by China such as battery and solar panel prices, which moved the cost curve lower despite higher interest rates and clean tech inflation. As a result, we estimate that the initial roughly 50% of global anthropogenic greenhouse gas (GHG) emissions—what we classify as "low-cost decarbonization"—can now be abated at an annual cost of about $1.0 trillion based on our 2023 Carbonomics cost curve. By sector, CO_2 cost for power generation remains the lowest on the Carbonomics cost curve while Transportation mostly sits in the "high cost" area of the decarbonization cost curve. That said, we estimate that the weighted average carbon abatement cost in power generation increased by about 3× year over year—from $20/ton in 2022 to $66/ton in 2023—owing to cost inflation in offshore wind and higher interest rates. In contrast, Transport saw a 30% year-over-year decrease in the weighted average carbon abatement cost in 2023—to $422/ton CO_2 equivalent—thanks to the material deflation in battery costs.

We also believe that carbon pricing will be a critical part of any effort to move to net-zero emissions, while incentivizing technological innovation and progress in decarbonization technologies. The current carbon market is developing worldwide but it still has limited reach in terms of compliance. At present, 73 carbon pricing initiatives are underway, covering 39 national and 33 regional governments worldwide. Carbon pricing initiatives cover only up to 24% of global GHG emissions, however, even with the addition of China in 2021, and the global weighted average carbon price is only $5/ton. In Europe, we argue that the carbon market is at a crossroads, growing from a successful but narrow instrument that facilitates the move away from coal power generation to a driver of decarbonization across much of the European economy. We expect lower natural gas prices in the second half of the decade (driven by a 50% increase in the global LNG market), which should provide an opportunity for EU policymakers to push the EU ETS to the price level required for the decarbonization of heavy industry (€100–€130/ton based on our 2023 Carbonomics cost curve) without energy cost inflation to industry and consumers. Carbon pricing also needs to be fair and prevent carbon leakage. The EU CBAM in 2026 could help address this issue by placing a tariff-like cost on emission-intensive imports and exports to reconcile the difference in carbon pricing between the EU and its trading partners.

Finally, ambitious new regulations are also emerging for clean tech innovations, and government incentives have potential to unlock large-scale clean tech development. We analyze in detail the example of the US IRA, estimating that its incentives have reduced the US Carbonomics cost curve by 75% and already unlocked around $500 billion of clean tech investments.

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GLOBAL TRENDS AND DEVELOPMENTS IN CARBON PRICING

Bei Cui
Research Fellow, Monash Centre for Financial Studies,
Monash University, Melbourne, Australia

Nga Pham, CFA
Senior Research Fellow, Monash Centre for Financial Studies,
Monash University, Melbourne, Australia

Ummul Ruthbah
Senior Research Fellow, Monash Centre for Financial Studies,
Monash University, Melbourne, Australia

Trinh Le
Research Fellow, Monash Centre for Financial Studies,
Monash University, Melbourne, Australia

Jan Ahrens
CEO, SparkChange, Bremen, Germany

Roger Cohen
Founder, C2Zero, Sydney

This comprehensive report delves into the global trends and developments in carbon pricing, a pivotal tool for governments, companies, and investors to mitigate climate change and achieve net-zero emissions by 2050. Our analysis of global carbon-pricing mechanisms reveals significant progress during the past few decades, with a marked increase in both the coverage of emissions and the sophistication of pricing instruments. Carbon pricing is a powerful tool for achieving net-zero emissions, providing financial incentives for reducing greenhouse gas emissions and supporting the development of low-carbon technologies. The Real Carbon Price Index offers a transparent global benchmark for carbon pricing, enabling better decision making for policymakers, businesses, and investors. Investors should care about carbon pricing because it affects the profitability of high-emission companies. Understanding the trends in carbon pricing will also assist investors in managing carbon-pricing-related regulatory risks. In the journey to net zero, investors play an important role in accelerating the shift to cleaner technologies, supporting sustainable long-term growth, and ensuring portfolios are resilient in a low-carbon economy.

Carbon pricing started in the early 1990s, when Finland became the first jurisdiction in the world to formally adopt a scheme mandating a price on carbon pollution. Although many countries and regions followed Finland's lead, jurisdictions with mandated carbon prices today remain in the minority. Only about 24% of global greenhouse gas (GHG) emissions are covered by a carbon price—through either an emissions trading scheme (ETS) or a carbon tax (World Bank 2024).

Putting a price on carbon has a single overriding aim: to create a financial imperative for organizations to consider the cost of emitting carbon (or polluting) in their operations and activities. As such, carbon pricing aims to incentivize organizations to cut emissions. According to CFA Institute Research and Policy Center (Urwin 2024), the net-zero transition journey relies on much more significant policy interventions by governments, including a much more robust carbon-pricing framework. The Carbon Pricing Leadership Coalition—composed of a number of economies, civil society representatives, and international institutions, such as the World Bank and the International Monetary Fund (IMF)—calls carbon pricing "one of the strongest policy instruments available for tackling climate change."[1]

Although all carbon-pricing schemes require polluters to pay to pollute, ETSs have the additional attribute of financially rewarding some organizations for abating pollution. From its starting point slightly more than three decades ago, carbon pricing has evolved slowly and disparately into today's somewhat fragmented global array of schemes, with many different mechanisms and inconsistent pricing, compliance, and enforcement levels. Carbon prices vary enormously, from as high as US$153 per tonne in Uruguay to as little as US$0.085 in Poland[2] and zero in the many jurisdictions that do not set a price on carbon. The scope of emissions covered within individual systems is as fragmented as the pricing, with no uniformity about which forms of pollution and polluting are covered. Encouragingly, amid increasing global pressure to reduce emissions, a degree of convergence in the design and pricing of schemes is becoming apparent. The ultimate end point would be a uniform global carbon price, which would mean the cost of polluting becomes independent of location or activity, and the reward for abatement would be consistent and universal. Complexities around measurement, compliance, enforcement, and political and other factors, however, may mean this outcome may never be fully realized.

Because of the highly disparate nature of existing carbon-pricing schemes, measuring and analyzing them in aggregate has been difficult. To try to overcome the inherent challenges, researchers at the Monash Centre for Financial Studies—in collaboration with carbon-focused businesses C2Zero and SparkChange—have developed the world's first global carbon price index. Based on mandated carbon prices set by regulators and governments worldwide, the Real Carbon Price Index (RCPI) provides a notional composite global price of carbon, which, like other financial indexes, can be tracked over time. Combined with its various subindexes and related source material for interpretation, the RCPI is a powerful new tool for researchers, investors, and others seeking to draw meaningful conclusions about the disparate but growing collection of carbon-pricing schemes globally.

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[1]See www.carbonpricingleadership.org/what.

[2]As of 31 October 2024.

Background and Significance

The net-zero commitment of various stakeholders in the global economy, including governments, companies, and investors, aims to balance GHG emissions produced and removed from the atmosphere by 2050. This concept is rooted in the UN Intergovernmental Panel on Climate Change's Fifth Assessment Report (Intergovernmental Panel on Climate Change 2014) and emphasized in a special report on limiting global warming to 1.5°C (Intergovernmental Panel on Climate Change 2018). Net-zero investing involves transforming investment strategies to reduce emissions, support low-emission technologies, and engage in policy advocacy. Integrating systemic thinking, net-zero investing emphasizes long-term sustainability and resilience against climate risks, aligning financial returns with environmental impact.

Carbon pricing is a critical incentivizing mechanism for decarbonization to achieve net zero, particularly for companies and investors, because it internalizes the environmental cost of carbon emissions. Carbon-pricing mechanisms enhance the overall efficiency of capital markets by correcting market failures related to the externalities of carbon emissions (Urwin 2024). Carbon pricing creates financial incentives for businesses to reduce their carbon footprint and adopt low-carbon technologies by assigning a monetary value to carbon emissions. For investors, this pricing model aligns economic interests with environmental goals, making responsible investments more attainable and viable.

Investors play a crucial role in driving the transition to a net-zero economy. Decarbonization has been integrated into the investment process through both strategic and tactical asset allocation by both asset owners and asset managers. The integration is a multifaceted approach that involves investors setting their net-zero commitment with clear carbon reduction targets, divesting from high-carbon assets, investing in climate solutions and companies with progressive transition, engaging with companies on climate issues, and using advanced data to form climate-related portfolio strategies. Investors can influence corporate behavior by directing capital toward more sustainable ventures, thus driving innovation and growth in the green economy. This strategic shift reflects the realization of climate change as a significant financial risk and the net-zero transition as an opportunity for long-term value creation.

There is a growing recognition of the significance of carbon costs in the long-term risks and opportunities associated with climate change for companies. These factors affect how investors manage the financial risks posed by carbon-intensive assets, which is critical in ensuring that investment portfolios are resilient to climate-related risks.

The transparent and predictable nature of carbon pricing allows investors to make informed decisions, supporting companies leading the transition to a low-carbon economy. The RCPI is the world's first and most comprehensive index of carbon prices, providing a transparent, global benchmark for carbon pricing. This index reflects the true cost of carbon emissions across various jurisdictions, enabling investors to make more-informed decisions. Understanding the real carbon price helps investors assess the financial risks and opportunities associated with carbon-intensive and low-carbon assets—and thus achieve better and optimal capital allocation toward responsible investment. Finally, putting the right price on carbon can encourage and finance innovation in green technologies, which are crucial for the transition to a net-zero economy (Cui, Ruthbah, Cohen, Ahrens, and Pham 2021).

Historical Evolution of Carbon-Pricing Mechanisms

The journey of carbon pricing reflects a progressive but uneven evolution over the past three decades. Initially implemented as a pioneering tool for GHG emissions, carbon-pricing mechanisms have grown in scope and sophistication. This section delves into the historical development and diversity of carbon pricing strategies.

Carbon Pricing Mechanisms

Carbon pricing is a crucial strategy for mitigating climate change by internalizing the external costs of GHG emissions. The main pricing mechanisms used globally are compliance systems, such as carbon taxes and market-based ETSs, and voluntary mechanisms.

Carbon Taxes

A carbon tax directly sets a price on carbon by defining a tax rate on GHG emissions or the carbon content of fossil fuels. This straightforward mechanism provides a clear economic signal to emitters. Companies must pay for every tonne of GHGs they emit, which motivates them to reduce emissions in order to lower their tax burden. Carbon taxes offer predictability in terms of carbon prices but do not guarantee a specific level of emission reduction.

The effectiveness of carbon taxes in reducing carbon emissions is well documented in various contexts and industries. A study by Floros and Vlachou (2005) indicates that a carbon tax of US$50 per tonne significantly reduced both direct and indirect carbon emissions from 1998 levels in Greek manufacturing. Alper (2018) shows that carbon taxes effectively reduce post-2020 industrial carbon emissions as carbon prices rise. Among 30 investigated provinces, Inner Mongolia, Shandong, Shanxi, and Hebei rank as the top four provinces in China with the largest potential for industrial CO_2 reduction following the implementation of a carbon tax, owing to their significant coal production/consumption and total energy consumption (Dong, Dai, Geng, Fujita, Liu, Xie, Wu, Fujii, Masui, and Tang 2017). Sweden's experience, detailed by Andersson (2019), demonstrates that high carbon taxes can significantly cut CO_2 emissions without hindering economic growth.

Market-Based ETSs

An ETS sets a cap on the total level of GHG emissions and allows industries to buy and sell permits to emit these gases. The cap is typically reduced over time to decrease total emissions. Under an ETS, companies that reduce their emissions below their allocated permits can sell their excess permits to other companies. This dynamic creates a financial incentive for companies to reduce emissions more cost effectively. An ETS provides flexibility and economic efficiency by letting the market determine the carbon price, although the price can be more volatile than a carbon tax.

The effectiveness of ETSs in reducing carbon emissions is supported by substantial empirical evidence. Using machine-learning systematic review and meta-analysis, Döbbeling-Hildebrandt, Miersch, Khanna, Bachelet, Bruns, Callaghan, Edenhofer, et al. (2024) demonstrate that at least 17 of 21 carbon trading schemes have led to substantial emission reductions, ranging from −5% to −21% (adjusted to −4% to −15% after accounting for publication bias). Other studies suggest that the EU ETS has successfully reduced GHG emissions. For example, Bayer and Aklin (2020) show that the EU ETS saved approximately 1.2 billion tonnes of CO_2 emissions from 2008 to 2016, equivalent to 3.8% relative to total emissions. Furthermore, Brohé and Burniaux (2015) and Teixidó, Verde, and Nicolli (2019) reveal that the EU ETS encourages businesses to invest in greener technologies.

Voluntary Carbon Markets

Beyond regulatory mechanisms, numerous voluntary carbon markets exist where carbon credits are traded. These credits represent realized or unrealized carbon abatement and allow for voluntary offsetting of pollution. Voluntary carbon markets are characterized by their fragmentation and lack of regulation, leading to significant variation in carbon credit prices. Despite their potential to foster innovation in carbon reduction projects, these markets often face challenges with respect to transparency, credibility, and standardization.

Specialized Offsets and Allowances

Some industries and sectors use specialized offsets and allowances tailored to their specific carbon reduction needs. Examples include offsets for aviation emissions under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) and allowances under sector-specific regulatory frameworks, such as the large-scale generation certificates issued by the Australian government for renewable energy generation projects.

The voluntary mechanism and specialized allowances are not included in the scope of the Monash/C2Zero RCPIs.

Carbon Taxes over Time

In January 1990, when Finland introduced the world's first carbon tax, its tax rate was initially set at only US$1.75 (€1.12) per tonne of CO_2 emitted, and the scheme accounted for only 0.1% of global emissions (Khastar, Aslani, and Nejati 2020; Sumner, Bird, and Dobos 2011; World Bank 2021). Since 1990, however, Finland's carbon price has significantly increased; by 2024, it was about US$72 (€62) per tonne (World Bank 2024). As of 31 October 2024, 21 European countries have carbon taxes, ranging from US$0.085 per tonne in Poland to US$153.013 per tonne in Uruguay. A further nine countries outside Europe have also introduced carbon taxes: Canada, Mexico, Colombia, Argentina, Uruguay, Chile, Japan, Singapore, and South Africa. According to the World Bank's Carbon Pricing Dashboard, a total of 31 national jurisdictions are covered by some form of carbon tax.

Japan's carbon tax program, introduced in 2012, is among the most comprehensive in the world—covering all fossil fuels for all sectors—and accounts for a greater share of global emission coverage than any other national or subnational tax initiative. Covering 80% of Japan's emissions, it represents 1.51% of global GHG emissions (Hofbauer Pérez and Rhode 2020; World Bank 2024). This results in part from Japan being the world's fifth-largest emitter of GHG emissions,[3] with 90% coming from energy-related activities (Timperley 2018).

In addition, there are eight subnational carbon tax programs covering five regions in Mexico, two in Canada, and one in Taiwan. In total, the national and subnational tax programs accounted for approximately 5 gigatons of CO_2 emissions in 2024, representing 6% of global GHG emissions (World Bank 2024).

ETSs over Time

Under ETSs—also referred to as cap-and-trade schemes—governments (or regulators) typically allocate or auction emission allowances to polluters, with a "cap" or upper limit on the quantity of emissions allowed within the system. Participants can trade allowances among themselves, buying them to cover their polluting activities or selling surplus allowances to other polluters. Over time, emission caps are lowered, forcing companies collectively to reduce their emissions through investment in sustainable technologies.[4]

One of the first ETSs was the EU ETS, launched in January 2005. As of June 2024, it covers emissions from electricity and heat, aviation, mining and extraction, and industry across the 27 EU member countries plus Iceland, Liechtenstein, Norway, and Northern Ireland, and it accounts for 2.59% of global

[3]See the World Population Review, "Greenhouse Gas Emissions by Country 2024." https://worldpopulationreview.com/country-rankings/greenhouse-gas-emissions-by-country.

[4]The various schemes are characterized by many similarities—and many differences—that are not covered in full detail in this document. For more information, see, for example, International Carbon Action Partnership (2021).

emissions. Nearly all pollution permits were allocated for free during the initial phase (Abnett 2020).

The introduction of the EU ETS led to a significant increase in the percentage of emissions covered by carbon pricing globally, from approximately 0.5% in 2004 to 5% in 2005, with the EU scheme accounting for 2.59% of global GHG emissions (World Bank 2024). At the time of its launch, however, the system was heavily oversupplied with allowances, resulting in a low, suboptimal carbon price that did little to discourage emissions (Abnett 2020). Since then, the scheme has been amended in each phase to control the oversupply of allowances and ensure higher, more robust carbon prices to achieve emission reduction targets. The most notable change was the introduction in 2019 of the Market Stability Reserve, a mechanism established to reduce the surplus of emission allowances in the market (European Commission 2021). These Phase 3 changes led to dramatic increases in the price of EU allowances, from around US$6 in April 2013 to US$69.94 in October 2024.

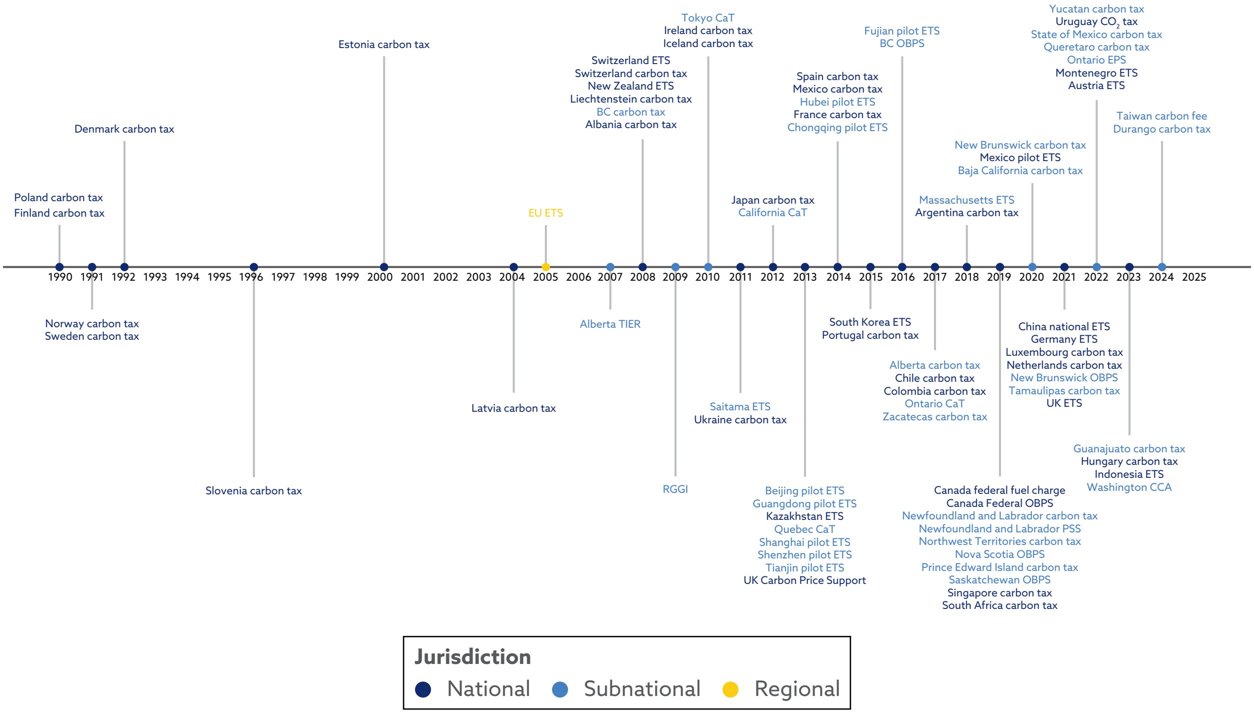
The EU ETS has inspired the development of emission trading in other countries and regions, including China's new national ETS, which accounts for the largest share of global GHG emissions—9.30%. Eleven ETSs are operating nationally: in Austria, Canada, Germany, Indonesia, Kazakhstan, Mexico (a pilot scheme), Montenegro, New Zealand, South Korea, Switzerland, and the United Kingdom. In addition, 20 ETS initiatives are operating in various subnational jurisdictions. Eight of these programs operate in the Chinese provinces of Beijing, Chongqing, Fujian, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin, part of China's pilot ETS program. Another significant scheme is the subnational cap-and-trade system for California and Quebec, known as the Western Climate Initiative (WCI). Established in 2014, it allows companies to buy and sell emission allowances on each other's carbon markets. The combined markets of the WCI and the Regional Greenhouse Gas Initiative (RGGI)—a joint initiative of several eastern US states—account for 0.28% of global GHG emissions (World Bank 2024). The Canadian province of Nova Scotia also introduced an ETS in 2018. These programs cover 10.18 gigatons of CO_2 emissions, or approximately 18% of global GHG emissions.

Exhibit 1 includes a timeline tracking the introduction of carbon taxes and ETSs in various jurisdictions.

Considering both carbon taxes and ETSs, 75 jurisdictions have a price on carbon, covering 23.35% of global carbon emissions. However, the physical carbon price is still zero for approximately 76% of global emissions, including those from many of the world's biggest polluters—including India, Russia, Brazil, Iran, Saudi Arabia, Turkey, and Australia.[5]

[5]Listed from highest emissions to lowest, those seven countries collectively account for about 20% of global emissions, according to data from the European Commission's EDGAR (Emissions Database for Global Atmospheric Research) Community GHG Database (https://edgar.jrc.ec.europa.eu/report_2023).

Exhibit 1. Timeline of the Introduction of Carbon Taxes and ETSs



Source: Data from World Bank (2024).

The Development of a Global Carbon Price Index

Carbon pricing is fragmented, with varying approaches and price levels across regions and countries. This fragmentation challenges businesses operating globally, because they must navigate a complex landscape of diverse carbon-pricing mechanisms. Differences in carbon prices can lead to competitive imbalances, where companies in regions with lower or no carbon pricing gain an unfair advantage. Fragmented pricing also complicates efforts to achieve global emission reduction targets, because of the lack of uniformity needed to drive consistent and effective climate action.

Governments, businesses, and international organizations are also increasingly supporting a unified global carbon price and coordinated global carbon-pricing framework. For example, the IMF proposes an international carbon price floor, which sets a minimum price for GHG emissions: US$75 per tonne in high-income economies, US$50 in middle-income economies, and US$25 in low-income economies. This tiered approach reflects differing economic capacities while promoting global emission reductions (Parry, Black, and Roaf 2021). The World Trade Organization initiated a Global Framework for Climate Mitigation policy, which sets a global average carbon price to meet climate goals; adjusts prices based on historical emissions, economic development, and climate impact costs; allocates revenues to support vulnerable economies; and allows alternative emission reduction policies, aiming to reduce economic disparities and prevent policy fragmentation (Bekkers, Yilmaz, Bacchetta, Ferrero, Jhunjhunwala, Métivier, Okogu, et al. 2024).

A single carbon price enhances market efficiency by simplifying the carbon trading market, reducing complexity, and increasing transparency. This uniformity creates a level playing field for businesses globally, eliminating competitive disadvantages and preventing "carbon leakage," whereby companies relocate to regions with lower or no carbon pricing.

Methodology of the RCPI Construction

The development of a robust and transparent global carbon price index requires a comprehensive and meticulous methodology. The RCPI leverages a blend of quantitative and qualitative data sources to capture the diverse and fragmented nature of global carbon pricing mechanisms. This section outlines the approach taken to construct the RCPI, highlighting the criteria used and the key data sources that underpin its accuracy and utility.

Criteria and Data Sources Used for RCPI

Index Constituents

Because of the absence of comprehensive and reliable data from the early years of carbon pricing in Europe, the Monash/C2Zero RCPI shows the evolution of the global aggregate carbon price from a starting point of 2013. By this time, the carbon price index "universe" consisted of 20 national, regional, and subnational jurisdictions. In subsequent years, the scope covered by the index increased, as did the number of instrument constituents. As of October 2024, 75 national, subnational, and regional jurisdictions had implemented a carbon tax or carbon ETS (World Bank 2024). Our indexes cover 70 of those jurisdictions. The other jurisdictions were excluded because of the lack of available data. Of the 36 jurisdictions with an ETS, the index includes only 32 for which data are available.[6]

Scope Data

The data on each jurisdiction's coverage of global GHG emissions (or scope) are sourced from the World Bank's Carbon Pricing Dashboard.[7] We updated our scope as the dashboard included more jurisdictions with scope information.

[6]For example, for the two Mexican subnational jurisdictions—Baja California and Tamaulipas—the scope or the tax rates were unavailable, prompting their exclusion from the index. The emissions covered by the UK Carbon Price Support overlap 100% with the EU ETS and are excluded from the index. The Kazakhstan ETS was implemented in 2013, but data for it are only available beginning in December 2019; therefore, Kazakhstan has been included in the index only since 2019.

[7]For 7 of the 70 jurisdictions in our index universe—Estonia, Iceland, Latvia, Liechtenstein, Prince Edward Island, the Northwest Territories, and the Netherlands—the scope was missing from the dashboard in 2021 when we introduced the index. For these jurisdictions, the scope was extracted from the "GHG emissions in the jurisdictions (2015)" and "Share of jurisdiction's GHG emissions covered" individual jurisdiction pages on World Bank's dashboard.

Price Data

Pricing is not available from a single source. Price disclosure varies across markets and instruments, and certain instruments' prices are not always available daily. Carbon tax rates in local currency units (LCUs) and US dollars are collected from the World Bank's annual State and Trends of Carbon Pricing reports, the Carbon Pricing Dashboard, and various government websites.[8] ETS carbon prices are sourced from various market data providers, including Bloomberg, Refinitiv, and WIND, as well as various government websites. Liquid spot prices (where available) are used for ETS carbon pricing. For jurisdictions with unavailable ETS spot prices, ETS auction prices or prices adjusted from ETS futures are used. In the event that no new prices for a particular jurisdiction are available, the index will continue to be calculated based on the last available prices.

Exhibit 2 shows the prices and the GHG percentage covered by each jurisdiction included in the RCPI as of 31 October 2024.

Large gaps remained among the average carbon prices set by the jurisdictions included in the RCPI and the target range of US$50–US$100 by 2030 suggested by the High-Level Commission on Carbon Prices (World Bank 2017) and the IMF's suggested 2030 price floor of US$75 per tonne for advanced economies and US$50 for high-income emerging market economies.[9] Only six jurisdictions—Finland, Liechtenstein, Norway, Sweden, Switzerland, and Uruguay, in order of ascending carbon price—have a carbon price higher than US$75, as of the end of October 2024. China's national ETS—the biggest contributor in terms of the percentage of global GHG emissions—and other pilot ETSs in China all price carbon at a fraction of the IMF's target.

Index Construction

The RCPI provides a comprehensive measure of global carbon prices, representing all carbon prices and all emissions from all jurisdictions globally. It includes both emissions subject to carbon prices and those with no price; the latter are included in the index using a price of zero. The index allows the calculation of a global carbon price and its evolution over time (adding dispersion and other measures) and provides tools for interpretation and analysis.

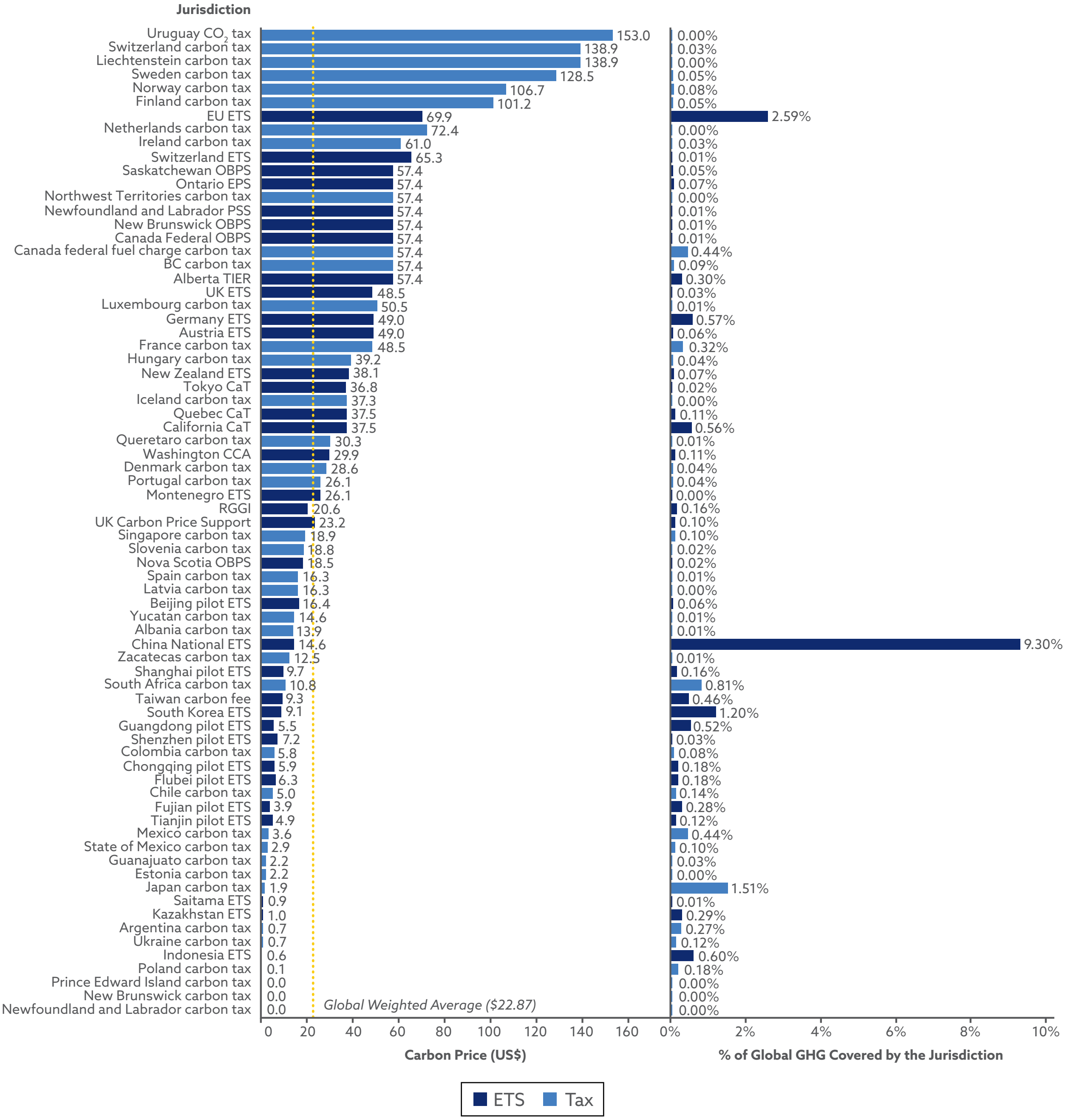
We use the following formula to calculate the level of the RCPI at any point in time:

$$\text{Index level} = \frac{1}{n}\sum_i w_i fx_i P_i,$$

[8]See www.realcarbonindex.org/indices.

[9]To keep warming below 2°C, the IMF suggested a 2030 price floor of US$75 per tonne for advanced economies, US$50 for high-income emerging market economies such as China, and US$25 for lower-income emerging markets such as India. See Parry (2021).

Exhibit 2. Carbon Price and the Scope of Global GHG Emissions Covered by Jurisdictions, 31 October 2024



where

- w_i is the percentage global scope (weighting) of emissions covered by instrument i, including the scope with zero price,
- $n = \sum_i w_i + w$(no carbon price): n is 100% for the global index and otherwise is the percentage coverage for relevant subindexes including the weighting for zero prices,
- $\sum_i w_i$ represents the scope or percentage of emissions in the index for which the price is nonzero,
- P is the price in the local currency of instrument i (note that for tax-based instruments, P_i will be largely static), and
- fx_i is the relevant foreign exchange rate for converting P_i (the local price) into the index currency.

Historical Carbon Price Movements

Various regional ETSs and carbon taxes were introduced in the last three decades, with European countries initially leading the way. China's pilot ETS in Guangdong, Hubei, Tianjin, and other regions appeared around 2014–2015, and Mexico, Portugal, and South Korea implemented their carbon taxes around 2015–2017. The introduction of carbon prices in new jurisdictions during the last few decades has significantly increased both the carbon price level and the scope of emissions covered under the index.

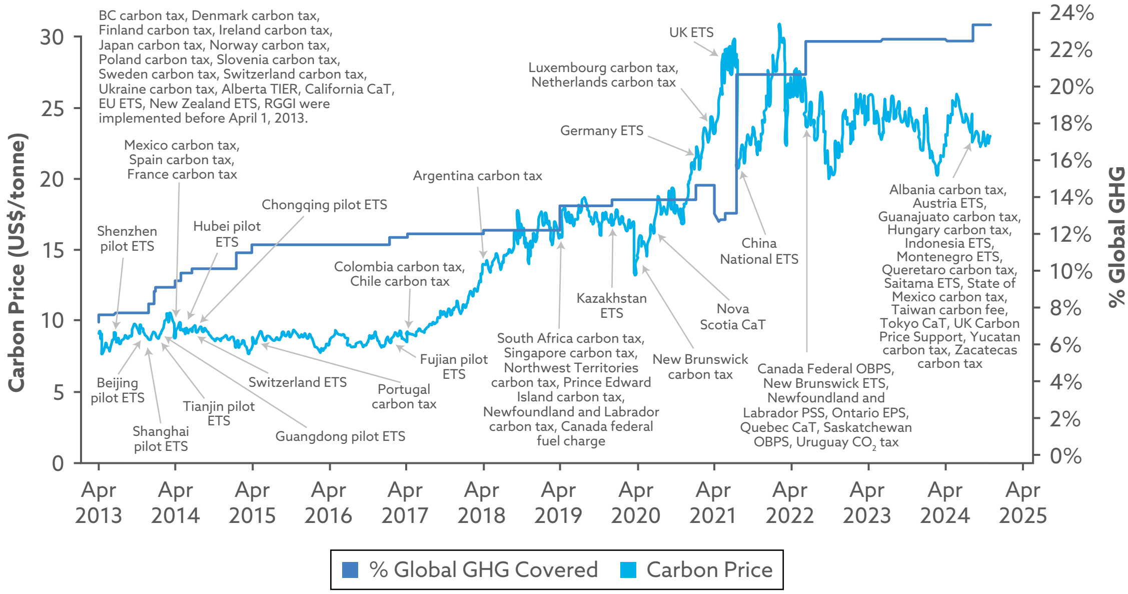
As shown in **Exhibit 3**, the RCPI has dramatically increased since the starting point, by almost 670%, from around US$0.70 in 2013 to US$5.34 in October 2024. The carbon price rose noticeably starting around 2017, coinciding with new implementations, such as the Fujian pilot ETS and carbon taxes in Argentina, Chile, and Colombia. The implementation of China's national ETS in July 2021 pushed the RCPI to a record high and extended the coverage to beyond 20% of global GHG emissions; this ETS represents the largest carbon market in the world.[10]

The coverage of global GHG emissions by both ETSs and carbon taxes has grown substantially, indicating a broader adoption of carbon-pricing mechanisms worldwide. Exhibit 3 highlights the expanding reach and evolving dynamics of carbon-pricing instruments in mandatory regimes during the last decade.

ETS coverage of global GHG emissions increased from 5.01% in 2013 to 17.69% in October 2024; during the same period, carbon tax regimes' coverage grew more modestly, from 2.87% to only 5.65%. The significant increase in ETS coverage reflects its growing role as a key tool in global climate policy. ETSs are

[10]China's national ETS covers more than 2,200 fossil-fuel power plants in China with about 5 billion tonnes of CO_2, which is 40% of the country's emissions; see https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-55.pdf.

Exhibit 3. The RCPI and the Timeline of Jurisdiction Inclusion, 2013–2024

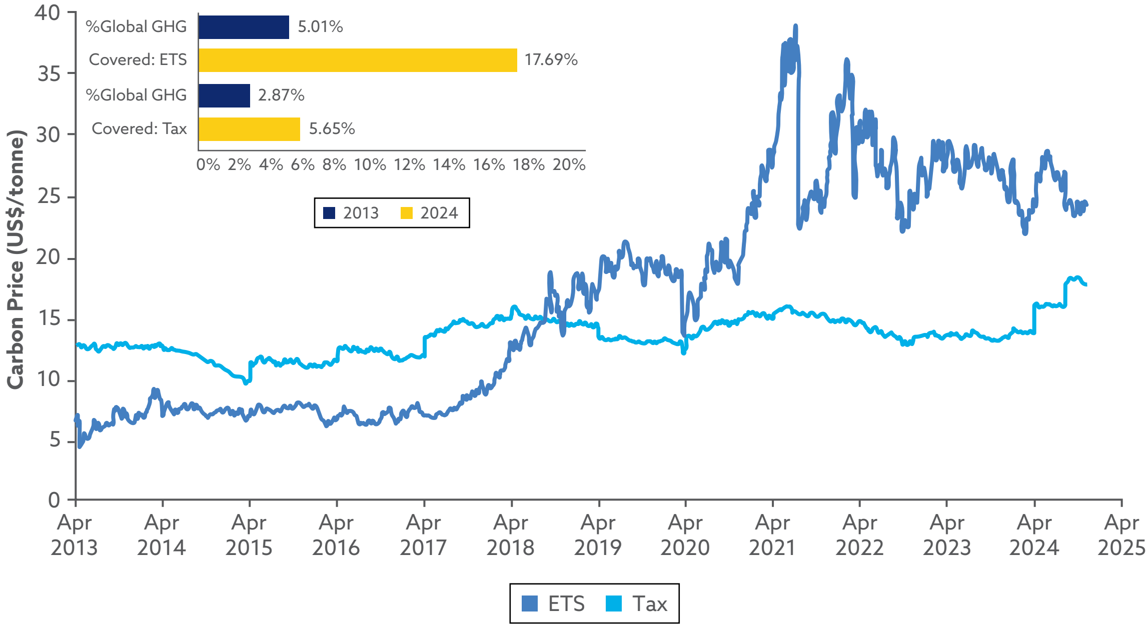


gaining popularity because they operate as a market-based mechanism that offers companies the flexibility to trade emission allowances and enables them to find the most cost-effective way to reduce emissions.

Exhibit 4 illustrates different pricing dynamics between ETSs and carbon taxes. The price index in Exhibit 4 represents the weighted average of ETSs and carbon taxes in jurisdictions that have carbon pricing. The weights are based on the scope of the GHG emissions covered. The price index of ETS jurisdictions has grown substantially since 2017–2018 and exhibited high volatility while the market price of carbon traded on these ETSs responds to major events and crises, such as the COVID-19 pandemic. Since mid-2018, the ETS carbon price has remained significantly higher than that of the carbon tax index. The steep rise in ETS prices from 2018 onward suggests increasing market activity, high carbon prices introduced by new ETSs (such as the UK ETS and Germany's ETS), and possibly stronger regulatory measures driving up the cost of emission allowances. An ETS typically sets a cap on total emissions, ensuring that the environmental goal is met. As the cap is reduced over time, total emissions decrease, putting upward pressure on the ETS's carbon prices.

In contrast, the carbon tax price index remained relatively steady—between US$10 and US$18 per tonne throughout the 2013–24 period—because jurisdictions do not often change their carbon tax level dramatically once it has been introduced. Its price level changes only when new jurisdictions join the index. The steadier nature of carbon tax prices suggests carbon taxes provide a more predictable cost for emissions but may lack the dynamic pricing signals of an ETS and flexibility for companies.

Exhibit 4. Carbon Prices under ETS and Tax Regimes, 2013–2024



Carbon Economy

Compliance carbon-pricing mechanisms are implemented to provide a financial incentive to invest in decarbonization technologies. They are not meant to be a penalty to fund climate change mitigation. Thus, to assess carbon-pricing levels in the context of the clean energy transition, it is imperative to evaluate abatement technology cost curves required to achieve the transition to a low-carbon future.

The High-Level Commission on Carbon Prices (World Bank 2017) found that a global average carbon price of US$50–US$100 per tonne is needed by 2030 to achieve the goals of the Paris Agreement. Parry, Black, and Zhunussova (2022, p. 15) found that a "price floor of $75, $50, and $25 per tonne for high-, medium- and low-income countries, respectively, would be sufficient to align global CO_2 emissions in 2030 with keeping global warming below 2°C, even with only six participants (Canada, China, EU, India, United Kingdom, United States)." Both estimates have a wide range for climate-transition-aligned carbon prices, but even the lowest ranges lead to a bleak verdict: The global average carbon price is nowhere near where it needs to be to incentivize the investments required to decarbonize the global economy and limit global warming below 2°C.

To put it in a broader context of the cost to the economy, the social cost of carbon has increased more than tenfold, from an estimated US$21 per tonne of carbon dioxide in 2010 to the latest estimate of US$225 in 2024 (See 2024). This increase highlights the need for faster movement in compliance carbon prices to incentivize changes in business behaviors and investments in decarbonization technology.

The IMF recognizes that different regions require different carbon prices, and the regional developments mirror this dynamic. Carbon-pricing mechanisms vary significantly across regions, as explained in the following section.

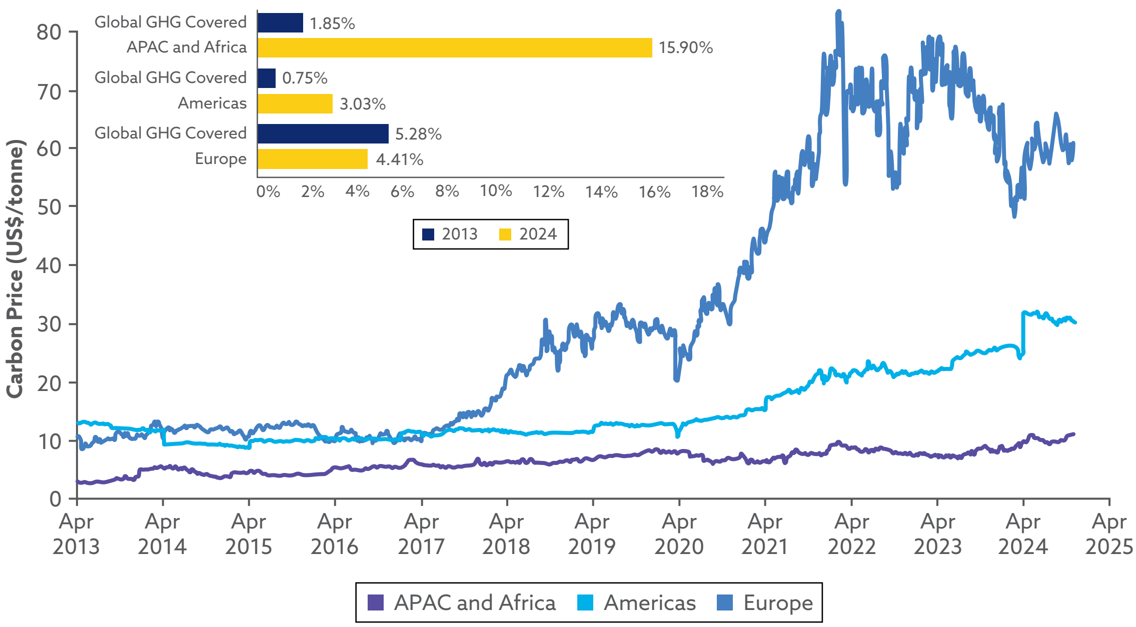
Regional Disparities

It is fascinating to examine regional disparities in the adoption of carbon-pricing mechanisms and the different levels of carbon prices. **Exhibit 5** provides a comprehensive overview of carbon prices in Asia Pacific (APAC) and Africa, the Americas, and Europe, together with the change in the scope of global GHG emissions covered by these regions during the last decade.

Although Europe exhibits a strong and increasingly stringent carbon market, the Americas and the APAC and Africa regions show more stable and steady price changes. The European regional index shows a significant upward trend during the last 10 years. Starting from around US$5 per tonne in 2013, it grew to around US$59 per tonne, on average, in 2024. This trend indicates a progressively tightening carbon market in Europe.

Notably, the European regional index peaked at US$83.25 per tonne in February 2022 but dropped below US$55 in March 2022 following the outbreak of the Russia–Ukraine War. The EU ETS, the major market in Europe, reached a historic peak of US$110.08 in early February and then plummeted by 14.25% within four trading days following the onset of the war (Real Carbon Price Index 2022). This drop marked one of the largest drawdowns in the history of the RCPI and the European regional index. Since then, both have also experienced a considerable increase in volatility.

Exhibit 5. Carbon Prices by Region, 2013–2024



The European regional index experienced another large drawdown in August 2022 when the EU ETS declined by 14.57% in response to Russia's extended shutdown of Nord Stream 1 and the growing likelihood of more sales of allowances to help fund the energy transition to reduce EU dependence on Russian fossil fuels—the REPowerEU plan (Real Carbon Price Index 2022).

The recent trends in carbon prices in Europe illustrate how susceptible these prices are to geopolitical risks and conflicts.

Case Study: The EU ETS

The EU ETS is a cornerstone of the EU's strategy to combat climate change and GHG emissions. Launched in 2005, the EU ETS operates across all EU countries plus Iceland, Liechtenstein, and Norway, covering approximately 40% of the EU's GHG emissions. It functions on a cap-and-trade principle, limiting the total emissions allowed from covered sectors (i.e., power and heat generation, energy-intensive industries, and commercial aviation) within the European Economic Area.

The EU ETS has evolved through four key phases. Phase 1 (2005–2007) was a pilot phase focused on establishing the market infrastructure and basic rules, primarily allocating free emission allowances. Overallocation led to a surplus, however, and hence a significant drop in carbon prices. Phase 2 (2008–2012) addressed this issue by tightening the cap and including additional gases, such as nitrous oxide and perfluorocarbons. This phase aligned with the Kyoto Protocol by allowing the use of international credits. Phase 3 (2013–2020) introduced significant reforms, including an EU-wide cap, expanded sector coverage, and the Market Stability Reserve, to enhance market stability. Phase 4 (2021–2030) aims to reduce net emissions by at least 62% by 2030, compared with 2005 levels. On 14 July 2021, the European Commission introduced some reforms to the Fit for 55 package, including revisions to the EU ETS. These revisions expand the EU ETS to cover maritime transport and introduce ETS 2 for buildings, road transport, and additional sectors. They also establish the Social Climate Fund, with €86.7 billion from 2026 to 2032 to support vulnerable groups; increase funding for the Innovation and Modernisation Funds; and adjust free allocation rules, including phasing out allowances for aviation and other industries.

Since its inception, the EU ETS has proven instrumental in driving down emissions from power and industrial plants by 37% through its cap-and-trade mechanism. Moreover, since 2013, the EU ETS has generated significant revenues, exceeding €152 billion, which contribute to national budgets. Beyond its financial impact, the EU ETS has served as a global model for similar carbon markets, illustrating the effectiveness of market-based mechanisms in combatting climate change on a worldwide scale.

The future trends in carbon prices are expected to be shaped by stronger climate policies, the expansion of carbon markets, economic conditions, technological advancements, investor and corporate actions, market dynamics, global cooperation, and social and political factors.

As governments set more ambitious climate targets, caps on emissions in ETSs will likely tighten, leading to higher carbon prices. The implementation of the EU's Carbon Border Adjustment Mechanism could raise carbon prices further by making it more expensive to import carbon-intensive goods.

The Americas and the APAC and Africa regions have shown more steady development during the last 10 years. The minimal change in carbon prices in APAC and Africa suggests either that carbon markets are still in nascent stages or that there are significant barriers to the implementation of more aggressive carbon-pricing strategies in these regions. However, the substantial increase in the proportion of global GHG emissions covered by carbon pricing in APAC and Africa from 2013 to 2024 indicates a promising trend toward greater engagement in climate action. Nevertheless, governments may need to develop more comprehensive and robust carbon-pricing policies to drive emission reductions.

The regional difference also illustrates the need for governments to improve on global coordination on carbon-pricing policies to prevent carbon leakage, where companies may choose to relocate to regions with less stringent carbon pricing.

Case Study: China's National ETS

In the late 2000s, China recognized the urgent need to control its rapidly increasing carbon emissions, leading to a commitment to international climate agreements and a shift in national policy direction toward more sustainable practices. Before implementing a nationwide carbon market, China launched pilot carbon trading systems in seven regions in 2013. These pilot projects, located in Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin, aimed to test and refine carbon-trading mechanisms suited to the Chinese context.

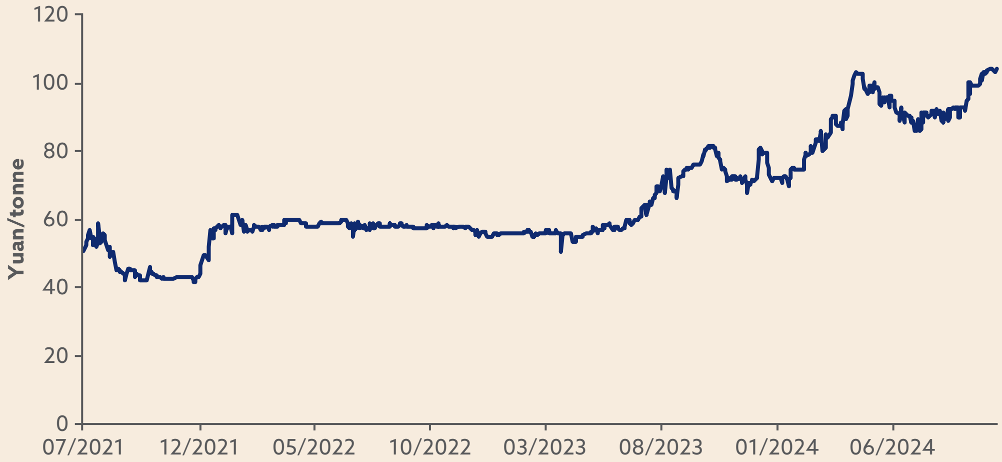
China announced its national ETS in 2017, with the official launch in January 2021. The Chinese Ministry of Ecology and Environment published key ETS policy documents, and by July 2021, trading commenced on the platform operated by the Shanghai Environment and Energy Exchange. Upon its inception, China's ETS became the world's largest carbon market, three times bigger than the European Union's system.

The national ETS initially covers more than 2,200 major emitters in the power sector. The current scope of the ETS includes annual emissions of nearly 5 billion tonnes of CO_2 a year, roughly 32% of China's total emissions and 9.3% of global total emissions (World Bank 2024). One allowance permits a company to emit 1 tonne of carbon. China plans to expand the ETS to include sectors like steel, cement, and aluminium by the end of 2024. This expansion is expected to cover around 60% of the country's total GHG emissions, thereby broadening the market's scope and potentially enhancing liquidity.

Trades are conducted electronically, allowing only spot transactions. Transactions are categorized as either listed or over-the-counter bulk trades. Currently, only covered entities are permitted to trade, excluding financial institutions and other speculators. Consequently, trading volumes and liquidity are major concerns. However, the Chinese government has indicated potential changes to enhance market dynamics and liquidity. As illustrated in **Exhibit 6**, on 24 April 2024, China's carbon price exceeded ¥100 (US$13.88) for the first time since the market's launch in mid-2021. On 21 October 2024, China's carbon price hit the record high of ¥104.25 (US$14.64) driven by large polluters increasing purchases ahead of stricter standards, yet permits remain significantly cheaper than equivalent permits in the EU, which closed at ~€61.4 (~US$66.4) per tonne on the same date.

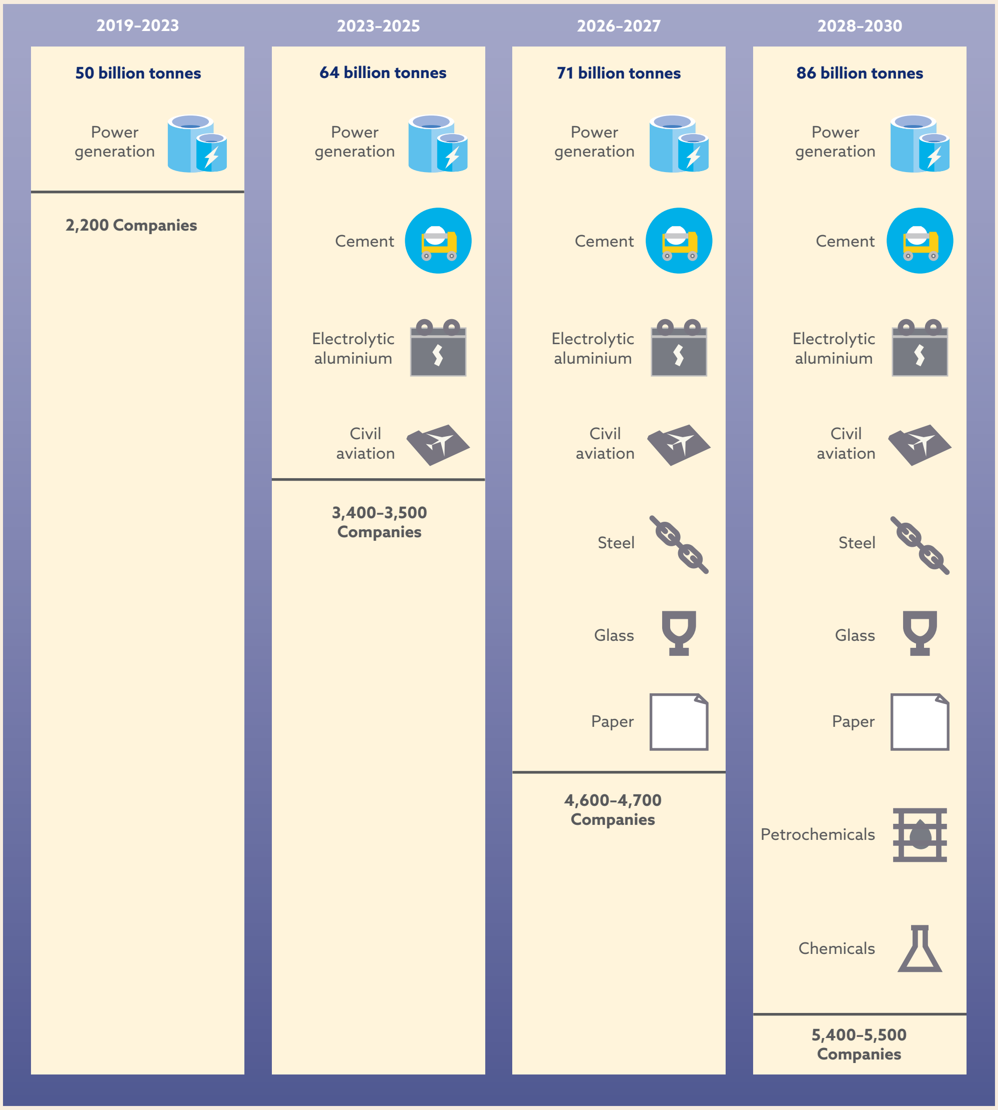
Investors can anticipate significant changes in China's carbon markets. China's ETS is set to expand, with plans to include heavy industry and manufacturing sectors, such as cement, aluminum, and steel, in response to the Carbon Border Adjustment Mechanism. This expansion will make it the largest global climate policy, covering more emissions than all other carbon markets worldwide combined.

Exhibit 6. China's National ETS Carbon Price, 2021–2024



According to the Center for Energy and Environmental Policy Research (2024), as shown in **Exhibit 7**, by the end of 2030, the annual number of enterprises covered by the national carbon market is expected to rise to approximately 5,500. The annual coverage of carbon dioxide emissions will exceed 8.6 billion tonnes, accounting for about 74% of the national total carbon dioxide emissions. The average transaction price of allowances is expected to surpass ¥200 per tonne.

Exhibit 7. Outlook on the Roadmap for Expanding Industry Coverage in China's National Carbon Market



Source: Center for Energy and Environmental Policy Research (2024).

Unlike the European Union's system, however, China's national ETS uses an emission-intensity-based approach, adjusting the cap according to actual production levels rather than an absolute cap. Additionally, quotas have been allocated for free during the first and second compliance cycles. Power generators with emission intensities exceeding the benchmarks face an allowance deficit. Although this approach boosts efficiency and phases out aging, inefficient thermal plants, it does not address overall absolute emissions.

During nearly a decade of pilot programs and three years focused on the national ETS, China's carbon market has established an institutional framework that clarifies stakeholder roles, enhances platform efficiency and data quality, and develops mechanisms for carbon price discovery and emission reduction incentives. Challenges persist, however, including limited industry coverage, lack of product variety, delayed allowance issuance, and low liquidity. To meet China's "dual carbon" goals, further improvements to the market system are essential.

Implications of Carbon Pricing for Capital Reallocation and Investors

Carbon price risk is significant for many companies, particularly for heavy-emitting companies. Therefore, it is essential that these companies manage such risks by developing an internal carbon price. An internal carbon price serves various purposes, ranging from business planning to driving carbon reduction initiatives. The following section discusses various internal carbon-pricing mechanisms and reports the discrepancies observed between reported internal prices and mandatory market prices. Companies should focus on increasing the adoption of internal carbon-pricing mechanisms and improving the transparency of their disclosures to align better with market realities and enhance accountability. The section also delves into the implications for investors' strategies including investing, hedging, engaging with their portfolio companies, and investment stewardship.

Implications for Capital Reallocation

Companies must stay abreast of evolving carbon-pricing regulations, particularly in regions where policies are more stringent, such as Europe. Noncompliance can result in significant penalties and legal risks. Firms operating in multiple regions need to navigate a complex landscape of different carbon-pricing mechanisms, requiring robust compliance and reporting frameworks.

Carbon pricing is no longer limited to companies participating in mandatory cap-and-trade programs. Today, businesses worldwide must incorporate carbon pricing into their models to accurately evaluate their assets, liabilities, and performance. A strategy to manage carbon price risk, especially for heavy-emitting companies, is to assess and integrate geopolitical risk into their internal carbon-pricing strategies. Companies can conduct scenario analyses of sudden changes in carbon prices and/or the introduction of new pricing mechanisms or new jurisdictions. These scenarios should consider various geopolitical, economic, and regulatory events and their potential impacts on carbon price levels and market stability. Setting an internal carbon price that accounts for potential disruptions can help manage financial risks associated with the volatile external carbon markets. Integral to this process is the ability to access accurate and updated carbon price information to benchmark the internal assumptions used in budgeting, capital allocation, and investment decisions.

According to the Carbon Disclosure Project (CDP)[11] survey in 2023, companies use internal carbon prices for various purposes—including business planning, project valuation for capital expenditure decisions, applying a carbon levy to business air travel, and internal allocation of costs to fund investments in energy efficiency and other carbon reduction initiatives. Although most companies use internal carbon pricing for all capital-expenditure decisions, some mentioned using it for only marginal projects. Some also reported using models that allow them to integrate carbon-related costs into traditional financial capital budgeting metrics.

There are three main alternative mechanisms for setting an internal carbon price: an internal carbon fee, a shadow price, and an implicit price.

An internal carbon fee is an internally determined fixed fee per tonne of carbon emitted by the organization. For example, Microsoft determines its carbon price from the total funds needed for all environmental initiatives divided by its projected emissions. The price is then charged to each business unit based on the emissions associated with their energy consumption and business air travel. Funds are collected from the business units to spend on environmental initiatives, such as energy-efficiency projects and carbon-offset projects. This approach is adopted in Australia by investment giant AMP and insurer QBE.

Alternatively, companies may use a shadow price—a hypothetical price used as a surcharge when evaluating the price of projects that involve the creation of carbon emissions. The purpose of the price was to support initiatives that are more emission efficient. Their prices ranged from just less than US$1.00 to almost US$150, with several companies using a substantially wide range of prices for scenario analysis.

The third alternative mechanism—an implicit price—generally involves organizations applying an average cost per tonne of emissions to meet their emission reduction targets.

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[11]See CDP Climate Change 2023 Questionnaire: https://guidance.cdp.net/en/guidance?cid=46&ctype=theme&idtype=ThemeID&incchild=1&microsite=0&otype=Questionnaire&tags=TAG-13071%2CTAG-605%2CTAG-599.

The main difference between an internal fee and the other two mechanisms—the shadow price and the implicit price—is that only the internal fee results in real financial flows within organizations. An example of this scenario occurs when a company uses an internal fee as a carbon levy on all business air travel (Scope 3) spent across the entire company. The funds from the levy are either used to purchase offsets or allocated to environmental initiatives.

Many companies are also engaging in voluntary markets to generate or purchase carbon offsets. The carbon prices from the mandatory market could serve as an anchor price for voluntary markets and, therefore, should be considered in such decisions.

Yet according to the CDP's worldwide survey in 2023,[12] only 13% of 10,475 companies responding to the survey reported using an internal carbon price. Another 19% reported that although they currently do not have an internal carbon price, they anticipate using one in the next two years. The remaining 78% either did not anticipate having one in the next two years or did not respond to the question.

The large disparities among countries on the level of corporate internal carbon pricing and the gap between internal carbon prices and the carbon prices set by the compliance markets, including taxes and ETSs, are illustrated in **Exhibit 8**.

Exhibit 8 highlights the varying degrees of alignment between corporate internal carbon pricing and national mandatory carbon pricing across various countries, among those companies that disclosed the internal carbon prices in the CDP survey (Carbon Disclosure Project 2023).[13] The exhibit illustrates the median internal carbon prices compared with the average carbon taxes and ETS prices weighted by the global GHG emissions covered by each scheme in the market, if there are various schemes in a single market.

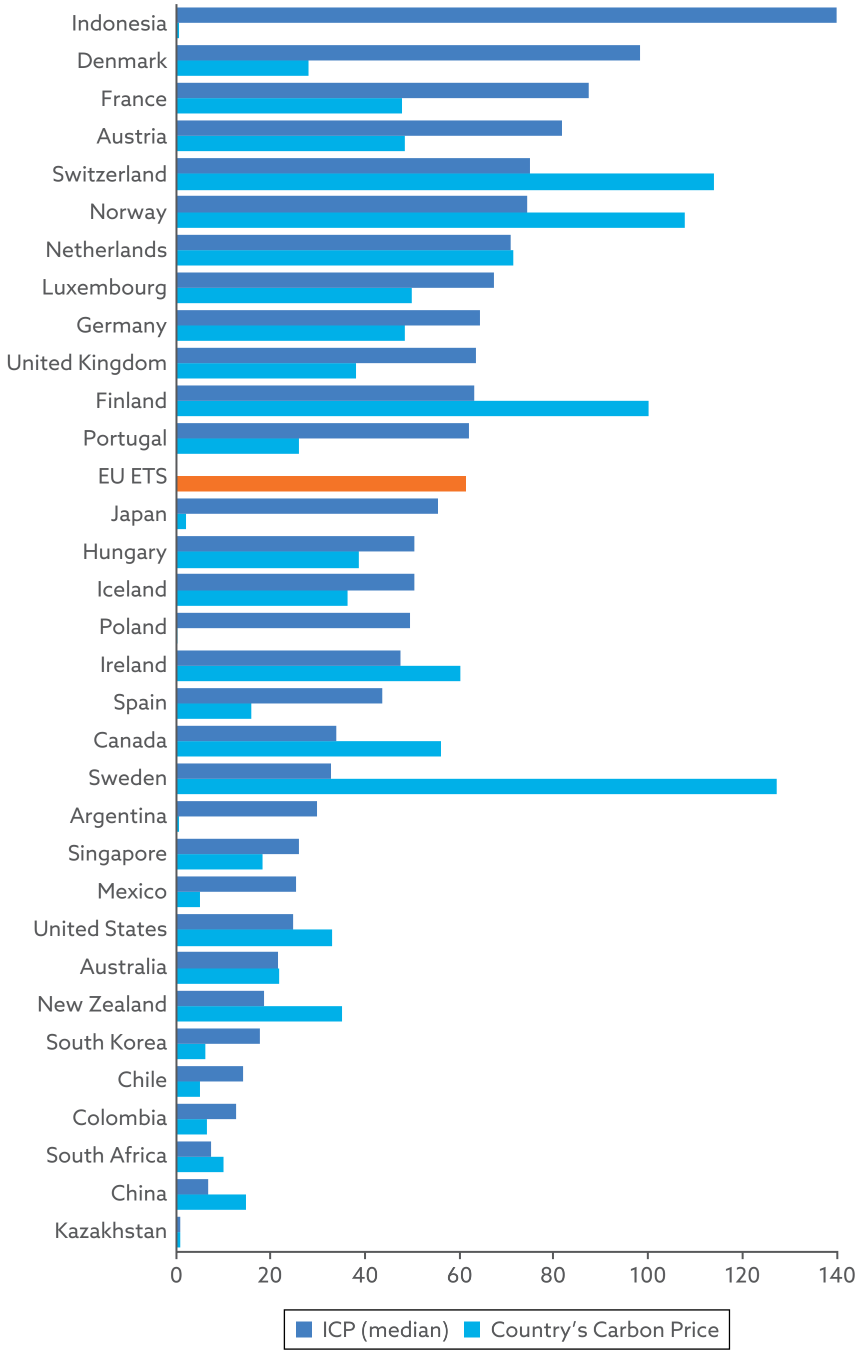
Corporations in some countries, such as Austria, Denmark, France, Germany, Luxembourg, Poland, and the United Kingdom, are proactively setting higher internal prices compared with the mandatory price of carbon. Notably, many of these countries are members of the EU ETS. Conversely, in other countries, such as Canada, China, Finland, Ireland, Norway, Sweden, Switzerland, and the United States, mandatory carbon prices are higher than companies' internal carbon prices.

The analysis reveals that the adoption of internal carbon prices among companies is still relatively low. Among those that have disclosed using an internal carbon price, there are significant discrepancies between their internal prices and the mandatory market prices. The authors recommend that

[12]CDP 2023 Climate Change Survey Dataset.

[13]Data for the internal price of carbon were taken from Question C11.3-C11.3a_C8 of the survey: "Provide details of how your organization uses an internal price on carbon: Actual price(s) used—minimum per metric ton CO_2e (in local currency)" (Carbon Disclosure Project 2023). Data for mandatory carbon prices were taken from the World Bank Carbon Dashboard.

Exhibit 8. Internal Carbon Prices vs. Carbon Prices in the Compliance Markets



Note: The carbon price for the EU ETS appears in orange to distinguish it from the other data because it tends to serve as a benchmark for markets participating in the EU ETS.

companies increase the adoption of internal carbon pricing and enhance the transparency of their disclosures.

Companies should also enhance their communication of measures taken to manage carbon price risks as part of their climate-related financial disclosures. Transparent reporting on how companies could be affected by future carbon costs, and the resulting corporate strategies, can build investor confidence in their net-zero investing journey.

Implications for Investors

Investing and Hedging

Carbon has also been considered one of the newest investment asset classes. In 2023, the carbon market reached US$909 billion in terms of traded value, with 12.5 billion tonnes of carbon allowances (Verma and Chestney 2023). Investors may also want to invest in carbon allowances either directly as a commodity or indirectly via synthetic products via the futures market to hedge against carbon price risks. With several liquid and investable markets, such as the EU ETS, the UK ETS, the Californian CaT, and the RGGI,[14] investors are increasingly able to access this new asset class.

First, the asset class can attract investors because returns are uncorrelated and the future returns profile looks attractive. Carbon has low correlations with traditional asset classes (such as equity and fixed income), providing an opportunity for investors searching for uncorrelated absolute returns. Furthermore, carbon markets usually include increasing scarcity by design, as ambitious emission reduction policies imply a decline in annually available carbon allowances.

Exhibit 9 shows a correlation matrix for the global carbon price, EU ETS, China ETS, US equity, US bond, global equity, and global bond returns.[15]

The return from the RCPI and the regional indexes[16] all have very low correlations with US equity, global equity, US bond, and global bond returns. For example, the RCPI's correlation with the US equity and US bond returns are 0.1638 and 0.0202, respectively, while its correlations with global equity and global bond returns are 0.2151 and −0.0074, respectively.

[14]These are the four most actively traded carbon markets in the world, each serving as the underlying index for ICE futures contracts (ICE EUA, ICE CCA, ICE RGGI, and ICE UKA futures contracts). The ICE Global Carbon Futures Index provides exposure to all four.

[15]The RCPI and aggregate carbon price for Europe and China span from 1 April 2013 to 31 October 2024. Daily returns are calculated using daily price data. Comparison indexes used for analysis are as follows: US equities, S&P 500 Index; global equities, MSCI World Index; US bonds, Bloomberg U.S. Aggregate Bond Index; and global bonds, Global Aggregate Bond Index (LEGATRUH).

[16]Note that the RCPI and the regional indexes are not directly investable.

Exhibit 9. Correlation between Returns of Carbon Price Indexes and Equity and Bond Returns, 2013 to October 2024

	RCPI Return	Europe RCPI Return	China RCPI Return	US Equity Return	Global Equity Return	US Bond Return	Global Bond Return
RCPI Return	1						
Europe RCPI Return	0.9106	1					
China RCPI Return	0.1831	0.0302	1				
US Equity Return	0.1638	0.1773	0.0131	1			
Global Equity Return	0.2151	0.2249	0.0334	0.9535	1		
US Bond Return	0.0202	0.0163	−0.0030	−0.0383	−0.0016	1	
Global Bond Return	−0.0074	−0.0164	−0.0033	−0.0147	0.0153	0.9323	1

Second, investors can be increasingly impacted in their equity and fixed income portfolios: As polluters face higher compliance carbon costs, they will aim to pass these costs on to consumers. If they are successful, this will impact inflation and therefore interest rates. Ferdinandusse, Kuik, and Priftis (2024) found that the EU climate policy may increase inflation in the Eurozone by up to 0.4 percentage points in 2026. In addition, Ruf (2024) found that carbon pricing may impact global equities by up to −10.9% by 2030.

Given that traditional investors are increasingly affected by carbon allowance prices, investors can hedge such exposure with EU carbon allowances overlay strategies (Huck 2023). By measuring the carbon price exposure of their investment portfolio and adding a carbon allowance overlay strategy, investors can expect the portfolio to achieve higher risk-adjusted returns.

Third, investing in emission allowances implies reducing the available supply of pollution permits to polluters and thus forces companies to decarbonize faster. Even if these allowances are released back into the market in the future, the concept of the time value of carbon[17] implies that such strategies benefit the environment.

[17]For more information on the time value of carbon, see, for example, Bradley (2024).

Responsible Investment and Stewardship

Carbon price is an important factor for investors on the path to net zero. It is essential for investors to understand how their portfolio companies are exposed to carbon price risks and, consequently, how these risks affect their overall portfolio. Key geopolitical, economic, and regulatory changes may substantially affect the supply and demand for carbon allowances among different ETSs globally, each to varying degrees. Like companies, investors must incorporate these risks into their strategic planning, risk management, and financial disclosures to navigate the volatile landscape effectively. The regional differences in carbon price trajectories and volatilities discussed in the previous section also highlight the need for investors to diversify their portfolios by investing in a mix of regions and sectors to reduce exposure to market volatility caused by geopolitical conflicts.

Carbon pricing has profound implications for responsible investment. By understanding and integrating the risks and opportunities associated with carbon prices, responsible investors can manage financial risks, capitalize on green investment opportunities, enhance ESG integration, and align their portfolios with global climate goals of reaching net zero.

Companies with significant carbon emissions face higher operational costs as carbon prices rise. Investments in fossil-fuel-based industries risk becoming stranded assets as carbon prices make these operations economically unfeasible. Responsible investors must assess how these costs impact company profitability and long-term viability and demand that companies have an effective transition plan to mitigate such risks.

Carbon pricing affects different sectors and different regions unevenly. Energy-intensive industries, such as utilities, manufacturing, and transportation, are more affected than others. Regions with higher and more volatile carbon prices, such as Europe, face different risks compared with regions with lower prices or emerging carbon-pricing systems, such as APAC and Africa.

Higher carbon prices, however, make renewable energy projects more competitive. Investing in solar, wind, hydro, and other renewable sources aligns with responsible investment principles and offers growth opportunities. Other potential investment candidates are companies that invest in energy efficiency technologies or commit to shifting the energy mix to reduce their carbon footprints and operational costs. Diversifying investments across sectors with smaller carbon footprints and across various markets can balance these risks.

As carbon pricing pressures companies to improve their sustainability performance, investors should prioritize engaging with investee companies about corporate climate strategies to mitigate the adverse impact of carbon price movements and build resilience to undesirable climate outcomes. This is how investors can support the transition to net zero in the real economy.

Conclusion

The journey toward achieving net-zero emissions by 2050 is complex and multifaceted, requiring coordinated efforts across global economies, industries, and financial markets. Carbon pricing emerges as a critical instrument in this endeavor, effectively internalizing the environmental costs of GHG emissions and creating financial incentives for businesses and investors to reduce their carbon footprints.

The analysis of global carbon-pricing mechanisms reveals significant progress during the past few decades, with a marked increase in both the coverage of emissions and the sophistication of pricing instruments. When it comes to price levels, however, most mechanisms exhibit low prices. This dynamic reflects either unambitious short-term decarbonization targets or weak mechanism design in which most carbon allowances are handed out free of charge. The RCPI provides a comprehensive measure of global carbon prices, reflecting the true cost of carbon emissions and serving as a valuable tool for investors and policymakers. Although price levels have increased during the past few years, they are nowhere near the required levels to incentivize enough investment in low-carbon technology. However, some regions are leading the way.

The EU ETS and China's national ETS illustrate the diverse approaches and challenges faced by different regions. Although the EU ETS has demonstrated substantial success in driving emission reductions on the back of high prices and generating revenue for climate initiatives, China's ETS highlights the potential for large-scale impact, albeit with ongoing challenges related to market liquidity, price levels, and scope of coverage.

For companies and investors, understanding and integrating carbon pricing into strategic decision making is essential. Internal carbon-pricing mechanisms, such as shadow prices and internal carbon fees, can help organizations prepare for future regulatory changes and manage financial risks associated with carbon-intensive assets.

Investors play a crucial role in the net-zero transition. By aligning their portfolios with climate goals and supporting companies with robust decarbonization strategies, they can drive innovation and growth in the green economy. Furthermore, the integration of carbon prices into investment strategies can enhance portfolio resilience and generate long-term value.

In the future, the continued evolution and harmonization of carbon-pricing mechanisms globally will be vital to achieving a uniform global carbon price. Such convergence will not only reduce competitive imbalances and carbon leakage but also accelerate the global transition to a sustainable, low-carbon economy. The future of carbon pricing will be shaped by stronger climate policies, technological advancements, and increased global cooperation, ultimately paving the way for a more sustainable and resilient world.

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Investment Innovations Toward Achieving Net Zero: Voices of Influence

II. Tactics

THE SCOPE OF NET ZERO: THE USE OF CARBON EMISSION DATA TO ACHIEVE PORTFOLIO GOALS

Robert Furdak, CFA
Chief Investment Officer, Responsible Investment, Man Group, Boston

Tracey Nilsen-Ames
Associate Portfolio Manager, Man Numeric, Boston

Anna-Marie Tomm
Data Science Analyst, Man Group, London

Jeremy Wee, CFA
Senior Portfolio Manager, Man Numeric, Boston

Valerie Xiang, CFA
Associate Portfolio Manager, Man Numeric, Boston

If we are going to meet the ambitious targets required to achieve net-zero emissions, we need to be able to measure the carbon emissions of the assets we hold. That may seem like a straightforward endeavor: Simply calculate the Scope 1, 2, and 3 emissions for your portfolio holdings. But doing so accurately is more complicated than it seems, especially if you hold a broad portfolio of global assets. Not all companies report carbon emissions, and data vendors that provide that information have different methodologies for handling and estimating missing data. In this chapter, we define the different scopes of carbon emissions and evaluate their coverage from different data vendors across various investment universes. We investigate how estimated data factor into portfolio-wide emission calculations. In particular, we focus on Scope 3 emissions, the largest component for most companies. Many believe addressing Scope 3 emissions is critical to achieving net zero, even though they are the least reliable emission metric. We delve into some of the challenges of Scope 3 emissions, such as relevance, estimating the components (upstream versus downstream), and double counting with other scopes. We explore ways to overcome some of these challenges. While measuring current Scope 1, 2, and 3 carbon emissions is an important exercise, the ultimate goal is to achieve net zero. The Science Based Targets initiative (SBTi) established requirements for the net-zero standard. We define these data, examine coverage statistics, and discuss how to build SBTi Paris-aligned portfolios and how they differ from low-carbon portfolios.

Introduction

Climate change is one of society's greatest challenges. If we have any hope of combatting the earth's rising temperature, we must set aggressive targets to reduce greenhouse gas (GHG) emissions. To accurately set those targets and monitor our progress toward achieving them, we must first be able to accurately measure the emissions generated. Doing so may seem straightforward, but it is a complex task. It is essential that we understand the various components of corporate emissions and how they are measured, reported, and incorporated into net-zero or emission-reduction commitments.

In this chapter, we delve into the topic of corporate emission data. We define the different scopes of GHGs, examine their coverage, and compare the quantity of GHG emissions for various sectors and regions. The different components of emissions can vary according to sector and business model, and we examine those interactions. Scope 3 emissions, which result not from activities from assets owned or controlled by the company but from its value chain, are the most difficult to calculate but are often the largest component of a company's emissions. We investigate the relationship between Scope 3 emissions and the other components and detail some of the issues surrounding Scope 3. We then move from historical Scope 1–3 GHG emissions to forward-looking SBTi data and evaluate how a company's projected emissions align to the Paris Agreement at different time horizons and examine what methods can be used to determine this alignment and how SBTi targets compare with historic emission data.

Achieving net zero is about policies, technologies, business models, and consumer preferences, as well as data. Investors need to accurately measure each component of that chain to set goals, monitor progress, and ensure we are progressing along a path toward a cooler planet.

Scope 1, 2, and 3 Emissions: An Overview

GHG accounting standards emerged in the mid-1990s and were formalized as part of the 1997 Kyoto Protocol.[1] Carbon accounting classifies emissions into two broad groups: nonfluorinated gases, such as carbon dioxide (CO_2) and methane (CH_4), and fluorinated gases, such as hydrofluorocarbons (HFCs). The Kyoto Protocol, the initial agreement to reduce global GHGs, created a system to convert these diverse emission types to a CO_2 equivalent to make it possible to compare them and to determine their individual and total contributions to global warming. In 2001, the World Resources Institute and the World Business Council for Sustainable Development published the Greenhouse Gas Protocol, which establishes a "comprehensive, global, standardized framework for measuring and managing emissions from private and public sector operations, value chains, products, cities, and policies."[2] This framework

[1]For more information, go to https://unfccc.int/kyoto_protocol.

[2]www.wri.org/initiatives/greenhouse-gas-protocol.

breaks down an organization's emissions into three categories or "scopes" based on the source. In this chapter, we focus on these three scopes of corporate emission data: their history, coverage, and data quality.

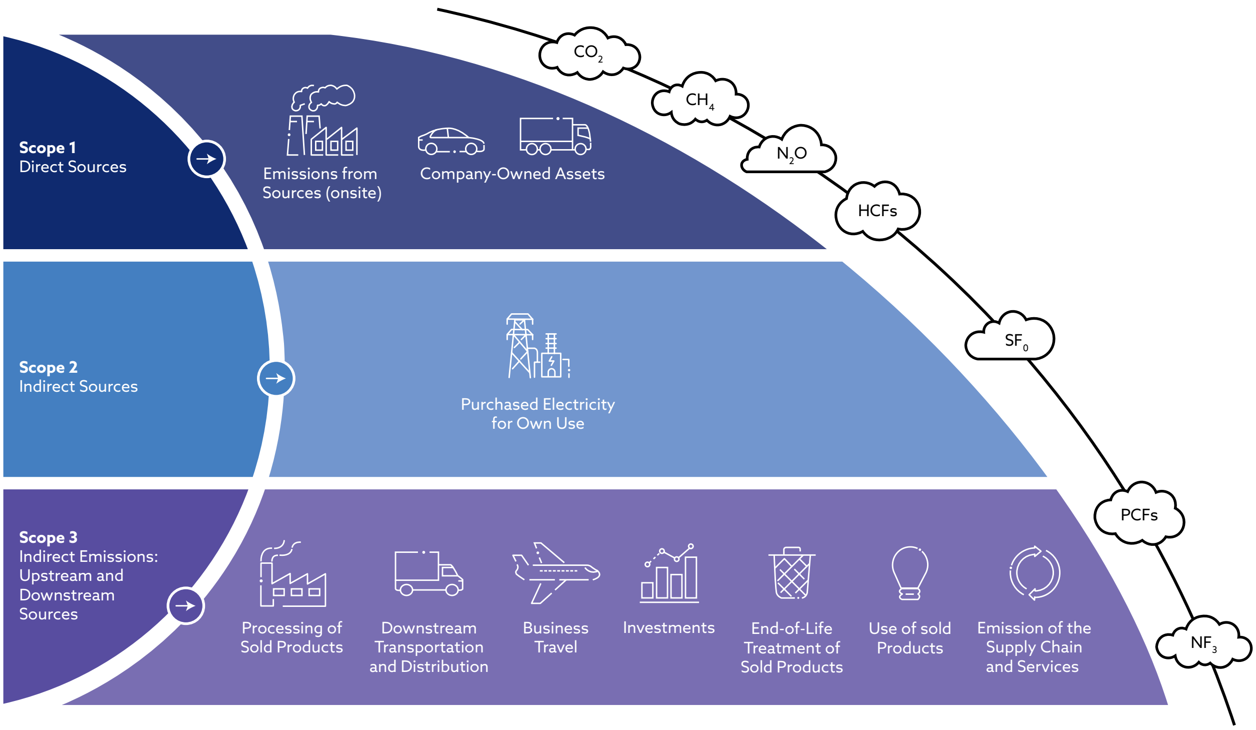
Definitions

Exhibit 1 illustrates the different components of corporate emissions.

Scope 1 emissions are direct GHG emissions from sources that are owned or controlled by the reporting company. They include emissions from combustion in owned or controlled boilers, furnaces, and vehicles and emissions from chemical production in owned or controlled process equipment. Examples include emissions from company vehicles, on-site fuel combustion, and manufacturing processes directly controlled by the company.

Scope 2 emissions are indirect GHG emissions from the generation of purchased electricity, steam, heating, and cooling consumed by the reporting company. Although the emissions occur at the facility where the electricity or other forms of energy are generated, they are accounted for in the company's GHG inventory because they are a consequence of the company's energy consumption. Examples include emissions from the generation of electricity purchased for lighting, heating, and cooling company facilities.

Exhibit 1. Scope 1, 2, and 3 Emissions



Scope 3 emissions encompass all other indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream activities. Scope 3 emissions are a result of activities from assets not owned or controlled by the reporting company but that the company indirectly impacts through its value chain. They include emissions from purchased goods and services, business travel, transportation and distribution, waste generation, and the use of sold products. Scope 3 emissions consist of two components:

- *Upstream emissions* are emissions from activities related to the production and supply of goods and services used by the reporting company, including raw material extraction, manufacturing, and transportation.
- *Downstream emissions* are emissions resulting from the distribution, processing, and use of the company's sold products, including emissions from product disposal or recycling.

Scope 4 emissions, introduced in 2013, are known as avoided emissions. Unlike the traditional scopes (Scope 1, 2, and 3), which focus on emissions directly or indirectly associated with a company's operations and value chain, Scope 4 emissions measure the reductions in emissions that occur as a result of the use of a product or service.[3] There is an increased focus on Scope 4 emissions, but they are difficult to calculate, not widely reported, and consequently outside the scope of this chapter.

Relevance for Investment Managers

Understanding and managing Scope 1, 2, and 3 emissions are critical for investors for several reasons:

- **Risk management:** Companies with significant GHG emissions may face regulatory risks, increased operational costs, and potential liabilities. Investors need to evaluate these risks to make informed investment decisions.
- **Reputation:** Companies that poorly manage emissions may suffer reputational damage, affecting customer loyalty and brand value. Increasingly, investors are considering environmental performance as part of their investment criteria.
- **Long-term sustainability:** Companies that proactively manage their emissions are often better positioned for long-term sustainability. This can lead to improved financial performance and create value for shareholders.

[3] For more information, go to https://plana.earth/glossary/scope-4-emissions.

Absolute emissions refer to the total quantity of GHG emissions released by a company, regardless of the company's size or output. They are measured in total units of emissions (e.g., metric tons of Scope 1, 2, and 3 emissions). Absolute emissions provide a clear picture of the total environmental impact of a company's activities.

Emission intensity is a metric that normalizes emission data to a specific business metric, such as revenue, production output, or employee count. It is typically expressed as emissions per unit of output (e.g., metric tons of CO_2e per unit of product, per dollar of revenue, or relative to the enterprise value of the company). Intensity emissions allow for comparisons among companies of different sizes and can indicate how efficiently a company is managing its GHG emissions relative to its business activities. However, it is subject to volatility of the denominator in that the variability of sales or the enterprise value of the company can cause changes to the intensity when the underlying emissions are relatively stable.

In conclusion, comprehensively understanding and managing Scope 1, 2, and 3 emissions not only help companies mitigate their environmental impact but also provide valuable insights for investors. By evaluating a company's emission profile and metrics, investors can better assess environmental risks, predict future performance, and align their portfolios with sustainable practices.

Using Multiple Vendors to Improve Emission Data Accuracy and Coverage

As previously discussed, carbon metrics are critical for assessing a company's environmental impact. Datasets from different providers are generally homogeneous, meaning they share common characteristics, such as the different emission scopes, among different vendors. While this situation makes these data relatively easy to compare and combine, it also presents a unique set of challenges.

Unlike financial statements, there are no official reporting standards for emission data and although there are generally accepted practices for reporting emissions, different vendors might use different methods to measure and report carbon emissions.

Additionally, each vendor may have different coverage universes and data update frequencies. We evaluated three of the primary vendors of carbon emission data. **Exhibit 2** shows the correlation of reported emissions between those three vendors.

In addition to validating data across providers, the coverage universe can be increased by combining data vendors. **Exhibit 3** shows the coverage of each of the three vendors over time. The chart illustrates the unique count of companies for which carbon intensity data are available, comparing individual vendors (Vendor 1, Vendor 2, and Vendor 3) and the combined dataset over time.

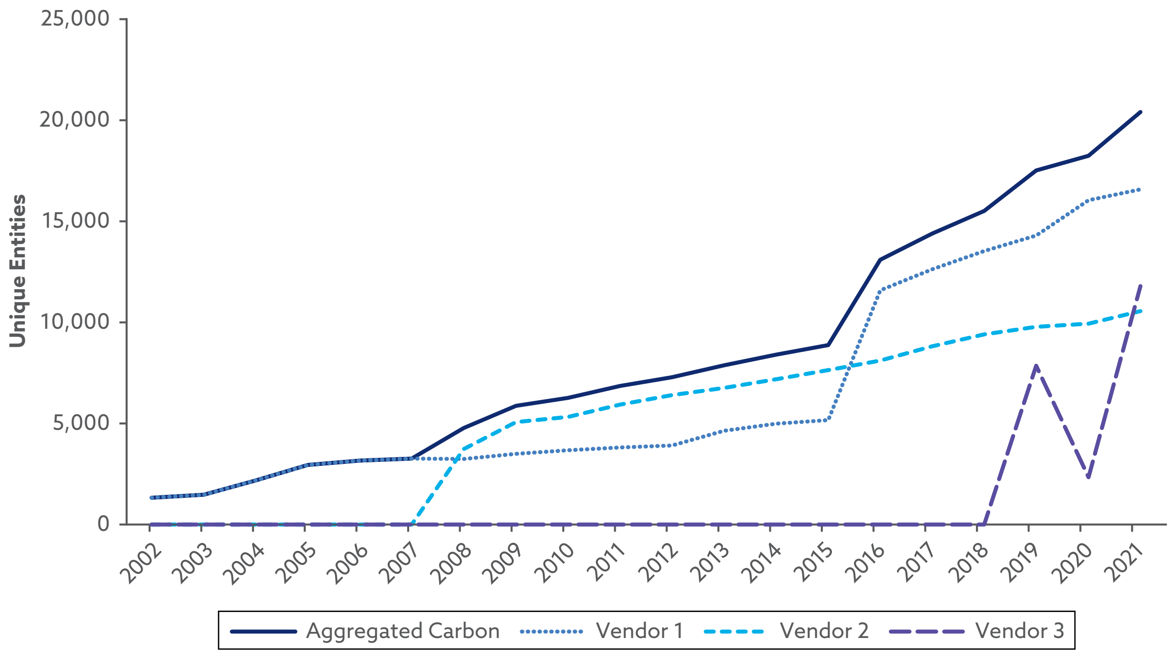
Exhibit 2. Average Correlation between Different Carbon Data Vendors during Overlapping Periods between 2012 and 2024

	Vendor 1	Vendor 2	Vendor 3
Vendor 1	1.00	0.12	0.43
Vendor 2	0.12	1.00	0.71
Vendor 3	0.43	0.71	1.00

Sources: Man Group and underlying vendor data.

The "Aggregated Carbon" line representing the combined carbon dataset shows a steady increase, reflecting the aggregation of data from all vendors. Vendor 1 consistently provides the largest number of company estimates, followed by Vendor 2 and Vendor 3. The noticeable spikes and drops in Vendor 3's data indicate variability in its reporting over the years. Overall, the combined dataset offers a more comprehensive coverage of companies, emphasizing the benefit of integrating multiple data sources to enhance the breadth and reliability of carbon intensity data for climate investment analysis. By validating and combining the data from different vendors, researchers and investors can reconcile the differences and inconsistencies in the data and gain a more accurate, timely, and comprehensive view of a company's carbon emissions.

Exhibit 3. Aggregated vs. Individual Vendors' Carbon Metrics, 2002–2021



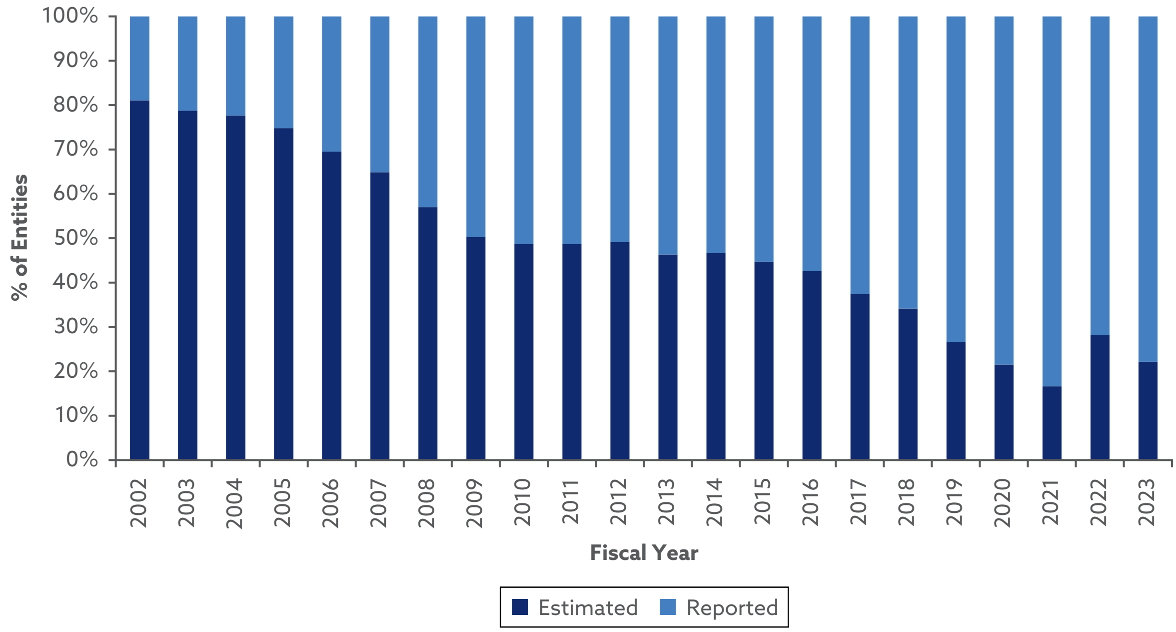
Source: Man Group.

The analysis in the rest of this section will rely on the data from this combined curated dataset, which cross-validates across vendors to maximize coverage, favoring more recent and reported data over older, estimated figures.[4]

Analysis of Carbon Data by Region and Sector

Corporations and investors have increased their focus on carbon emissions over the last 20 years, especially since the Paris Agreement was signed in 2016. Consequently, disclosures of corporate carbon emissions have increased over that time. **Exhibit 4** illustrates the percentage of reported versus estimated Scope 1 and 2 carbon emissions since 2002 for the MSCI All Country World Index (ACWI), a broad equity index of developed and emerging markets. Reported emissions are those that are directly reported by the company, whereas estimated emissions are included in vendor data but are estimated by the vendor, usually based on industry average emissions. It is evident that the proportion of reported emissions has increased dramatically—from roughly 20% in 2002 to roughly 80% today. (Note that as of the time of this analysis, not all fiscal-year 2023 emission data had been reported—hence the increased use of estimated data for the latest fiscal year.) This trend indicates an improvement in transparency and accuracy of emission reporting, reflecting the growing emphasis on precise climate data for informed investment decisions.

Exhibit 4. Time Series of Reported vs. Estimated Scope 1 and 2 Emissions



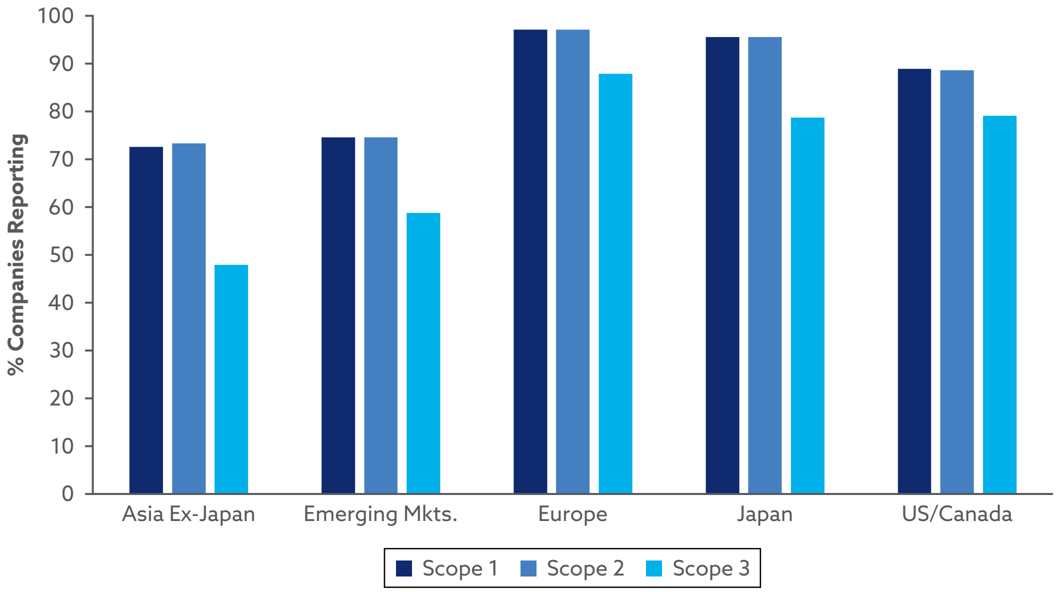
Sources: Man Group; MSCI ACWI universe.

[4] www.man.com/maninstitute/unlocking-the-hidden-potential-ESG-data.

Reported emissions differ by scope. Scopes 1 and 2 are from company-owned assets or electricity directly purchased, are typically easier to calculate, and have higher reporting statistics. In contrast, Scope 3 results from assets and usage not directly controlled by the company and are consequently more difficult to calculate and have lower reported levels. We will explore Scope 3 emissions in the next section of this chapter. **Exhibit 5** illustrates the reported scope disclosures by region for fiscal year 2021, categorized by scope. Note that Scope 3 emissions are counted as "reported" if any component is reported by the company. Typically, the Scope 3 metrics that are easier to calculate, such as corporate travel or emissions from investments, are reported and the upstream and downstream metrics (see the breakdown in Exhibit 1) that are more difficult to calculate are not reported. While this increases the percentage of companies reporting Scope 3, it greatly underestimates the actual emissions. The consolidated carbon dataset in this section tries to account for this by including estimates to fully represent Scope 3 emissions.

Europe leads the way in carbon emission reporting. Emission disclosures are mandated for FY 2024 by the Corporate Sustainability Reporting Directive (CSRD), which requires all large companies and all listed companies (except listed microenterprises) to disclose "risks and opportunities arising from social and environmental issues and . . . the impact of their activities on people and the environment."[5] In the developed markets, Japan and North America have the next highest disclosure rates, followed by Asia ex-Japan. Scope 1 and 2

Exhibit 5. Reported Regional Disclosure by Scope



Sources: Man Group; MSCI ACWI universe (FY 2021).

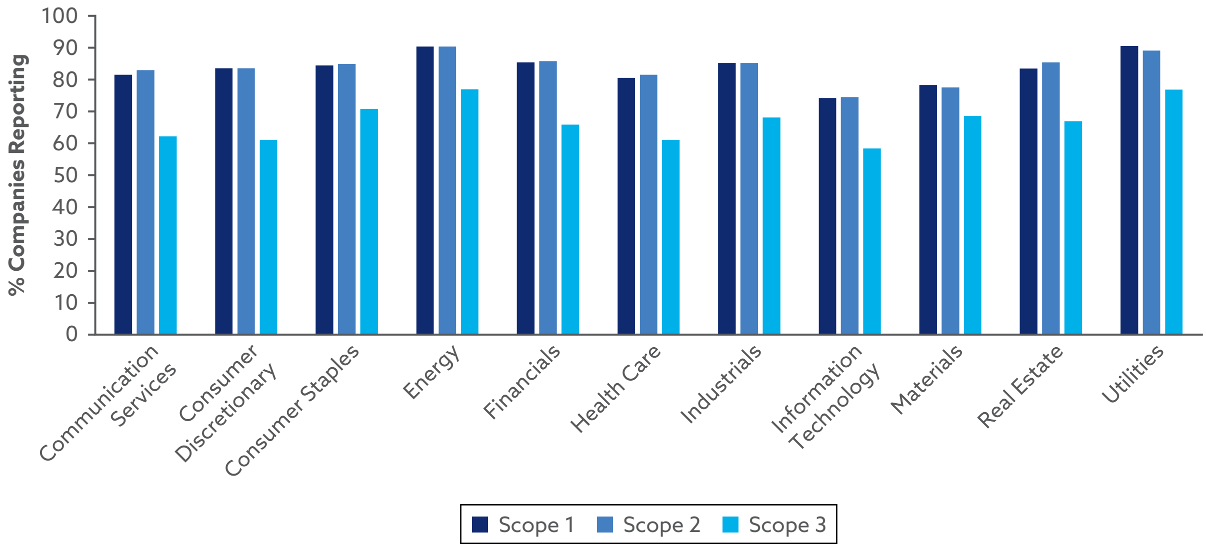
[5]https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en.

disclosures are very similar within regions, with Scope 3 having lower reporting levels. The emerging markets, which have a large Asian component, are similar to Asian developed markets but have about 10% higher Scope 3 reporting levels.

Carbon emissions also vary by sector, with the highest-emitting sectors typically having the highest disclosure rates. **Exhibit 6** breaks down the percentage of companies reporting emissions by scope across various Global Industry Classification Standard (GICS) sectors for the MSCI ACWI for fiscal year 2021. Energy, utilities, and materials, the three highest-emitting sectors (as shown in **Exhibit 7** and **Exhibit 8**), also have the highest reporting rates. Low-emitting sectors, such as technology, communication services, and financials, have the lowest reporting levels. As with the country-level exhibits, reporting rates for Scope 3 are much lower than they are for Scope 1 and 2.

Regarding the level of total carbon emissions, Exhibit 7 shows the distribution, by sector, of total Scope 1–3 emissions. Three things stand out. First, absolute emissions vary greatly by sector, with energy, utilities, and materials generally having the highest total emissions. Second, a sector's emissions vary by scope. Scope 1 represents the bulk of the emissions in the utilities and energy sectors, while Scope 3 dominates in the materials, consumer discretionary, and consumer staples sectors (we will delve deeper into this in the next section).[6] Third, the distributions are very skewed for all three scopes. There is a much wider distribution of high emitters outside the interquartile range (shaded box) than

Exhibit 6. Reported Sector Disclosure by Scope

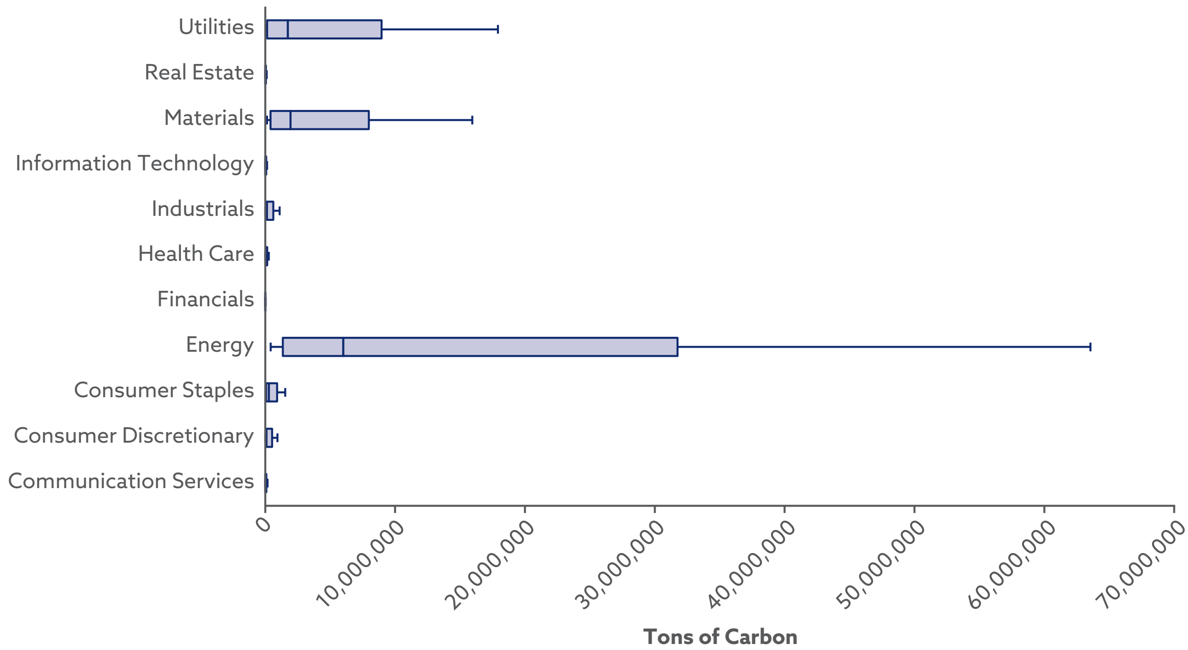


Sources: Man Group; MSCI ACWI (FY 2021).

[6]There is some debate about the accurate calculation of downstream Scope 3 emissions for energy companies. See Department for Energy Security and Net Zero, "Scope 3 Emissions in the UK Reporting Landscape: Call for Evidence" (October 2023). https://assets.publishing.service.gov.uk/media/652ea475697260000dccf9db/scope-3-emissions-in-the-uk-reporting-landscape.pdf.

Exhibit 7. Distribution of Scope 1, 2, and 3 Emissions by Sector

A. Scope 1 Emissions



B. Scope 2 Emissions

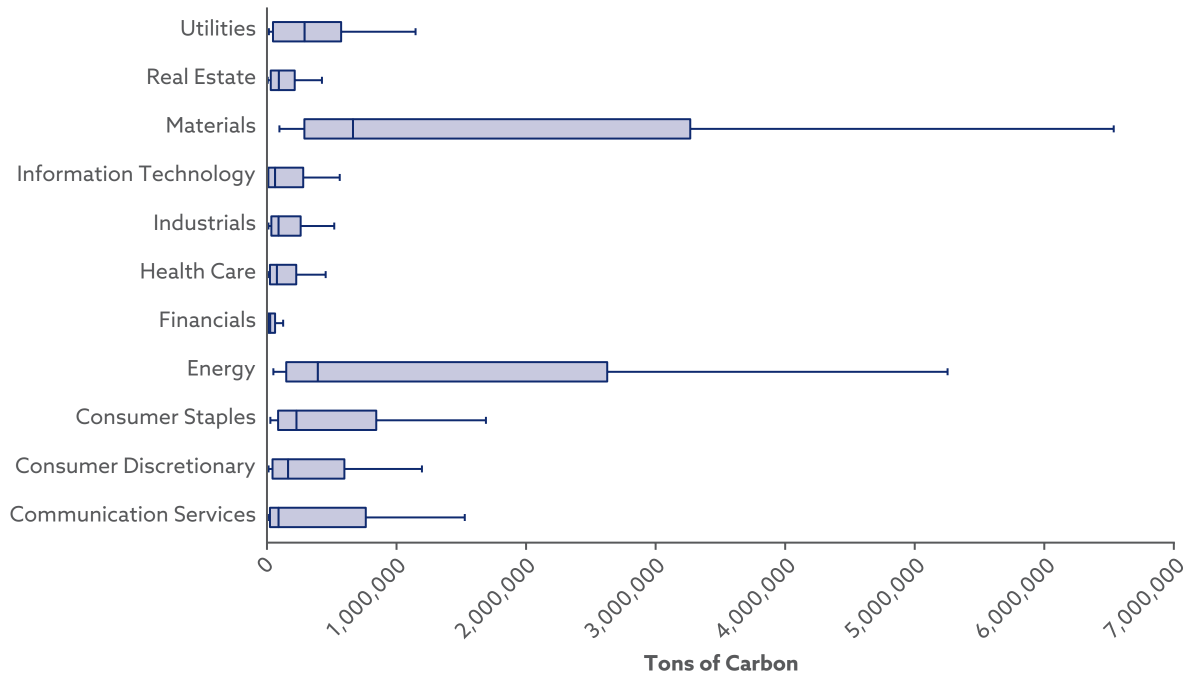
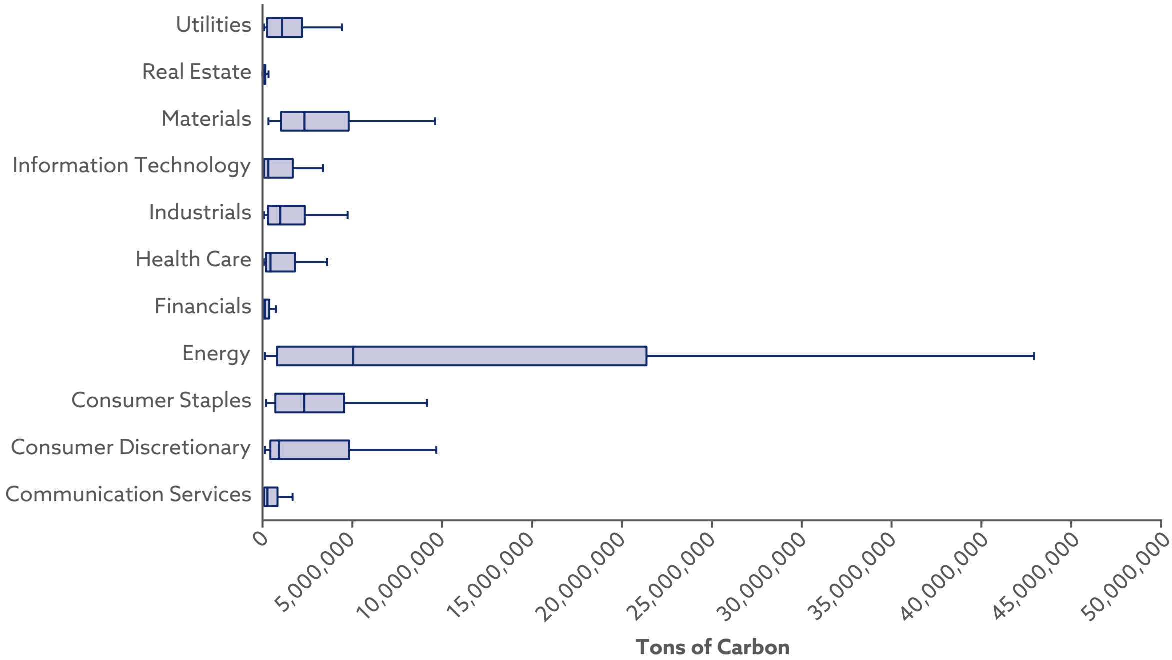


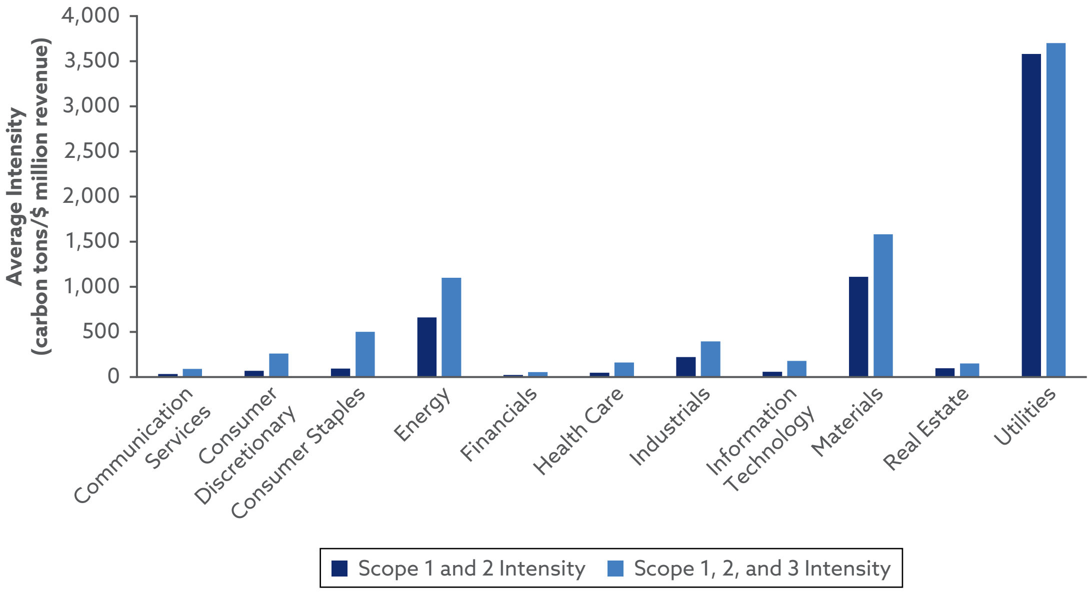
Exhibit 7. Distribution of Scope 1, 2, and 3 Emissions by Sector (*continued*)

C. Scope 3 Emissions



Sources: Man Group; MSCI ACWI (FY 2023).

Exhibit 8. Average Carbon Intensity by GICS Sector (Scope 1 and 2 Combined and Scope 1, 2, and 3 Combined)



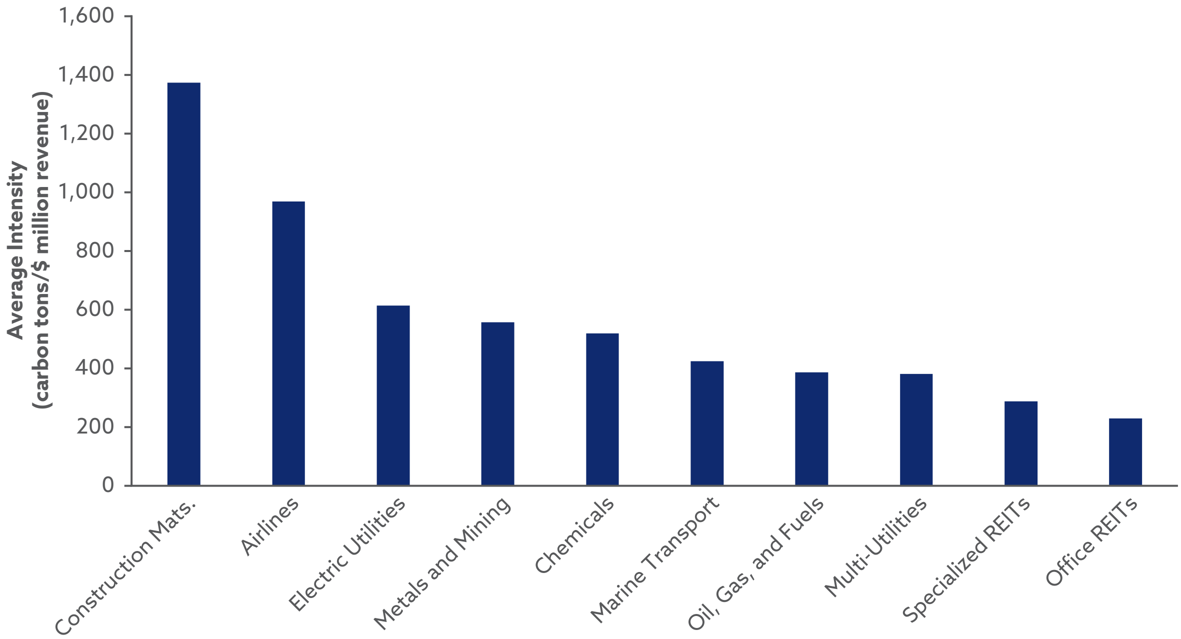
Sources: Man Group; MSCI ACWI universe (FY 2023).

there is for low emitters, which often influences portfolio analytics, where even small positions in extremely high emitters can have an outsized influence in reported carbon statistics.

To normalize for size, emission intensity levels are the preferred choice. They measure the tons of carbon emitted scaled per million dollars of revenue. The first set of bars in Exhibit 8 show the Scope 1 and 2 emissions combined (the most widely disclosed and most often quoted figure), with the second set of bars detailing all three scopes combined. The materials sector has the highest emission intensity (3,581 Scope 1 and 2; 3,702 Scope 1, 2, and 3), more than double the emission intensity of energy, the second highest sector. Financials have the lowest emission intensity (22 Scope 1 and 2; 54 Scope 1, 2, and 3), followed by communication services and health care. As noted previously, average emission intensity can vary due to both extreme emissions of certain companies and variability of the denominator—in this case, sales. The data used in the following analysis adjust for extreme outliers.

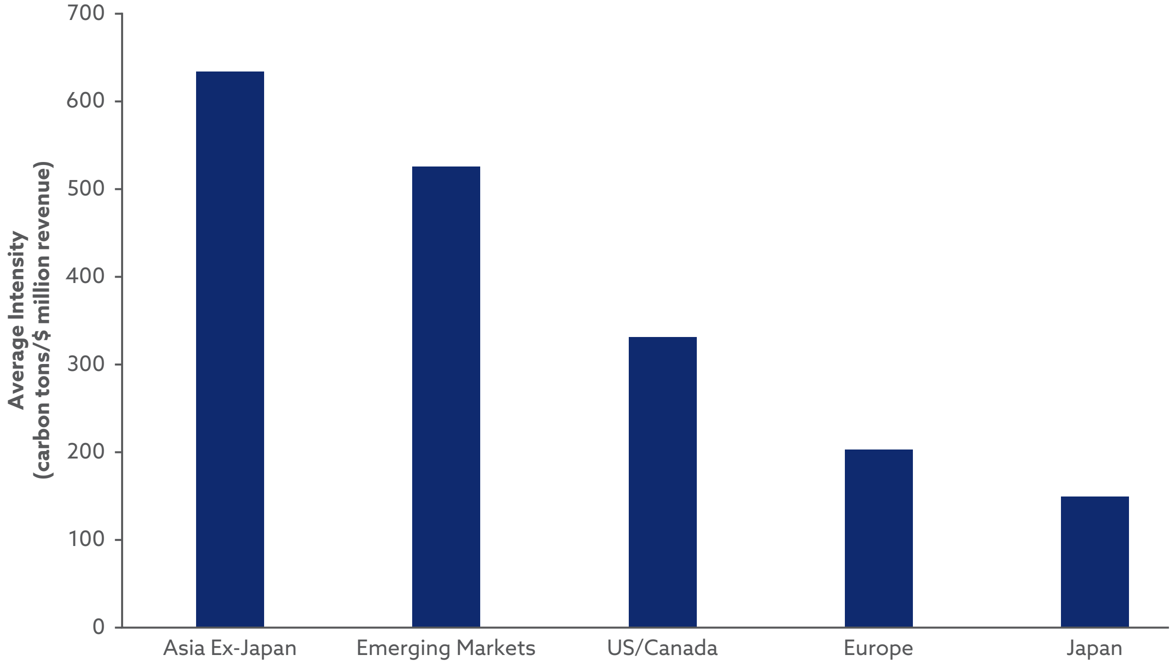
The highest-emitting industries or companies are not always in the highest-emitting sectors. **Exhibit 9** shows the 10 highest-emitting industries in the MSCI ACWI using combined Scope 1 and 2 intensity. Industries in the materials sector represent 4 of the top 10 industries. The construction materials

Exhibit 9. Average Carbon Intensity for High-Emitting GICS Industries (Scope 1 and 2)



Sources: Man Group; MSCI ACWI universe (FY 2023).

Exhibit 10. Average Carbon Intensity by Region (Scope 1 and 2)



Sources: Man Group; MSCI ACWI universe (FY 2023).

industry—primarily cement producers—leads the way, with chemicals, metals and mining, and paper and forest products also present in the top 10. Two industries in the industrials sector—airlines and marine transport—are in the top 10.

Asia leads emission intensity at the regional level. **Exhibit 10** details the regional emissions for the MSCI ACWI using combined Scope 1 and 2 intensity. Asia ex-Japan (developed) has the highest emissions, followed by emerging markets (currently ≈75% Asia). Europe, which has made emission reductions a priority, has about one-third the emissions of developed Asia. Japan has the lowest emissions, but that is partially driven by that market's sector composition, which has relatively low weights in the high-emitting utilities and energy sectors (see Exhibits 6 and 7).

Scope 3 Emissions

To truly understand a company's emission profile, one must account for all sources of corporate emissions. This process has begun in earnest, but most of the analysis focuses on Scope 1 and 2 emissions. However, Scope 3 emissions—those attributed to a company's value chain—are becoming increasingly recognized as equally if not more important. Scope 3 emissions are significant contributors to the carbon output of the company and can change the relative attractiveness of the overall emission intensities of the sectors, industries, and stocks when incorporated into the analysis. Scope 3 emissions will become increasingly important and necessary for accurate GHG accounting. Even though the US Securities and Exchange Commission removed Scope 3 reporting from its "Final Rules," many European regulations (including the CSRD), the International Sustainability Standards Board, and the state of California require that large companies report their Scope 3 emissions, to be phased in starting in 2025.[7]

Given the rising relevance of Scope 3 emissions, this section focuses on understanding this historically difficult-to-measure and consequently overlooked category. We discuss the current GHG Protocol accounting guidelines in the context of current data quality and how Scope 3 differs from Scope 1 and 2. The remainder of the analysis in this section focuses on emission data from S&P Trucost, which provides the most detailed information on Scope 1 and 2 emission intensity, as well as Scope 3 intensity broken down by upstream and downstream activities.

Definitions

Because Scope 1 and 2 emissions are within the owned operations of the business, they are the easiest to measure and most frequently reported. However, Scope 3 emissions are those in the upstream or downstream value chain specifically not reported in Scope 2. Because Scope 3 emissions come from sources outside the company's directly owned operations, they are more difficult to estimate but can be very impactful to the overall company's carbon footprint.

Measuring Scope 3 is a challenging problem; these emissions must be estimated by either the company itself or a third party. While the GHG Protocol supplies accounting guidance, the methodologies companies use may not be standardized. The GHG Protocol breaks Scope 3 into upstream and downstream emissions and, more specifically, into 15 categories.[8] Upstream emissions include those from the production of product inputs, such as purchased goods and services. In contrast, downstream emissions refer to emissions that occur from such sources as the use of a company's products.

One might believe Scope 3 is out of a company's control, but companies can make efforts to mitigate these emissions. For instance, they can use less emission-intensive materials to build their products, thus lowering upstream emissions, or they can create a product that uses less carbon throughout its product life cycle. Neither example would be captured in Scope 1 and 2, but they are nevertheless decisions that companies can make. In addition, a company can outsource all or part of its manufacturing process, effectively reducing its Scope 1 emissions, without truly lowering their emission footprint. Thus, it is important to account for Scope 3 to ensure that Scope 1 and 2 are not being reduced at the expense of increasing Scope 3 emissions, or vice versa.

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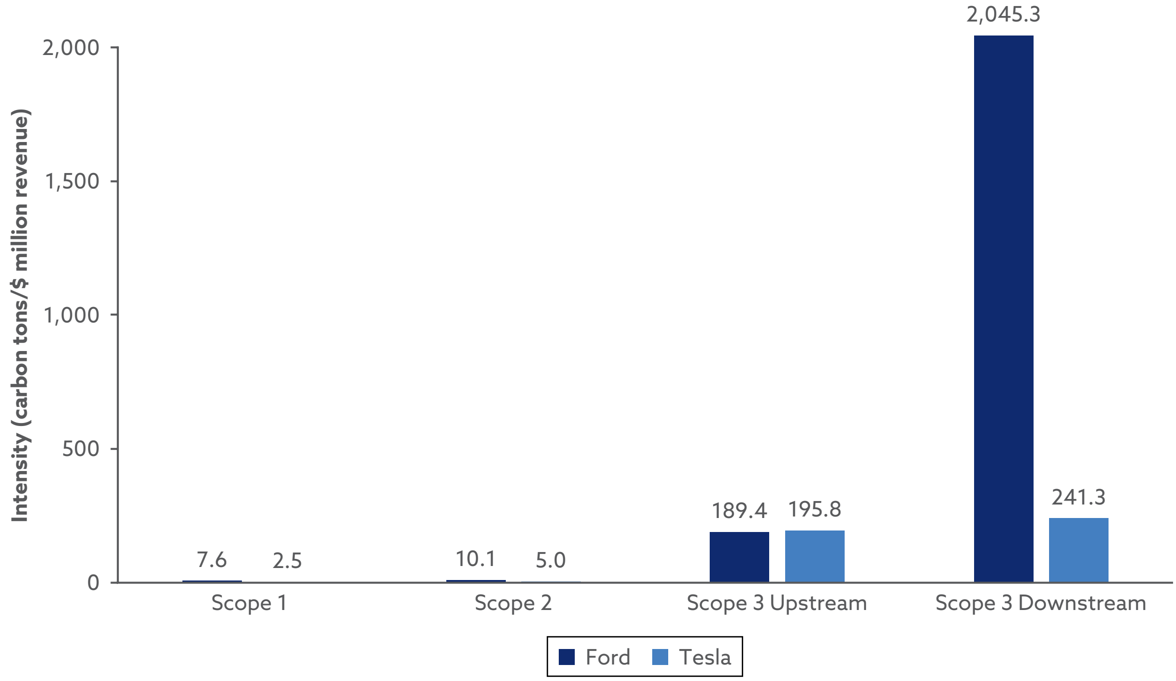
[7]Aligned Incentives, "Navigating Mandatory Scope 3 Emissions Reporting in the EU, US, and Beyond" (26 April 2024). https://alignedincentives.com/mandatory-scope-3-emissions-reporting-eu-us-uk-international/.

[8]World Resources Institute and World Business Council for Sustainable Development, "Corporate Value Chain (Scope 3) Accounting and Reporting Standard: Supplement to the GHG Protocol Corporate Accounting and Reporting Standard" (September 2011). https://ghgprotocol.org/sites/default/files/standards/Corporate-Value-Chain-Accounting-Reporing-Standard_041613_2.pdf.

Exhibit 11. Ford and Tesla Carbon Intensity, FY 2022



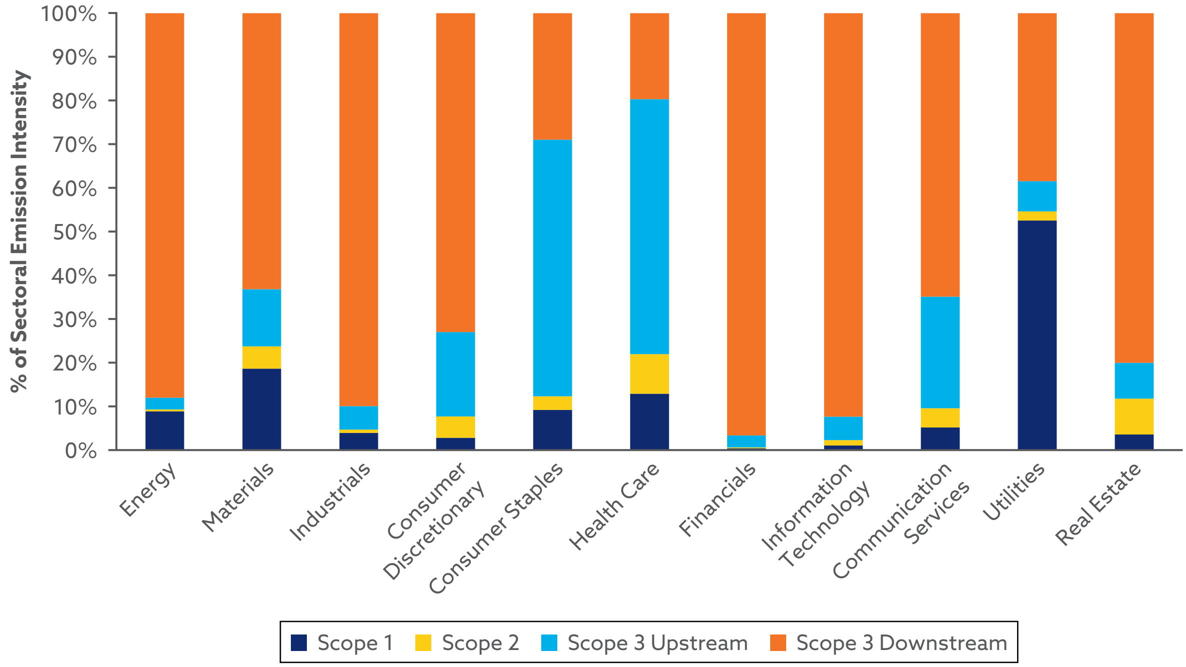
Source: S&P Trucost.

For example, Ford and Tesla have very low and similar Scope 1 and 2 emission intensity, while Scope 3 accounts for most of their emissions (see **Exhibit 11**). This situation is persistent across many companies, and thus incorporating only Scope 1 and 2 when evaluating such companies can miss a significant portion of their carbon emissions. Similar to Scope 1 and 2, Scope 3 data can be significantly skewed toward positive outliers (as shown in Exhibit 7), which can make these data difficult to incorporate in analytics and portfolio construction without special care.

Breaking down Scope 3 further, Ford and Tesla have similar upstream Scope 3 emissions from their auto production, but Tesla has much lower downstream Scope 3 emissions given its fleet consists solely of electric vehicles (EVs). If Ford wants to reduce its downstream emissions, it needs to either encourage its customers to drive less, extending the life of their car, or get them to switch to an EV model, which may be less popular or profitable. This fact creates a potential conflict for Ford in trying to maximize profitability.

The relative importance of Scope 3 can depend on a company's industry and business model. To examine this, we show the average percentage breakdown of Scope 1, 2, and 3 (upstream and downstream) carbon intensity by sector (**Exhibit 12**). When breaking down into upstream and downstream Scope 3 emissions, we see that there are large differences across sectors in terms of the dominant source of the emissions, making both important. At the sector

Exhibit 12. Average Percentage Breakdown of Carbon Intensity by Sector, FY 2023



Sources: Man Group; S&P Trucost.

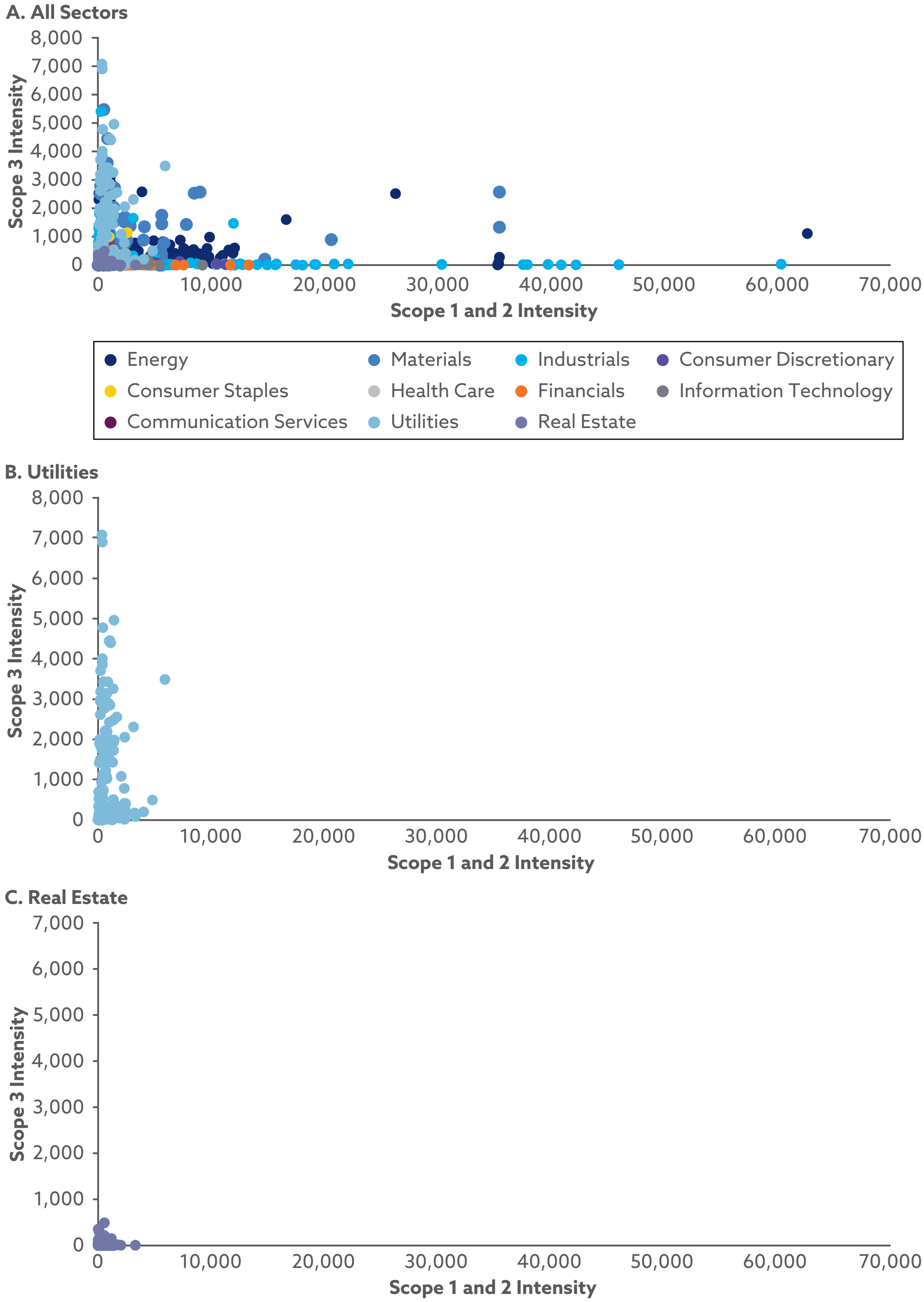
level, Scope 3 accounts for around 90% of total emission intensity in consumer staples but less than 50% for utilities, where Scope 1 is on average the most significant contributor to carbon intensity. These variations suggest that the incorporation of Scope 3 may paint a different picture of what sectors or industries are actually more or less energy intensive relative to the picture shown by Scope 1 and 2 alone.

Contrasting Scope 3 with Scope 1 and 2

Using estimated values from S&P Trucost, we can see quite a difference in the emission profile of the scope categorization by sector for upstream emissions. Plotting Scope 1 and 2 versus upstream Scope 3 emission intensity shows the relationship is fairly sector dependent (**Exhibit 13**).

The utilities sector (Panel B of Exhibit 13) has relatively low Scope 1 and 2 emissions and relatively high Scope 3 emissions. The outliers with higher Scope 1 and 2 numbers in this sector are generally power and energy generation companies. The real estate sector (Panel C of Exhibit 13), in contrast, reveals very small values for all three scopes, with the more extreme emissions from hotel and diversified real estate investment trusts (REITs) that have buildings used for high-emitting activities, such as data centers. Note that accounting for emissions for REITs is complicated and depends on project

Exhibit 13. Scope 1 and 2 vs. Scope 3 Carbon Intensity by Sector, FY 2023



Sources: Man Group; S&P Trucost.

financing and the type of lease used.[9] These details are often not disclosed. Overall, the correlation of Scope 1 and 2 with Scope 3 emissions varies across sectors, highlighting the different structural relationship of emissions. These dynamics are even more prevalent when looking at stock-level data, which have approximately zero correlation.

Potential Problems with Scope 3

Although the importance of Scope 3 emissions is clear, issues remain when using the data, such as spotty estimation techniques, relatively low reporting levels, and double counting of emissions when summing across companies. We now turn to the issues faced when using these data to accurately compare a company's total emissions across all three scopes or perform aggregated group emission levels.

Large Level of Estimation

As Exhibit 5 showed, Scope 3 is generally less reported than Scope 1 and 2 (as low as 48% in Asia ex-Japan). Because Scope 3 data vendors may be estimating a large percentage of Scope 3 values, it is important to understand the estimation methodology. Upstream and downstream emission intensity coverage from S&P Trucost begins in FY 2002 and FY 2017, respectively. For the upstream model, S&P Trucost uses an environmentally extended input–output model; relationships between sectors are used to attribute carbon intensity in a company's supply chain. Downstream emissions are either estimated through a bottom-up approach (for the oil and gas, coal, and automotive industries) or imputed at the subindustry level using reported emissions. Because Scope 3 can be difficult to measure, there are some limitations in using largely estimated data. For instance, we do not find large variation in Scope 3 intensity by sector, which may be the result of estimation techniques, such as imputation by subindustry. S&P Trucost also notes as another potential issue that the estimated values may be lower than the true Scope 3 emissions because the companies that report might be those that have lower emission intensity.[10]

Double Counting Across Companies

For business-to-business firms, one company's Scope 3 can make up another company's Scope 1 and 2. This situation can be both problematic (from a total emission perspective) and desirable (on a comparison basis).[11] Take, for example, a grocery store that outsources delivery of its goods to a trucking company. The trucks' emissions would count as upstream supply-chain emissions for the grocery store and thus be reported in Scope 3. However, the same emissions would count toward the trucking company's Scope 1. Therefore,

[9]www.gc-insights.com/report/pcaf's-new-guidance-for-accounting-ghge-in-real-estate-sector#:~:text=For%20real%20estate%20investment%20trusts,proportionally%20according%20to%20their%20share.

[10]www.spglobal.com/spdji/en/documents/additional-material/faq-trucost.pdf.

[11]GHG Protocol, "Scope 3 Frequently Asked Questions" (June 2022), p. 20. https://ghgprotocol.org/sites/default/files/2022-12/Scope%203%20Detailed%20FAQ.pdf.

summing Scope 1 and Scope 3 for both companies would overstate total emissions. The matter is further complicated because the trucking company is carrying goods for other entities, so not all those emissions should be attributed to the grocery store. One potential solution to understand the degree of double counting would be to use detailed supply-chain data to see what percentage of the trucking company's revenues are from different grocery store chains and use that as a proxy for allocating its Scope 1 emissions to that chain's Scope 3 emissions. To be clear, despite an overstatement of total emissions of the grocery store and trucking company, we believe that we need to account for Scope 3 emissions not only to understand the extent of the grocery store's carbon footprint but also to fairly compare it with potentially more vertically integrated competitors. For instance, in the case of a competitor grocery store that transports its own goods via company-owned trucks, these emissions would count toward their Scope 1. If we were to compare only the Scope 1 emissions of the two grocery store companies, the store that outsources may appear more carbon efficient because we have not accounted for the full impact of outsourced upstream emissions.

There are also clear cases where emission overlap would not be an issue. A simple example would be a car company producing vehicles for personal use. Because the end user is not a business, these cars would not be counted in another company's emissions. However, it is not always that clear. The auto emissions incurred by Walmart's 2.2 million employees commuting to work are included in Walmart's Scope 3, but the personal use of those same cars is not. However, for the manufacturer, 100% of the auto use is included in its Scope 3. In an estimation by MSCI, approximately 80% of Scope 3 emissions are counted toward another company's Scope 1 and 2.[12]

One final consideration about double counting is the group of stocks that are being aggregated, which might have a significant impact on the amount of double counting that would be present. If an industry-level analysis on carbon emissions were the goal, there could be significantly more overlap than that for a diverse portfolio of 100 stocks.

Scope 3: Conclusion

We do not expect the current issues with Scope 3 emission data—mainly the low level of reporting and lack of reporting standards, allowing for inconsistent reporting—to improve through increased regulation and market demand. There are, however, ways we can gain insight through relative comparisons across companies and sectors, as well as trend analysis. Although Scope 3 data are more cumbersome to gather and interpret, this information is essential to capturing a full view of a company's carbon emissions.

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[12]B. Baker, "Scope 3 Carbon Emissions: Seeing the Full Picture" MSCI (17 September 2020). www.msci.com/www/blog-posts/scope-3-carbon-emissions-seeing/02092372761.

Paris Alignment Data

While the carbon emission data described previously have improved in quality recently, one drawback is that the data are backward-looking and focused on *historical* emissions. In planning for a Paris-aligned future, the primary focus of companies should be on their trajectory toward net zero and reducing *future* emissions.

The Science Based Targets initiative (SBTi)—a joint initiative between such key players as CDP, UN Global Compact, World Resources Institute, and World Wide Fund for Nature—established requirements for the net-zero standard. One key principle behind the standard is that "a company is only considered to have reached net-zero when it has achieved its long-term science-based target and neutralized any residual emission,"[13] which for most companies means long-term target emission reductions of at least 90% by 2050.

The year 2050 is more than two decades away, and a company committed to net zero should "set near- and long-term targets" to achieve that goal (another tenet of SBTi's net-zero principle). As companies commit to net zero, they report forecast target future emissions by year with the SBTi, alongside the budgeted emissions allocated using the SBTi methodology. They set a "base year" and near-term and long-term "target years":

- *Base years:* The base year is set as the emission baseline that future emissions are compared with. Working with SBTi, companies ensure that the base year has verifiable Scope 1, 2, and 3 emission data and is representative of typical business activity.
- *Target years:* SBTi requires near-term targets of 5–10 years and long-term targets of year 2050 or before.

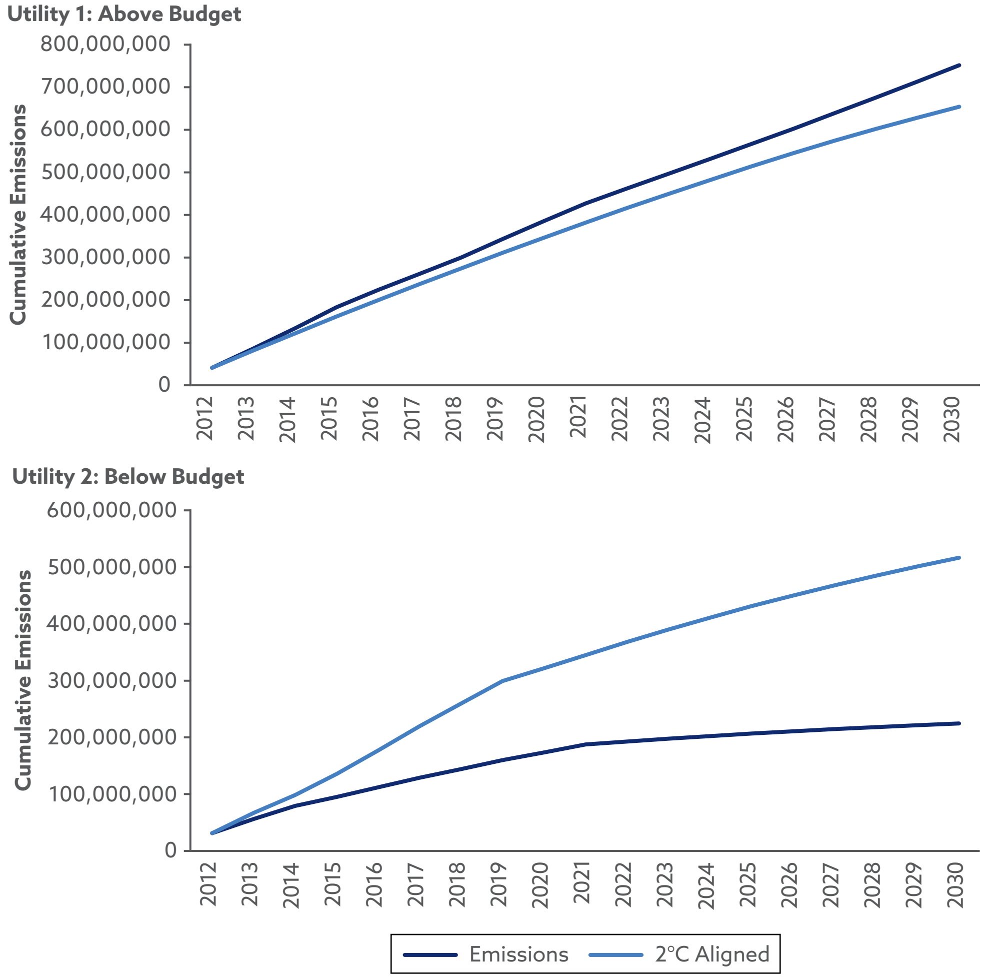
As it may be arbitrary to make projections out to 2050, investors can look at the over- or under-forecast of company emissions into the near future (near-term SBTi target) as an indication of whether a company is on the explicit path to net zero. **Exhibit 14** shows two contrasting utility companies, comparing future expected emissions with budgeted (aligned) emissions up to the near-term target of 2030. Utility 1 is above budget and hence not Paris aligned, while Utility 2 is below budget and Paris aligned.

Historical Emissions Do Not Equal SBTi Alignment or Net Zero

It is important to note that a lower-emission company is not necessarily more "2°C aligned" than a higher-emission company. Indeed, as **Exhibit 15** shows, there is very little relationship between carbon intensity (historical) and 2°C alignment (future). Typically, carbon intensity is measured based on a company's previous-year emissions over sales (in carbon tons/$ million revenue).

[13]https://sciencebasedtargets.org/net-zero.

Exhibit 14. Projected Emissions vs. 2°C Aligned Emissions, 2012–2030



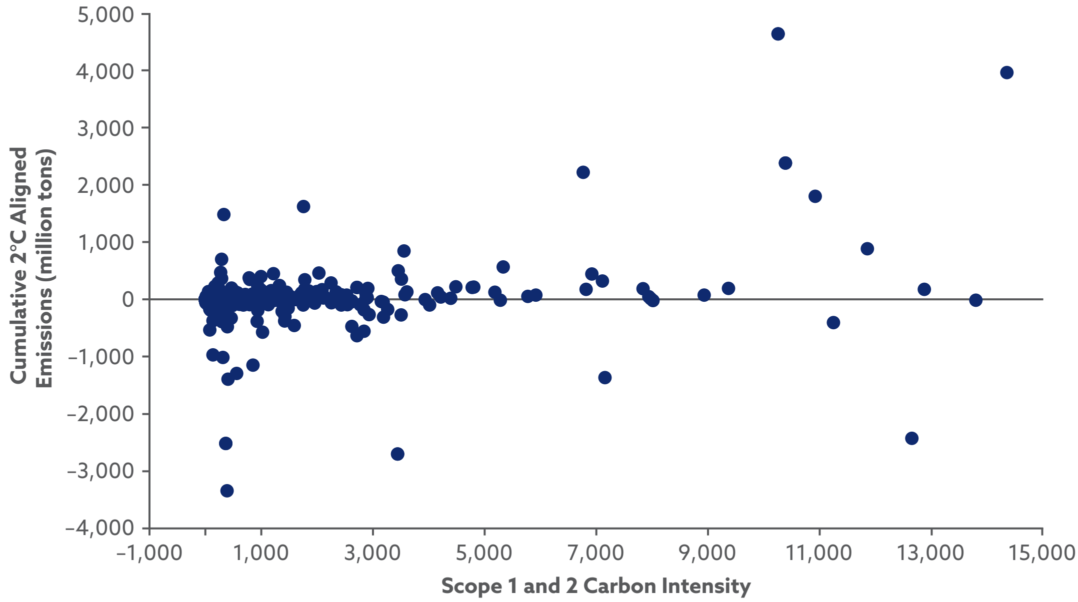
Notes: 2012 is the base year of the analysis. Alignment is measured by cumulative above/below constraints since the base year to 2030. Hence, historical emissions are important to the extent that companies are penalized should their actual emissions exceed projected emissions.

Sources: S&P Trucost; SBTi; as of 30 June 2024.

It is a backward-looking measure and does not take into account a company's future emissions.

For example, Utility 2 is an integrated electric company servicing multiple states and is regarded as a leader in the sector when it comes to alternative energy. At a carbon intensity of 278 carbon tons/$ million revenue (versus the MSCI World Index at 100 carbon tons/$ million revenue), the company looks unfavorable from a historical emissions perspective (see **Exhibit 16**). However, it is considered by many experts to be a leader in net-zero initiatives, including its Climate Change Investment Initiative, which includes providing investments to startups developing new technologies to reduce greenhouse gases. It has

Exhibit 15. Carbon Intensity vs. 2°C Alignment, 30 June 2024



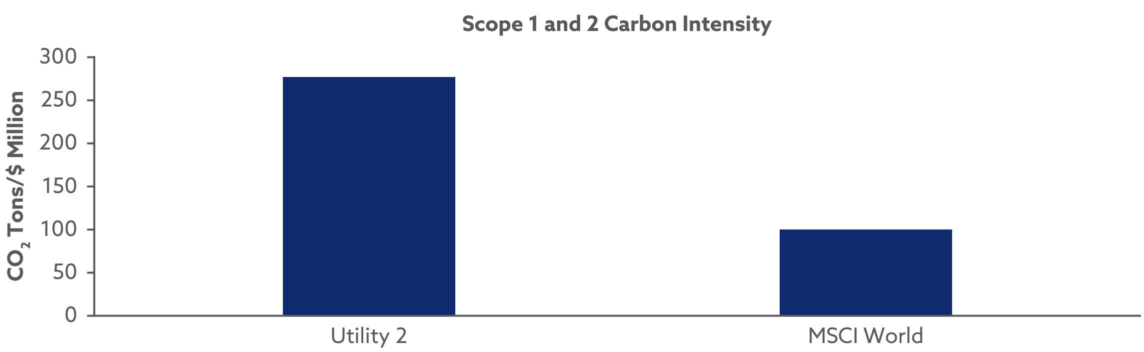
Sources: S&P Trucost; SBTi; MSCI ACWI.

been given an A– rating by CDP. Most importantly, it has significantly beaten the SBTi 2°C budgeted emissions by 277 million tons of CO_2 emissions, clearly doing more than its fair share of contributing toward a greener world.

Note that being "net zero" is a much more stringent requirement than being "carbon neutral." For example, Alphabet has recently removed its claims of

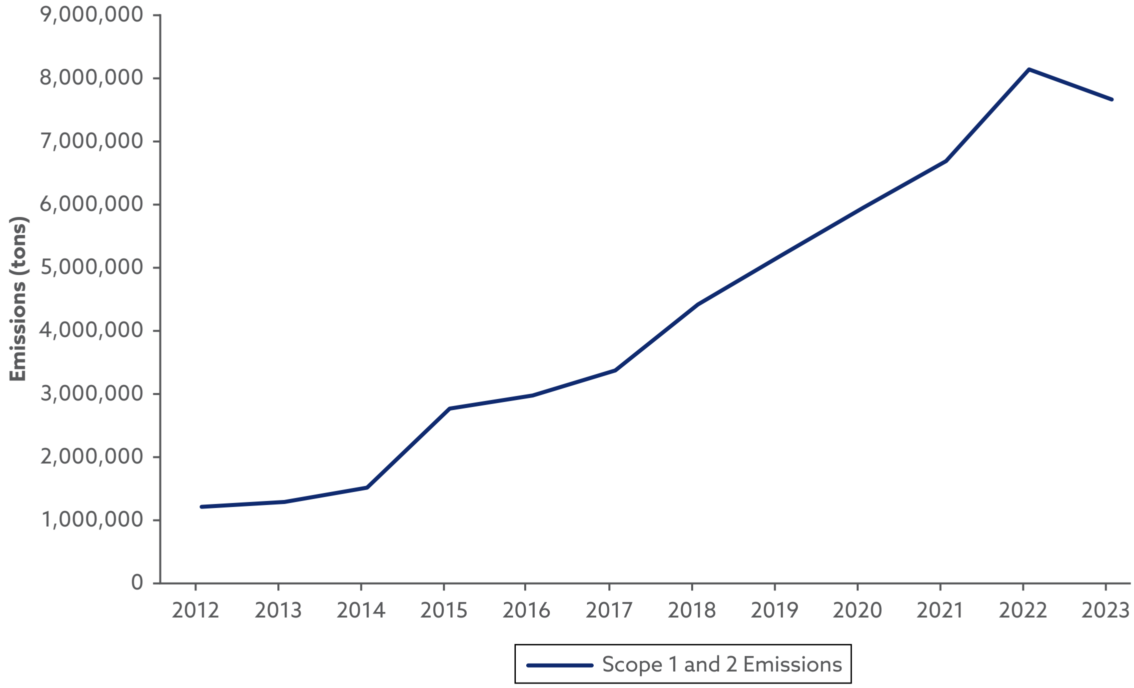
Exhibit 16. Key Carbon Metrics of Utility 2, 30 June 2024

Carbon Intensity (CO_2 tons/$ million revenue)	278
Cumulative tCO_2e under/over 2°C Carbon Budget (2025 Horizon)	–277 million
% Revenue from Nuclear Energy	34.10%



Sources: S&P Trucost; SBTi.

Exhibit 17. Alphabet's Carbon Emissions, 2012–2023



Sources: S&P Trucost; SBTi.

being "carbon neutral since 2007."[14] Previously, the company achieved carbon neutrality by purchasing renewable energy offsets, while it continued to emit (based on 2023 data) 7.7 million tons of CO_2 emissions (Scope 1 and 2), as shown in **Exhibit 17**. Of course, this would be insufficient based on SBTi's Corporate Net-Zero Standard, which explicitly requires companies to focus on "rapid, deep emission cuts" rather than achieving net zero by purchasing offsets.

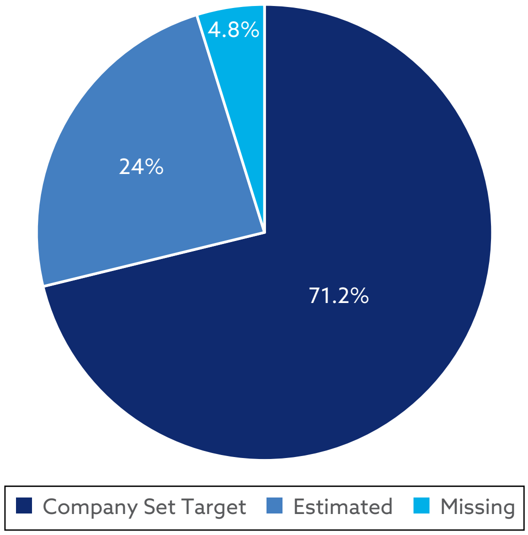
Data Coverage, Distribution, and Implications

Because not all companies have registered their commitments to SBTi, one should use the Paris-aligned data with an understanding of the assumptions the data vendor used to extend coverage to a broader universe. As of 30 June 2024, approximately 71% of the weight of the MSCI ACWI is sourced from company-set targets while the rest are estimated (either via subindustry or company trends) by the vendor (**Exhibit 18**).

An examination of the SBTi 2°C alignment data paints a picture that is somewhat bleak (see **Exhibit 19**): Only 47% of companies in the MSCI ACWI are

[14]S. Pichai, "Our Third Decade of Climate Action: Realizing a Carbon-Free Future," *The Keyword* (blog, 14 September 2020). https://blog.google/outreach-initiatives/sustainability/our-third-decade-climate-action-realizing-carbon-free-future/.

Exhibit 18. SBTi Data Coverage, 30 June 2024

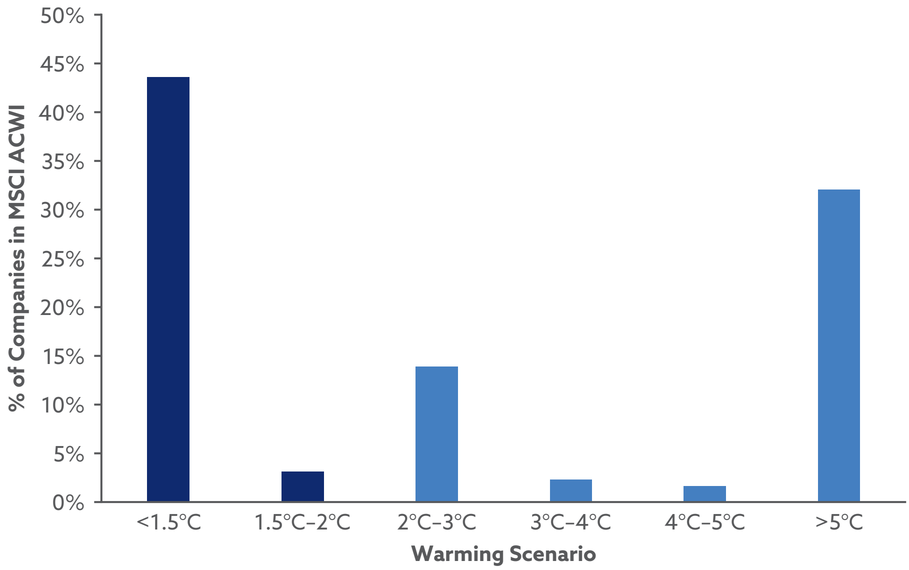


Sources: S&P Trucost; SBTi.

aligned with the 2°C goal (1.5°C–2°C and <1.5°C buckets), while more than 30% of companies are aligned at greater than 5°C.

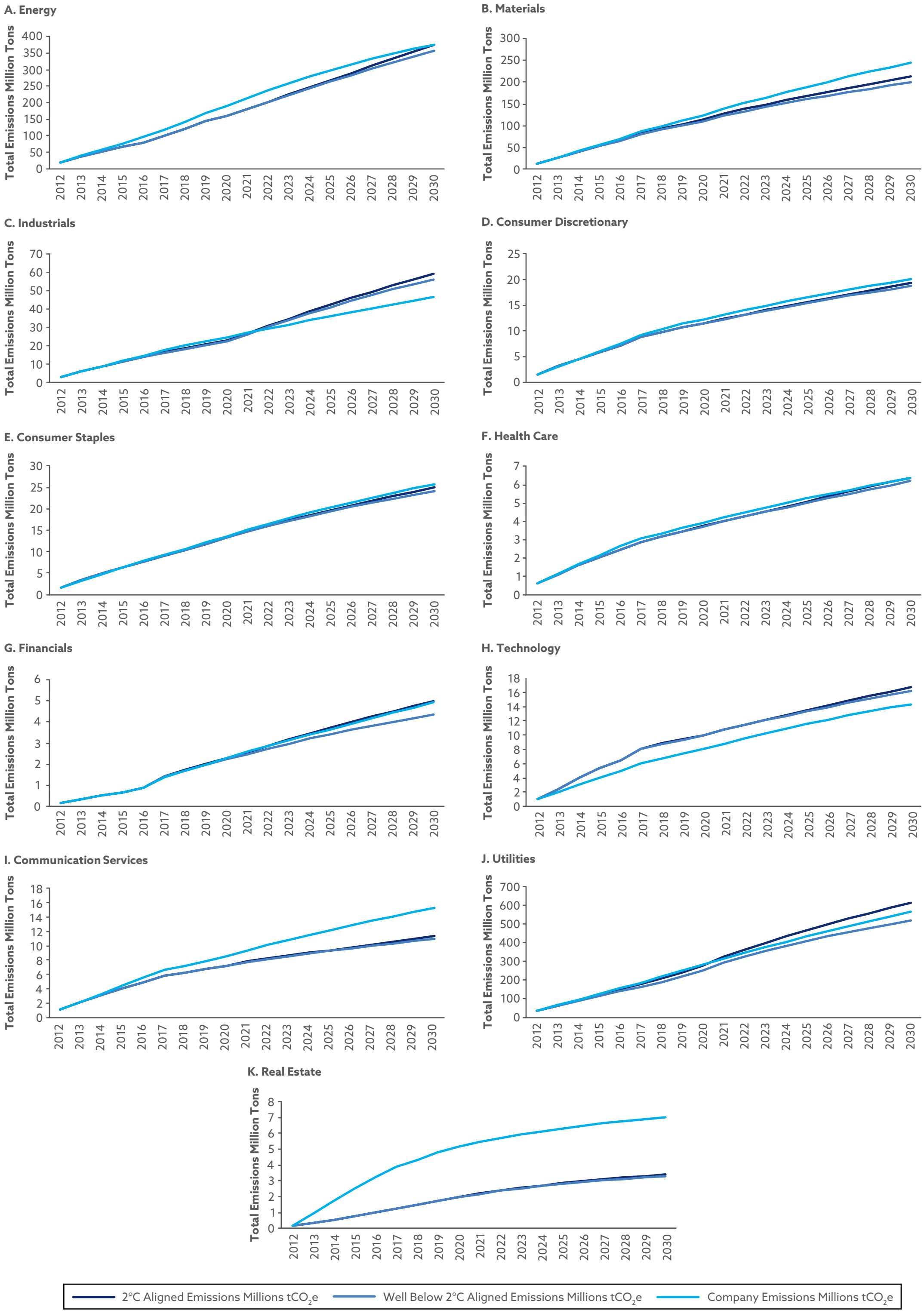
A look at the emission trajectory by sector shows a similar picture (see **Exhibit 20** and **Exhibit 21**), where many sectors are also not 2°C aligned.

Exhibit 19. SBTi Emission Alignment by Various Warning Scenarios, MSCI ACWI, 30 June 2024



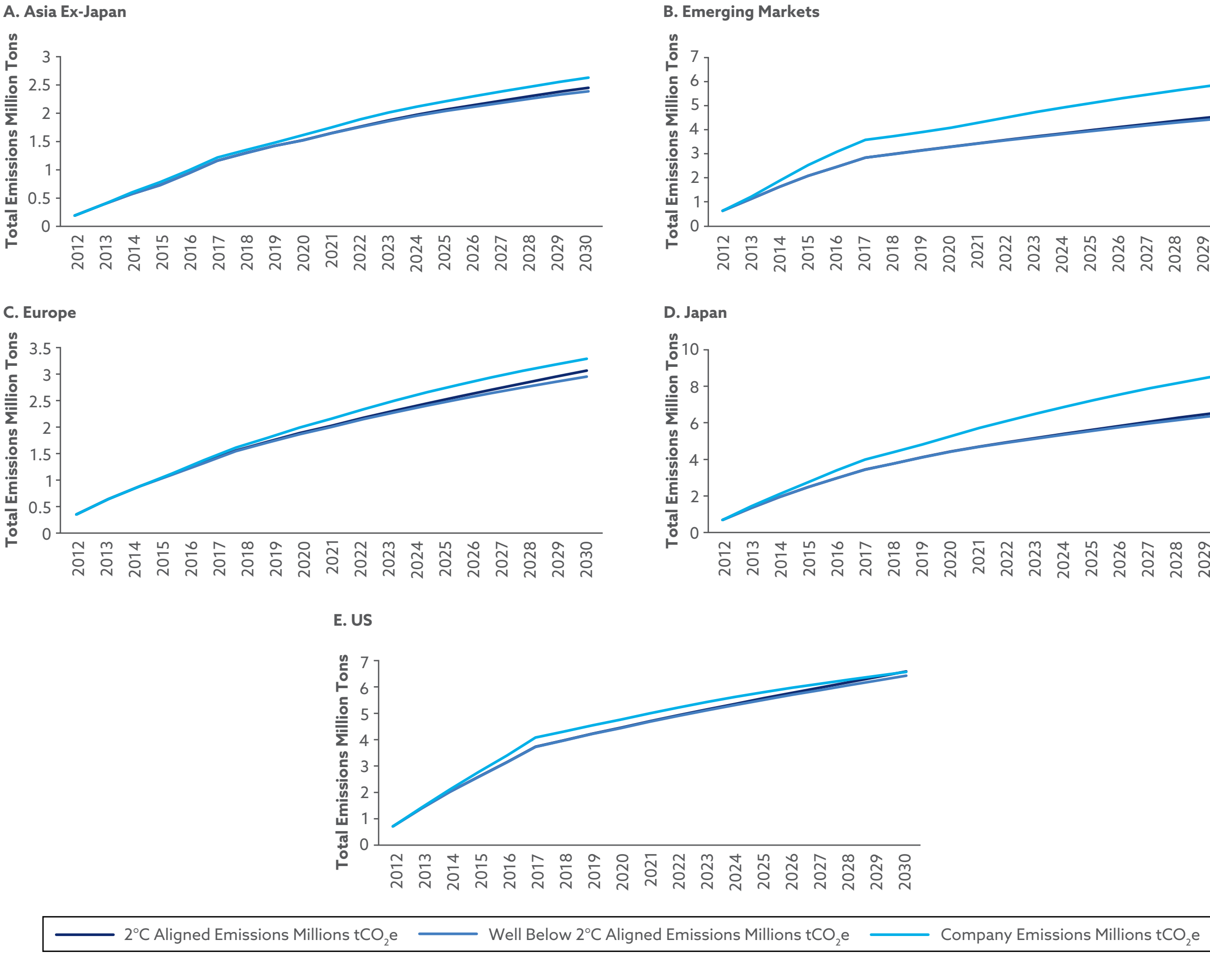
Sources: S&P Trucost; SBTi.

Exhibit 20. SBTi Emission Trajectory by Sector, 2012–2030



Sources: S&P Trucost; SBTi.

Exhibit 21. SBTi Emission Trajectory by Region, 2012–2030



Sources: S&P Trucost; SBTi.

For an ESG (environmental, social, and governance) manager focused on making a difference, it is imperative to focus on future alignment when evaluating companies for possible investment and/or engagement. Investors should recognize that certain companies are more predisposed to higher emissions than others. Instead of punishing a high-emitting cement or steel company, it is the company's future plans for committing resources or capital that are more important, in our view.

As with historical carbon emission data, careful attention also needs to be paid to the distribution of the data. Much like historical carbon emission data, the SBTi data are skewed (see **Exhibit 22**). But while the skew of historical emissions is all toward extreme emitters, the skew of the 2°C data occurs in both over- and under-budget amounts. In addition, the source, accuracy, collection methods, and coverage all need to be carefully considered in incorporating carbon-budgeted or Paris-aligned data into an investment process.

Exhibit 22. Distribution of Various Warming Scenarios: Million Tons of CO_2 under/over Budget, 30 June 2024

Sources: S&P Trucost; SBTi; MSCI ACWI.

Conclusion

To achieve net zero, investors must direct capital to those companies that will have the biggest impact on reducing future emissions. If we are to make informed decisions, we must have accurate data on both historical and expected emissions. Emission data have improved dramatically in the last 10–15 years, but these data are far from perfect and are much less standardized than the financial statement data used for most investment decision making. However, we should not let these issues deter our efforts. Investors always deal with uncertainty and must make the best decisions with the available information. Using climate data is no different.

Investors must understand emission data—what these data measure, how they are reported or estimated, and how the different scopes relate to each other. We showed that Scope 1 and 2 emission reporting is better than Scope 3 reporting and that reporting is best in Europe and in high-emitting sectors, such as utilities and energy. The data are very skewed, with large outliers in most sectors (on a relative basis). This is true for both the raw emission data and emissions scaled by company revenue. Users of carbon emission data must be aware of these issues to make the most informed decisions and assess potential pitfalls.

Practitioners have increased their focus on Scope 3 emissions to gain an accurate picture of a company's total value chain. While this gives the most accurate picture of emissions, Scope 3 comes with its own set of issues, such as proper measurement, double counting, and company comparison (owned operations versus outsourced operations). Despite being more cumbersome to gather and interpret, Scope 3 emission data are essential to capturing a full view of a company's carbon emissions.

Scope 1, 2, and 3 emissions are relevant to assess the current emissions and historical trends, but they are backward looking. Paris-aligned or SBTi data give us the best view of companies' future emission trajectory and their ability to achieve net zero. In fact, many high emitters are aggressively investing to decarbonize and are well below the 1.5°C Paris-alignment goal. But as with historic emissions, investors must be aware of the pitfalls and biases of using forward-looking SBTi data.

Climate change is one of society's greatest challenges. If we have any hope of achieving the goals of the Paris Agreement, we must set targets and monitor our progress toward achieving them, which relies on data. Emission data are imperfect, so it is important for practitioners to understand these data to ensure we are progressing down the path toward limiting climate change.

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ATTRIBUTION OF PORTFOLIOS WITH CLIMATE-RELATED SIGNALS

Andrew Ang
Managing Director, BlackRock, New York City

Debarshi Basu
Managing Director, BlackRock, New York City

Marco Corsi
Managing Director, BlackRock, London

We attribute returns for portfolios constructed with climate-related signals—past and forward-looking carbon commitments; water withdrawal intensity, which falls into natural capital; and a signal of climate-related intellectual property. A key feature of the attribution is it sums to 100%, and we apply the attribution method to returns, ex ante *and* ex post *risk, and tracking error. The decompositions without residuals better allow investors to evaluate the various contributions of these climate-related signals to risk and return, enabling more efficient and customized capital deployment. We find there is relatively low correlation among these signals, so they offer potential diversification benefits, and there are significant interactions of the climate-related signals with* ex post *carbon emissions.*

Introduction

The transition to net zero is a topic relevant to many investors looking to mitigate the risk and take advantage of the investment opportunities associated with this critical shift. Measuring the risk and return of different approaches associated with the net-zero transition—such as current and future carbon emissions, the conservation of natural capital, and investments in new green technologies—is important for the allocation of capital, setting optimal taxes and subsidies, and assessing the real investments of governments and corporations (see Intergovernmental Panel on Climate Change 2023). But evaluating the returns and risk of different net-zero approaches can be difficult because companies may pursue more than one of these approaches simultaneously. Similarly, the majority of investors typically hold diversified portfolios anchored around a major market benchmark, and there may be several climate-related characteristics taken into account when constructing their portfolios.

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In this chapter, we attribute contributions of different climate-related signals to portfolio returns and *ex ante* and *ex post* risk.[1] The attribution method follows Moehle, Boyd, and Ang (2022), which computes Shapley (1951, 1953) attribution values in a quantitative investment context. A key feature is that the attributions sum to 100%; that is, the Shapley attribution measures the contribution of each climate-related signal such that the individual signal returns sum to the actual portfolio return. In our specific example, we decompose the risk and returns of a climate-aware portfolio that maximizes exposure to carbon emissions (both past and forward-looking commitments), water withdrawal intensity, and green R&D investments as proxied by green patents, subject to a tracking error limit relative to the MSCI World Index with sector, country, and asset-level constraints.

The Shapley attribution has several other attractive features. The attribution is symmetric: If features *i* and *j* contribute the same amount when they are added to different portfolios, then they have the same attribution. It also is linearly additive: If the contribution to feature *i* is added to the contribution of feature *j*, the attribution to the combined (*i* + *j*) features is the sum of the individual contributions. In fact, Young (1985) and others show that the Shapley attribution is the *only* attribution method that satisfies all these desirable criteria.[2]

We find that constructing a portfolio with multiple dimensions of transition-related variables—as opposed to only carbon emissions, water withdrawal, or green patents signals taken one at a time—improves diversification. A portfolio constructed with exposure to all three climate-related characteristics generates an excess return of 63 bps per year over the benchmark MSCI World Index. The portfolio's annualized active risk is 160 bps relative to the MSCI World universe over 1 February 2017 to 1 June 2024 (a period of 88 months). The portfolio delivers a 67% reduction in carbon emission intensity relative to the benchmark's carbon emission intensity, with all three components of the score contributing to the reduction in emissions. It is notable that this level of reduction in carbon emissions is achieved without using an explicit decarbonatization constraint in the optimization.[3]

A benefit of being able to compute total attribution of signals is that investors with various degrees of preferences for different sustainability approaches can use the decompositions to customize the weights of different signals—and in this case, upweight or downweight the various climate-related components. In our results, water efficiency and green patents also lead to *ex post* reductions in carbon emissions without explicitly targeting carbon emissions. In particular,

[1]Note that the terms "net zero" and "transition" have a distinct meaning, especially in a regulatory context. In this chapter, we use the broader term "climate-related" to encompass climate-related goals that might not be directly included in specific net-zero frameworks. See, for example, Commission Delegated Regulation (EU) 2020/1818 of 17 July 2020: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R1818.

[2]Shapley attribution is the only attribution method that satisfies the properties of (1) efficiency, where the individual signals sum to the actual portfolio return; (2) symmetry; (3) linear additivity, as defined in this chapter; and (4) null value, where the return is the benchmark return when no features are activated.

[3]Approaches that lower the total carbon emission intensity of a portfolio through a constraint in an optimization are taken by Bolton, Kacperczyk, and Samama (2022); Hodges, Ren, Schwaiger, and Ang (2022); and Le Guenedal and Roncalli (2022), among others.

these two climate-related signals reduce the portfolio carbon emission intensity by −18 and −7 metric tons per $1 million sales (t/mn$ sales), respectively, relative to the benchmark ACWI portfolio. (As expected, exposure to lowering the carbon emission scores reduces carbon emission intensity, by −39 t/mn$ sales.) Such attribution makes it easier to understand the drivers behind a portfolio-level outcome and enables customized selection of desired climate-related characteristics to meet individuals' specific objectives.

This chapter is part of a growing literature that investigates the relationship of climate-related signals to stock returns. Some of this relationship is ambiguous: Bolton and Kacperczyk (2023) report that companies with higher carbon emissions have high excess returns, whereas Kazdin, Schwaiger, Wendt, and Ang (2021) find the opposite result. Ang, Garvey, and Schwaiger (2024) report that companies with higher profitability adjusted for carbon emissions and industry have higher returns. In contrast, Aswani, Raghunandan, and Rajgopal (2024) find there is no relation between carbon emissions and stock returns. Other studies examine climate-related variables other than carbon emissions; for example, Hsu, Li, and Tsou (2023) report that companies with higher levels of pollution are riskier and have higher returns. Of course, climate-related variables are a special case of the more general environmental, social, and governance (ESG) area. Using more than 16,000 global stocks and data from seven different ESG providers, Alves, Krüger, and van Dijk (2024) find that there is no relation between ESG ratings, regulations, or disclosure standards and stock returns. In our study, we focus on return attribution of climate-related variables in the context of an investment strategy but cannot make any statements on the relationship between returns and broader ESG scores.

The Shapley attribution we consider has not been covered in the large attribution literature in finance.[4] Some of these studies, such as Jensen (1968), Brinson, Hood, and Beebower (1986), and Fama and French (2010), use time-series data and compute alphas relative to a benchmark. These regression-based methods are dependent on the order of variables assumed in the regression. Studies using holdings-level data, such as Grinold and Kahn (2000) and Grinold (2006), often have large residuals, which are return components not attributable to any feature. In contrast, our return decompositions are not dependent on sequential order, are residual free, and sum to 100%.

[4]There is now wide use of Shapley values in machine learning with the use of SHAP (SHapley Additive exPlanations) functions—which enable the performance gain of a predictive procedure to be attributed to different inputs of the model. See Lundberg and Lee (2017) and https://shap.readthedocs.io/en/latest/. There are many methods related to SHAP, including Baseline SHAP, Kernel SHAP, Tree SHAP, and Deep SHAP.

Climate-Related Portfolio Construction

In this section, we describe the climate-related variables and the portfolio construction.

Data and Signals

Our full panel dataset consists of 23,646 firm-month observations from February 2017 to June 2024 consisting of stock returns, climate-related scores, and carbon emissions.

Stock Return Universe

The universe for the portfolio is the MSCI World Index, which incorporates large- and mid-cap companies from 23 developed markets. The portfolio averages 1,626 stocks across the sample from February 2017 to June 2024.

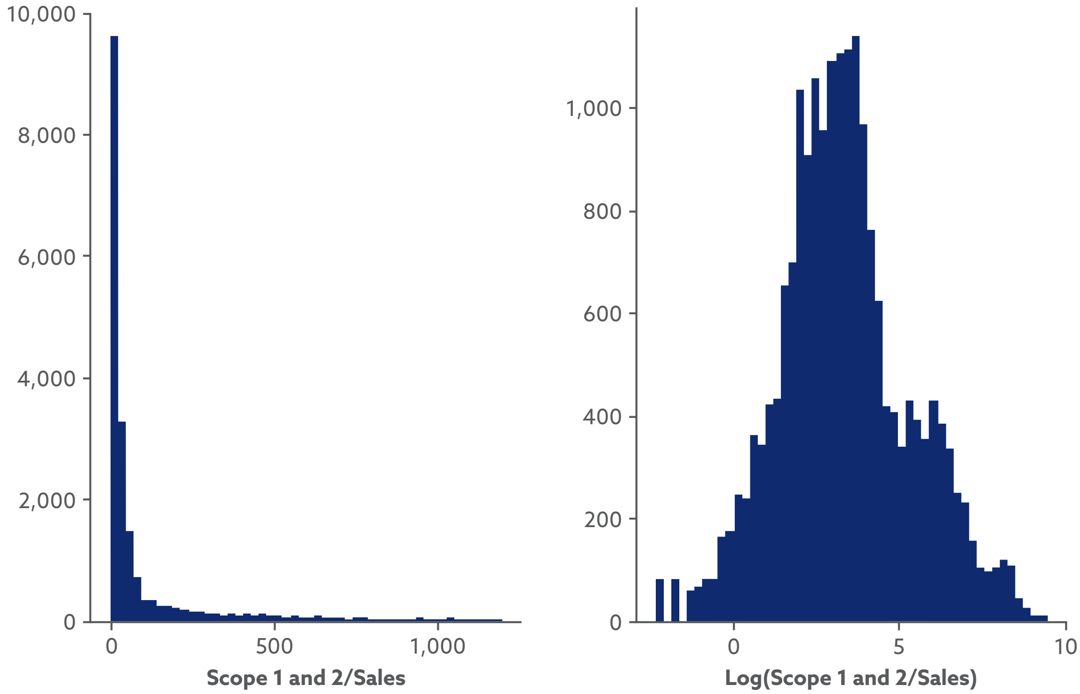
Climate-Related Variables

For the purpose of demonstrating Shapley attribution on the portfolio constructed with climate-related characteristics, we take three signals. The first signal is *carbon emissions*, which uses historical Scope 1 and 2 emission intensity over sales from MSCI and a forward-looking commitment measure. The former represents a company's most recent Scope 1 and Scope 2 greenhouse gas (GHG) emissions measured in metric ton CO_2 equivalent, which is normalized by sales in millions of US dollars. As can be seen from **Exhibit 1**, the emission numbers exhibit a pronounced right skew, which is driven by a small number of companies with very large carbon emission intensities (see comments by Hodges, Ren, Schwaiger, and Ang 2022; Bolton and Kacperczyk 2023). We use the log transformation to remove the positive skewness, which results in the histogram reported in the right-hand plot of Exhibit 1. We *Z*-score and truncate this variable between [−3, 3].

For future carbon commitments, we use an indicator variable of 1 or 0, which is exponentially weighted in the past, depending on whether a firm has set science-based carbon emission targets and is a signatory of the Science Based Targets initiative (SBTi). Garvey, Iyer, and Nash (2018) and Ang, Garvey, and Schwaiger (2024) show that firms with lower carbon emissions have, on average, higher profitability and efficiency metrics. In addition, Trinks, Ibikunle, Mulder, and Scholtens (2022) show that these firms also have lower systematic risk.

The final carbon emission signal takes 80% past carbon emissions and 20% carbon commitments. The lower weight on carbon commitments is motivated by the smaller number of firms that have made SBTi commitments to lowering future emissions. We *Z*-score so the variable has a mean of zero before using it in the portfolio construction process.

Exhibit 1. Log Transformation of Carbon Emissions



Notes: The histogram of the raw Scope 1 and 2 carbon emission intensity (which is normalized by sales) is plotted in the left panel. The log transformation of the raw data is plotted in the right panel.

The second signal, the natural capital signal, is *water withdrawal intensity* obtained from MSCI. The metric represents the company's reported water withdrawal (measured in cubic meters) normalized to revenues ($ millions). As with carbon emissions, water withdrawal intensity exhibits a right skew, so we log transform and *Z*-score the raw data.

The final signal measures climate-related intangible capital by *green patents*, as introduced by Chan, Hogan, Schwaiger, and Ang (2020). Often, patents are the culmination of investment in research and development, and a large literature uses patents to proxy for intangible asset information (see, for example, Lee, Sun, Wang, and Zhang 2019). Green patents are patents that promote innovation consistent with the UN Sustainable Development Goals, as defined by the World Intellectual Property Organization. We follow Chan, Hogan, Schwaiger, and Ang (2020) and take the two-year rolling sum of the number of green patents owned by each company divided by market capitalization, which is then *Z*-scored. Green patents are a measure of intellectual property investments associated with the transition.

Finally, we further *Z*-score each of the three climate-related signals on a sector-by-sector basis over the MSCI World universe.

Portfolio Construction

We construct a portfolio using the climate-related scores and carbon emissions as follows. Our portfolio is long only and uses the following optimization for *N* portfolio weights, $\boldsymbol{h}_{active}$:

$$\boldsymbol{h}_{active} = \arg\max_{h} U(h) = \arg\max_{h} \boldsymbol{h}^{T}\alpha - \lambda \boldsymbol{h}^{T}\mathbf{V}\boldsymbol{h}, \quad (1)$$

where

$\boldsymbol{\alpha}$ is an $N \times 1$ vector that is an equal-weighted average of the three climate-related scores for each constituent of the benchmark

λ is a coefficient of risk aversion

V is the variance–covariance matrix ($N \times N$) from a factor model from the Aladdin risk system (see Bass, Gladstone, and Ang 2017)

We set λ to 0.25, which corresponds to an *ex ante* tracking error between 100 bps and 150 bps of risk.

The objective function in Equation 1 maximizes the combined climate-related score of all stocks in the MSCI World Index and treats the climate-related scores as alpha components. In this formulation, we are not addressing whether there is an empirical relation between the climate-related scores and returns; the optimization exogenously assumes that the investor desires the maximum climate-related score for the portfolio subject to risk.

In addition, we assume the following constraints:

$$\boldsymbol{h} \geq -\mathbf{h}_{\mathbf{benchmark}}.$$

$$-3.0\% \leq \boldsymbol{h} \leq +3.0\%.$$

$$\left| \sum_{i \in \text{Country}_j} h_i \right| \leq 2.0\%. \ \forall \ \text{Country}_j \in \text{Benchmark}.$$

$$\left| \sum_{i \in \text{Sector}_k} h_i \right| \leq 2.0\%. \ \forall \ \text{Sector}_k \in \text{Benchmark}.$$

Note that $\mathbf{h}_{\mathbf{benchmark}}$ is an $N \times 1$ vector of market-cap weights in the MSCI World Index benchmark. The constraints can be interpreted as follows. The first constraint guarantees the portfolio is long only. In the second constraint, the active weight relative to the benchmark of a single security is less than or equal to 3.0%. The third and fourth constraints represent that the active country weight is limited to 2% and the maximum active sector weight is 2%, respectively.

We rebalance the portfolio on the last business day of February and August in line with the NYSE trading calendar. On the semiannual rebalance dates, we liquidate the old positions and purchase the new positions. We assume full reinvestment without any cash balances and hold these positions until the next annual rebalance date, when the process is repeated. We ignore transaction costs for our analysis for simplicity, but it is straightforward to include an additional linear term in Equation 1 to take them into account.

Finally, for the portfolio benchmark, we use a modified version of the MSCI World Index that rebalances only twice a year,[5] in February and August. Doing so ensures that the relative performance between the portfolio and its benchmark is not affected by differences in the respective rebalancing schedules.

Shapley Attribution

We lay out an intuitive exposition of Shapley (1951, 1953) attribution using a geometric interpretation. A more general formula is in the Appendix.

We work with three features, $i = 1, 2, 3$, which can be interpreted as the three climate-related signals. We denote the portfolio return as $f(\mathbf{x})$, where the vector $\mathbf{x}$ is a configuration with all features. The benchmark MSCI ACWI return without any climate considerations is given by $\mathbf{x} = (0, 0, 0)$, with corresponding return $f(0, 0, 0)$. The portfolio return with all climate return signals is denoted by $f(1, 1, 1)$, and we denote the full configuration by $\mathbf{x} = (1, 1, 1) = \mathbf{1}$. We wish to decompose the full portfolio return, $f(1, 1, 1)$, into the three individual components.

Lifts

In Equation 2, we define the marginal contribution for feature i, or lift, as the change in performance by adding feature i:

$$f(\mathbf{x}+\mathbf{e}_i)-f(\mathbf{x}), \tag{2}$$

where $\mathbf{e}_i$ is a vector of zeros with a 1 in the ith position. The marginal contribution depends on which features are turned on in the configuration $\mathbf{x}$ and then adds the ith feature.

In the context of the optimization of Equation 1, the entries of 1 in the vector $\mathbf{x}$ correspond to nonzero entries of the alpha vector, $\boldsymbol{\alpha}$. For example, $\mathbf{x} = (1, 0, 0)$ corresponds to having scores only for the first climate-related signal of carbon emissions turned on in the optimization. In this case, the alpha vector in Equation 1 takes the form $\boldsymbol{\alpha} = (z_1 + 0 + 0)$, where z_1 represents the carbon emission scores, 0 is zero so there are no scores for the two other

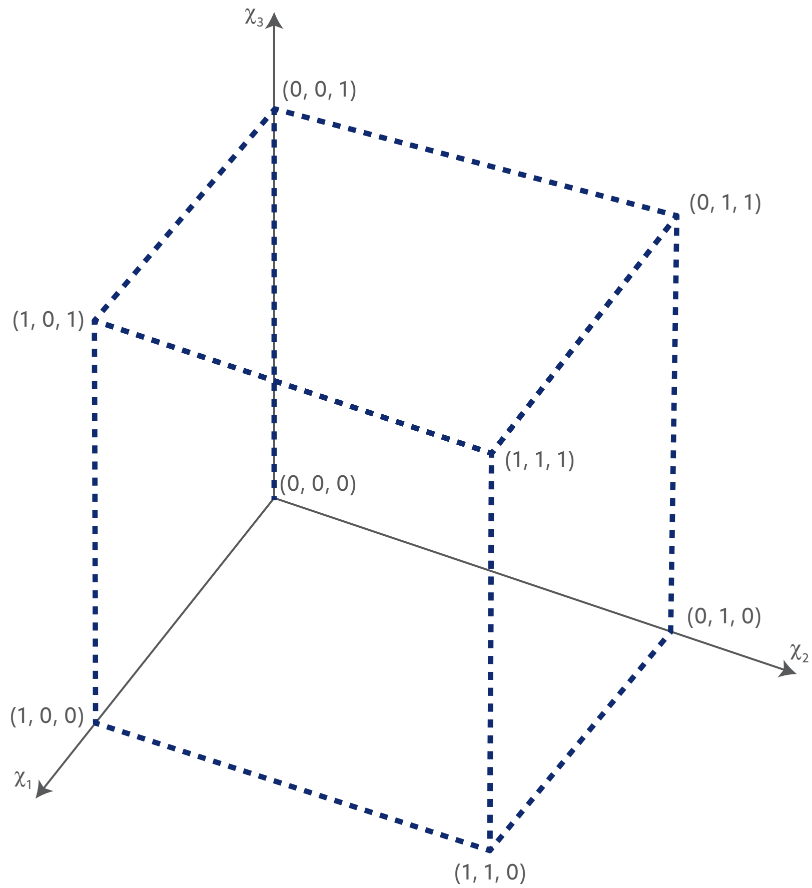
[5]The MSCI World Index rebalances four times a year, on the last business day of February, May, August, and November.

climate-related signals (water withdrawal and green patents, represented by z_2 and z_3, respectively).

Hypercube Interpretation

For *n* features, we visualize a hypercube with each feature corresponding to a vertex of a hypercube. For example, for three features, the axes in **Exhibit 2** correspond to three features: x_1, x_2, and x_3. The origin, (0, 0, 0), represents the benchmark or zero, and the full set of features, (1, 1, 1), represents the actual portfolio return. The 1 entries in the vector **x** represent the features that are turned on. For example, **x** = (0, 1, 0) represents the feature *i* = 2 turned on. The point (1, 1, 1) represents the portfolio return with all climate-related features enabled.

Exhibit 2. Hypercube Interpretation of Marginal Contributions: Vertices Are Feature Configurations



With n = 3 features, there are six possible paths from (0, 0, 0) to (1, 1, 1):

$$1 \to 2 \to 3$$
$$1 \to 3 \to 2$$
$$2 \to 1 \to 3$$
$$2 \to 3 \to 1$$
$$3 \to 1 \to 2$$
$$3 \to 2 \to 1$$

For these paths, it is understood that we always start from (0, 0, 0) and then turn on the features in the order listed in each permutation.

Traveling on the edges from configuration **x** to $\mathbf{x} + \mathbf{e}_i$ represents the lift $f(\mathbf{x} + \mathbf{e}_i) - f(\mathbf{x})$. For example, the edge from (0, 0, 0) to (1, 0, 0) represents adding Feature 1 starting from no features (or the origin). Then, traveling along the edge from (1, 0, 0) to (1, 1, 0) adds Feature 2 starting from a configuration with only Feature 1.

Marginal Contributions

We state the marginal contributions corresponding to the first feature, i = 1, for the six permutations:

Permutation	Marginal Contribution for $i = 1$
$1 \to 2 \to 3$	$f(1,0,0) - f(0,0,0)$
$1 \to 3 \to 2$	$f(1,0,0) - f(0,0,0)$
$2 \to 1 \to 3$	$f(1,1,0) - f(0,1,0)$
$2 \to 3 \to 1$	$f(1,1,1) - f(0,1,1)$
$3 \to 1 \to 2$	$f(1,0,1) - f(0,0,1)$
$3 \to 2 \to 1$	$f(1,1,1) - f(0,1,1)$

Take the first permutation, $1 \to 2 \to 3$. After starting at the benchmark, (0, 0, 0), we turn on the first feature. The marginal contribution is then $f(1, 0, 0) - f(0, 0, 0)$. Then sequentially adding Features 2 and 3 (going from $2 \to 3$ after Feature 1 is added) no longer involves Feature 1, and the subsequent path does not further contribute to the lift of Feature 1.

The second permutation, $1 \to 3 \to 2$, is similar to the first permutation, $1 \to 2 \to 3$, because Feature 1 is added first and thus the contribution of Feature 1 is the same: $f(1, 0, 0) - f(0, 0, 0)$.

In the permutation $2 \to 1 \to 3$, the marginal contribution of the i = 1 feature is enabled after the second feature is already turned on: **x** = (0, 1, 0). Thus, in the permutation $2 \rightarrow 1 \rightarrow 3$, the marginal contribution of the $i = 1$ feature is $f(\mathbf{x} + \mathbf{e}_i) - f(\mathbf{x}) = f(1, 1, 0) - f(0, 1, 0)$.

In the permutation $2 \rightarrow 3 \rightarrow 1$, Feature 1 is turned on last, after Features 2 and 3 are active, so the starting configuration is $\mathbf{x} = (0, 1, 1)$. In this case, the marginal contribution of the $i = 1$ feature is $f(\mathbf{x} + \mathbf{e}_i) - f(\mathbf{x}) = f(1, 1, 1) - f(0, 1, 1)$.

In the permutation $3 \rightarrow 1 \rightarrow 2$, we turn on Feature 1 after turning on Feature 3. Thus, the starting point is $\mathbf{x} = (0, 0, 1)$. The marginal contribution of Feature 1 is $f(1, 0, 1) - f(0, 0, 1)$. Feature 2's subsequent addition does not further contribute to the lift of Feature 1.

Finally, in the permutation $3 \rightarrow 2 \rightarrow 1$, we move to Feature 1 after already turning on Features 3 and 2. Thus, the marginal lift of Feature 1 is $f(1, 1, 1) - f(0, 1, 1)$.

It is important to note that each of the $f(\cdot)$ evaluations is a different optimization of Equation 1 where the α vector takes on different values depending on which features are turned on.

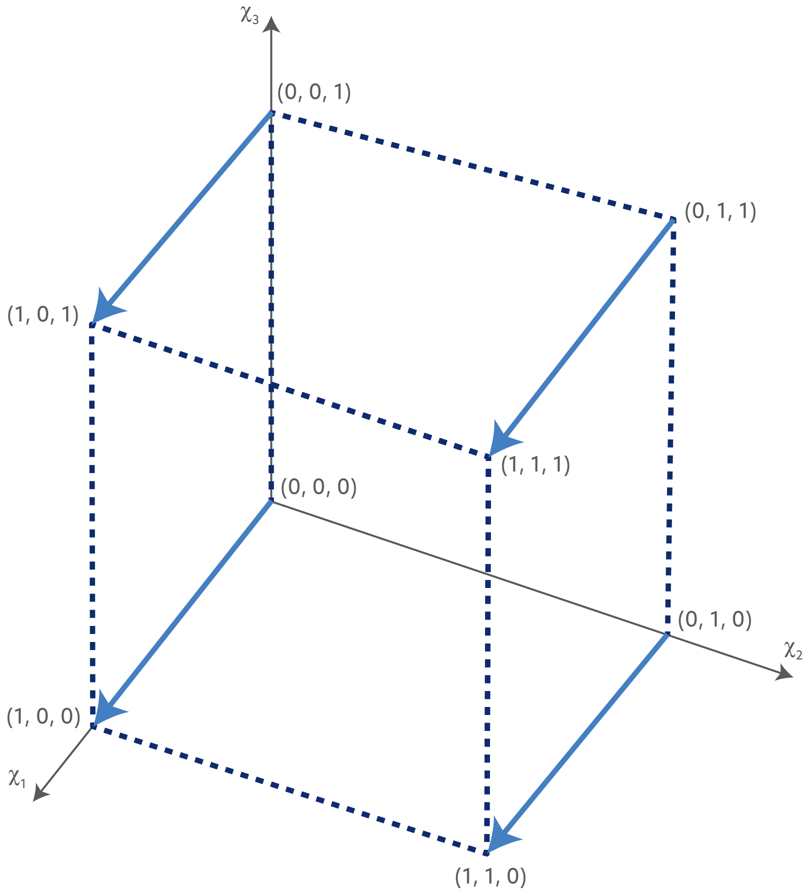
We can add up all the marginal contributions to Feature 1, a_1, in each of the permutations:

$$a_1 = \frac{2}{6}\left[f(1,0,0) - f(0,0,0)\right] + \frac{1}{6}\left[f(1,1,0) - f(0,1,0)\right] + \frac{1}{6}\left[f(1,1,1) - f(0,1,1)\right] + \frac{2}{6}\left[f(1,0,1) - f(0,0,1)\right].$$

We define the Shapley attribution of Feature 1 as a_1 above. There is a coefficient of 2 for the marginal contribution $f(1, 0, 0) - f(0, 0, 0)$ because two paths include the edge (0, 0, 0) to (1, 0, 0) on the hypercube that are the permutations $0 \rightarrow 1 \rightarrow 2 \rightarrow 3$ and $0 \rightarrow 1 \rightarrow 3 \rightarrow 2$. The terms with a 1 in the numerator contain only one edge across the six permutations. For example, only one path includes the edge (0, 1, 0) to (1, 1, 0) that occurs for the permutation $0 \rightarrow 2 \rightarrow 1 \rightarrow 3$. **Exhibit 3** shows the four distinct edges in the hypercube for three features that correspond to the marginal performance change for Feature 1. Note there are four edges but six permutations, so for two permutations, the marginal contribution for Feature 1 is repeated.

The Shapley attributions for the second and third features, $i = 2$ and $i = 3$, respectively, given by a_2 and a_3, respectively, can be obtained in a similar fashion.

Exhibit 3. Hypercube Interpretation of Marginal Contributions for Feature 1



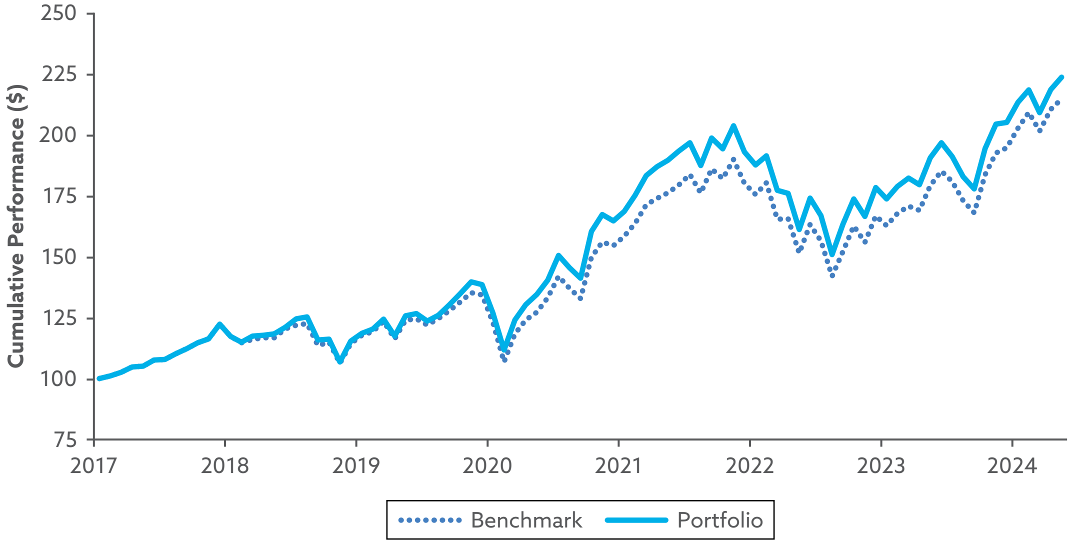
Empirical Results

We present Shapley attribution results over the period February 2017 to June 2024.

Portfolio Performance

Exhibit 4 presents the performance of the climate-related portfolio versus the benchmark from February 2017 to June 2024. We start with $100 at the beginning of February 2017. Over the time period, the climate-related portfolio has an annualized return of 1.03% per month, compared to 0.98% per month for the benchmark, which is an outperformance of 63 bps per year. The annualized *ex post* tracking error over the sample of the climate-related portfolio versus the benchmark is 1.63%.

Exhibit 4. Climate Portfolio Performance



Attribution

Exhibit 5 reports our main results and breaks down returns, total risk (volatility), and tracking error relative to the MSCI ACWI benchmark. We also report portfolio-level metrics corresponding to the three climate-related signals: the carbon emission intensity and percentage of firms with SBTi commitments, water withdrawal scores, and green patent scores.

We first turn to return attributions in the first row. Over the sample period from February 2017 to June 2024, the portfolio return was 11.11% per year. We can attribute this to the carbon, water, and green patent signals, which are 14 bps, 58 bps, and −9 bps, respectively (all annualized). Starting with the benchmark return of 11.11% per year, we have

Portfolio return = Benchmark + Carbon + Water + Green patent,

or

11.74% = 11.11% + 0.14% + 0.58% – 0.09%.

Thus, over the sample, most of the outperformance has been driven by water, whereas green patents have slightly detracted. Note that the attribution, unlike regression-based or holdings-based methods, sums to 100%.

Of the realized volatility of 16.4%, the largest contribution is the benchmark of 16.09%—as by construction, with the optimization in Equation 1 setting risk aversion and sector, country, and holdings constraints to limit deviations from the benchmark. The largest contribution to the 1.63% tracking error is from carbon (77 bps), followed by water (67 bps) and green patents (19 bps).

Exhibit 5. Shapley Attributions

	Portfolio[a]	Benchmark	Carbon Attribution	Water Attribution	Green Patent Attribution
Realized Return[b] (ann.)	11.74% (63 bps)	11.11%	14 bps	58 bps	−9 bps
Realized Volatility[b] (ann.)	16.41% (32 bps)	16.09%	29 bps	−9 bps	12 bps
Realized Tracking Error[b] (ann.)	1.63%	—	77 bps	67 bps	19 bps
Carbon Emission Intensity[c] (t/mn$ sales)	31.38 (−63.80)	95.15	−39.06	−17.59	−7.12
Percentage of Portfolio with SBTi Approved Target[c]	65.10% (22%)	43.47%	16.08%	4.32%	1.23%
Water Withdrawal Score[c]	66.46%	19.84%	−7.61%	63.00%	−8.77%
Green Patent Score[c]	24.67%	—	−7.11%	−9.47%	41.25%

Notes: The exhibit shows Shapley attributions applied to the portfolio realized return, volatility, tracking error, carbon emission intensity, and the percentage of portfolio with SBTi commitments, water withdrawal score, and green patent score. The return, volatility, and tracking error are annualized. [a]Numbers in parentheses indicate the difference between the portfolio and the benchmark. [b]All figures are annualized, based on monthly return over the period February 2017 to June 2024. [c]Figures are weighted averages calculated point in time as of the end of February 2024.

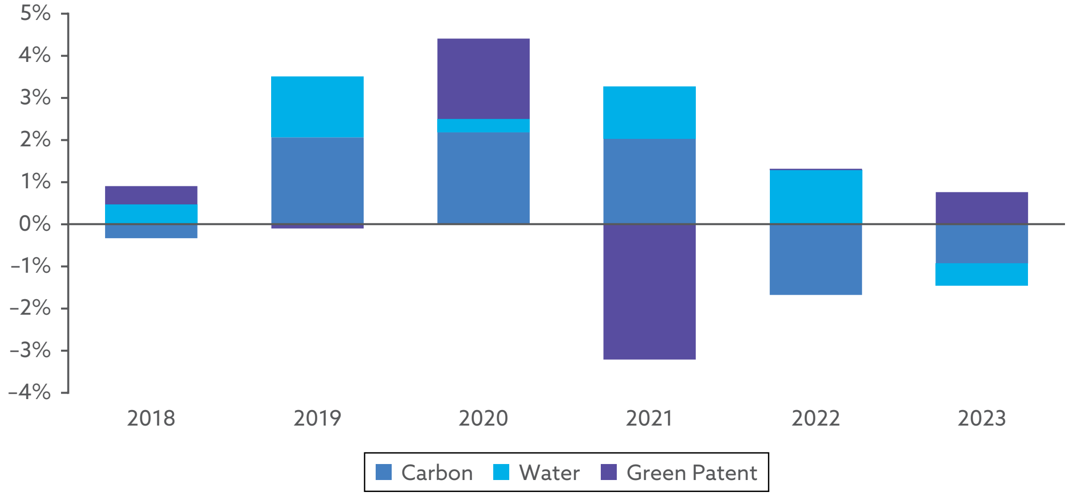
Note also that there are no risk attributions to "residual" or "idiosyncratic" components.

Of the portfolio climate-related scores, we expect each signal to have the largest contribution to the portfolio-level scores corresponding to each signal, which is evident, for example, from the fact that the largest attribution to carbon emissions is the carbon score. But there are also interesting and large cross-effects that are important for carbon emissions. The carbon emission intensity of the portfolio is 31.4 t/mn$ sales, which represents a 67% reduction compared to the ACWI benchmark of 95.2 t/mn$ sales. The water signal reduces carbon emission intensity by 17.6 t/mn$ sales, and green patents reduce carbon emission intensity by 7.1 t/mn$ sales. These reductions are on top of the reduction of 39.6 t/mn$ sales from the carbon signal. Thus, the natural capital and green intellectual property signals also contribute to carbon emission reductions even though carbon emission is not directly captured in the definition of these signals.

Shapley Attribution over Time

Exhibit 6 reports the Shapley attribution of yearly active returns. The carbon signal contributes positively from 2018 to 2021 but is negative in 2022 and 2023. The negative returns to the carbon signal are due to the Russian invasion of Ukraine in February 2022, which led to large increases in energy prices. Although the full sample attribution to green patents is slightly negative (−9 bps per year; see Exhibit 5), it provides an important source of diversification

Exhibit 6. Shapley Attribution of Annual Active Returns, 2018–2023



in certain periods—particularly in 2020. The year 2020 saw the COVID-19 shock, where after an initial sharp decline of the market in Q1 2020, there was a significant increase in growth and technology stocks that helped society function during social distancing (for further remarks, see Ang 2023). The water signal has positive returns in all years except 2023. Overall, the three climate-related signals exhibit different behavior and thus provide diversification to the full climate-related portfolio.

Conclusion

We provide a method of attribution following Shapley (1951, 1953) that exactly decomposes portfolio statistics to individual features. We apply the Shapley attribution to a climate-related portfolio that maximizes past carbon emissions and future commitments, water withdrawal intensity, and green intellectual property proxied by green patents. Over the February 2017 to June 2024 sample, the carbon and water signals positively contribute to the portfolio outperforming the MSCI ACWI benchmark, and the green patent signal slightly detracts from performance relative to the benchmark. The largest contribution to realized tracking error is from the carbon reduction signal. Interestingly, the large 67% reduction in carbon emission intensity relative to MSCI ACWI is due to all three climate-related signals, not just the signal that explicitly measures reductions in carbon emissions.

While we can measure and attribute any portfolio statistic associated with the signals or other inputs into the portfolio construction process, Shapley attribution does not make any statement on causal mechanisms. The causal relationship is often important for choosing a particular climate-related signal and also for the choice by investors of certain sustainable investment approaches. While we cannot speak to causality, proper attribution of investment performance is a useful input for verifying and measuring causal effects.

Appendix: Computation of Shapley Attribution

The Shapley attribution for feature *i*, a_i is defined in Equation A.1 as

$$a_i = \frac{1}{n!}\sum_{\pi} a_{i,\pi}, \tag{A.1}$$

where $a_{i,\pi}$ is the marginal contribution, or lift, for permutation π for feature *i* defined in Equation 2. The sum in Equation A.1 is over all *n*! permutations. In our example in the main text, there are 3! = 6 permutations. We can interpret the six ways of transversing the hypercube from 0 to **1** as equally likely in the denominator of Equation A.1 (see Exhibits 2 and 3).

The general formula for the Shapley attribution for feature *i* for features *i* = 1, ..., *n* is shown in Equation A.2 as

$$a_i = \sum_{x \in \chi_i} \frac{(\mathbf{1}'\mathbf{x})!(n - \mathbf{1}'\mathbf{x} - 1)!}{n!}[f(\mathbf{x} + \mathbf{e}_i) - f(\mathbf{x})] \tag{A.2}$$

where **1** is an $n \times 1$ vector of ones and $\chi_i = \{\mathbf{x} \mid x_i = 0\}$ is the set of configurations without feature *i*.

The drawback with Shapley attributions is that there are 2^n configurations that need to be evaluated for *n* features, which is unwieldy for a large *n*. In this case, Moehle, Boyd, and Ang (2022) show that we can use a sampling procedure to evaluate Equation A.2 using a multinomial distribution.

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ALIGNING INVESTMENTS WITH THE PARIS AGREEMENT: FRAMEWORKS FOR A NET-ZERO PATHWAY

Raul Leote de Carvalho

Deputy Head of the Quant Research Group, BNP Paribas Asset Management, Nanterre, France

Jane Ambachtsheer

Honorary Research Associate, Smith School of Enterprise and the Environment, University of Oxford, and Global Head of Sustainability, BNP Paribas Asset Management, Toronto

Alexander Bernhardt

Global Head of Sustainability Research, BNP Paribas Asset Management, Boston

Thibaud Clisson

Climate Change Lead, Sustainability Centre, BNP Paribas Asset Management, Nanterre, France

Henry Morgan

ESG Quant Analyst, Sustainability Centre, BNP Paribas Asset Management, Nanterre, France

Guillaume Kovarcik

Quant Analyst, Quant Research Group, BNP Paribas Asset Management, Nanterre, France

François Soupé

Co-Head of the Quant Research Group, BNP Paribas Asset Management, Nanterre, France

We explore two strategies for institutional investors to align equity portfolios with net-zero pathways, drawing on the latest research and industry best practices. We compare the forward-looking approach using "Net Zero Achieving, Aligned, Aligning" screens with the Paris Aligned Benchmark rules framework. The merits and weaknesses of each are discussed, along with an assessment of their potential to support the ambitions of different institutional investors when it comes to steering their portfolios to meet net-zero commitments.

The views and opinions expressed herein are those of the authors and do not necessarily reflect the views of BNP Paribas Asset Management, its affiliates, or employees.

Introduction

As the world faces the urgent challenge of curbing climate change, institutional investors are increasingly seeking ways to align their portfolios with net-zero-financed emission targets. No unique framework to reach this goal exists, however. According to Giese, Nagy, and Cote (2021), institutional investors can take three types of direct actions for this purpose.

First, investors can shift capital away from more carbon-intensive investments toward less carbon-intensive ones, expecting to impact the share price of companies, their cost of capital, and their access to capital. This shift can be achieved by tilting portfolios toward companies with lower carbon intensity, by tilting portfolios toward the decarbonization leaders based on forward-looking assessments of their rate of decarbonization, or through a combination of both. Second, institutional investors can engage with individual companies directly, whether through shareholder voting or other stewardship activities, with the aim of accelerating decarbonization efforts among laggards. Third, investors can contribute to the decarbonization of the economy by directing investments toward companies providing climate solutions (i.e., products and services relevant for the energy transition and climate change mitigation).

Companies with lower carbon intensity can be found by comparing their carbon emissions normalized by the size of the company using sales, enterprise value, or market capitalization (Ducoulombier and Liu 2021). The GHG Protocol Corporate Accounting and Reporting Standard (GHG Protocol Corporate Standard) categorizes a company's greenhouse gas (GHG) absolute emissions into three *scopes*: Scope 1, direct emissions from owned or controlled sources; Scope 2, indirect emissions from purchased energy; and Scope 3, indirect emissions from the value chain, including upstream and downstream emissions. Scopes 1 and 2, increasingly reported or predicted with sufficient accuracy (Heurtebize, Soupé, and de Carvalho 2022; Assael, Heurtebize, Carlier, and Soupé 2023), are used in calculating the carbon intensities. Scope 3, originally designed just to help companies assess their own global carbon contribution (Ducoulombier 2021), is increasingly a metric that investors expect to see included in company comparisons, despite often being estimated with varying methodologies (Ducoulombier 2021; Busch, Johnson, and Pioch 2022) and difficult to predict (Nguyen, Diaz-Rainey, Kitto, McNeil, Pittman, and Zhang 2023).

In a study on tilting portfolios in favor of decarbonization leaders, Voisin, Tankov, Hilke, and Pauthier (2020) investigated 11 forward-looking methodologies, which include classifications into aligned or not aligned companies, climate scores, percentage of (mis)alignment, and implied temperature rises. They found that results tend to be sensitive to the methodology used.

Methodologies to aggregate all portfolio contributions toward net zero using implied temperature rise indicators have also been proposed. Such methods aim to measure the proximity of a portfolio's climate performance through carbon intensity, investments in high-climate-score companies, and temperature benchmarks chosen or built based on one or several temperature trajectories. Voisin et al. (2020), however, revealed significant disparities in results from various methodologies applied to the same portfolio. Additionally, de Franco, Nicolle, and Tran (2023) found that the asset-weighted average of asset temperatures underestimates the temperature alignment of major equity. Such unrealistic assessment has generated heated debates about the usefulness of portfolio temperature alignment metrics for transition risk and impact proxies.

Despite all these possible choices, Atta-Darkua, Glossner, Krueger, and Matos (2022) found that institutional investors have primarily decarbonized portfolios by tilting their investments toward lower-emitting companies and to some extent toward climate solution providers and companies with greener revenues. However, they found limited evidence of engagement, even after the 2015 Paris Agreement.

At present, we can identify two leading investment frameworks for a net-zero pathway, which put different emphasis on the three types of direct actions for net-zero investing described previously. The first, the Paris Aligned Benchmark (PAB) approach, based on a regulatory framework proposed by the European Commission, has been adopted by many institutional investors (Azizuddin 2021), in particular in Europe. This framework sets investment constraints for the design of benchmark indexes with a focus on shifting capital away from more carbon-intensive toward less carbon-intensive investments while significantly reducing the carbon intensity of portfolios. It can be used directly for investment purposes—for example, via passive replication of those benchmark indexes or by using those same indexes as benchmarks of active investment strategies.

The second leading framework, which we call the Net Zero Achieving, Aligned, Aligning (NZ:AAA), is a forward-looking approach based on the recommendations in the Paris Alignment Investment Initiative proposed by the Institutional Investors Group on Climate Change (IIGCC), which can be used to screen assets and construct either benchmark indexes or active portfolios. IIGCC criticized the PAB framework by claiming that focusing on current carbon intensity is less important than real-world impact and recommended selecting companies for portfolios based on (1) the net-zero alignment of their forward-looking carbon reduction targets and commitments, (2) the contribution of their products and services to climate solutions, and (3) the expected success of engaging with the companies not yet aligned with net zero. The IIGCC criticism reflects the ongoing debate about the real-world impact from divestment and exclusions of stocks or sectors from portfolios (e.g., Dordi and Weber 2019; Kölbel, Heeb, Paetzold, and Busch 2020; Berle, He, and Ødegaard 2022; Eccles, Rajgopal, and Xie 2022; Rohleder, Wilkens, and Zink 2022; de Franco et al. 2023; Gehricke, Aschakulporn, Suleman, and Wilkinson 2023) and a growing preference for engagement (e.g., Wagemans, van Koppen, and Mol 2018; Blitz and Swinkels 2020; Hoepner, Oikonomou, Sautner, Starks, and Zhou 2024).

In this chapter, we provide practical guidance for investors and practitioners on constructing equity portfolios that adhere to the NZ:AAA recommendations and the PAB constraints using a portfolio construction approach with the objective of minimizing tracking error relative to market-cap-weighted portfolios. We examine both methodologies and their effects on portfolio diversification at the stock and sector levels, on expected risk and returns, and on expected success in terms of driving down real-world carbon emissions. We also discuss the fit of each framework with recommendations from organizations advocating for financial sector net-zero alignment by 2050 and beyond, which are joined by an expanding number of institutional investors. To our knowledge, it is the first time such analysis has been performed, and we believe our study represents a timely and useful contribution to the existing literature on net-zero investing.

From our analysis, we find that PAB rules are effective at reducing the portfolio carbon intensity and provide a clear trajectory for carbon intensity reduction. They may not produce long-term cumulative emission reductions, however, because of their reliance on the reduction of backward-looking historical carbon intensities and the lack of considering a forward-looking dimension[1]—for example, credible plans of companies to decarbonize. Moreover, by divesting from carbon-intensive companies, the PAB framework neither incentivizes investor engagement and stewardship aimed at accelerating a company's progress toward net-zero targets nor invests in companies that, despite higher carbon intensity, may significantly contribute to climate solutions via their products and services. In addition, the PAB framework does not consider that companies in different sectors have varying starting points and thus different levels of effort to achieve net zero.

Conversely, the NZ:AAA framework puts the focus on investing in companies with credible forward-looking commitments to net zero and in companies that contribute to the energy transition with their products and services, with much less focus on achieving overly ambitious levels of decarbonization today. This framework also facilitates engagement with a view to reducing GHG emissions from companies by not excluding all high emitters. Finally, the NZ:AAA framework promotes a smoother transition to net zero by recognizing the varying efforts needed by companies to align with a 1.5°C target. For these reasons, this framework not only is more likely than the PAB framework to deliver real-world reduction in carbon emissions but also is a better fit with the recommendations from the UN High-Level Expert Group, the Institutional Investors Group on Climate Change, and the UN-convened Net-Zero Asset Owner Alliance.

This chapter is organized as follows. In the "Methods and Data" section, we describe the application of each framework in the context of equity investments. For NZ:AAA, we outline the criteria for selecting companies based

[1]The EU PAB regulation does recommend that the weight of companies that set and publish GHG emission reduction targets should be increased in PAB benchmark indexes provided they publish targets and can demonstrate success in their reduction of emissions. This recommendation, however, is voluntary and represents an additional constraint not considered here.

on the alignment of their carbon-reduction targets, contribution of their activity to climate solutions, or the expected success of engagement. For PAB, we summarize the key portfolio decarbonization constraints, as well its exclusions and sector allocation constraints. We also we provide details of portfolio construction using a minimum-tracking-error portfolio optimization.

In the “Results” section, we discuss the practical consequences of adopting either of these frameworks for net-zero investing. Using the MSCI ACWI, MSCI World, MSCI Europe, and S&P 500 indexes as investment universes, we examine the effects on the number of stocks, on the sectors, and on market capitalization available after exclusions. We also explore the effects of adopting minimum-tracking-error portfolios on their expected tracking error, sector biases, and sustainability characteristics.

In the “Discussion” section, we delve into the strengths and weaknesses of each framework, with a focus on the probability of alignment with net zero by 2050, engagement and stewardship, exposure to a net-zero premium should it exist, portfolio diversification, immediate decarbonization, relevance of the effort of companies to reach net zero, forward-looking pledges of companies to reduce carbon emissions, and the impact of their activity on the success of the energy transition. We also examine the alignment of the frameworks with the recommendations of various institutional investor organizations advocating for net zero by 2050 and beyond.

Methods and Data

In this section, we outline the methodologies of the two net-zero frameworks for equity investments and the construction of minimum-tracking-error portfolios.

Net Zero Achieving, Aligned, Aligning Screens

The NZ:AAA screens are based on the forward-looking framework recommended by the Paris Aligned Investment Initiative (PAII) and proposed by IIGCC (2021). The PAII recommends investing in companies based on (1) their current and forward-looking alignment criteria that constitute a net-zero transition plan, (2) engagement and stewardship relating to how the company will achieve net-targets, and (3) the contribution from their activity to climate solutions. It considers that net zero is more likely achieved by maintaining investment in companies that can deliver real-world impacts and by driving reductions through stewardship and engagement rather than just excluding all high-emission companies from portfolios.

IIGCC (2021) is not explicit, however, about how to assess companies’ revenues from climate solutions or the extent to which portfolios should be tilted in favor of those companies. Nor is it explicit about to what extent portfolios should favor companies with ambitious carbon reduction targets or companies that are priorities for engagement. Investors are given the leeway to make their own choices. In **Exhibit 1**, we show how we chose to categorize companies into the Achieving, Aligned, or Aligning categories. As recommended by IIGCC (2021), we use criteria based on alignment metrics and forward-looking targets. For simplification, we chose to include the companies screened based on their activity contribution to the climate solutions in these categories rather than creating a separate category for them.

For the application of criteria based on alignment metrics and targets, we first used the Science Based Targets initiative (SBTi) dataset available in May 2023. No companies were flagged as close to their sector trajectory, and thus, no Achieving companies were found using this criterion. Several companies,

Exhibit 1. Classification of Companies into Achieving, Aligned, and Aligning Based on Either Alignment Metrics and Targets or Revenues from Climate Solutions

				Achieving Net Zero	Aligned to a Net-Zero Pathway	Aligning to a Net-Zero Pathway
	Criteria Based on Alignment Metrics and Targets					
Either companies	committed to net-zero emissions by 2050 and beyond			Yes	Yes	
	with carbon performance at or close to their net-zero-by-2050 sector trajectory			Yes		
	that disclose Scope 1, Scope 2, and material Scope 3 carbon emissions				Yes	Yes
	with short- and medium-term carbon reduction targets assessed as aligned with temperature increase		below 1.5°C		Yes	
			below 2.0°C			Yes
	Criteria Based on Revenues from Climate Solutions					
Or companies	with turnover alignment	with EU Taxonomy on climate change mitigation	at least 50%	Yes		
			at least 20%		Yes	
Or companies	with turnover alignment	with climate mitigation Sustainable Development Goals, or SDGs (max. 20% misaligned with other SDGs)	at least 50%	Yes		
			at least 20%		Yes	

however, were classified as Aligned because they had commitments with short- and medium-term targets at or below 1.5°C. Similarly, we found companies that were classified as Aligning because they had commitments with short- and medium-term targets assessed either at or well below 2.0°C.

The SBTi dataset includes a number of additional companies with commitments to disclose Scope 1, Scope 2, and material Scope 3 emissions. Under the PAII, these companies would have been classified as "Committed to Aligning." Instead, we opted to use other data sources as inputs to reclassify these companies as either Aligned or Aligning or to simply exclude them.

For such companies, we used the SBTi tool with data inputs from the Carbon Disclosure Project (CDP) and classified as Aligned all companies producing a ≤1.5°C output for any assessed time frame and all companies with Management Quality Level 4 and a short-, medium-, or long-term carbon performance ≤1.5°C in the Transition Pathway initiative (TPi) assessment. We also classified as Aligned all such companies that passed Indicators 1–6 in the Climate Action 100+ Net Zero Company Benchmark, or CA100+ Benchmark.[2]

Using a similar procedure, we classified as Aligning all such companies producing a >1.5°C but ≤2°C output for any assessed time frame when using CDP data as inputs for the SBTi tool and all such companies with at least Management Quality Level 3 and a short-, medium- or long-term carbon performance between >1.5°C but ≤2°C in the TPi assessment. In addition, we classified as Aligning all companies that passed Indicators 1–3 in the CA100+ Benchmark.

For the first set of revenue-based criteria, we used the Bloomberg EU Taxonomy dataset available at the end of May 2023 and classified as Achieving (Aligned) companies with ≥50% (≥20%) of their turnover aligned with EU Taxonomy climate change mitigation. Turnover refers to the amounts derived from the sale of products and services after the deduction of sales rebates, value-added tax, and other taxes directly linked to it.

For the second set of revenue-based criteria, we used the Matter SDG dataset available from FactSet at the end of May 2023 and classified as Achieving (Aligned) companies with ≥50% (≥20%) of their turnover aligned with climate-mitigation-linked SDG Targets 7.2, 7.3, 7.b, and 9.4 and with no more than 20% of their turnover misaligned with other SDGs.

We excluded all other companies with nonexistent or insufficiently robust climate commitments.

According to IIGCC (2021), this classification enables investors to set and measure the performance of portfolios against net-zero targets and should also inform their strategy for alignment actions. Companies not yet showing

[2]www.climateaction100.org/net-zero-company-benchmark/methodology/.

adequate progress toward meeting NZ:AAA criteria should be the priority for engagement or reweighting in portfolio construction.

When it comes to divestment or exclusions, IIGCC (2021) suggests that consideration should be given to the companies that fail all criteria and are not expected to transition within a time frame consistent with a global net-zero pathway. Companies that do not continue to improve performance against the criteria over the longer term should also be investigated.

Paris Aligned Benchmarks

The European Commission's Regulation (EU) 2020/1818 introduces standards for the methodology of low-carbon benchmarks in the EU, outlining the minimum requirements for the design of PABs and EU Climate Transition Benchmarks (CTBs). These requirements are based on the commitments set forth in the Paris Agreement and rely on the 1.5°C scenario, with no or limited overshoot, referred to in the Intergovernmental Panel on Climate Change's (IPCC's) special report on global warming of 1.5°C (IPCC 2018). The regulation is consistent with the European Commission's objective of attaining net-zero GHG emissions by 2050.

Here, we focus only on the more ambitious PABs. **Exhibit 2** summarizes the minimum standards of the PAB regulation The regulation specifies the high-impact sectors.[3] Because of the poor quality of available Scope 3 emission data (Ducoulombier 2021; Busch et al. 2022; Nguyen et al. 2023), we did not use these data, not even for the energy and mining sectors as required by the EU regulation.[4]

Following the EU regulation, the GHG intensity of each company is calculated by dividing the sum of its GHG emissions by its enterprise value including cash (EVIC). The regulation determines that when calculating the decarbonization trajectory, the GHG intensity of each company is divided by an inflation adjustment factor, defined as the ratio of the average EVIC of the benchmark at the end of the calendar year to the average EVIC of the benchmark at the end of previous calendar year. These choices imposed by regulation have two consequences that are not always fully appreciated.

First, this inflation adjustment factor forces the absolute emissions of PABs to fall over time. Without this adjustment, absolute emissions of PABs could increase if the EVIC of constituent companies increased faster than their emissions—for example, from sufficiently large increases in share prices from

[3]The high-impact sectors identified in the regulation are as follows: agriculture, forestry, and fishing; mining and quarrying; manufacturing; electricity, gas, steam, and air conditioning supply; water supply, sewerage, waste management, and remediation activities; construction; wholesale and retail trade; transportation and storage; real estate activities.

[4]The EU PAB regulation requires including Scope 3 emissions for the energy and mining sectors already today; for the transportation, construction, buildings, materials, and industrial sectors not later than two years from inception; and for all other sectors within four years from inception.

Exhibit 2. Regulatory Constraints on Paris Aligned Benchmarks

Category	Minimum Standard
Reduction of GHG intensity relative to investable universe	Minimum 50%
Decarbonization trajectory reducing average GHG intensity	Minimum 7% p.a.
Allocation to high-impact sectors	At least equal to their aggregate exposure in the underlying investable universe
Exclusion of companies	>1% of revenues from hard coal and lignite: exploration, mining, extraction, distribution, or refining
	>10% of revenues from oil fuels: exploration, mining, extraction, distribution, or refining
	>50% of revenues from gaseous fuels: exploration, extraction, manufacturing, or distribution
	>50% of revenues from electricity generation with GHG intensity >100 g CO_2e/kWh
	In violation of United Nations Global Compact principles
	In violation of OECD Guidelines for Multinational Enterprises on Responsible Business Conduct
	Related to controversial weapons
	Related to tobacco: cultivation and production

one year to the next. This adjustment is thus crucial for PABs to reduce their absolute emissions over time.

Second, the GHG intensity of a company may fall even if its carbon emissions increase, provided that its EVIC increases faster than the GHG emissions. Similarly, the carbon intensity of a company that is successfully reducing its carbon emissions may increase if its EVIC decreases fast enough—for example, because of the company's share price falling.

Minimum-Tracking-Error Portfolios Against Market-Cap-Weighted Indexes

Both the IIGCC (2021) recommendations for the NZ:AAA framework and the PAB constraints leave sufficiently leeway for portfolio construction. In that sense, we cannot speak of a unique NZ:AAA or PAB portfolio. Instead, we can speak only of portfolios that fit with the recommendations from IIGCC (2021) or portfolios that meet the PAB constraints.

As proposed by Andersson, Bolton, and Samama (2016), we opted for portfolios with the stock weights that minimize the tracking error against the market-cap-weighted portfolio while investing only in stocks screened by the NZ:AAA framework or, alternatively, stocks that meet all the PAB constraints, including the required stock exclusions. We used the BlackRock Fundamental Risk for Equity (BFRE) models for each region at the end of May 2023 for the optimization and calculation of *ex ante* tracking error and beta. As discussed by Andersson et al. (2016), minimum-tracking-error portfolios offer a feasible solution that is likely to be useful for many investors—in particular, institutional investors with large portfolios that tend to set constraints on the tracking error risk they can accommodate relative to the market-cap-weighted portfolios. This solution is also pragmatic for as long as we lack a good enough estimate of a net-zero risk premium. Having such an estimate would be required if we were to better size a risk budget allocation to that premium.

Should a positive net-zero risk premium exist, the minimum-tracking-error portfolios are not necessarily the most efficient for all investors. Although such portfolios are mean–variance efficient, they do not consider views on expected returns: They simply minimize the active risk budget allocated to all risks against the market-cap portfolio, including to any exposure to a net-zero risk premium. Investors convinced of the existence of a net-zero risk premium associated with the stocks leading the low-carbon transition should invest in portfolios with larger active weights versus market-cap-weighted portfolios. Nevertheless, the minimum-tracking-error portfolios required to invest in only Aligned or Achieving companies, or in only Aligning, Aligned, or Achieving companies or subject to PAB constraints should still outperform the market-cap index in the medium to long term, should a positive net-zero risk premium exist.

Results

In this section, we compare the two frameworks when applied to equities. First, for each framework, we investigate how many stocks are excluded in each region and sector and how much market capitalization is excluded from the investment universe. Second, we consider minimum-tracking-error portfolios to investigate the impact on expected risk and sustainability characteristics of an investment strategy that aims to replicate the performance of the underlying market-cap-weighted portfolio while implementing the recommendations or constraints of each framework. Finally, we summarize our views on each framework's strengths and weaknesses, and we discuss their fit with the recommendations of some key organizations that focus on financial sector alignment with net zero by 2050 and beyond.

Breadth of the Investment Universe

In **Exhibit 3**, we show the number and the market cap of the stocks that passed each filter from each framework at the end of May 2023. A is used for companies classified as Achieving, AA for companies classified as either

Exhibit 3. Number of Stocks and Market Cap from Each Region Screened Using Different Net-Zero Filters

Investment Universe	Description	Index	Achieving, Aligned, Aligning A	AA	AAA	Not AAA	Paris Aligned PAB	Not PAB
MSCI ACWI	Number of stocks	2,883	149	666	1,065	1,818	2,473	410
	% of stocks	100%	5.2%	23.1%	36.9%	63.1%	85.8%	14.2%
	% of market cap	100%	3.5%	41.5%	61.1%	38.9%	89.4%	10.6%
MSCI World	Number of stocks	1,506	74	499	798	708	1,338	168
	% of stocks	100%	4.9%	33.1%	53.0%	47.0%	88.8%	11.2%
	% of market cap	100%	3.6%	44.4%	64.3%	35.7%	89.6%	10.4%
MSCI Europe	Number of stocks	423	25	223	302	121	394	29
	% of stocks	100%	5.9%	52.7%	71.4%	28.6%	93.1%	6.9%
	% of market cap	100%	5.0%	60.8%	78.7%	21.3%	89.6%	10.4%
S&P 500	Number of stocks	503	19	142	252	251	440	63
	% of stocks	100%	3.8%	28.2%	50.1%	49.9%	87.5%	12.5%
	% of market cap	100%	3.0%	44.6%	63.5%	36.5%	90.0%	10.0%

Sources: MSCI; S&P Dow Jones; authors' calculations.

Aligned or Achieving, and AAA for all companies classified as Aligning, Aligned, or Achieving.

Based on the NZ:AAA framework, there are not yet many companies achieving net zero. Moreover, companies currently qualifying as Achieving do so through their activity contribution to climate solutions rather than through alignment of emissions with net-zero pathways. At the global level, only 5.2% of stocks making up 3.5% of the total market capitalization of the MSCI ACWI meet the required criteria. More European companies are achieving net zero than US companies.

If we consider all AAA companies, then the investable universe grows to 36.9% in terms of the number of companies and 61.1% of the market cap of the

MSCI ACWI universe. In the MSCI World, 53.0% of stocks representing 64.3% of the market cap pass the AAA criteria. In the MSCI Europe, 71.4% of stocks representing 78.7% of the market cap meet the AAA criteria index. For the United States, only 50.1% of the stocks in the S&P 500 pass the AAA criteria. Nevertheless, they represent 63.5% of the market-cap weight of the index.

After applying the exclusions imposed by the EU PAB regulation, PABs can still invest in 85.5% of the stocks in the MSCI ACWI, representing 89.4% of market cap. This finding does not mean that any of those stocks can have a large weight in PAB indexes, however, because of the additional constraints (e.g., those on the portfolio carbon intensity reduction). We will consider the impact of other constraints later.

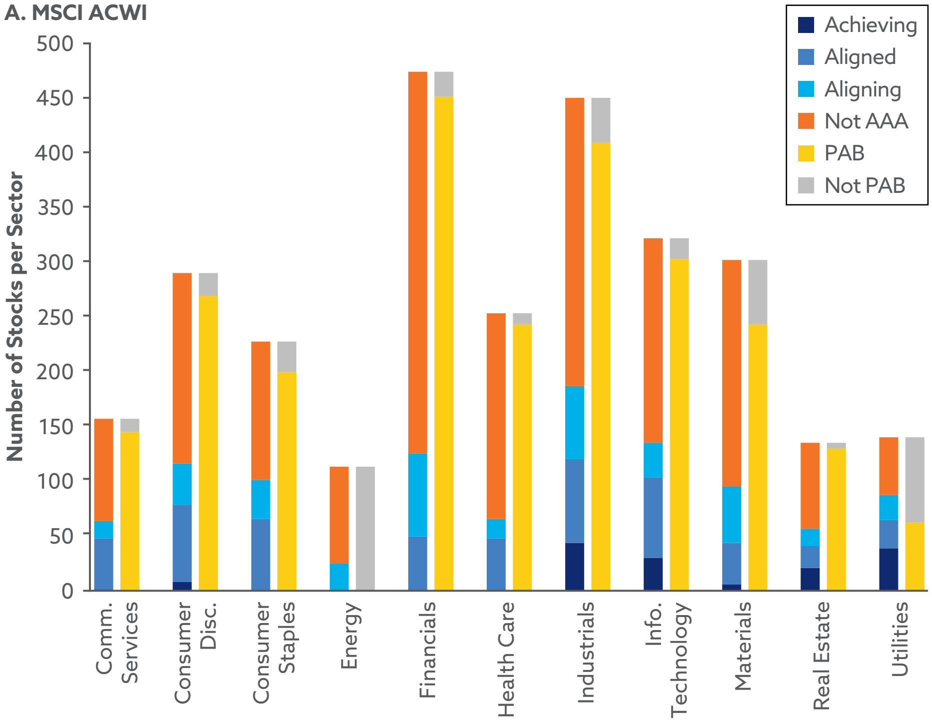
An example of a company classified as Achieving is Iberdrola, with 52% of its turnover aligned with EU Taxonomy. It has committed to net zero and has set targets assessed by SBTi to be in line with a 1.5°C pathway. Alstom is an example of an Aligned company, committed to net zero and with target pledges assessed to be in line with a 1.5°C pathway. Alstom's most significant impact arises from reducing material Scope 3 emissions, from helping to replace diesel trains with electric and hydrogen trains. John Deere is an example of an Aligning company; it has had its targets verified by SBTi and has committed to reduce its Scope 1 and 2 emissions by 50% by 2030 from its 2021 baseline, which is aligned with a 2°C trajectory and thus not ambitious enough to be classified as Aligned. Finally, PGE Polska is an example of a company excluded by the criteria used in the NZ:AAA screens, with turnover alignment with the EU Taxonomy and the climate-mitigation-linked SDGs below 20%, TPi management quality at only Level 1, and not ambitious enough when it comes to decarbonization targets, aligned with a trajectory above 2°C.

In **Exhibit 4**, we show the number of screened stocks in each sector at the end of May 2023 for the stocks in the MSCI ACWI, MSCI World, MSCI Europe, and S&P 500. No stocks from the consumer staples, energy, financials, or health care sectors were classified as Achieving. All stocks classified as Achieving did so through the alignment of their revenue stream with the EU Taxonomy climate change mitigation or climate-mitigation-linked SDGs. Such stocks are found in the industrials, information technology, real estate, and utilities sectors. The picture changes significantly if we add aligned companies with only the energy sector excluded. If we add stocks that are aligning, then we find stocks from every sector. For the PAB framework, no stock from the energy sector passes the exclusion criteria. Additionally, PAB exclusions tend to screen out at least some stocks from all other sectors.

In **Exhibit 5**, we show the sum of the market-cap weight of the stocks in each sector that passed the various screens at the end of May 2023. The figures represent the sum of the weight in the market-cap-weighted portfolio of all stocks from a given sector that pass each respective screen.

Exhibit 4. Number of Screened Stocks per Sector Based on NZ:AAA and PAB Frameworks

A. MSCI ACWI



B. MSCI World

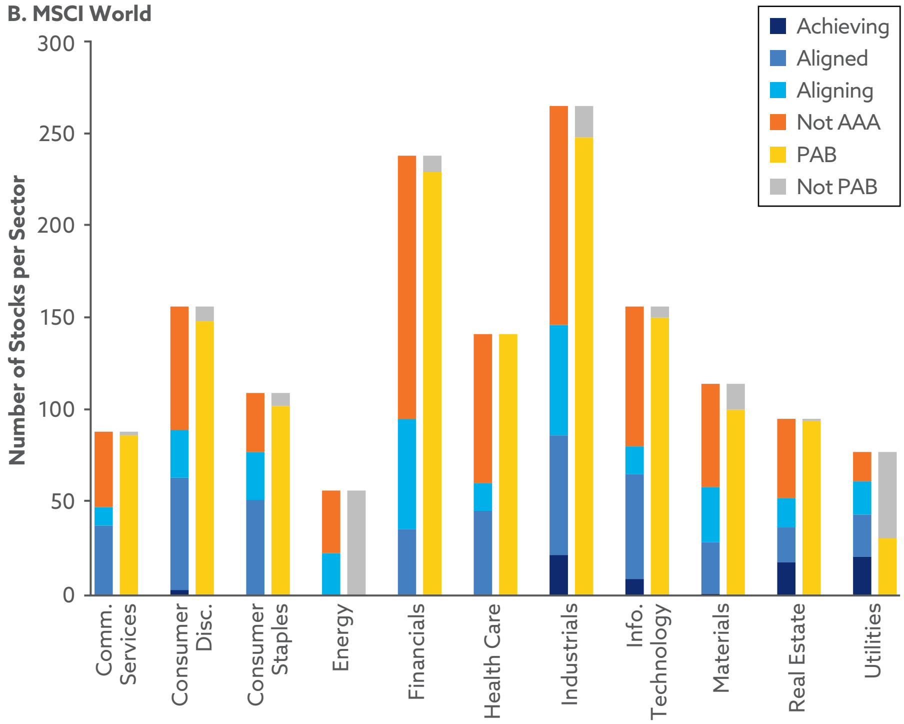
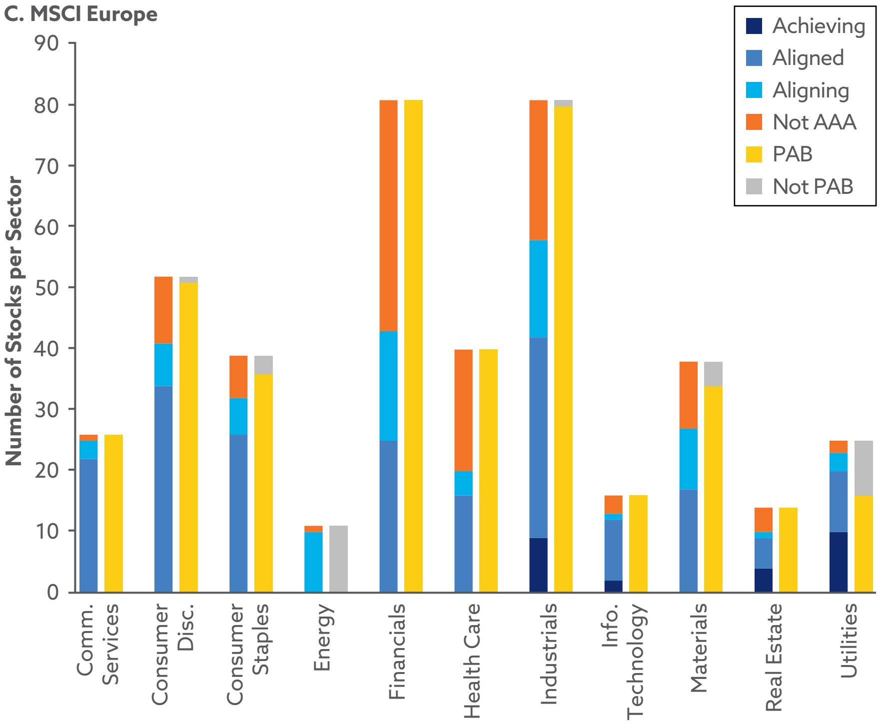
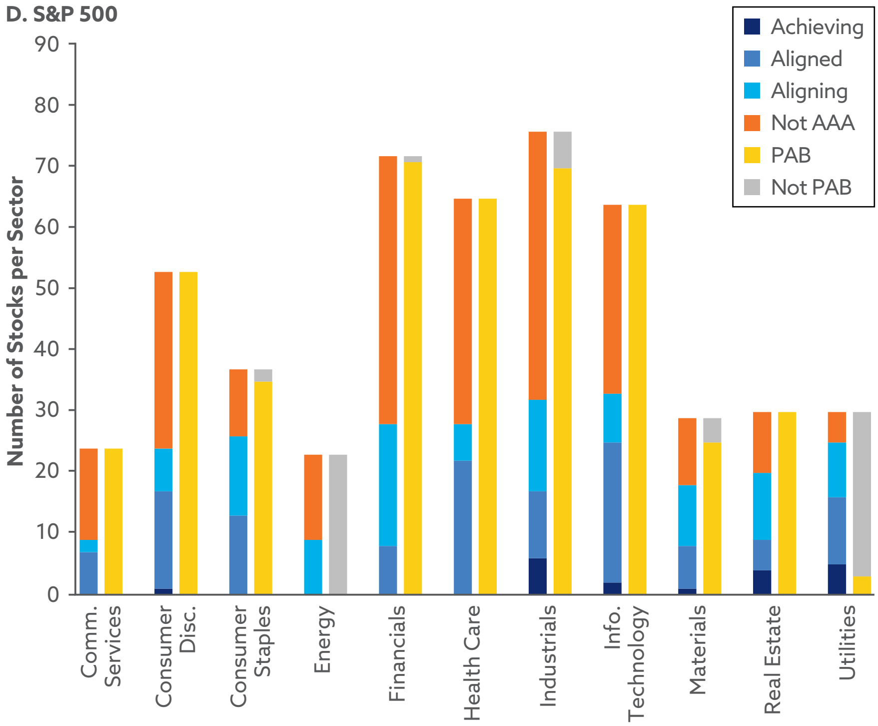


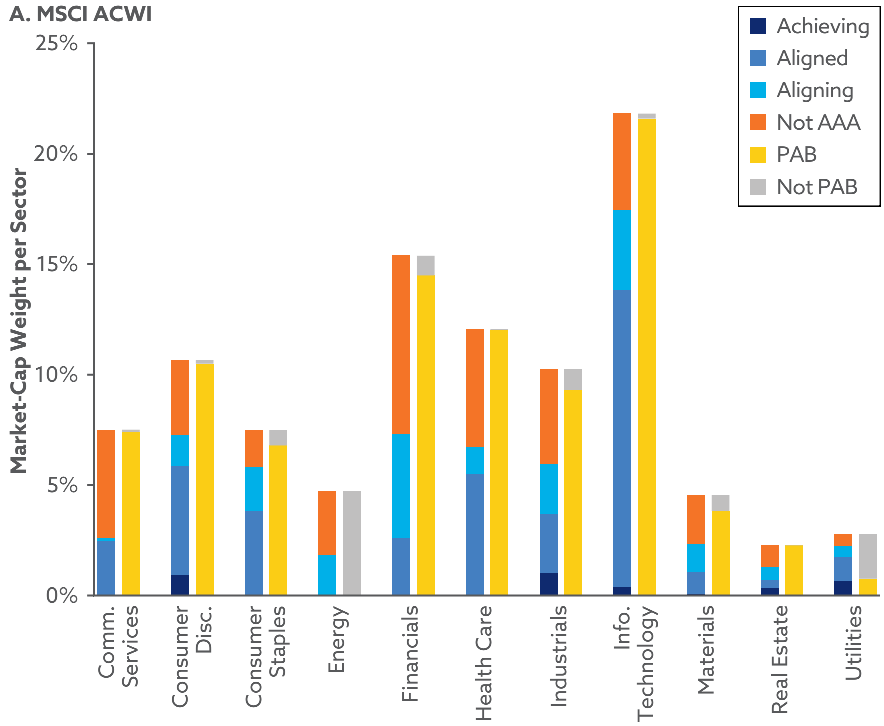
Exhibit 4. Number of Screened Stocks per Sector Based on NZ:AAA and PAB Frameworks *(continued)*





Sources: MSCI; S&P Dow Jones; authors' calculations.

Exhibit 5. Market Cap of Screened Stocks per Sector Based on NZ:AAA and PAB Frameworks



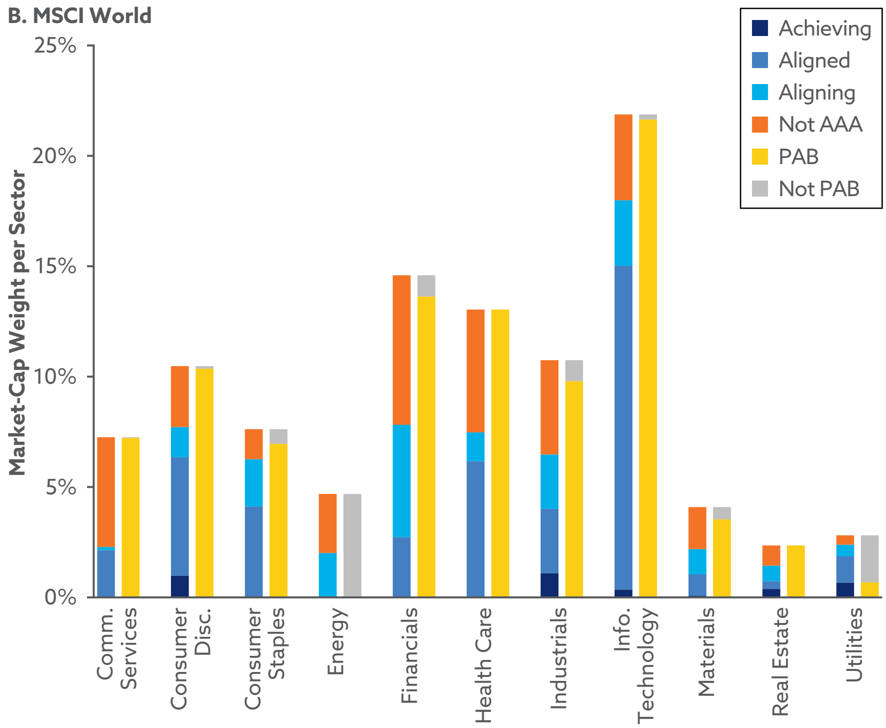
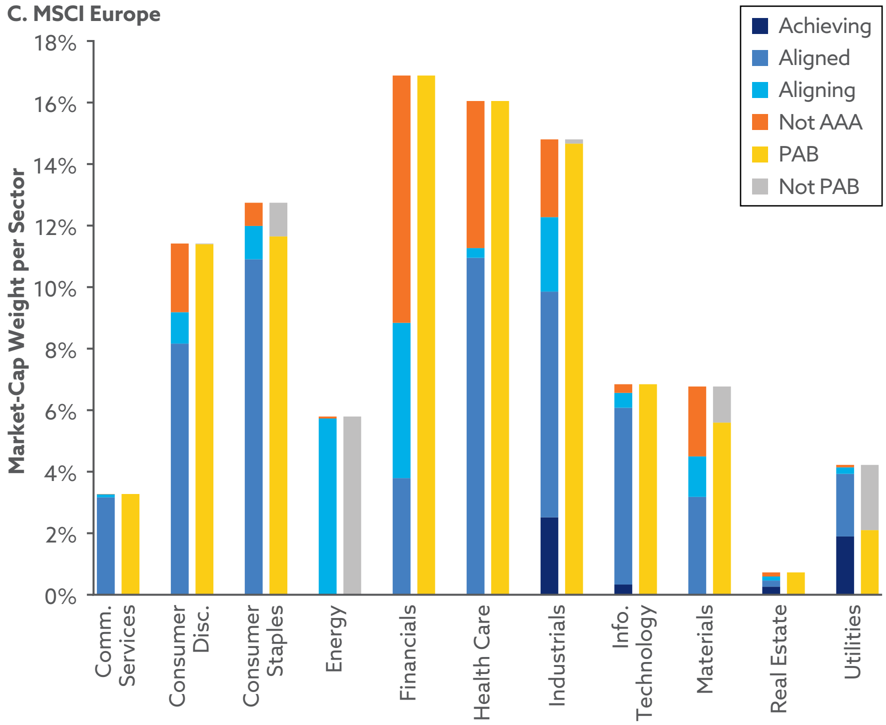
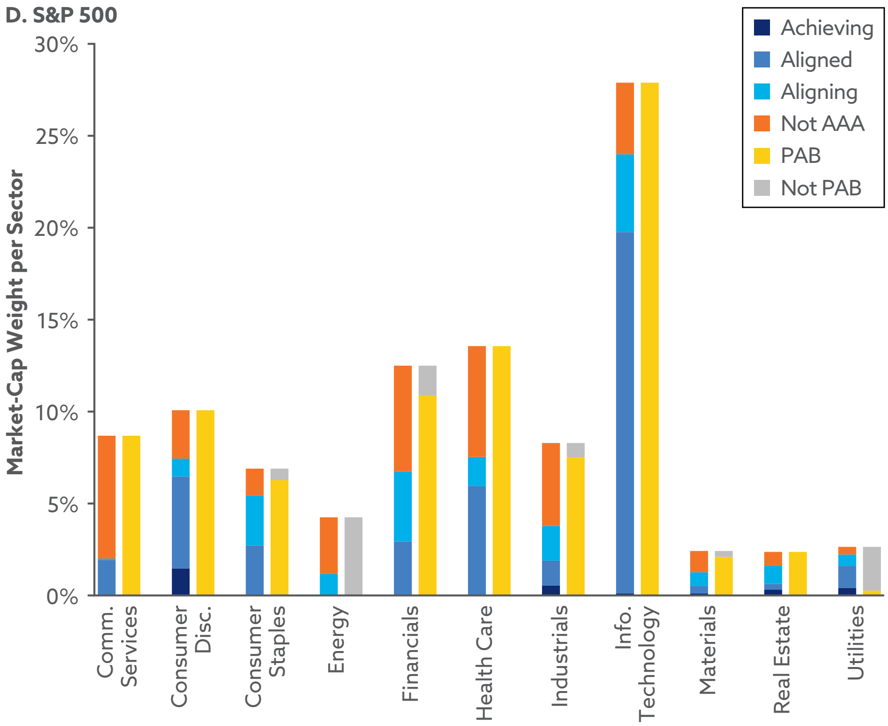


Exhibit 5. Market Cap of Screened Stocks per Sector Based on NZ:AAA and PAB Frameworks *(continued)*





Sources: MSCI; S&P Dow Jones; authors' calculations.

For the largest sector in the MSCI ACWI, information technology (21.9%), the market-cap weight of AAA stocks adds up to 17.5%. Larger sectors, such as consumer discretionary, consumer staples, financials, and industrials, tend to have half or more of their market-cap weight made up of AAA stocks. Materials, real estate, and energy—relatively small sectors—have only about half of their market-cap weight represented by AAA stocks.

Unlike the NZ:AAA framework, for the PAB framework, most of the market cap of all sectors except for energy and utilities is not impacted by stock exclusions. Nevertheless, the total market-cap weight of the utility sector is one of the smallest, varying between 2.7% for stocks in the S&P 500 and 4.2% for stocks in the MSCI Europe. Only the real estate sector has a smaller market-cap weight than utilities.

Minimum-Tracking-Error Portfolios Against Market-Cap-Weighted Indexes

We now look at the impact of the frameworks on the risk, active share, sector allocation, and sustainability of the minimum-tracking-error portfolios for each region at the end of May 2023.

This analysis, based on portfolios on a single date, is not necessarily representative of the future, considering that portfolios will be sensitive to how fast companies align with net-zero pathways and how fast the transition to clean energy will occur, as well as the fact that portfolios will have to be rebalanced periodically. If net zero is reached by 2050, then these minimum-tracking-error portfolios should converge toward the market-cap-weighted portfolio as 2050 approaches. Conversely, if not enough companies align with their net-zero pathway fast enough and, as a result, the number of excluded companies grows over time, then higher tracking errors should grow over time.

Risk and Active Share

The results in **Exhibit 6** are based on data at the end of May 2023. We can infer that minimum-tracking-error portfolios tend to invest in fewer stocks than those available after exclusions by comparing these results with those in Exhibit 1.

The tracking error of the portfolios invested in AAA stocks is small—only 0.8% for global portfolios and 0.7% for the MSCI Europe. For the S&P 500, it is just slightly higher—1.2%. Moreover, the beta is 1 in all cases. From this perspective, active market risk exposures in the minimum-tracking-error portfolios invested in AAA stocks appear well hedged.

For portfolios invested in AA stocks only, the tracking errors are still small: 1.3% and 1.4% for global and European stocks, respectively. For US stocks, at 2.0%, tracking error is still not too high. Again, beta is 1 for all these portfolios. Thus, investing only in Achieving and Aligned (AA) stocks while minimizing the tracking error against the market-cap-weighted portfolios potentially could

Exhibit 6. Risk and Active Share of Minimum-Tracking-Error Portfolios

Investment Universe	Description	Index	Achieving, Aligned, Aligning			PAB
			A	AA	AAA	
MSCI ACWI	Number of stocks	2,883	82	444	856	1,863
	Tracking error		4.3%	1.3%	0.8%	0.4%
	Volatility	17.6%	17.9%	17.6%	17.6%	17.6%
	Beta	1.00	0.99	1.00	1.00	1.00
	Active share		97.1%	63.3%	42.7%	19.3%
MSCI World	Number of stocks	1,506	51	391	648	1,100
	Tracking error	0.0%	4.7%	1.4%	0.8%	0.5%
	Volatility	17.9%	18.3%	17.9%	17.9%	17.9%
	Beta	1.00	0.99	0.99	1.00	1.00
	Active share		96.9%	61.1%	40.0%	18.8%
MSCI Europe	Number of stocks	423	25	198	298	357
	Tracking error		6.7%	1.3%	0.7%	0.8%
	Volatility	19.6%	20.9%	19.6%	19.6%	19.6%
	Beta	1.00	1.01	1.00	1.00	1.00
	Active share		95.0%	43.9%	22.7%	20.8%
S&P 500	Number of stocks	503	19	135	243	398
	Tracking error		6.8%	2.0%	1.2%	0.7%
	Volatility	18.7%	19.9%	18.6%	18.6%	18.7%
	Beta	1.00	1.00	0.99	1.00	1.00
	Active share		97.0%	55.9%	37.1%	17.5%

Sources: MSCI; S&P Dow Jones; BFRE models; authors' calculations.

align stock investments with net zero and a temperature increase at or below 1.5°C above preindustrial levels while creating a relatively small impact on risk exposures.

This would no longer be the case, however, if we invested only in Achieving stocks, with tracking errors ranging from 4.3% for the MSCI ACWI to 6.8%

for the S&P 500. We could then expect significant deviations in the performance of these portfolios relative to the performance of the market-cap-weighted portfolios. Thanks to a beta close to 1, however, these larger excess returns are still unlikely to be correlated with the returns of their respective market-cap-weighted portfolios. In terms of absolute volatility, however, these portfolios tend to be somewhat more volatile than all other portfolios considered here.

For minimum-tracking-error portfolios based on the PAB framework, applying all required constraints, including those on decarbonization and minimum allocation to high-impact sectors, we find even smaller tracking errors, varying between 0.4% for the MSCI ACWI and 0.8% for the MSCI Europe, and betas again equal to 1. These findings indicate that the PABs should be able to mimic the returns of the market-cap-weighted indexes over the medium to long term even more effectively than the AAA portfolios, with an even smaller residual performance.

Sector Biases

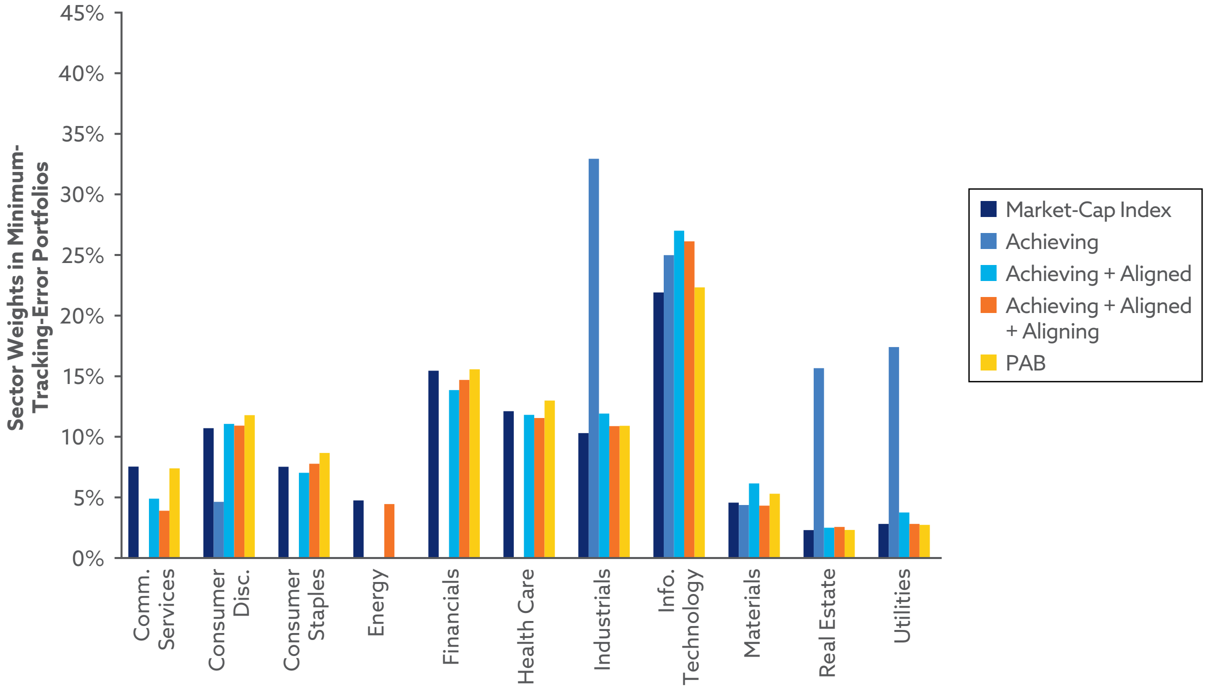
In **Exhibit 7**, we show the sector allocation in the minimum-tracking-error portfolios at the end of May 2023. The AAA minimum-tracking-error portfolio is the most sector diversified, investing in all sectors, including the energy sector for which the allocation is close to that in the market-cap-weighted portfolio. The AA and PAB portfolios are well diversified in terms of sector allocation but do not invest in energy stocks. The least diversified are the portfolios invested only in achieving stocks. These portfolios do not invest in communication services, consumer staples, energy, financials, or health care. Such sector biases are likely to generate significant contributions to tracking error and excess returns, even at short-term horizons, resulting from the differences in sector performance.

The information technology sector has the largest weight not only in the US and global market-cap-weighted indices but also in their respective minimum-tracking-error portfolios. This holds true even when the number of stocks excluded from this sector is large, as is the case for the A, AA, and AAA portfolios. A large allocation to the sector is required in order to minimize the tracking error relative to the market-cap-weighted portfolios, even if this allocation may be relatively underdiversified in terms of number of stocks from the sector. In turn, despite a similarly large allocation in the S&P 500, the allocation to the information technology sector in the minimum-tracking-error portfolio invested only in A stocks is small, with only two semiconductor and semiconductor equipment stocks from the information technology sector passing the screen.

Because of the large number of stocks and sectors excluded, the portfolios invested in Achieving stocks have the largest sector weight deviations relative to the market-cap-weighted portfolios, significantly overweighting the industrials, real estate, and utilities sectors. The large sector deviations partially explain the larger tracking error for these portfolios.

Exhibit 7. Sector Allocation of Minimum-Tracking-Error Portfolios Based on the NZ:AAA and PAB Frameworks

A. MSCI ACWI



B. MSCI World

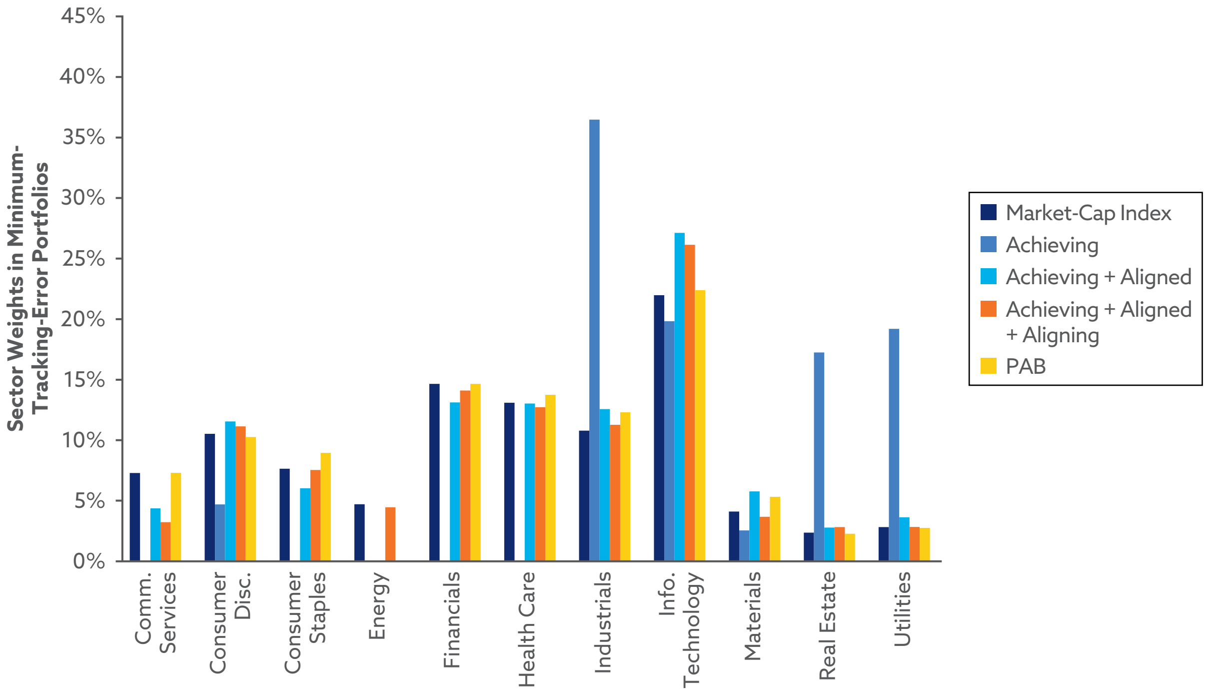
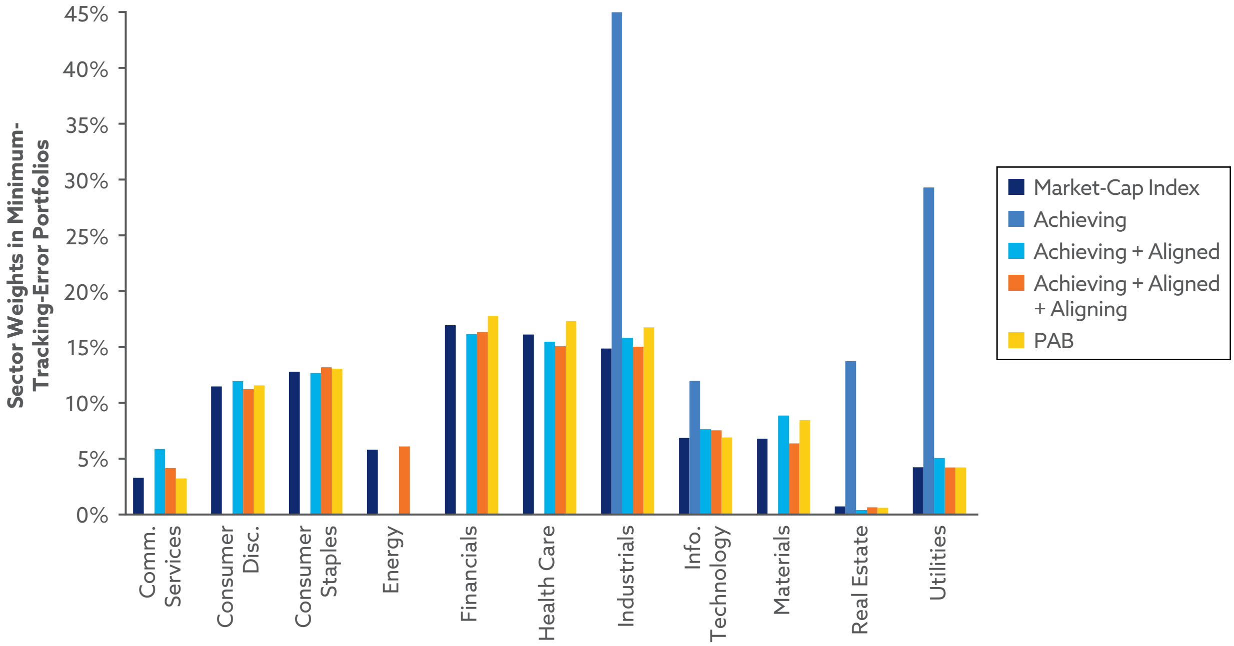
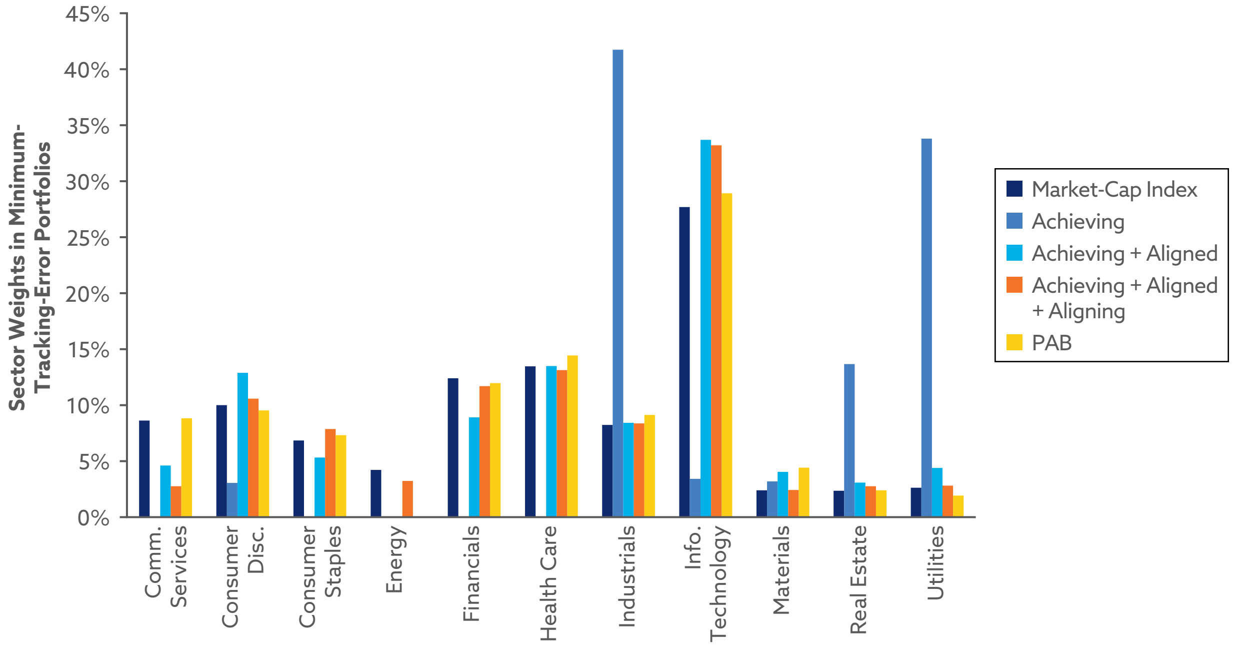


Exhibit 7. Sector Allocation of Minimum-Tracking-Error Portfolios Based on the NZ:AAA and PAB Frameworks *(continued)*

C. MSCI Europe



D. S&P 500



Sources: MSCI; S&P Dow Jones; BFRE models; authors' calculations.

Sustainability Characteristics

In **Exhibit 8**, we show the sustainability characteristics of these same minimum-tracking-error portfolios at the end of May 2023, compared with market-cap-weighted portfolios.

When no ESG constraints were imposed, the AAA minimum-tracking-error portfolios tended to have a higher ESG score than the market-cap-weighted portfolios, except for European portfolios, which already have the highest ESG

Exhibit 8. Sustainability Characteristics of Minimum-Tracking-Error Portfolios

Investment Universe	Description	Index	Achieving, Aligned, Aligning			PAB
			A	AA	AAA	
MSCI ACWI	ESG	54.3	54.2	59.6	57.2	57.7
	CO_2e intensity	72.6	81.1	54.7	62.5	36.3
	SI	37.9%	83.0%	46.2%	44.5%	39.6%
	EU Taxonomy	2.7%	26.9%	5.8%	4.2%	2.7%
MSCI World	ESG	54.4	54.6	59.3	57.1	57.7
	CO_2e intensity	60.6	65.2	45.7	50.3	30.3
	SI	38.6%	87.8%	44.9%	43.5%	40.6%
	EU Taxonomy	2.7%	27.3%	5.3%	3.9%	2.7%
MSCI Europe	ESG	59.5	63.5	62.4	60.6	61.8
	CO_2e intensity	77.7	37.7	91.2	82.6	38.8
	SI	55.4%	97.5%	63.8%	57.9%	59.6%
	EU Taxonomy	2.6%	28.5%	3.6%	2.6%	2.5%
S&P 500	ESG	53.1	52.0	58.4	56.0	57.0
	CO_2e intensity	54.4	101.6	34.5	36.9	27.2
	SI	34.0%	74.1%	38.8%	39.0%	37.3%
	EU Taxonomy	3.1%	26.6%	5.8%	4.4%	3.4%

Notes: The ESG scores used here compare companies in a matrix of 20 sectors in four geographical regions leading to 80 peer groups. ESG scores range from 0 for the worst performers to 99 for the top performers, with 50 being neutral. Carbon intensity is measured in tons of CO_2e/EUR1 million EVIC. Under the EU Sustainable Finance Disclosures Regulation (SFDR), sustainable investment (SI) is an investment in an economic activity that contributes to an environmental or social objective, does not significantly harm any environmental or social objective, and follows good governance practices. The EU Taxonomy defines economic activities that can be considered environmentally sustainable.

Sources: MSCI; S&P Dow Jones; BFRE models; ESG scores: Sustainalytics financial material factor raw data and ISS and Proxinvest governance data; company emission data: Trucost, CDP, and Bloomberg; EVIC data: FactSet; SI data: BNP Paribas Asset Management; EU Taxonomy data: Bloomberg; authors' calculations.

score of all market-cap-weighted portfolios. We found the same dynamic for the PAB framework as well. The ESG tilts relative to the respective market-cap-weighted portfolios arise mainly from the fact that the screened stocks tend to have higher ESG scores.

If we consider the minimum-tracking-error portfolios invested only in Achieving stocks, it is no longer the case that the ESG score is higher than that for the market-cap-weighted portfolios. Again, European portfolios are the exception.

Also, note that the carbon intensity of the minimum-tracking-error portfolios invested only in Achieving stocks can be higher than that for the market-cap-weighted portfolios, as is the case for global and US stocks. This finding is largely attributable to the significant overweight of the industrials sector in the Achieving portfolio. Many climate solution providers at the global level are classified as industrials and have carbon-intensive operations (Scopes 1 and 2) but produce products or services that serve to reduce downstream emissions (Scope 3). This is not the case in Europe, however, where of the 25 European companies achieving net zero, only 4 have a carbon intensity above that of the MSCI Europe portfolio.

For the AA and AAA minimum-tracking-error portfolios, the European portfolios have a higher carbon intensity than the market-cap-weighted portfolios. This finding makes sense because European high emitters are more prone to publishing carbon reduction targets, a requirement in the NZ:AAA framework. In turn, the minimum-tracking-error portfolios constructed with PAB constraints have the lowest carbon intensity, much lower than that of the respective market-cap-weighted portfolios. This finding can be explained by the explicit decarbonization constraints used to construct those portfolios—in particular, the constraint to reduce the GHG intensity by at least by 50% relative to the market-cap-weighted portfolios.

Finally, when it comes to the portfolio allocation to stocks qualifying as SFDR sustainable investments and to the portfolio allocation to company revenues generated from activities deemed sustainable by the EU Taxonomy, the minimum-tracking-error portfolios invested in Achieving stocks tend to have the highest allocations, with levels typically above those in the market-cap-weighted portfolios. This finding should be no surprise, because such stocks are screened by criteria that include turnover alignment with the EU Taxonomy climate change mitigation and with climate-mitigation-linked SDGs.

Allocations to Achieving, Aligned, Aligning and Fossil Fuel Stocks

In **Exhibit 9**, we show the sum of the weights of stocks classified as Achieving, Aligned, and Aligning and as fossil fuel stocks in the market-cap-weighted portfolios and in the minimum-tracking-error portfolios at the end of May 2023.

The market-cap-weighted portfolios have the largest allocation to Aligned stocks, with about 40% for all regions except Europe, where it is higher (55.8%).

Exhibit 9. Allocation of Minimum-Tracking-Error Portfolios

Investment Universe	Description	Index	Achieving, Aligned, Aligning			PAB
			A	AA	AAA	
MSCI ACWI	Achieving	3.5%	100%	8.7%	6.2%	3.3%
	Aligned	38.0%	0.0%	91.3%	57.7%	38.8%
	Aligning	19.6%	0.0%	0.0%	36.1%	18.6%
	Fossil fuels	9.4%	10.2%	3.5%	8.2%	4.1%
MSCI World	Achieving	3.6%	100%	7.8%	5.5%	3.4%
	Aligned	40.8%	0.0%	92.2%	60.3%	41.5%
	Aligning	19.9%	0.0%	0.0%	34.2%	18.7%
	Fossil fuels	9.4%	12.1%	3.7%	8.3%	3.2%
MSCI Europe	Achieving	5.0%	100%	5.1%	5.4%	4.9%
	Aligned	55.8%	0.0%	94.9%	70.4%	59.0%
	Aligning	17.9%	0.0%	0.0%	24.3%	13.6%
	Fossil fuels	10.0%	19.5%	2.4%	9.7%	2.5%
S&P 500	Achieving	3.0%	100%	7.5%	4.4%	2.8%
	Aligned	41.7%	0.0%	92.5%	62.7%	42.3%
	Aligning	18.9%	0.0%	0.0%	32.8%	19.3%
	Fossil fuels	8.6%	17.8%	5.6%	6.5%	1.9%

Sources: MSCI; S&P Dow Jones; BFRE models; author's calculations.

Aligning stocks make up between 17.9% and 19.9%, and the allocation to Achieving stocks is in the range of 3%–5%. Fossil fuel stocks make up about 10% or less of the weight of market-cap-weighted portfolios.

The minimum-tracking-error portfolios invested in AAA stocks significantly overweight Aligned and Aligning stocks relative to the market-cap-weighted portfolios, slightly overweight Achieving stocks, and underweight fossil fuels relative to the market cap-weighted portfolios. In turn, the minimum-tracking-error portfolio invested only in AA stocks tends to be mainly allocated to Aligned stocks, with allocations above 90%.

The minimum-tracking-error portfolios invested in Achieving stocks tend to overweight fossil fuel stocks relative to the market-cap-weight portfolios, in particular for Europe and the United States. This finding reflects the fact that several such companies meet the criterion of turnover alignment with climate change mitigation solutions.

The PAB minimum-tracking-error portfolios have an allocation to AAA stocks similar to that of market-cap-weighted indexes and a significant underweight to fossil fuel stocks.

Discussion

In this section, we summarize the strengths and weaknesses of each framework and discuss how each framework meets the recommendations of various institutional investor organizations promoting net-zero investing.

Strengths and Weaknesses of Each Framework

Our views on the strengths and weaknesses of each framework are summarized in **Exhibit 10**.

The likelihood of being aligned with a 1.5°C trajectory to net zero is higher for portfolios investing in Achieving and Aligned companies provided that those companies deliver on their commitments. The more we invest in companies classified as Aligning (i.e., with a 2°C trajectory to net zero), the less the portfolio is aligned with a 1.5°C trajectory, at least without successful engagement to push Aligning companies to increase their decarbonization efforts. In contrast, companies classified as Achieving because they offer climate solutions are contributing to the energy transition and thus to achieving net zero, even those with high emissions today.

Exhibit 10. Strengths and Weaknesses of Each Net-Zero Investment Framework

	Achieving, Aligned, Aligning			Paris Aligned
	A	AA	AAA	PAB
Probability of alignment of portfolio with net zero by 2050	High	High	Medium	High
Exposure to net-zero risk premium	High	Medium	Low	Low
Ability to diversify portfolio	Weak	Medium	Strong	Strong
Immediate decarbonization of portfolio	Weak	Medium	Medium	High
Account for the varying efforts of companies to reach net zero	Yes	Yes	Yes	No
Focus on funding the energy transition	Strong	Medium	Medium	Weak
Forward-looking approach to net zero	Yes	Yes	Yes	Partial
Ability to engage and support stewardship with higher-impact companies	Strong	Strong	Strong	Weak
EU Taxonomy exposure	Strong	Medium	Medium	Weak

By construction, the minimum-tracking-error portfolios minimize the active exposure of the portfolio to systematic risk factors relative to the market-cap-weighted portfolio. The only exposure they can never fully remove is that created by each net-zero framework's constraints and thus the exposure to a net-zero risk premium, should it exist. Thus, higher tracking error and active share should also indicate higher likely exposure to a potential net-zero risk premium. In this respect, should such a premium exist, we expect the portfolios invested only in Achieving stocks to more likely to profit from it.

Conversely, the ability to diversify the portfolio measures the extent to which frameworks exclude fewer stocks and fewer sectors. In this sense, the PAB framework allows for stronger diversification, with the lowest tracking error and beta equal to 1 relative to market-cap-weighted portfolios.

The PAB framework is more effective when it comes to immediate decarbonization of portfolios. Conversely, as shown in Exhibit 8, the NZ:AAA framework may not even reduce the portfolio's carbon intensity today relative to market-cap-weighted portfolios. This failure to reduce the carbon intensity arises from investing in companies generating revenues from climate solutions despite their current elevated carbon intensity and should be seen as a feature of the NZ:AAA framework, however, rather than a weakness.

The PAB rulebook, with strict requirements for the emission trajectory, may not be the most efficient system to reduce real-world emissions over time. To achieve their necessary decarbonization rate, PAB strategies may need to reallocate capital to lower-impact industries, even within high-impact sectors. Such an approach may not encourage companies in high-impact industries to transition to greener operations, decoupling PAB strategies from the real economy and impeding genuine progress toward the 1.5°C target. A more nuanced framework is more likely to avoid these unintended consequences.

The net-zero pathways of companies depend on how far they need to travel from their current business models to achieve alignment with the 1.5°C target. For some companies, the transition will be relatively easy, and for others, it will be more difficult. A best-in-class framework in each sector and region encourages companies from all starting points to make the required incremental changes toward net zero by 2050. Creating portfolios that support an economy-wide transition to a 1.5°C world while also avoiding any unintended negative consequences that could hinder this goal is crucial. The NZ:AAA framework offers a key advantage here: It promotes a smooth transition toward net zero while recognizing that some companies need to make more of an effort than others.

Given how challenging it is to measure Scope 3 emissions, investing solely based on emissions may lead to the exclusion of some climate solution companies just because of their high Scope 1 and 2 carbon intensity. Better aligning with net-zero goals requires strategies that invest explicitly in solution providers based on what they sell rather than just the carbon intensity of their operations. The NZ:AAA framework offers this benefit, covering a wider range of sectors.

Moreover, net zero may be more efficiently accomplished by investing capital in assets whose emissions are decreasing over time and driving emission reductions through stewardship and engagement with the companies that need to act the most. This approach can be one of the most effective ways to drive real-world impacts within public equity investments. For the PAB framework, there is limited leverage for engagement. In contrast, the NZ:AAA framework allows for targeted and nuanced conversations with companies in specific sectors and regions, which can lead to a focus on their future decarbonization strategy rather than relying solely on their past decarbonization performance.

Finally, although the NZ:AAA framework is based on current and forward-looking alignment criteria that aim to capture the transition potential of companies, the PAB framework instead relies primarily on past carbon data for companies, without considering their anticipated trajectory. And although the annual increase in required decarbonization can be seen as forward looking, as explained by Bolton, Kacperczyk, and Samama (2022), the annual 7% carbon reduction specified in the PAB regulation should be adjusted to take into account different inception dates and to reflect the fact that the remaining carbon budget is finite and depleting rapidly. In that sense, a PAB index created today requires a much faster rate of decarbonization to still achieve net zero by 2050 than one implemented since 2019.

Alignment with Net-Zero Recommendations

We now discuss the alignment of the net-zero frameworks with the recommendations of various organizations that aim to decarbonize the economy and achieve net-zero emissions by 2050 and beyond.

UN High-Level Expert Group

On 31 March 2022, the UN established the High-Level Expert Group on the Net-Zero Emissions Commitments of Non-State Entities (HLEG) to develop stronger and clearer standards for net-zero emission pledges by non-state entities—including businesses, investors, cities, and regions—and speed up their implementation. In November 2022, it published five principles seeking short- and medium-term emission reductions targeting net zero by 2050, along with 10 recommendations providing more detail on what is expected from net-zero commitments made by businesses, financial institutions, cities, and regions (HLEG 2022).

Overall, we can expect that the more businesses and financial institutions adopt the HLEG recommendations, the greater the number of companies achieving net zero. Meanwhile, in our view, the NZ:AAA framework fits the HLEG recommendations, in particular about pledges, setting targets, transition away from fossil fuels, creating a transition plan, and disclosing actionable plans. However, the HLEG recommendations go beyond the criteria currently checked by the NZ:AAA framework. Points such as corporate lobbying alignment with net-zero outcomes are covered by the work of organizations such as Influence Map and included in the dashboard produced by Climate Action 100+. An example is the Global Standard on Responsible Climate Lobbying project, initiated by AP7, BNP Paribas Asset Management, and the Church of England Pensions Board in a process supported by Chronos Sustainability, which issued 14 indicators[5] intended to be applied consistently across all regions and sectors, with companies taking responsibility for the impact of their advocacy. These investors expect corrective action from companies where there is misalignment with the goals of the Paris Agreement.

Institutional Investors Group on Climate Change

As mentioned before, the PAII was launched by IIGCC in May 2019 to explore how investors can align portfolios with the goals of the Paris Agreement. In March 2021, the PAII published the Net Zero Investment Framework (NZIF) guidelines (see IIGCC 2021), embraced by IIGCC (Europe), Ceres (North America), the Asia Investment Group on Climate Change, and the Investor Group on Climate Change, or IGCC (Australasia). These networks support investors representing more than USD50 trillion to implement the NZIF 1.0. The objectives of the framework are (1) to decarbonize investment portfolios to achieve net-zero emissions by 2050 and (2) to increase investments in the required climate solutions.

The PAII suggests that the PABs are too aggressive in terms of emission intensity reduction and prefers to incentivize the allocation to assets whose emissions are declining over time and to climate solutions. It believes that net zero is more likely achieved by maintaining investment in assets where the real-world impact is maximized through stewardship and engagement with companies that need to transition, rather than excluding them.

The NZ:AAA framework used here is based on the PAII's NZIF 1.0. Small differences from the NZIF 1.0 include the fact that we considered only four categories (versus five for the PAII) and that we combined the climate solutions dimension directly in the Achieving and Aligned screens. Despite those differences, the NZ:AAA framework fits with the NZIF recommendations and can be used as the starting point for the implementation of the NZIF guidelines for portfolio construction, engagement, and stewardship.

[5]Descriptions of the indicators can be found at https://climate-lobbying.com/wp-content/uploads/2022/03/2022_global-standard-responsible-climate-lobbying_APPENDIX.pdf.

UN-Convened Net-Zero Asset Owner Alliance (NZAOA)

NZAOA is a member-led initiative of institutional investors with USD11 trillion under management. The alliance is committed to transitioning its investment portfolios to net zero by 2050, consistent with a maximum temperature rise of 1.5°C above preindustrial levels.

NZAOA worries that PAB indexes from index vendors may not take into account that (1) policyholders can expect to earn returns commensurate with market-cap-weighted indexes; (2) such PAB indexes may have large tracking error relative to market-cap-weighted indexes,[6] perhaps even growing over time; and (3) members have differing investment horizons, risk and return expectations, and decarbonization targets. NZAOA also discourages the use of PABs because of their too-rapid decarbonization, which is not consistent with the NZAOA principle of allowing for different speeds of decarbonization across sectors and geographies.

The 10 NZAOA key principles for net-zero-aligned benchmarks (NZAOA 2022) seem relatively well aligned with the proposals from the PAII's NZIF 1.0, although NZAOA is vague about engagement and stewardship. Nevertheless, we believe that NZAOA's members can comply with those principles by using the NZ:AAA framework.

Net Zero Asset Managers (NZAM) Initiative

The NZAM is a global group of asset managers committed to achieving net-zero GHG emissions by 2050 or earlier to limit global warming to 1.5°C above preindustrial levels. Launched in December 2020, this initiative is convened by six investor networks: AIGCC (Asia), Ceres (North America), IGCC (Australasia), IIGCC (Europe), CDP (global), and the Principles for Responsible Investment, or PRI (global). The initiative had 273 signatories with approximately USD61 trillion in assets under management as of 31 May 2022.

At present, the NZAM seems open when it comes to the framework used to achieve global net-zero emissions by 2050 or sooner and puts the focus on disclosing, engaging, partnering with clients, defining interim targets, and making sure that the climate action plan is robust and delivered. In that sense, asset managers are free to use a combination of frameworks for products, provided that the sum will put the products on the path to delivering net-zero emissions by 2050 or sooner on all assets under management.

[6]In this chapter, we use PABs with only the minimum required regulatory constraints applied. Our results show a low tracking error for these PABs relative to market-cap-weighted benchmark portfolios. The commercially available PAB indexes, however, often apply a number of additional constraints that increase their tracking error and concentration.

Glasgow Financial Alliance for Net Zero (GFANZ)

GFANZ was created in April 2021 by the UN Special Envoy on Climate Action and the COP26 presidency, in partnership with the UNFCCC's Race to Zero campaign. GFANZ is a global coalition of 500 leading financial institutions from more than 50 countries committed to accelerating the decarbonization of the economy. It has two missions: to expand the number of net-zero-committed financial institutions and to establish a forum for addressing sector-wide challenges associated with the net-zero transition. GFANZ represents seven financial sector net-zero alliances (including NZAOA, NZAM, and the Net-Zero Banking Alliance), each with its own governance structure.

GFANZ (2022) has proposed voluntary guidance for financial institutions to use portfolio alignment metrics. The guidance presents a broad pan-sector framework for portfolio alignment measurement and metric selection. Each financial institution is encouraged to use elements of the guidance based on such considerations as its target audience for disclosures and the contractual and regulatory environment within which it operates. In view of this, we believe GFANZ is somewhat agnostic when it comes to defining a net-zero strategy.

Conclusion

In this chapter, we explored two frameworks for achieving net-zero pathways in investment portfolios: Net Zero Achieving, Aligned, Aligning screens and the Paris Aligned Benchmark rules.

The AAA classification is based on forward-looking data, putting less emphasis on decarbonizing significantly today. Instead, it enables investors to identify, engage with, and steward high-emitting companies. It also maintains exposure to climate solution providers.

The PAB framework focuses on strong decarbonization and establishing a trajectory to reduce portfolios' carbon intensity, relying on historical emission data. It does not support engagement and stewardship with many higher emitters, given that it calls for divestment from them, without clarity on whether doing so will actually reduce emissions.

Our analysis identifies the strengths and limitations of these two frameworks, suggesting that investors' objectives and risk tolerance should be carefully considered when choosing between them. We examined the expected impact of both on the market capitalization and the number of stocks and sectors available for investing in various regions. Both the NZ:AAA and PAB frameworks allow for well-diversified portfolios, with low tracking error relative to market-cap-weighted portfolios. This finding shows that investors can likely align their equity portfolios with net zero without unduly compromising their fiduciary obligations.

We also explored the opportunity for each framework to contribute to net-zero outcomes and discussed how the frameworks align with the recommendations of various organizations that focus on financial sector alignment with net zero by 2050. The NZ:AAA framework seems to align better with the recommendations of the Net-Zero Asset Owner Alliance. In addition, the NZ:AAA framework can identify companies that broadly meet the recommendations, particularly by focusing on Achieving and Aligned companies. Moreover, the NZ:AAA framework is based on the Net Zero Investment Framework recommendations issued by IIGCC. The PAB framework falls short of meeting several recommendations, particularly because of its aggressive decarbonization and divestment from high-impact companies, which makes engagement and stewardship with those companies more challenging.

To conclude, we believe institutional investors have a crucial role to play in driving the transition to a net-zero emissions future. This chapter helps illustrate and clarify the strengths and weaknesses of two important frameworks for investing for net zero by 2050 and beyond.

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BUILDING "NET-ZERO-ALIGNED" PORTFOLIOS

Antonios Lazanas
Global Head of Portfolio, Index, and Sustainability Quant Research, Bloomberg, New York City

Zarvan Khambatta, CFA
Global Head of Sustainability Quant Research, Bloomberg, New York City

Yingjin Gan
Global Head of Index Research, Bloomberg, New York City

Lingjuan Ma
Senior Researcher, Index Research Team, Bloomberg, London

Niall Smith
Senior Researcher, Sustainability Quant Research Team, Bloomberg, London

An increasing number of investors support a transition to a net-zero economy. The incorporation of net-zero ambitions into financial portfolios presents new considerations and uncertainties. We discuss some of these challenges and propose a methodology that allows for the construction of portfolios or indexes that are consistent with net-zero goals. In particular, we recommend the use of granular regional and sector-specific emission pathways to allow investors to make effective use of their risk budget.

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Introduction

The economy is decarbonizing at a rate that is insufficient to meet global climate goals (United Nations Environment Programme 2023; Black, Parry, and Zhunussova 2023). A variety of trends have emerged that demonstrate the intent of companies and investors to systematically decarbonize, including increased disclosure of climate-related risks, emission reduction target setting, and more precise standards for financed emission accounting. Sustainable and climate-aware benchmarks and associated regulatory guidelines have also come to the fore (e.g., Paris-Aligned Benchmarks, Climate Transition Benchmark). Despite these developments, however, financial markets continue to grapple with the concept of net-zero alignment of investment portfolios, with numerous different approaches having been proposed (Le Guenedal, Lombard, Roncalli, and Sekine 2022; Bolton, Kacperczyk, and Samama 2022). This struggle arises from varying interpretations of net zero, disagreement over what should constitute alignment, and the conceptual and analytical challenges faced when constructing portfolios that reflect a realistic decarbonization trajectory across heterogeneous sectors and geographies.

In this chapter, we elaborate on the intricacies of constructing net-zero-aligned portfolios. We first provide background on carbon budgets and transition pathways, outlining considerations for investors when designing net-zero strategies using a reference scenario. Next, we describe our approach to constructing portfolios that align with a net-zero trajectory. The methodology we propose is agnostic to the scenario selection and can be applied to any specified pathway or combination thereof.

This chapter builds upon existing literature in several ways. First, we provide guidance on the considerations to make when selecting a representative pathway. Second, we underline the importance of regional and sector specificity when measuring alignment and devise a framework for systematically applying modeled climate pathways to corporate issuers. Third, we propose a methodology for constructing a net-zero-aligned portfolio subject to a carbon budget constraint that is periodically rebalanced to ensure weights maintain alignment with the chosen pathway and the associated region–sector decomposition. Fourth, we provide an analysis of two hypothetical model portfolios' characteristics that are subject to these constraints. Finally, throughout, we highlight points for portfolio managers to consider when devising such strategies and maintaining net-zero alignment on an ongoing basis.

What Is Net Zero?

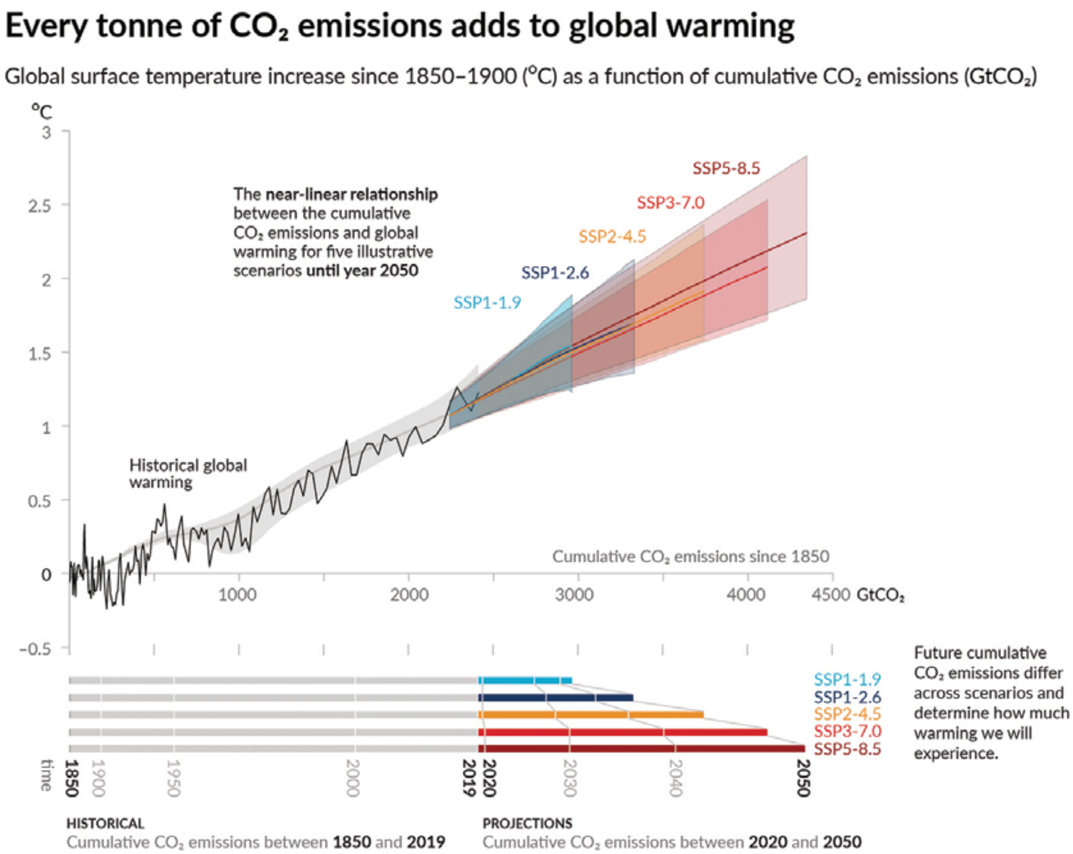
The concept of net zero has been diluted in recent years, with many companies and financial market participants using the term loosely to express decarbonization ambitions. The term originated in the climate science community to describe a state of equilibrium of the global carbon cycle, whereby "sources" of greenhouse gas emissions to the atmosphere are balanced by "sinks" that remove these gases. Greenhouse gases (GHGs) are gases in the atmosphere that trap heat and contribute to global warming. The Kyoto Convention classified seven gases as GHGs (sometimes collectively referred to as the "Kyoto gases"): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF_6), and nitrogen trifluoride (NF_3). Of those, the dominant ones are carbon dioxide and methane.

The envisaged state where human contributions of GHG emissions to the atmosphere are at a net value of zero is described as necessary to halt further global warming. The term was used formally by the Intergovernmental Panel on Climate Change (IPCC) in its 2018 special report on global warming of 1.5°C, after which it rapidly gained traction more widely. "Reaching and sustaining net-zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal time scales (high confidence)" (IPCC 2022, p. 5).

The persistence of carbon dioxide in the atmosphere underscores the importance of achieving net zero. CO_2 has a relatively long residence time, ranging from approximately 5 to 200 years, with a significant portion remaining for up to 2,000 years due to the relatively slow drawdown by natural carbon sinks (Archer, Eby, Brovkin, Ridgwell, Cao, Mikolajewicz, Caldeira, et al. 2009). This means that CO_2 emissions accumulate and their effects on global temperatures persist long after their release. Natural carbon sinks, such as oceans and forests, will eventually absorb atmospheric carbon, but this process can take millennia (Friedlingstein et al. 2023). Hence, carbon emissions and other GHGs emitted today lead to a "permanent" increase in surface temperatures, at least in terms of the timescales of humans alive today.

The described properties of atmospheric CO_2 suggest that emissions from human activities in a given year are not the ideal metric to track in the pursuit of net zero. The total emissions over time—cumulative emissions—are what will ultimately determine the extent of global mean temperature rise and the cascade of climate impacts on society and the economy, as exemplified by the near-linear relationship in **Exhibit 1** (IPCC 2023a).

Exhibit 1. Temperature Rise and Cumulative Emissions



Source: IPCC (2023a, Figure SPM.10).

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By extension, in order to stop or reverse the increase in global warming, GHG emissions from human activities will need to come to near zero at some point in time (Matthews and Cadeira 2008), irrespective of the targeted temperature rise selected (whether 1.5°C, 1.75°C, or 2.0°C). The variable that drives the difference in the amount of peak warming that will result from human activities is the total amount of GHGs emitted over time (cumulative emissions) until the point at which net zero is reached.

The quantity of emissions permissible between now and the point at which net zero is achieved is described as the remaining carbon budget. The concept of a carbon budget is a constraint that places a ceiling on emissions allowed to take place, while still maintaining global mean temperature rise below a particular threshold. What this threshold or temperature goal should be is a topic of debate in and of itself. In 2015, the Paris Agreement resulted in almost all countries committing to efforts to limit warming to "well below 2°C" and to "pursue efforts to limit warming to 1.5°C." But why 1.5°C?

The 1.5°C Threshold and the Remaining Carbon Budget

Limiting warming to 1.5°C aims to mitigate the more catastrophic impacts of climate change. Every increment of additional warming is projected to increase the frequency and severity of multiple and concurrent climate hazards—including droughts, heat waves, extreme rainfall, and flooding—and drive higher rates of biodiversity loss and extinction (IPCC 2022). The rationale for this warming threshold also relates to feedback mechanisms within the Earth System. For example, losses in sea ice reduce the overall reflectivity of the Earth's surface (albedo) and further contribute to warming. Lastly, each increment of additional warming increases the likelihood of tail risk events, such as a shutdown of the Atlantic meridional overturning circulation ocean current or the shearing and rapid melting of the West Antarctic Ice Sheet. These events are referred to as climate tipping points that can lead to a "cascade" of larger-scale climate impacts. While these possibilities are uncertain, every degree of additional warming increases the likelihood of these risks materializing. At global mean temperatures more than 2.0°C above preindustrial levels, the destabilization of the Earth System in light of these feedback effects, tipping points, and nonlinear dynamics becomes more likely (Steffen, Rockström, Richardson, Lenton, Folke, Liverman, Summerhayes, et al. 2018).

Considering these risks, the IPCC (2023b, p. 19) has cautioned against breaching the 1.5°C threshold:

> If global warming transiently exceeds 1.5°C in the coming decades or later (overshoot), then many human and natural systems will face additional severe risks, compared to remaining below 1.5°C (high confidence). Depending on the magnitude and duration of overshoot, some impacts will cause release of additional greenhouse gases (medium confidence) and some will be irreversible, even if global warming is reduced (high confidence).

Estimates vary substantially for the remaining carbon budget corresponding to limiting temperature rise to below 1.5°C for a few reasons. The main reason is that researchers use different types of models and approaches for deriving these estimates, such as

- simulating the climate response under increasing levels of emissions using dedicated Earth System models;
- integrated assessment models (IAMs), which use carbon budgets as inputs and produce a range of compatible economic, energy production, and energy use scenarios; and
- modeling exercises constrained by empirical observations of the climate.

There are also many geophysical uncertainties to consider. We do not know exactly how much temperature rise will result from a certain quantity of emissions, because of certain properties of the Earth System, such as feedback loops (e.g., permafrost methane release) and natural variability (e.g., El Niño and La Niña). All of this means the carbon budget should not be seen as a discrete value but, rather, as an estimate with an associated exceedance probability. Part of this uncertainty is modeled in the different outcomes of the simulations and is codified in different ways. In **Exhibit 2**, we present data published in the IPCC's Sixth Assessment Report (IPCC 2023a), which reports the percentage of simulation paths that exceeded a specific temperature target as a function of the total cumulative CO_2 emissions. For example, if the world emits an additional 500 gigatons of CO_2, global warming will be more than 1.5°C in 50% of the paths. Hence, this path is characterized as having a 1.5°C target with limited overshoot.

Exhibit 2. Distribution of Remaining Carbon Budgets

Global Warming: 1850–1900 and 2010–2019 (°C)		**Historical Cumulative CO_2 Emissions from 1850 to 2019 in Gigatons of CO_2 ($GtCO_2$)**					
1.07 (0.8–1.3; likely range)		**2,390 (±240; likely range)**					
Approximate global warming relative to 1850–1900 until temperature limit (°C)	Additional global warming relative to 2010–2019 until temperature limit (°C)	Estimated remaining carbon budgets from the beginning of 2020 ($GtCO_2$) *Likelihood of limiting global warming to temperature limit*					Variations in reductions of non-CO_2 emissions
		17%	33%	50%	67%	83%	
1.5	**0.43**	*900*	*650*	*500*	*400*	*300*	Higher or lower reductions in non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	**0.63**	*1,450*	*1,050*	*860*	*700*	*550*	
2.0	**0.93**	*2,300*	*1,700*	*1,350*	*1,150*	*900*	

Source: IPCC (2023a, Table SPM.2).

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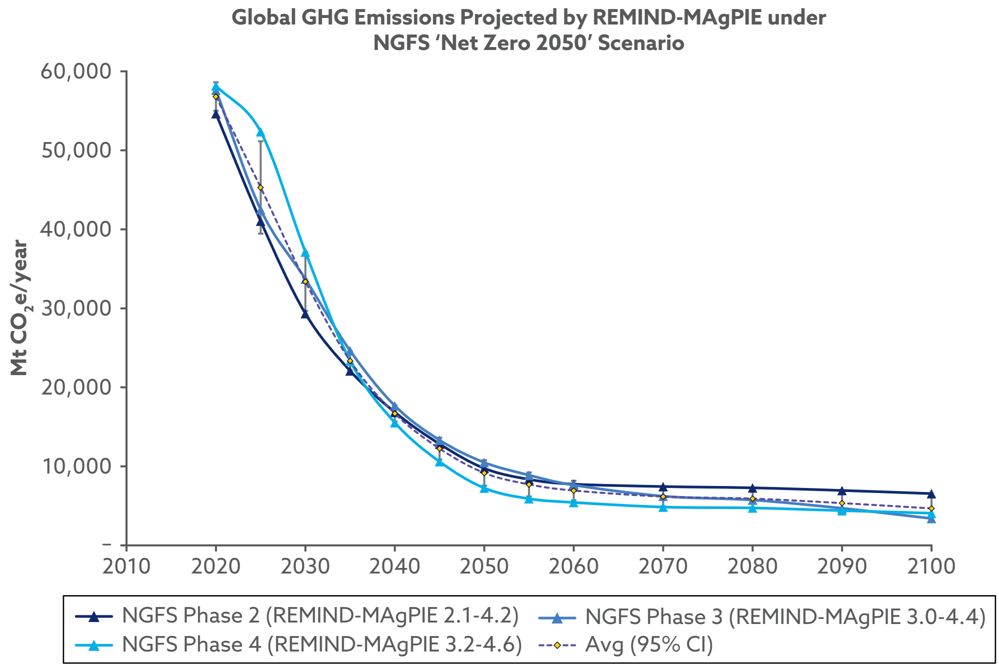
Investors striving to align portfolios to net zero using a carbon budget constraint should be cognizant of these uncertainties, not just for transparency and communication but also because of the likelihood that the budget needs to be updated over time in light of new scientific evidence and improved modeling.

Applying Net-Zero Considerations to Companies and Portfolios

There are many possible pathways to achieve a particular carbon budget. Climate scenarios, developed to understand how systems might evolve under different conditions, play a crucial role. Integrated assessment models represent these complex systems and their interactions to inform policy decisions. Investors must consider such factors as temperature outcomes, the role of carbon dioxide removal technologies, the likelihood of overshoot of the temperature goal, and the timing and pace of decarbonization when selecting a scenario. Selecting a representative pathway also involves being aware of models' relative strengths and weaknesses, such as how land-use change is modeled and the role of carbon capture and storage technology. Finally, practitioners should have systems in place for updating projections as new scenario phases and model versions are released, as demonstrated in **Exhibit 3** (NGFS 2023).

Exhibit 3. Changing GHG Emission Projections Due to Model and Data Updates



Note: The figure shows global GHG projections under the 1× Network for Greening the Financial System (NGFS) scenario and the 1× IAM, showing a range of values across published "phases."

Source: Data are from the NGFS Phase 4 Scenario Explorer (https://data.ene.iiasa.ac.at/ngfs/). The chart was originally created by Bloomberg.

The concept of net zero for investment portfolios should focus on targeting a reduction in cumulative GHG emissions to levels that are near zero. The targeted reduction should be grounded in some scenario-based carbon budget (Le Guenedal et al. 2022). Crucially, the method of assessing alignment should incentivize immediate and significant reductions in GHG emissions. Companies in the portfolio should be assessed against expected emission reduction trajectories that, in aggregate, resemble the modeled transition pathway to the best degree possible. This means accounting for the vastly different economic activities that the portfolio companies are involved in, as well as their locations of operation.

Principles

In 2020, the European Union issued guidelines for benchmark construction known as Paris Aligned Benchmarks (PABs). The guidelines include a number of exclusions of high-emitting economic sectors and activities, as well as a specific target for emission intensity reduction at the portfolio level. Initial implementations of the guidelines applied the emission reduction target universally without recognizing the ability of different economic sectors to decarbonize or the impact that such strict decarbonization targets may have on emerging economies. Eventually, it was understood that a one-size-fits-all approach was too crude and did not account for socioeconomic or technological reality.

This realization led to the development of the *pathways* concept. In this framework, the world economy is split into economic regions, and different GHG reduction pathways are prescribed for each. Developed economies are held accountable for the contribution of their historical emissions to climate change, which allowed them to prosper, and are therefore held to more aggressive emission reduction targets. In contrast, emerging and developing economies are allowed to maintain or even increase their emissions, permitting them to grow their economies without incurring large energy transition costs. This is commonly referred to as the principle of "common but differentiated responsibilities," which we will refer to as the *fairness principle*. Further, each region is split into economic sectors with different emission reduction pathways prescribed for each sector to account for technological and economic reality: the principle of *feasibility*. For example, the energy and automotive sectors are required to decarbonize much faster than the aviation sector, for which no viable technological substitutes are on the horizon. The total emissions prescribed by the various regional/sectoral pathways sum up to the global net-zero emission pathway.

Companies that are active in a particular region and sector are evaluated according to their emission intensity—that is, the emissions they contribute divided by a measure of their size. Companies with relatively high intensity are characterized as "brown," and those with relatively low intensity are characterized as "green." Investors concerned about climate change are seeking to direct their investments so that they can influence companies to reduce their emission footprint. One school of thought encourages the active ownership of brown companies with the goal of influencing their behavior through such strategies as voting and engagement. Another school of thought seeks to redirect investment dollars from brown to green companies.

Some studies have documented empirical evidence of a link between carbon intensity and cost of capital (Trinks, Ibikunle, Mulder, and Scholtens 2022). The theory is that even higher demand for green companies' securities could lead to a further relative reduction in the cost of capital for green companies over brown ones. That, in turn, could increase green companies' competitiveness and could translate to green companies gaining market share, thus reducing the total emissions of a sector without significantly affecting its size. To effect real change, though, it would require a significant set of investors to adopt green investing. It would also require that investors apply a similar philosophy across all sources of funding: public and private debt and equity markets. The principle underlying this investment approach is *substitutability*—that is, the fact that the products of companies within a given sector are substitutes for each other.

Investors may also consider that tilting their equity portfolios toward green companies may reduce their exposure to *climate transition risk*. While markets may have already priced the higher expected climate transition cost that brown companies are facing, the possibility of a faster and more dramatic climate change leading to stricter regulation of GHG emissions may not have been fully understood, exposing brown portfolios to significant tail risk.

Portfolio Construction

We now discuss how investors can tilt their portfolios toward greener companies while adhering to the fairness and feasibility concepts of the pathways. We estimate the relationship between the deviation of a tilted portfolio versus its benchmark (measured by the tracking error volatility) and the amount of emission intensity reduction achieved by the portfolio.

Transition Scenario Selection

As discussed before, a multitude of transition scenarios are consistent with the "1.5°C with limited overshoot" goal. These scenarios are produced by running a combination of Earth System models and integrated assessment models. For example, the IPCC's Sixth Assessment Report identifies 97 different scenarios (called the C1 group of scenarios) that are compatible with limiting global temperature rise to below 1.5°C with limited overshoot (IPCC 2023a). Under all these scenarios, global GHG emissions must reach net zero between 2050 and 2055. The 97 scenarios are grouped into three categories, each represented by an illustrative pathway to net zero: shifting development pathways, low demand, and high renewables.

The Network for Greening the Financial System (NGFS) identifies seven different transition scenario groups: Current Policies, Nationally Determined Contributions, Fragmented World, Delayed Transitions, Low Demand, Below 2°C, and Net-Zero 2050. Of these, the Low Demand and the Net-Zero 2050 scenarios are compatible with the 1.5°C global warming goal. For each of these scenarios, three different integrated assessment models are used to produce different compatible sets of pathways. Choosing a particular scenario has significant implications for portfolio construction. In this chapter, we have chosen to use data for the NGFS Net-Zero 2050 scenario generated by the REMIND-MAgPIE model. We chose this particular scenario and model because, based on our analysis, we have found evidence that it is highly representative of the IPCC C1 category of scenarios (n = 97) on the basis of (1) cumulative carbon emissions and (2) the future energy technology mix.

NGFS scenarios are updated annually. According to NGFS, the latest version (Phase 4), published in 2023, reflects the "latest economic and climate data, model versions and policy commitments, reflecting new country-level commitments to reach net-zero emissions made until March 2023."[1] NGFS also states that "the new scenarios also reflect the latest trends in renewable energy technologies (e.g., solar and wind), key mitigation technologies and the energy-market implications of the war in Ukraine."[2]

The NGFS scenarios contain projections for many climate and economic variables. Scenario emission projections are reported both for all GHGs considered in the Kyoto Protocol of 1997 (Kyoto gases) and for just carbon dioxide (CO_2). Kyoto gases are reported for 12 economic regions (see **Exhibit 4**) and five broad industrial sectors (see **Exhibit 5**). Carbon dioxide is projected for many industries at the global and regional levels.

Exhibit 4. NGFS REMIND-MAgPIE 3.2-4.6 Kyoto Gases Countries and Economic Regions

United States	China	Reforming ex-USSR	Latin America and Caribbean
EU28	India	Non-EU28 Europe	Middle East, North Africa, Central Asia
Japan	Canada, New Zealand, Australia	Other Asia	Sub-Saharan Africa

Exhibit 5. NGFS REMIND-MAgPIE 3.2-4.6 Kyoto Gases Economic Sectors

Transportation	Industry
Energy Supply	Agriculture, Forestry, and Other Land Use
Residential and Commercial	

[1]See www.ngfs.net/ngfs-scenarios-portal/ under the section titled "What Is New in the 2023 Version (Phase IV) of the NGFS Scenarios?"

[2]Ibid.

Peer Group Selection

The key assumption behind the green investment approach is the substitutability of the outputs of companies. For this reason, starting with a broad universe, we need to define peer groups of companies that produce substitutable products. For example, auto manufacturers will form one peer group including both electric vehicle manufacturers and traditional fossil fuel engine car manufacturers. In contrast, electricity producers and electricity distribution companies need to be in different groups. Since conglomerates and vertically integrated companies may belong to more than one group, more complex algorithms are required for their classification.

The choice of peer groups is guided by the granularity of pathways defined in the transition scenario. However, we may decide to further split the groups defined by the scenario pathways if they are too broad and contain companies that are not direct substitutes. If the portfolio universe contains too few companies associated with particular pathways, however, we may decide to merge groups together.

The treatment of sparsely populated buckets warrants further discussion. While pathways aim to prescribe emission trajectories for entire economic sectors, it is quite possible that within a geographical region there are very few public companies in that sector. If we wish to maintain the market weights of peer groups unchanged, respecting the fairness and feasibility principles, companies within a thin bucket will be allowed to be brown with little impact. Consider the case of a bucket with a single company—for example, an electric utility in an emerging market. If the weight of this bucket remains unchanged in the net-zero portfolio, then this company can ignore its pathway and be brown without its market weight being affected. To address this issue, we will seek to avoid thin buckets by combining multiple related peer groups together. However, we need to understand that combining peer groups undermines the principle of fairness if we combine groups across regions or undermines the principle of substitutability if we combine groups across industries. Therefore, such grouping must be performed thoughtfully to ensure the minimum violation of the principles. For example, we can combine groups across emerging market regions but not across developed and emerging markets, or we can combine groups whose products are weak substitutes for each other.

Ultimately, the choice of peer groups, which is possibly the most significant portfolio construction choice, has a degree of subjectivity and will depend on the universe of companies for which reliable emission data are available.

Emission Budget Allocation

The next step of portfolio construction is to allocate an emission budget to each peer group. The budget must be selected in a manner consistent with the chosen net-zero scenario. We do that by first associating the peer group with a particular scenario emission variable.

Note that the peer group does not represent all emitting entities whose net-zero budget is specified by the associated scenario variable. Indeed, transition scenarios specify allowable emissions from all agents, governments, households, and private and public companies. Furthermore, the peer group definition may be narrower than the economic sector associated with the scenario variable. For this reason, instead of reading the absolute value of emissions specified by the pathway of the associated variable, we apply only the rate of change of the variable relative to the base year of the scenario. Doing so allows us to use different measures of emissions in each peer group so that the chosen measure is the most representative of the emission contribution for that group. Generally, our preference would be the broadest definition of a company's carbon footprint—GHG Scope 1, 2, and 3, including financing activities. However, data availability is much higher for the most relevant parts of the carbon footprint of each company. Hence, for each peer group, we use a customized definition of emissions based on materiality and data availability. For example, we use Scope 1 + 2 GHG emissions for steel producers, whereas for the automotive sector we use Scope 1 + 2 + 3 GHG emissions. Furthermore, for the financial sector, we measure the emissions of companies funded by the financial institution rather than the direct emissions of the financial company.

The underlying assumption in this approach is that the aggregate emissions of companies in each peer group are consistent with the net-zero pathway on the base year of the scenario. This allows us not only to compare companies with each other within the peer group but also to evaluate the evolution of aggregate emissions of each peer group relative to the net-zero scenario.

If we denote the base year of the transition scenario with t_0, the emissions for which an individual company i is responsible with $E_{i,t}$, the actual and net-zero-compliant emissions of its peer group with $E_{p,t}$ and $E_{p,t}^{NZ}$, respectively, and the net-zero emissions of the corresponding scenario variable with $E_{S,t}^{NZ}$, we express our assumptions with the following equations:

$$E_{p,t_0} = \sum_{i \in p} E_{i,t_0}. \tag{1a}$$

$$E_{p,t}^{NZ} = E_{p,t_0} \frac{E_{S,t}^{NZ}}{E_{S,t_0}^{NZ}}. \tag{1b}$$

We will call the net-zero compliant emissions of a peer group the *emission budget* for that group.

The actual emissions of a peer group are equal to the sum of the emissions of the companies in the group. When investors seek to construct climate-aware portfolios, they typically do so within an asset class—that is, equity or bond portfolios separately. It is, therefore, useful to attempt to allocate the total emissions of a company to its various funding sources. This can be done by allocating emissions proportionally to the contribution of each funding source to the enterprise value including cash (EVIC):[3]

$$E_{i,t} = \frac{MV_{i,t}^{equity}}{EVIC_{i,t}} E_{i,t} + \frac{N_{i,t}^{bonds}}{EVIC_{i,t}} E_{i,t} + \frac{MV_{i,t}^{other}}{EVIC_{i,t}} E_{i,t}. \quad (2)$$

The total emissions that correspond to a peer group of companies can then be written as follows:

$$E_{p,t} = \sum_{i \in p} \frac{MV_{i,t}^{equity}}{EVIC_{i,t}} E_{i,t} + \sum_{i \in p} \frac{N_{i,t}^{bonds}}{EVIC_{i,t}} E_{i,t} + \sum_{i \in p} \frac{MV_{i,t}^{other}}{EVIC_{i,t}} E_{i,t}. \quad (3)$$

A sufficient condition to ensure that the total emissions of the peer group companies are below their emission budget is to allocate the budget proportionately to the three components of EVIC:

$$E_{p,t}^{equity} = \sum_{i \in p} \frac{MV_{i,t}^{equity}}{EVIC_{i,t}} E_{i,t} \le \frac{MV_{p,t}^{equity}}{EVIC_{p,t}} E_{p,t}^{NZ}. \quad (4a)$$

$$E_{p,t}^{bonds} = \sum_{i \in p} \frac{N_{i,t}^{bonds}}{EVIC_{i,t}} E_{i,t} \le \frac{N_{p,t}^{bonds}}{EVIC_{p,t}} E_{p,t}^{NZ}. \quad (4b)$$

$$E_{p,t}^{other} = \sum_{i \in p} \frac{MV_{i,t}^{other}}{EVIC_{i,t}} E_{i,t} \le \frac{MV_{p,t}^{other}}{EVIC_{p,t}} E_{p,t}^{NZ}. \quad (4c)$$

Let us first consider the case of equities. If we consider a peer group as a portfolio that holds all the shares of the companies in the group, the emissions that correspond to the equity component of the peer group can be expressed as the market-value-weighted sum of the equity-financed emission intensity of each company, as follows:

$$E_{p,t}^{equity} = \sum_{i \in p} \frac{MV_{i,t}^{equity}}{EVIC_{i,t}} E_{i,t} = MV_{p,t}^{equity} \sum_{i \in p} \frac{MV_{i,t}^{equity}}{MV_{p,t}^{equity}} \frac{E_{i,t}}{EVIC_{i,t}} = MV_{p,t}^{equity} \sum_{i \in p} w_{i,t} \frac{E_{i,t}}{EVIC_{i,t}}. \quad (5)$$

Many investors prefer to define emission intensity in terms of company revenues rather than EVIC. Indeed, revenues represent a more stable representation of each company's production volume. If $R_{i,t}$ represents a measure of a company's revenues at time t, Equation 5 can be rewritten as follows:

$$E_{p,t}^{equity} = MV_{p,t}^{equity} \sum_{i \in p} w_{i,t} \frac{R_{i,t}}{EVIC_{i,t}} \frac{E_{i,t}}{R_{i,t}} \approx R_{p,t} \frac{MV_{p,t}^{equity}}{EVIC_{p,t}} \sum_{i \in p} w_{i,t} \frac{E_{i,t}}{R_{i,t}}. \quad (6)$$

[3]EVIC consists of the market value of all outstanding shares of a company, the notional amount of all bond instruments, and the cash in hand including all other private financing vehicles.

In Equation 6, we made the simplifying assumption that the ratio of revenues to EVIC is approximately the same for all firms within a peer group; hence, $\frac{R_{i,t}}{EVIC_{i,t}} \approx \frac{R_{p,t}}{EVIC_{p,t}}$.

We can now combine Equation 4a and Equation 6 and write the emission budget constraint for the equity component of peer group companies as follows:

$$\sum_{i \in p} w_{i,t} \frac{E_{i,t}}{R_{i,t}} \leq \frac{E_{p,t}^{NZ}}{R_{p,t}}. \tag{7}$$

The same equation can also be derived for bond portfolios under the additional assumption that the prices of all bonds of the peer group are similar. While this may not be accurate, its impact on the eventual calculations is small.

Even while a revenue-based calculation of emission intensity is a better representation of the actual physical emission intensity of companies, it is still not perfect. Revenues of companies fluctuate year over year and are affected by inflation and price fluctuations. Furthermore, revenues do not include inventory changes. For these reasons, revenues need to be smoothed and possibly winsorized before they can be used in the emission intensity calculation. In the following, we will represent the smoothed-revenues-based emission intensity of a company with $e_{i,t}$. We can now write the emission budget constraint as follows:

$$\sum_{i \in p} w_{i,t} e_{i,t} \leq \frac{E_{p,t}^{NZ}}{R_{p,t}} \equiv e_{p,t}^{NZ} \tag{8}$$

The left-hand side of the equation is commonly referred to in the literature as the weighted average carbon intensity (WACI).

Portfolio Construction with Mean–Variance Optimization

To simplify the calculations, we will assume a two-stage portfolio construction process, where the size of the investment in a company is first allocated within its peer group, and then the relative investment in each peer group is decided in a second phase.

The net-zero pathways represent an aggressive climate goal of keeping the global temperature rise below 1.5°C and, therefore, prescribe fast decarbonization. If the real-world aggregate decarbonization is slower, the emission budget constraint will be violated for most peer groups. The goal of green portfolio construction is to shift financing toward greener companies so that the total emissions of each peer group remain below their pathway-implied level at each time period. As discussed earlier, it is assumed that directing investments to greener companies will have an impact on the ability of companies to grow and will ultimately be reflected in the production size and emissions of companies. The underlying principle of this method is substitutability—that is, that the relative size of companies in a peer group can change without affecting the total size (e.g., revenues) of the group.

Let us represent a set of alternative company weights with $\omega_{i,t}$. Then, the total peer group emissions will be $R_{p,t} \sum_{i \in p} \omega_{i,t} e_{i,t}$. We would like to identify the set of weights, $\omega_{i,t}$, that satisfies the budget constraint (Equation 8). In general, many such weights satisfy the budget constraint. Of these, we can choose weights minimizing a measure of portfolio risk—either absolute risk or tracking error to a benchmark. Furthermore, because most investors want to avoid leverage, we require that the sum of investments in all companies be equal to their available capital.

If $\mathbf{\Sigma}_t$ represents the covariance matrix of investment returns between companies at time *t*, we can express the problem of finding the weights that satisfy the budget constraint in an efficient way as an optimization problem, expressed in vector–matrix notation:[4]

Minimize return variance:	$\min_{\omega_t}\{\omega_t' \Sigma_t \omega_t\}$
Emission budget constraint:	$\omega_t' \mathbf{e}_t \le e_{p,t}^{NZ}$
No leverage:	$\omega_t' \mathbf{1} = 1.$

For clarity of expression, we introduce the following notation:

- We denote the sum of the elements of the inverse covariance matrix with $\frac{1}{\upsilon_t} \equiv \mathbf{1}' \Sigma_t^{-1} \mathbf{1}$.
- We define the risk-weighted intensity average of the peer group as $\mu_t \equiv \frac{\mathbf{1}' \Sigma_t^{-1} \mathbf{e}_t}{\mathbf{1}' \Sigma_t^{-1} \mathbf{1}} = \upsilon_t \mathbf{1}' \Sigma_t^{-1} \mathbf{e}_t$.
- We define the risk-weighted variance of the intensity of companies in the peer group as $\sigma_t^2 \equiv \frac{\mathbf{e}_t' \Sigma_t^{-1} \mathbf{e}_t}{\mathbf{e}_t' \Sigma_t^{-1} \mathbf{1}} - \mu_t^2 = \upsilon_t \mathbf{e}_t' \Sigma_t^{-1} \mathbf{e}_t - \mu_t^2$.

The resulting optimal portfolio weights are given by the following equation:

$$\omega_t = \underbrace{\upsilon_t \Sigma_t^{-1} \mathbf{1}}_{\substack{\text{Minimum-}\\ \text{variance}\\ \text{weights}}} + \upsilon_t \Sigma_t^{-1} \underbrace{\frac{e_{p,t}^{NZ} - \mu_t}{\sigma_t}}_{\substack{\text{Normalized}\\ \text{target}\\ \text{intensity}\\ \text{change}}} \underbrace{\frac{\mathbf{e}_t - \mu_t \mathbf{1}}{\sigma_t}}_{\substack{\text{Emission}\\ \text{intensity}\\ \text{weighted}\\ \text{z-score}}}. \tag{9}$$

Investors who have no access to a risk model may simply assume that all issuers are equally risky and are perfectly uncorrelated. In this case, the normalized

[4] We use the symbol **1** to represent a vector of ones and the notation **X**′ to represent the transpose of vector or matrix **X**.

covariance matrix is the identity matrix divided by the number of issuers, and the minimum variance weights become equal weights.

Investors who are concerned about the deviation from a benchmark rather than absolute risk can use tracking error instead of absolute risk as an objective in the optimization problem. The solution is identical except that the starting weights are the benchmark weights rather than the minimum-variance weights.

In the previous formulation, the budget and no-leverage constraints are "hard"; that is, the investors prefer to take more risk rather than breach any of these constraints, something that can lead to solutions with excessive risk if the budget is too aggressive. In certain cases, however, there may not be a feasible set of weights—for example, if all issuer emission intensities are too high relative to the budget. To alleviate this issue, investors can make the budget constraint soft—that is, accept breaching the budget constraint to keep the resulting risk at acceptable levels. By expressing the relative preference between risk and emission budget with a relative risk aversion parameter λ_t, the problem can be formulated as follows:

Minimize risk and emissions: $\min_{\omega_t}\{\omega_t' \Sigma_t \omega_t + \lambda_t \omega_t' \mathbf{e}_t\}$

No leverage: $\omega_t' \mathbf{1} = 1.$

The resulting optimal weights are the minimum-variance weights tilted proportionately to their distance from the risk-weighted average sector intensity. The tilting strength is determined by the investor's relative preference for the portfolio risk and breaching the emission budget.

$$\omega_t = \upsilon_t \Sigma_t^{-1} \mathbf{1} + \lambda_t \Sigma_t^{-1}(\mathbf{e}_t - \mu_t \mathbf{1}). \tag{10}$$

The tilting strength determines both the resulting portfolio variance, V_t, and emission intensity, E_t:

$$V_t = \omega_t' \Sigma_t \omega_t = \upsilon_t + \lambda_t^2 \frac{\sigma_t^2}{\upsilon_t}. \tag{11}$$

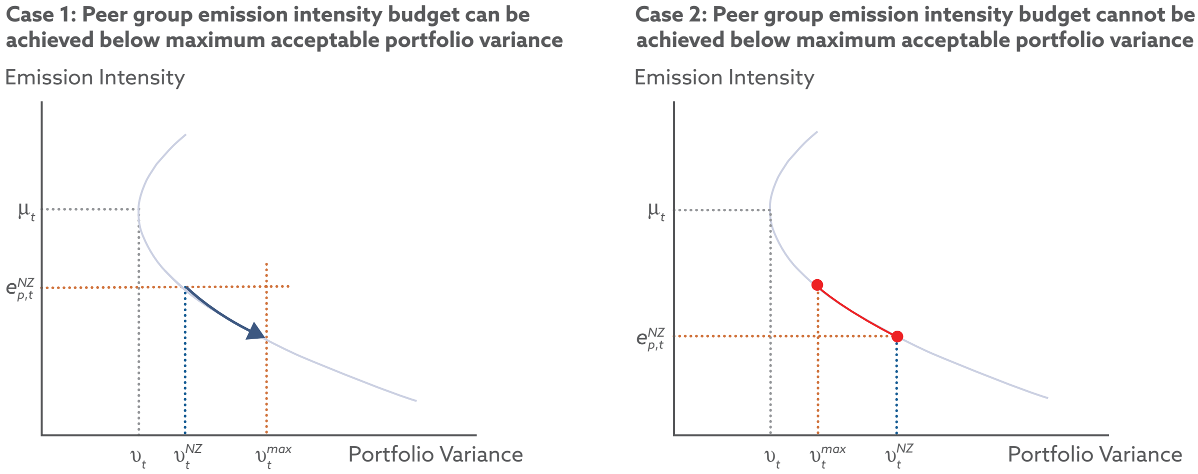
$$E_t = \omega_t' \mathbf{e}_t = \mu_t + \lambda_t \frac{\sigma_t^2}{\upsilon_t}. \tag{12}$$

As expected, if we set emissions equal to the emission budget, then Equation 10 reverts to Equation 9. This formulation allows us to build the efficient frontier between portfolio variance and emissions. Indeed, by eliminating the parameter λ_t, we get

$$V_t = \upsilon_t + \upsilon_t \frac{(E_t - \mu_t)^2}{\sigma_t^2}. \tag{13}$$

Portfolio variance is minimized for $\lambda_t = 0$ and is equal to υ_t. This corresponds to peer group emission intensity of μ_t. If the level of risk required to achieve the target peer group emissions is below a maximum acceptable portfolio variance

Exhibit 6. Efficient Frontier and Portfolio Choice



υ^{max}_t, as in the left panel of **Exhibit 6**, then the solution is acceptable. As a matter of fact, lower emissions can be achieved if portfolio weights are permitted to drift further toward lower-intensity issuers until the portfolio has the maximum acceptable variance (the arrow in the left panel of Exhibit 6). If, however, the emission budget requires the portfolio to have risk exceeding υ^{max}_t, as in the right panel in Exhibit 6, then investors must choose whether to accept higher emission intensity or higher risk or breach both constraints while staying on the efficient frontier (red section of the efficient frontier in the right panel in Exhibit 6).

In practical cases, portfolios are subject to additional constraints, such as no shorting; risk constraints, such as minimum and maximum issuer weights and industry and country exposures relative to the benchmark; and most importantly, regulatory constraints, such as exclusions of certain sectors and issuers. Once these additional constraints are added, the problem can no longer be solved analytically; it requires using iterative optimization algorithms. However, one needs to be judicious in including too many constraints in portfolio construction as they may lead to conflicts, rendering the problem infeasible. In such cases, investors may need to establish trade-offs between constraint breaches.

Portfolio Construction Without Mean–Variance Optimization

Some investors may prefer simpler portfolio construction approaches to avoid the perceived complexity of the mean–variance methodology. One such popular approach prescribes that portfolio weight shifts relative to the benchmark weights, $\mathbf{w}_t$, be proportional to the starting weights and the distance of the issuer emission intensity from the pathway-prescribed intensity:[5]

$$\omega_t = \mathbf{w}_t - \lambda_t \mathbf{W}_t (\mathbf{e}_t - e^{NZ}_{p,t} \mathbf{1}). \quad (14)$$

[5]We use the notation $\mathbf{W}_t$ to denote a diagonal matrix with elements equal to $\mathbf{w}_t$.

Equation 14 seeks to underweight companies whose intensity is higher than the pathway intensity (brown companies) and overweight those with intensity below the pathway (green companies). However, it does not guarantee lack of leverage for the resulting portfolio. In fact, the no-leverage constraint requires λ to be zero if the weighted average intensity of the peer group is different from the pathway-prescribed intensity, as shown in Equation 15:

$$\omega_t'\mathbf{1}=1 \Rightarrow \mathbf{w}_t\mathbf{1}-\lambda_t(\mathbf{e}_t'-e_{p,t}^{NZ}\mathbf{1}')\mathbf{W}_t\mathbf{1}=1 \Rightarrow \lambda_t(\mathbf{e}_t'\mathbf{w}_t-e_{p,t}^{NZ})=0. \tag{15}$$

One may attempt to normalize the weights so that they sum to 1; however, this has the unintended consequence of replacing the pathway intensity with the weighted average peer group intensity as the pivot intensity for overweighting or underweighting issuers. Indeed, as shown in Appendix A, the normalized weights are given by the following equation:

$$\omega_t^* = \mathbf{w}_t - \lambda \mathbf{W}_t \frac{\mathbf{e}_t - (\mathbf{w}_t'\mathbf{e}_t)\mathbf{1}}{1-\lambda_t(\mathbf{w}_t'\mathbf{e}_t - e_{p,t}^{NZ})}. \tag{16}$$

One way around this issue is to introduce a second parameter in the weight shift function. For example, we can use different tilt strengths for overweighting green issuers versus underweighting brown issuers:

$$\omega_t = \mathbf{w}_t - \lambda_t^+ \mathbf{W}_t(\mathbf{e}_t - e_{p,t}^{NZ}\mathbf{1})^+ - \lambda_t^- \mathbf{W}_t(\mathbf{e}_t - e_{p,t}^{NZ}\mathbf{1})^-. \tag{17}$$

Now, both the leverage and the emission budget constraints can be satisfied and used to estimate the appropriate values of the lambda parameters. However, portfolio risk is not explicitly controlled. To do so, one would have to formulate the problem once again as an optimization problem with a trade-off parameter λ_t between risk and emission intensity:

Minimize risk and emissions: $\min_{\lambda_t^+,\lambda_t^-}\{\omega_t'\Sigma_t\omega_t + \lambda_t\omega_t'\mathbf{e}_t\}$

No leverage: $\omega_t'\mathbf{1}=1.$

Using Projected Emissions

So far, we have assumed a static view of company emissions, evaluating companies using only the latest known emission information. However, the net-zero concept is dynamic, requiring economic agents to reduce their emissions gradually over time and eventually achieving net-zero emissions for the economy as a whole. It would make sense then to evaluate companies according to their projected path toward net-zero emissions. We can consider two sources of information on which we could make a projection: historical performance and company-disclosed targets. Regardless of which projection method we use, we can rewrite the budget constraint for a future time $t + \Delta t$, holding company weights constant:

$$R_{p,t+\Delta t} \sum_{i \in p} \omega_{i,t} e_{i,t+\Delta t} \leq E^{NZ}_{p,t+\Delta t} \Leftrightarrow \sum_{i \in p} \omega_{i,t} e_{i,t+\Delta t} \leq \frac{E^{NZ}_{p,t+\Delta t}}{R_{p,t+\Delta t}} \equiv e^{NZ}_{p,t+\Delta t}. \quad (18)$$

In Equation 18, we need to estimate three quantities: (i) the pathway-prescribed peer group emissions, $E^{NZ}_{p,t+\Delta t}$; (ii) the peer group projected revenues, $R_{p,t+\Delta t}$; and (iii) the company projected emission intensity, $e_{i,t+\Delta t}$.

(i) The pathway-prescribed emissions for the peer group can be estimated using Equation 1b applied for time $t + \Delta t$:

$$E^{NZ}_{p,t+\Delta t} = E_{p,t_0} \frac{E^{NZ}_{S,t+\Delta t}}{E^{NZ}_{S,t_0}}.$$

(ii) The peer group projected revenues can be estimated by extrapolating historical growth rate, or by drawing on projections of economic output from integrated assessment models under the representative scenario. It is also possible to use revenue projections from analysts' estimates.

(iii) We can use two sources of information to project company emission intensity in the future: historical observations and company-provided emission targets. Historical intensity observations can be extrapolated to provide a time-series estimate of intensity. Company-provided emission targets, if available, typically require interpretation, reconciliation, and interpolation to be translated into projected intensity at any future point in time. The two can be combined to arrive at a single path of future projected emission intensity of the company.

We can now derive the emission budget constraint for the entire time period $[t, t + \Delta t]$. Assuming that the company weights in the peer group remain constant during this period, we can write the following formula:

$$\sum_{i} \omega_{i,t} \int_{\tau=t}^{t+\Delta t} R_{p,\tau} e_{i,\tau} d\tau \leq \int_{\tau=t}^{t+\Delta t} E^{NZ}_{p,\tau} d\tau. \quad (19)$$

If both of the quantities $E^{NZ}_{p,\tau}$ and $R_{p,\tau} e_{i,\tau}$ change linearly over time, we can rewrite the budget constraint as follows:

$$\sum_{i} \omega_{i,t} \left(e_{i,t} + \frac{R_{p,t+\Delta t}}{R_{p,t}} e_{i,t+\Delta t} \right) \leq \left(e^{NZ}_{p,t} + \frac{R_{p,t+\Delta t}}{R_{p,t}} e^{NZ}_{p,t+\Delta t} \right). \quad (20)$$

Essentially, this is a modified budget constraint that linearly combines the current and projected budget constraints. The problem can be solved with any of the previously discussed methodologies by using the modified budget constraint. Additionally, users may decide to use different weights to combine the current and forward emission budgets reflecting their preferences and confidence in the estimates.

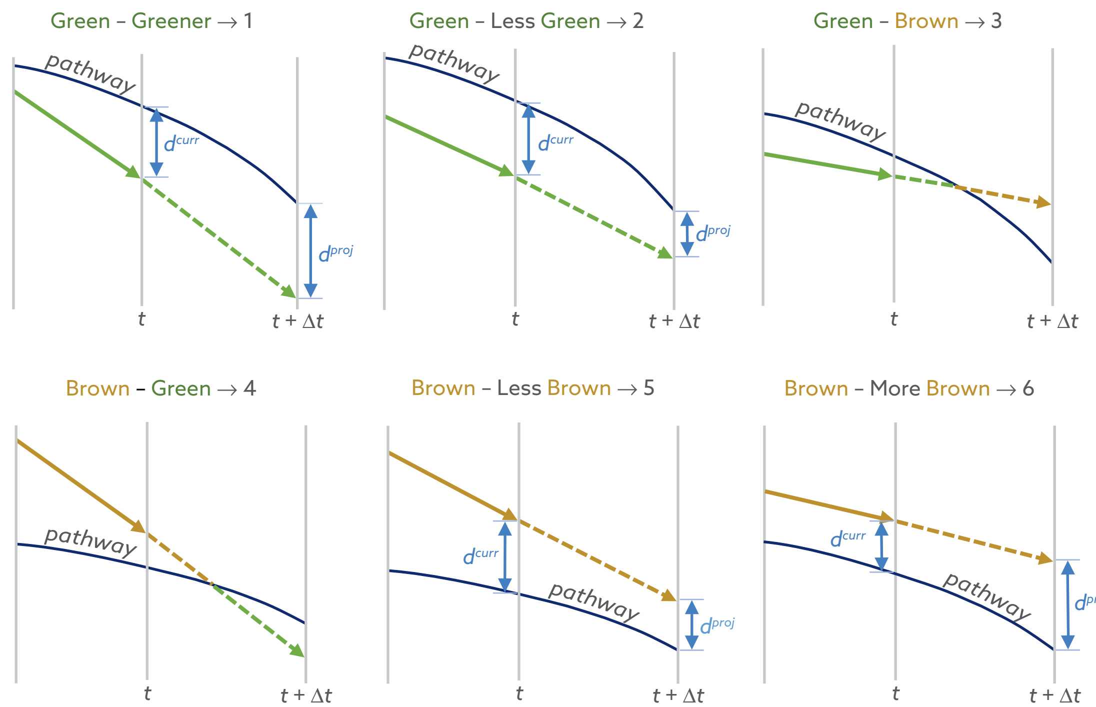
Using Alignment Scores

The methodology we have shown is elegant, but it applies very precise tools to data that are often inconsistent and, in many cases, estimated rather than reported—particularly for Scope 3 emission data. In addition, we have made a number of assumptions that, although reasonable, introduce another source of imprecision. To provide a simple solution that is more robust to data inputs, we introduce the idea of condensing the company emission data into a company *net-zero alignment score* that injects robustness into characterizing companies as green or brown. We will then seek to maximize the "greenness" of the portfolio as defined by its weighted alignment score subject to risk and leverage constraints.

There are many ways to build an alignment score. In the following, we propose one way that captures all concepts outlined in this chapter, uses both current and projected emission intensities, and does so in a manner that is transparent and interpretable.

If both the current and projected emission intensities of a company are lower than the pathway intensity and the distance from the pathway is growing (green getting greener), then the company is awarded a score of 1 (see **Exhibit 7**). If both the current and projected emission intensities of a company are lower than the pathway intensity and the distance is getting smaller

Exhibit 7. A Potential Pathway Alignment Score Scheme



(i.e., the company decarbonizes at a slower rate than the one required by the pathway), it receives a score of 2. If the current emission intensity is below the pathway but the projected intensity is above it (green becoming brown), it receives a score of 3. Currently, brown companies are split into three categories: Those that decarbonize fast enough so that their projected intensity falls below the pathway (brown becoming green) get a score of 4. Those that decarbonize faster than the pathway, reducing the distance from the pathway intensity but not falling below, receive a score of 5. Those that decarbonize slower than the pathway receive a score of 6.

As discussed previously, projected emissions can be estimated using either the historical trend or the company-disclosed targets. Scores can be calculated using both, if available, and combined using weights that reflect the confidence in or preference for either method. Further advantages of constructing a composite score are the ability to introduce additional metrics that are related to the future carbon footprint of a company, such as availability and quality of emission reporting, participation in net-zero alliances, emission reduction pledges, and green capital expenditures.

As shown in Exhibit 7, the proposed score is a reasonable proxy for the net area between the company emission intensity projected curve and the pathway (positive if the company curve is above the pathway, negative if it is below). This area corresponds to the excess cumulative GHGs of the company over its fair share of pathway-determined net-zero compatible emissions, which is the variable we ultimately want to target.

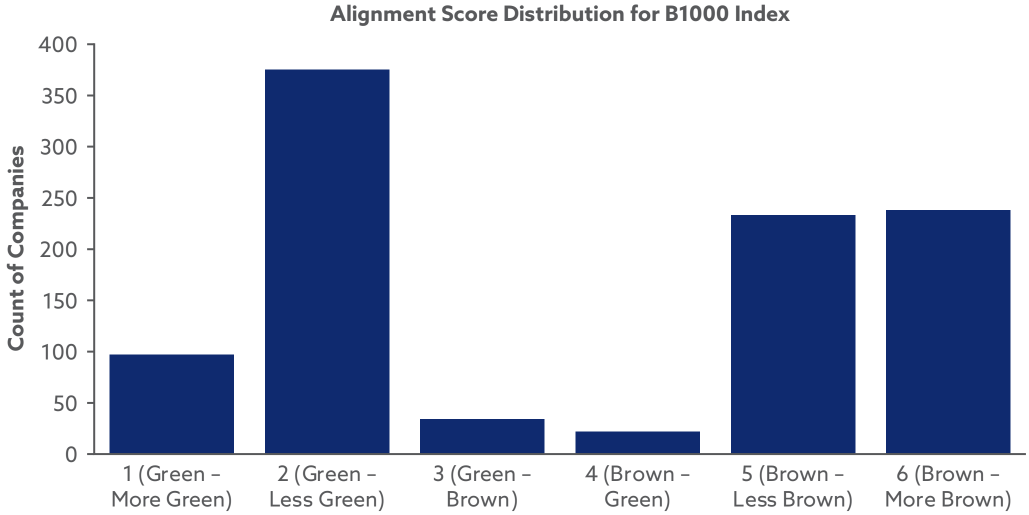
Once a score is constructed, the portfolio construction problem can be solved in any of the previously discussed methodologies by replacing the company emissions with the vector of their alignment scores, $\mathbf{s}_t$.

One criticism of this approach is that it does not directly control the resulting emissions of the portfolio and does not ensure that they are consistent with the net-zero pathway. However, it is a fallacy to believe that a methodology directly targeting portfolio emissions does so, given the numerous assumptions and imprecise data involved in portfolio construction. Furthermore, investors can calculate the resulting current and/or forward emission intensity of the optimal portfolio and adjust the trade-off parameters of the optimization problem to achieve the emission intensity level they wish to target.

Illustration: An Equity Example

Using Bloomberg data, we compiled alignment scores for all companies in the Bloomberg 1000 Equity (B1000) Index as of 29 September 2023. The average alignment score for this universe is 3.30. About half the companies are characterized as green, with the majority of those becoming less green relative to the pathway, as shown in **Exhibit 8**. Half the brown companies are improving, with a small fraction of those expected to become green on the forward date ($t + \Delta t$ in Exhibit 7).

Exhibit 8. Distribution of Alignment Scores for the Companies in the Bloomberg 1000 Equity (B1000) Index as of 29 September 2023



Source: Bloomberg.

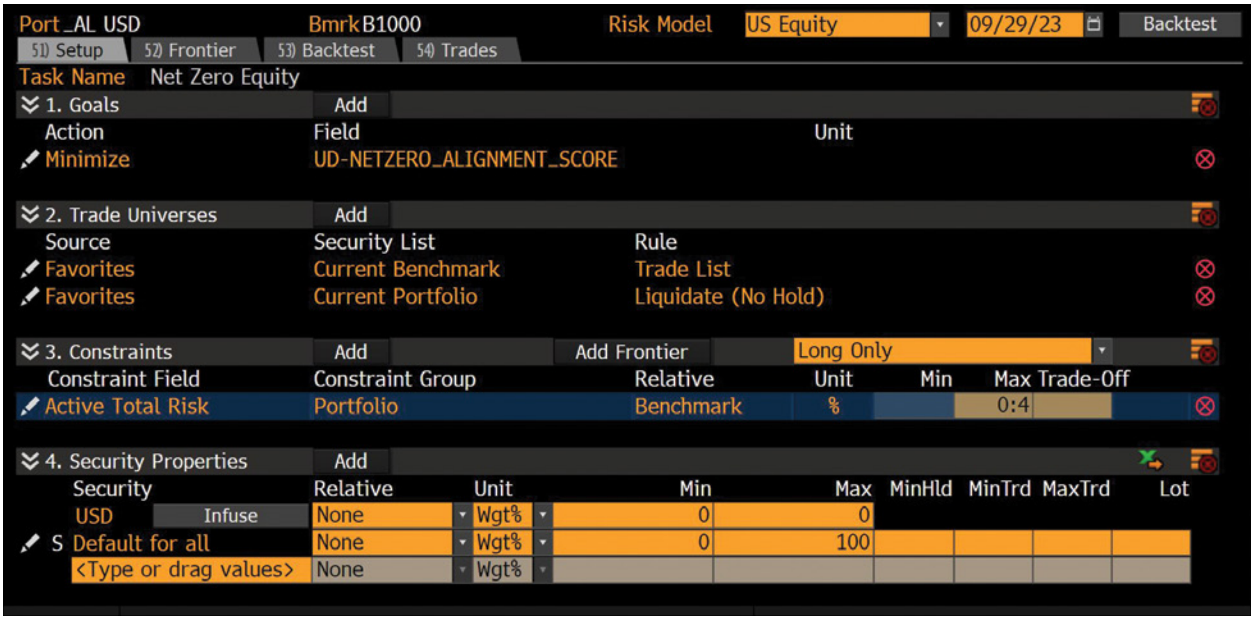
We seek to construct a portfolio that is "greener" than the B1000 index by reweighting the securities in the index to minimize the alignment score while controlling the tracking error relative to the index. In addition, we allow no leverage or short positions. The setup of the problem using the Bloomberg Optimizer is shown in **Exhibit 9**. For measuring tracking error volatility, we use the Bloomberg MAC3 GRM US Equity risk model at a quarterly horizon.[6]

The Bloomberg Optimizer allows users to specify a range of maximum allowable tracking error and generates the efficient frontier shown in **Exhibit 10**. We can see that when we ask the optimizer to construct a portfolio with zero tracking error to the index, it returns the index itself with the index alignment score of 3.32. For a very modest tracking error of 1% per year, the alignment score of the portfolio drops to 1.79. If the tracking error constraint is relaxed to a still quite modest 2% per year, the alignment score drops even further, to 1.32. The minimum alignment score of 1.00 (i.e., the score that results from selecting only improving green companies) can be achieved with a tracking error of 3.88% per year.

Investors who do not have access to the full power of a commercial optimizer and risk model can simplify the problem by adopting a CAPM-based risk model and expressing the portfolio weights as a function of a small set of parameters that can be handled by a less powerful optimizer. For example, if we assume that all stocks have equal market betas and the same specific risk, the covariance

[6]The Bloomberg MAC3 GRM suite of risk models allows users to choose an appropriate risk measurement horizon and provides a risk estimate calibrated to the chosen horizon. In portfolio construction, it is typical to choose a horizon that aligns with the rebalancing frequency of the investment strategy. Shorter-horizon models are used to measure the day-to-day investment risk.

Exhibit 9. Setup of the Bloomberg Optimizer



Source: Bloomberg.

Exhibit 10. The Equity Efficient Frontier: Net-Zero Alignment Score as a Function of Tracking Error Volatility (TEV)

Source: Bloomberg.

matrix of active portfolio returns is reduced to the identity matrix multiplied by the specific risk variance. We modify Equation 17 to define the weights as a function of alignment scores instead of the emission intensities. The parameter, s_0, is set to 3.5 to ensure that green companies are overweighted and brown companies are underweighted.

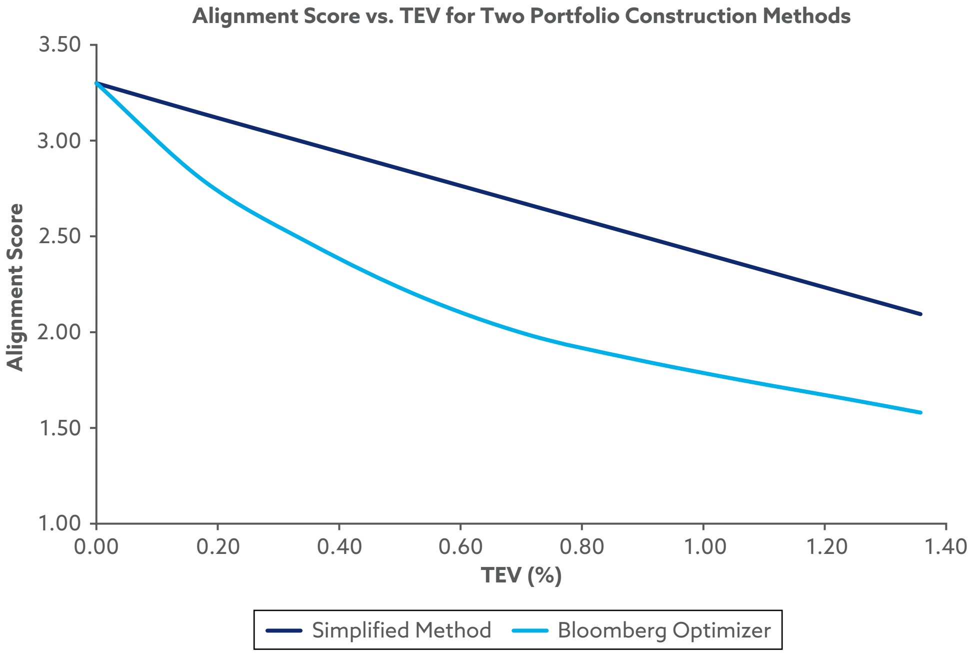
$$\omega_t = \mathbf{w}_t - \lambda_t^{+}\mathbf{W}_t(\mathbf{s}_t - s_0\mathbf{1})^{+} - \lambda_t^{-}\mathbf{W}_t(\mathbf{s}_t - s_0\mathbf{1})^{-}. \quad (21)$$

We now set up the portfolio construction problem as follows:

Minimize risk and alignment score:	$\min_{\lambda_t^{+},\lambda_t^{-}}\{\omega_t'\omega_t + \lambda_t\omega_t'\mathbf{s}_t\}$
No leverage:	$\omega_t'\mathbf{1} = 1$
No shorting:	$\omega_t \geq 0.$

This problem can be easily solved to produce the efficient frontier. Using a specific risk volatility of 20%,[7] we can construct a portfolio with a TEV to the B1000 index of 1% per year with an alignment score of 2.40—considerably higher than the 1.78 score the Bloomberg Optimizer can achieve for the same tracking error. Of course, this result should be expected because of the additional structure imposed on the weight function. In **Exhibit 11**, we compare

Exhibit 11. Comparing the Efficient Frontiers of the Two Portfolio Construction Methods



Source: Bloomberg.

[7]This value is very close to the median specific volatility of the stocks in the B1000 index universe as of 29 September 2023.

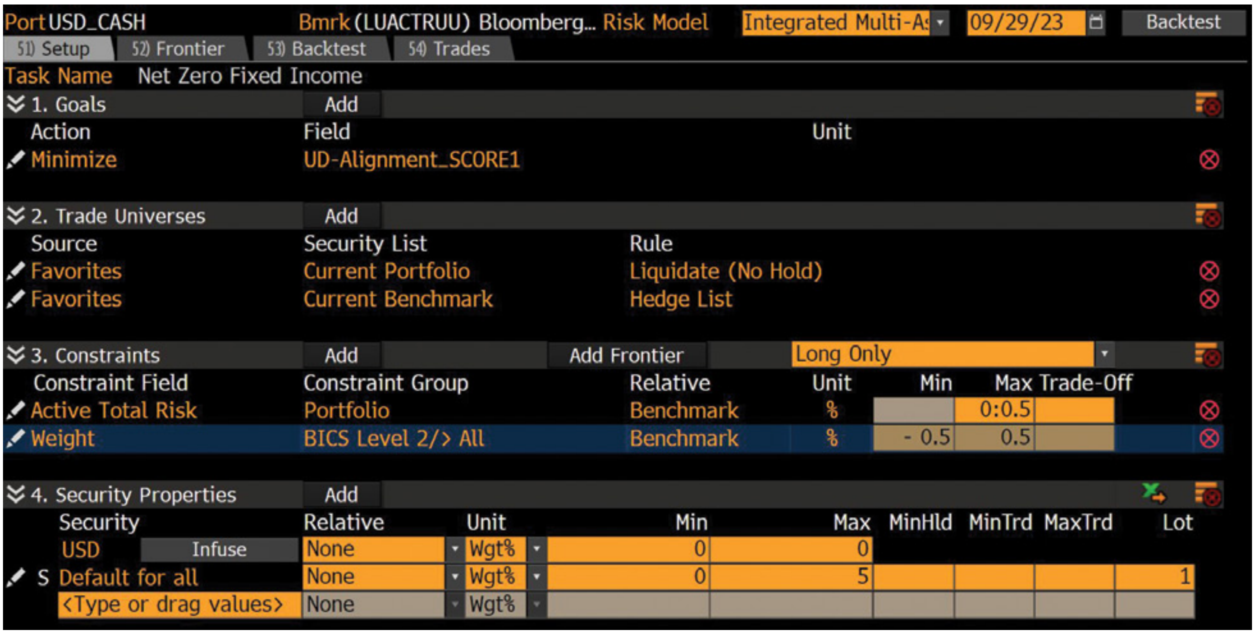
the efficient frontiers achieved with the Bloomberg Optimizer without any structure on the weight function and the one produced by the simpler and more constrained version described previously.

Illustration: A Fixed-Income Example

In this example, we seek to construct a portfolio that is "greener" than the Bloomberg US Investment Grade (IG) Corporate Bond Index. The optimization problem is set up in a similar way as the equity example with additional sector weight constraints (see **Exhibit 12**).

The efficient frontier for the bond portfolio is provided in **Exhibit 13**. Compared with the equity example, the efficient frontier is much steeper, with maximum TEV of 0.31% per year for a minimum alignment score of 1. In the equity example, the maximum TEV is 3.84% (see Exhibit 10). There are a few explanations for the difference. The primary one is that the equity index has a significantly higher volatility than the fixed-income index, and specific risk accounts for a much smaller portion of the total risk for an average IG corporate bond than it does for a stock. Additionally, the greater number of securities in the bond index (slightly fewer than 100 stocks in the equity index and nearly 500 bonds in the bond index have alignment scores of 1) also plays a part in the bond portfolio being able to achieve a portfolio alignment score of 1 with a lower TEV to the benchmark.

Exhibit 12. Setup of the Bloomberg Optimization for Fixed Income



Source: Bloomberg.

Exhibit 13. The Fixed-Income Efficient Frontier: Net-Zero Alignment Score as a Function of TEV

Optimal Portfolio	Active Total Risk (Constraint)	UD-Alignment_SCORE1 (Goal)
Portfolio 1	0	3.39
Portfolio 2	0.13	1.4
Portfolio 3	0.25	1.07
Portfolio 4	0.31	1.02
Portfolio 5	0.31	1.02

Source: Bloomberg.

Combining Peer Group Subportfolios into an Overall Portfolio

So far, we have discussed how to reallocate investment to different companies within a peer group. To combine the peer groups into a total portfolio, the investors can use an array of methodologies. The simplest one retains the benchmark weights for each peer group. If companies within each peer group have been reweighted such that the peer group emissions are consistent with the pathway, then the entire portfolio will be consistent with the pathway. An alternative way is to solve the same portfolio construction problem by treating each peer group as an individual unit with its own alignment score. The portfolio construction problem can be augmented with additional constraints controlling exposure to certain sectors or regions.

Conclusion

The construction of investment portfolios that are aligned with a realistic net-zero transition scenario is a task filled with unique challenges, as outlined throughout this chapter. These are challenges to which we must find adequate solutions if capital markets are to effectively incentivize decarbonization in line with global climate goals. The urgency to act in accordance with ambitious goals, such as the 1.5°C temperature limit set by the Paris Agreement, cannot be understated. Addressing this urgency will therefore require ongoing innovation in approaches to climate-aligned portfolio management.

One of the key challenges that portfolio managers will face is the uncertainty associated with estimated carbon budgets and the variability in climate scenarios and transition pathways. Investors will have to navigate this highly technical landscape when determining a representative pathway based on their objectives and acknowledge that these carbon budgets and associated pathways will need to be updated incrementally over time as new evidence emerges. The next set of challenges relates to the allocation of emission budgets within a portfolio, a problem that requires a careful balance between scientific rigor and practical considerations given data availability and the need for scalability. The methodology proposed in this chapter seeks to allocate carbon budget constraints based on rates of change in emission intensity terms. In doing so, the approach addresses a central limitation identified with other approaches to date, in that it allows us to use the full detail of modeled transition pathways and treat securities with region and sector specificity, thereby reflecting a more realistic decarbonization profile.

We have extended the approach by introducing projected emissions, such that alignment with the pathway's carbon budget is assessed in both the current period and a future period. We use projected emissions because of the conceptual acknowledgment that net-zero alignment is dynamic and that there are additional sources of information that can add value, such as historical trends in emissions and disclosed emission reduction targets. Despite the logic behind the outlined methodology, however, we recognize the sources of uncertainty introduced through our stated assumptions and challenges with the reliability of company emission data. For these reasons, we have built a net-zero alignment score that draws on the full detail of the outlined methodology but characterizes the current and projected alignment of issuers through an interpretable integer score. We then use this net-zero alignment score in conjunction with the Bloomberg Optimizer to demonstrate how an equity portfolio can be constructed to maximize "greenness" within a specified tolerance for tracking error.

The approach outlined in this chapter provides a platform for further research and ideation on the topic of net-zero-aligned portfolio construction. While we have a well-documented and robust process for determining our reference scenario, simulations of portfolios aligned with a wider range of transition pathways (characterized by different evolutions of socioeconomic and energy systems) are likely to yield interesting results for further consideration. Further iteration on the definition of peer groups can help form more insights on the trade-offs between the principles of fairness and substitutability. Other improvements may include additional factors, such as proxy measures for the credibility of company transition plans that can help us form a clearer picture of projected alignment. We hope that the quality and extent of relevant input data progressively improve over time. Further research is required to refine the net-zero alignment analytic to ensure it is as robust and comprehensive as possible.

Appendix A. Calculation of Normalized Weights

We will show that it is infeasible to use a single parameter to tilt higher the weights of green issuers and tilt lower the weight of brown issuers while constructing a portfolio with no leverage.

The functional form of weight tilts is given by the following formula:

$$\omega_t - \mathbf{w}_t = -\lambda_t \mathbf{W}_t(\mathbf{e}_t - e_{p,t}^{NZ}\mathbf{1}).$$

Normalizing by the sum of the new weights, $\omega_t'\mathbf{1}$, we get to the final weight tilts:

$$\omega_t^* - \mathbf{w}_t = \frac{\mathbf{w}_t - \lambda_t \mathbf{W}_t(\mathbf{e}_t - e_{p,t}^{NZ}\mathbf{1})}{\omega_t'\mathbf{1}} - \mathbf{w}_t.$$

Using the equation $\omega_t'\mathbf{1} = 1 - \lambda_t(\mathbf{w}_t'\mathbf{e}_t - e_{p,t}^{NZ})$, we get

$$\omega_t^* - \mathbf{w}_t = -\lambda_t \frac{\mathbf{W}_t(\mathbf{e}_t - e_{p,t}^{NZ}\mathbf{1}) - \mathbf{w}_t(\mathbf{w}_t'\mathbf{e}_t - e_{p,t}^{NZ})}{1 - \lambda_t(\mathbf{w}_t'\mathbf{e}_t - e_{p,t}^{NZ})}.$$

Working out the numerator, we arrive at the normalized weight tilt functional form:

$$\omega_t^* - \mathbf{w}_t = -\lambda_t \mathbf{W}_t \frac{\mathbf{e}_t - (\mathbf{w}_t'\mathbf{e}_t)\mathbf{1}}{1 - \lambda_t(\mathbf{w}_t'\mathbf{e}_t - e_{p,t}^{NZ})}.$$

We can see that the pivot intensity that determines positive and negative shifts is not the pathway intensity anymore; it has been replaced with the weighted average peer group intensity.

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NET-ZERO INVESTING: HARNESSING THE POWER OF UNSTRUCTURED DATA

Andy Moniz, CFA
Senior Vice President, Director of Responsible Investing,
Acadian Asset Management, London

Devin Nial
Senior Vice President, Portfolio Manager, ESG, Acadian Asset Management,
Boston

Matthew Picone, CFA
Senior Vice President, Portfolio Manager, ESG, Acadian Asset Management,
Sydney

Lukasz Pomorski
Senior Vice President, Portfolio Manager, Acadian Asset Management, Boston

Jerry Yu, CFA
Assistant Vice President, Associate Portfolio Manager, ESG, Acadian Asset
Management, Boston

Climate is increasingly important for investors, but to address it in an investment portfolio, one needs to overcome a significant data challenge. On the one hand, data providers try to cater to investor demand with various datasets; on the other hand, such offering is often a black box that may heavily depend on noisy historical data. This situation is of particular concern to net-zero investors, who need solutions that can be plausibly tied to companies' emission trajectories over very long periods of time. The purpose of this chapter is to explain how investors may respond to this challenge and to propose a realistic implementation that addresses it. We highlight how climate investors can leverage unstructured data through natural language processing (NLP), how they should incorporate new information that becomes available over time, and how they may deal with the uncertainty inherent in climate alignment estimates. Our example application showcases the use of NLP and unstructured data and also stresses many other design choices that, in our view, will improve net-zero solutions.

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Introduction

Climate considerations are increasingly important for investors, with use cases ranging from identifying potential risks and opportunities that may affect a financial portfolio to identifying targets for proxy voting and company engagement. These activities critically depend on the availability and quality of climate data; unfortunately, this is a major issue for investors. While multiple data providers offer a range of climate solutions, there are legitimate concerns about the usefulness of such data. For example, much of the data capture only historical firm behavior, but potential risk, opportunities, and engagement goals are all forward looking. This tension is particularly important for investors aiming to build net-zero-aligned portfolios. On the one hand, the idea behind net-zero investing is deceptively easy to explain: Build a portfolio of securities that are well positioned should the world economy decarbonize, potentially all the way to "net zero." On the other hand, translating this straightforward idea to an actual portfolio is exceedingly difficult because it requires investors to map company characteristics today to decades out into the future. Today, few companies can credibly claim to have achieved net zero, so building a realistic portfolio necessarily requires investors to take a stance on how issuer behavior may evolve, possibly over multiple decades. Moreover, data quality is often dubious because of both measurement problems and, perhaps even more importantly, the vagueness of corporate communications or outright greenwashing. Increasingly, many companies proclaim the desire to decarbonize and may even commit to specific targets. However, the credibility of these targets likely differs among companies, and investors today have relatively few tools to be able to assess this.

We believe that to address these challenges, investors need to increasingly rely on alternative data and on new techniques to extract actionable insights from such data. We focus primarily on textual data that may be disseminated by either the company in question or external stakeholders (e.g., nongovernmental organizations and the news media) and on the tools designed to process such data, collectively referred to as natural language processing (NLP). We explain why these data and this approach are critical for understanding firms' climate exposure and potential greenwashing by the underlying issuers. We follow up with a case study that explains in detail how one may build a measure of net-zero alignment in practice.

Our practical example illustrates an important theme that we believe all realistic climate solutions must share. There is no silver bullet to address portfolio climate needs, so investors must be prepared to use creative solutions that blend multiple data sources and techniques. The case study we present leverages NLP, but to build the overall climate measure, it also needs data that may not be directly climate related (e.g., sell-side analyst earnings forecasts) and additional statistical techniques (e.g., Bayesian updating, to update the measure as new data become available and to build not just a point estimate but also a range of possible outcomes for a given firm).

Limitations of Existing Data Solutions

Given the growing interest in climate and net-zero investing, it is not surprising that data providers have proposed a plethora of potential solutions. Unfortunately, such solutions tend to suffer from two major weaknesses: First, they usually provide only partial coverage of the investment universe, and second, they sometimes only have a tenuous relationship with the stated goal of alignment with economic outcomes far out into the future (Heal and Millner 2014; Pindyck 2017). Coverage is a perennial issue in sustainable investment, reflecting more company disclosure for large-cap issuers and for developed issuers. While intuitive, the lack of coverage is a problem for many asset owners who worry about the climate alignment of their overall portfolio and not just their, say, large-cap developed mandates. To illustrate this issue, one could survey the offering of net-zero index providers. While there are popular large-cap net-zero indexes (MSCI World Climate Paris Aligned Index, just to give one example), to the best of our knowledge, no similar small-cap indexes exist. Clearly, this situation clashes with the guidance from the Net-Zero Asset Owner Alliance that advises investors to "bring the focus of addressing the systemic risk of climate change to the entirety of investments and operations" (UN Environment Programme 2024).

The second issue is that the currently available data may be only a very noisy measure of net-zero alignment (Schneider and Kuntz-Duriseti 2002; Thiele 2020). This is partially a function of regulation. For example, the net-zero indexes, such as the one mentioned previously, reflect the EU's minimum technical standards that prominently feature measures of carbon intensity. However, carbon intensity captures a company's emissions today and perhaps in the near future (for a relevant analysis, see Bixby, Brixton, and Pomorski 2022), so it may not always be a good measure of emissions that are still decades away. Moreover, when data providers come up with their proprietary measures, they may use subjective or relatively opaque methodologies (Task Force on Climate-related Financial Disclosures 2020) and may struggle to demonstrate the link between them and the desired future economic outcomes. Indeed, the implied temperature scores published by data providers, often provided with decimal-point precision, suggest an unwarranted high degree of accuracy of climate forecasts (Robinson-Tillett 2022). This leads to a paradoxical situation in which we are inundated with different climate alignment data that meaningfully differ across providers, making it challenging for the asset owner to identify and justify which specific source to rely on. For example, even if an investor decides on a specific type of data (e.g., Scope 3 emissions or implied temperature scores), such data can have very low correlations between providers, potentially leading to very different investment outcomes.

Proposed Solution: Machine Learning to the Rescue

We argue that machine learning (ML) techniques offer a viable alternative to improve an investor's situation for two overlapping reasons. First, insights about long-term climate exposure and outcomes can realistically be obtained only from unstructured data. Second, to process unstructured data, one has little choice but to resort to ML and, in particular, to one specific subarea of these tools, NLP.

The first argument is that the data net-zero investors need are likely to be unstructured. It is probably unrealistic to expect that issuers might produce numerical data that can plausibly describe their climate exposure in, say, 2050. Even if a company does produce such an estimate or scenario, it will reflect a range of assumptions that may be specific to the given company and thus not generalizable to others. Understanding such assumptions should plausibly affect one's assessment of the company's climate exposure and alignment. For example, a company may pledge a net-zero commitment. On its own, this may seem to be a positive development, but the full assessment will likely require a careful analysis of the specific steps the company is planning to undertake, intermediate targets and milestones, current and planned future disclosures, and so on. Such diverse information will not be presented in a numerical form, and it may not even lend itself to a tabular template. Instead, it will likely be a narrative, with free-form language describing the company's ambitions.

The second argument is that to process such data at scale, it is perhaps inevitable to eventually use ML techniques. Continuing with the previous example, it is, of course, conceivable that human analysts can process information about any one issuer's net-zero commitment and arrive at an informed view about its quality and likelihood of success. Unfortunately, this model does not scale. Even large data providers may not be able to hire hundreds of analysts to assess the thousands of issuers that a large investor may hold in its portfolio. We cannot solve the coverage issue with standard statistical techniques, such as regression-type tools. As we explained previously, at least some relevant information will not be numerical, which will prevent a purely "parametric" approach. Moreover, we may have somewhat different information about each individual issuer, and we cannot resolve the problem by simply hiring hundreds of analysts. It seems unlikely that human researchers could produce data that would be comparable across a wide range, possibly thousands, of issuers. The human analyst thought process is ultimately a black box that may not easily translate between how two skilled analysts may view a given company. In our view, ML is the only realistic solution that can reliably scale and that can handle the complexity of the underlying data.

In addition to efficiently handling large volumes of unstructured data, ML could also be helpful for investors building a holistic measure that aggregates a number of climate indicators, each of which is only weakly correlated with the desired outcome. This is especially true when there are nonlinearities and interactions between various pieces of data, which we believe is likely in climate investing. Some issuers that are clearly brown today are likely to be among the most important drivers of lowering carbon emissions in the future. For example, some energy or utility companies with current high emissions may be well positioned to meet the world's future nonnegotiable energy needs; they may also have the resources and a clear economic incentive to pursue the relevant research and development today (e.g., Cohen, Gurun, and Nguyen 2020).

Example Application: Company Decarbonization Alignment

Of course, although ML may sound good in principle, such techniques can only be beneficial when used in a carefully designed application. To illustrate one such application, we now turn to perhaps the most obvious data need net-zero investors face: predicting a company's decarbonization alignment in the future.

To assess the decarbonization alignment, we need to build a view of the company's carbon emissions at some point decades away—say, in 2050. We can then map the estimated emissions to a specific pathway and thus determine whether the firm belongs in a net-zero portfolio.

As we will show, predicting emissions will indeed involve ML and, in particular, NLP. Although these techniques will be a critical component of the resulting measure, even the most advanced ML cannot get there on its own. We need to provide additional structure and creative solutions for such tools to lead to actionable investment insights.

Structure of the Forecast

To start, we express emissions in tons as a product of the firm's expected sales and its carbon intensity:[1]

$$E\left(\text{Emissions in tons}_{Firm\,j}^{2050}\right) = E\left(\text{Sales}_{Firm\,j}^{2050}\right) \times E\left(\text{Intensity}_{Firm\,j}^{2050}\right). \qquad (1)$$

We rely on this identity because we believe it is more straightforward to predict these individual components than emissions in tons directly. For example, if we were to predict a company's emissions in the near future (say, in 2027 instead of 2050), we could directly use sell-side sales forecasts for the first term in the product of Equation 1. Sell-side analyst forecasts, reported in such databases as I/B/E/S, are informed predictions based on market trends, economic conditions, and company performance. For the second term of the product, expected carbon intensity in 2027, we could perhaps assume that the firm's intensity will be unchanged over such a short period of time and simply use a historical number.

It is more complicated to arrive at a forecast in 2050. For example, sell-side analyst forecasts are available for only up to five years into the future. We need to find a way to extend such forecasts for another few decades. One option is

[1]Technically, the equation is an approximation: The expected value of a product does not generally equal the product of the expectations. As mentioned previously, practical solutions may require some compromises and necessary approximations.

to use solutions proposed in academic literature, such as a three-stage residual income model inspired by Gebhardt, Lee, and Swaminathan (2001):

- The first stage of the model integrates I/B/E/S sell-side analyst forecasts over the first five fiscal years (from FY0 to FY5).
- The second stage assumes that sales forecasts mean revert to a peer-group median between FY5 and FY10.
- The third stage assumes sales reach a long-run equilibrium after FY10.

Next, we need to forecast carbon intensity. Unfortunately, unlike with sales, we do not have as much guidance from academic literature on how a firm's intensity may evolve over time. We need to resort to some simplifying assumptions:

- We begin with the presumption that a company's carbon intensity will remain unchanged from its reported year-end value.
- If a company has announced a decarbonization target, however, this assumption is superseded by the target value. Since decarbonization targets are published by companies on an inconsistent basis, with differing baselines and target dates, we standardize targets and compute the expected decarbonization by the target year.

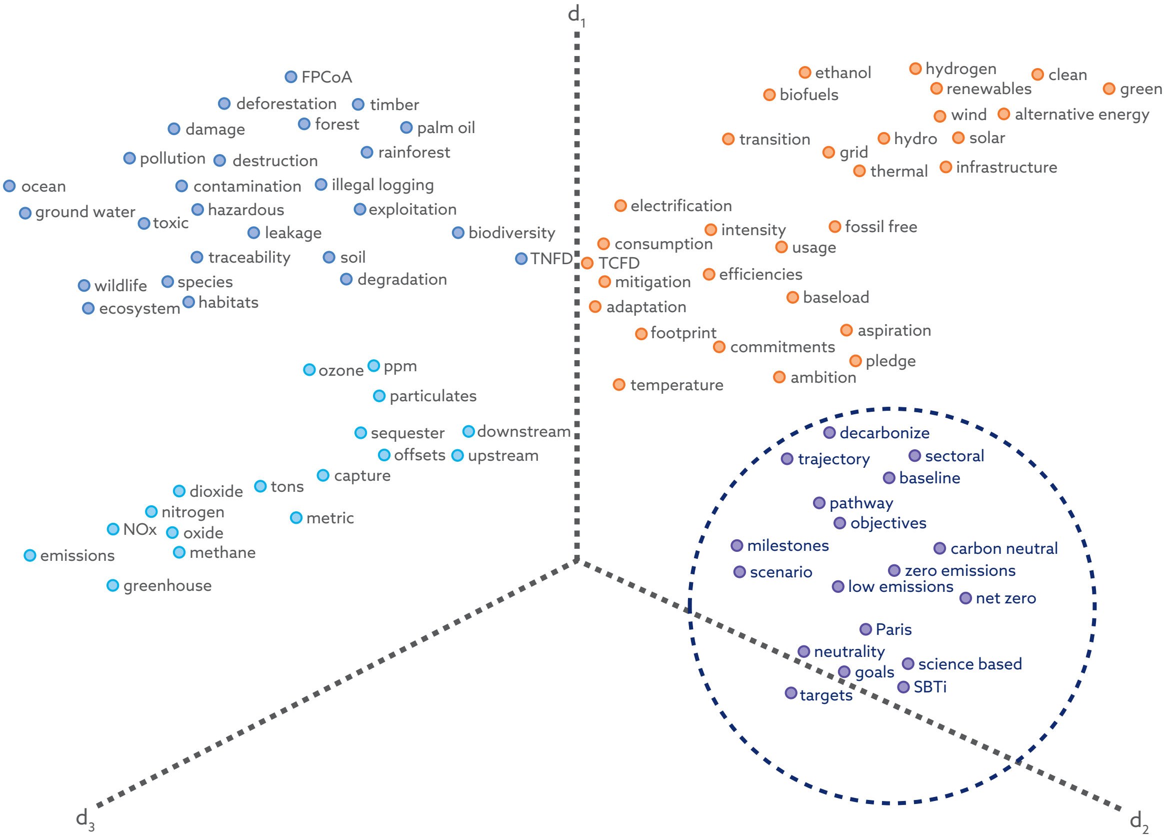
Of course, some companies with no pledges today may still pledge a decarbonization commitment at some point in the future, and some firms may change their carbon intensity over time even absent such commitments. Later, we will show how we update the distribution of intensity forecasts over time as such new data arrive.

After we forecast both sales and carbon intensity, we can return to Equation 1 and multiply the forecasts to arrive at a distribution of carbon emission forecasts across companies.

How Realistic Are Companies' Decarbonization Commitments?

Relying on a company's stated decarbonization target implicitly assumes that a company will follow through on its commitment. However, taking a commitment at face value and using it directly in our intensity forecast is probably overly optimistic. Thus, we refine this assumption and construct a proxy to assess the credibility of a company's decarbonization commitment. To do so, we will turn to ML and NLP. Specifically, at the cost of introducing some technical jargon, we fine-tune a large language model (LLM) using a supervised learning technique that teaches the model to interpret climate disclosures. Embeddings condense a huge volume of textual data within a high-dimensional vector space to encode better semantic and syntactic meaning. For instance, such phrases as "net-zero goals" and "Paris alignment" will be represented closer together in vector space than more vague terms such as "ambitions" and "pledges" will be. We illustrate this concept in **Exhibit 1** using

Exhibit 1. Mapping Company Disclosures to Climate Categories



Notes: This exhibit uses *t*-SNE to show a two-dimensional projection of embeddings for words and phrases. Words with similar meanings are clustered together.

t-distributed stochastic neighbor embedding (*t*-SNE), a dimensionality reduction technique designed to visualize high-dimensional data by giving each word a location within a two-dimensional map (van der Maaten and Hinton 2008). Exhibit 1 illustrates how the various words found in textual documents map to climate categories, clustering around such concepts as "emissions," "energy transition," or "decarbonization plans."

The LLM detects mentions of decarbonization plans in company documents. Examples include earnings call transcripts, corporate sustainability reports, and regulatory filings. The output of the LLM is a probabilistic classification that assesses the credibility of a company's decarbonization plans based on perceived alignment to the Task Force on Climate-related Financial Disclosures (TCFD) and Science Based Targets initiative (SBTi) frameworks. We refer to this as the LLM score. Intuitively, we find that companies that publish numeric information, including dates, baselines, and targets, are typically scored higher by the LLM and deemed more likely to follow through on their decarbonization commitments. In effect, the score seeks to proxy the management quality of a company through management's ability to address sustainability risks and opportunities. We illustrate this in **Exhibit 2** with example sentences for two companies.

Exhibit 2. LLM Classification for Two Hypothetical Companies

	Company A	Company B
Country	Australia	Australia
Industry	Construction materials	Construction materials
Climate target	"We're targeting to reduce our absolute Scope 1 and 2 emissions by 46% and to reduce our relevant Scope 3 emissions by 22% . . . by FY 2030."	"40% reduction in Scope 1 and Scope 2 greenhouse gas intensity by 2030."
Evidence	"Our medium-term decarbonization opportunities, which we're maturing, include optimizing our supply chain logistics and low-carbon and no-carbon alternative fuel options."	"We're pretty optimistic we're going to be able to continue to drive greater efficiencies in our operating plans."
LLM classification	High certainty of meeting the target	Low certainty of meeting the target

Such examples highlight that seemingly similar corporate pledges, such as 40% reduction in emissions, may lead to very different overall assessments based on a careful analysis of additional company disclosures. Of course, while we advocate using NLP for such analyses, we urge investors to include spot checks and "sniff tests," perhaps similar to the previous examples, where human analysts verify model output. We believe scalable, systematic processes can yield a lot of value for investors—but they should not be used sight unseen and fly purely on autopilot.

To demonstrate the benefits of using unstructured data, we perform a statistical analysis to evaluate whether the LLM score is positively correlated with independent company assessments conducted by climate experts using data from the Transition Pathway Initiative (TPI). The TPI's data underpin the Climate Action 100+ Net Zero Company Benchmark and assess performance on emission reductions, governance, and disclosure on and implementation of net-zero transition plans. As of March 2024, 151 institutional investors globally pledged their support to the TPI, representing approximately $60 trillion in assets under management. TPI scores are available for only a small fraction of investible companies, limiting their usefulness as a comprehensive portfolio solution. Still, we believe such data could go a long way to validate and thus increase investors' comfort with other types of climate data, such as the LLM score.

Specifically, we examine whether the LLM score helps explain the TPI Management Quality score. The TPI Management Quality score consists of six levels. Levels 0 and 1 refer to companies that do not develop basic capacity to address climate risks and opportunities, lack disclosures on their carbon practices and performance, and do not integrate climate considerations into operational decision making. By contrast, Levels 4 and 5 refer to companies that develop a strategic and holistic understanding of climate risks and opportunities, with detailed and actionable transition plans that align business practices and capital expenditure decisions to their decarbonization goals.[2]

[2]See Dietz, Bienkowska, Jahn, Hastreiter, Komar, Scheer, and Sullivan (2021).

The regression specification includes three sets of variables. The first set comprises company fundamentals, including the percentage of revenue derived from the extraction of conventional and unconventional oil and gas, fossil-fuel reserves, thermal coal, and alternative energy. We further include a company's latest reported Scope 1 and 2 carbon emissions and carbon intensity. Taken together, these fundamental metrics seek to proxy exposure to carbon-related risks and opportunities as reported in a company's financial statements. The second set of variables includes a company's announced decarbonization targets. We include indicator variables equal to 1 if a company has publicly disclosed a target, if it has announced a science-based target, and if the target is approved by the SBTi and equal to zero otherwise. The final set of variables captures the comprehensiveness of a company's decarbonization plans. We include the LLM score and MSCI's Carbon Emissions Management Score.[3] The latter score integrates an assessment of how aggressive any decarbonization target is, whether a company has a track record of achieving its targets, how aggressively the company has sought to use cleaner sources of energy, and carbon capture and storage/sequestration of its operational emissions. The results of the logistic regressions as of June 2024 are provided in **Exhibit 3**.

Exhibit 3. LLM Score Helps Capture Differences in TPI Management Quality Scores across Firms

	TPI Management Quality Laggards		TPI Management Quality Leaders	
	(1)	(2)	(3)	(4)
LLM		−1.086 (−4.150)***		0.426 (2.584)***
Carbon emissions	−0.161 (−1.200)	−0.094 (−0.645)	0.525 (2.752)***	0.489 (2.3103)**
Carbon intensity	−0.0019 (−0.016)	−0.067 (−0.521)	−0.390 (−4.011)***	−0.351 (−3.534)***
% Conventional oil & gas	−0.923 (−1.737)*	−0.713 (−1.392)	0.087 (−0.573)	0.043 (0.273)
% Unconventional oil & gas	−1.356 (−0.973)	−2.5794 (−0.779)	0.046 (−0.271)	0.069 (0.408)
% Thermal coal	0.203 (1.786)*	0.310 (1.733)*	−0.104 (−0.809)	−0.105 (−0.807)
% Alternative energy	0.401 (1.368)	0.513 (1.512)	0.039 (0.269)	0.089 (0.612)
Dummy$^{Carbon\ Underground\ 200}$	1.233 (1.895)*	1.652 (1.931)*	0.544 (1.262)	0.468 (1.081)

(*continued*)

Exhibit 3. LLM Score Helps Capture Differences in TPI Management Quality Scores across Firms (*continued*)

	TPI Management Quality Laggards		TPI Management Quality Leaders	
	(1)	(2)	(3)	(4)
$Dummy^{Numeric\ target}$	−0.594 (−1.095)	−0.573 (−1.047)	2.026 (3.081)***	1.985 (2.990)***
$Dummy^{SBTi\ approved}$	−1.417 (−2.117)**	−1.052 (−2.061)**	1.699 (6.072)***	1.65 (5.848)***
$Dummy^{SBTi\ commitment}$	−1.332 (−1.419)	−1.019 (−1.268)	0.2909 (0.854)	0.249 (0.727)
MSCI Carbon Management	−0.432 (−1.621)	−0.366 (−1.581)	0.129 (1.252)	0.089 (0.841)
Sector fixed effects	Yes	Yes	Yes	Yes
Pseudo R^2	0.274	0.332	0.235	0.345
N	528	528	528	528

Notes: This exhibit reports the results of a logistic regression in which the dependent variable is the TPI Management Quality score. The dependent variable in columns 1 and 2 is an indicator variable equal to 1 if a company has a TPI Management Quality score of 0 or 1 and is equal to 0 otherwise. The dependent variable in columns 3 and 4 is an indicator variable equal to 1 if a company has a TPI score of 4 or 5 and is equal to 0 otherwise. An intercept term is included in the regression, although it is not displayed given space limitations. "LLM" represents the output of a probabilistic text classification derived from an LLM that scores the perceived credibility of a company's decarbonization plans. "Carbon emissions" represents the cross-sectional *Z*-score of a company's Scope 1 and 2 carbon emissions. "Carbon intensity" is the region- and industry-relative *Z*-score of a company's carbon intensity. "% Conventional oil & gas" is the percentage of revenue a company derives from conventional oil and gas. "% Unconventional oil & gas" is the percentage of revenue a company derives from unconventional oil and gas. "% Thermal coal" is the percentage of revenue derived from the mining of thermal coal, including lignite, bituminous, anthracite, and steam coal. "% Alternative energy" is the percentage of revenue derived from renewable energy sources. $Dummy^{Carbon\ Underground\ 200}$ is an indicator equal to 1 if a company is on the Carbon Underground 200 list; the list identifies the top 100 coal and the top 100 oil and gas public companies ranked by the potential carbon emission content of their reported reserves. $Dummy^{Numeric\ target}$ is an indicator variable equal to 1 if a company has disclosed its target percentage reduction in its carbon emissions and is equal to 0 otherwise. $Dummy^{SBTi\ approved}$ is an indicator variable equal to 1 if a company has had its target approved by the SBTi. $Dummy^{SBTi\ commitment}$ is an indicator variable equal to 1 if a company has committed to setting science-based targets. MSCI Carbon Management is MSCI's assessment of how aggressive a decarbonization target is, whether a company has a track record of achieving its targets, and how aggressively it has sought to use cleaner sources of energy. For each variable, we report corresponding *z*-values, where ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The sample period is June 2024.

Source: Carbon and revenue data are sourced from MSCI.

Columns 1 and 2 in Exhibit 3 provide the results of a logistic regression where the dependent variable is an indicator variable equal to 1 if a company has a TPI Management Quality score of 0 or 1. We observe that climate laggards are more likely to derive revenue from thermal coal and appear on the Carbon Underground 200 list, consistent with the view that such companies may hold stranded assets. Column 2 includes the LLM score and shows a highly significant, negative coefficient, which means the lower the LLM score, the more likely the company is to be considered a climate laggard. In columns 3 and 4, the dependent variable is changed to an indicator variable equal to 1 if a company has a TPI Management Quality score of 4 or 5. Companies are more likely to be categorized by the TPI as a climate leader if they have lower carbon intensities than peers and have a target approved by the SBTi. Column 4 shows that the LLM score is highly statistically significant, showing that the higher the LLM score, the more likely the firm is to be considered a climate leader. A statistically significant relationship between the LLM score and the TPI Management Quality score points to the ability of an LLM to assess the credibility of companies' decarbonization plans, thereby codifying the perceptions of climate experts. Taken together, the regression results are consistent with the idea that the LLM score captures additional information beyond the company fundamental data and numeric disclosure targets.

Importantly, the LLM score is not meant to replace TPI measures. These measures are noisy themselves and may not reflect all relevant information about a given issuer. They do, however, capture *some* relevant information. Exhibit 3 suggests that the LLM score also incorporates such information, as reflected in both the statistical significance of the estimates and in the increase in the R^2 when we incorporate LLM: The R^2 for the laggards increases by about 20% of its level, and that of the leaders increases by about 47% of its level.

Bayesian Approach: Updating the Distribution over Time

With any data analysis, we must recognize that the underlying companies and their environment change over time and adjust our forecasts accordingly. Perhaps the most straightforward approach would be to recompute the forecasts, as explained previously, every time the underlying data changes. This approach is substandard, if only because data are noisy and any given snapshot may lead to erroneous inferences about a given company. This may be because of both outright mistakes in the data and potential greenwashing or other strategic manipulation by the company—or even because of transient economy-wide shocks. For example, corporate emissions were depressed in 2020 because of COVID-19, but it would have been a mistake to assume the 2020 reported figures are the optimal predictor of future emissions. Indeed, emissions reverted to the long-term historical average soon thereafter.

We can do better by gradually updating our forecasts as more data become available. To formalize this intuition, we use a Bayesian approach, which allows us not only to effectively update our forecasts over time but also to model the inherent uncertainty associated with companies' decarbonization trajectories. In general, Bayesian inference offers a framework to incorporate prior knowledge, such as historical data and expert opinions, with new evidence. These inputs may be combined to provide a probabilistic assessment of a company's decarbonization trajectory. One of the major advantages of Bayesian inference is that it offers not just point estimates but also confidence intervals for parameters. This probabilistic aspect may enable investors to assess risks more comprehensively.

There are three essential components underlying Bayesian statistics (for an overview, see van de Schoot, Kaplan, Denissen, Asendorpf, Neyer, and van Aken 2014). The first is the background knowledge on the parameters of the model—that is, all knowledge captured by the prior distribution, such as a normal distribution, before seeing the data.[4] The choice of prior reflects how much information we have before data collection and how accurate we believe the information to be. The variance of the prior distribution reflects our uncertainty about the population parameter. A smaller variance implies greater confidence that the prior mean reflects the population mean. In other words, the prior distribution represents the current state of knowledge or current description of uncertainty about the model parameters prior to data being observed. The second key component is information about the data. It is the observed evidence (i.e., the sample distribution) expressed in terms of the likelihood function of the data given the parameters. The third component is based on combining the first two components, known as the posterior distribution, and reflects one's updated knowledge, balancing prior knowledge with observed data. We describe these three components of the model in turn.

Prior Distribution

At the outset of the analysis, it is perhaps easiest to start with a diffuse (uninformed) prior and then adjust it given historical information. In other words, the analyst would use such historical information to compute the emission forecasts as described earlier without imposing any first-principles restriction on the outcome. For analytical ease, we chose to model the log ratio of a company's 2030 emissions to its latest annual emissions with a normal prior distribution. These priors can approximate the diffuse case when we assume they have a large variance. Thus, we allow for a wide range of possible outcomes before we see the data.

Sample Distribution

The sample distribution is derived from the company's realized carbon emission trajectory. As companies report their actual emissions over time, these data are used to construct the empirical distribution of observed emissions and capture a company's operational changes, market conditions, and policy impacts. We assume that the log ratio of a company's realized emissions to its latest annual emissions also follows a normal distribution. We use a statistical time-series ARIMA (autoregressive integrated moving average) model to compute a forecast for each company's carbon emission trajectory to 2030 and obtain the mean forecast and standard error.[5]

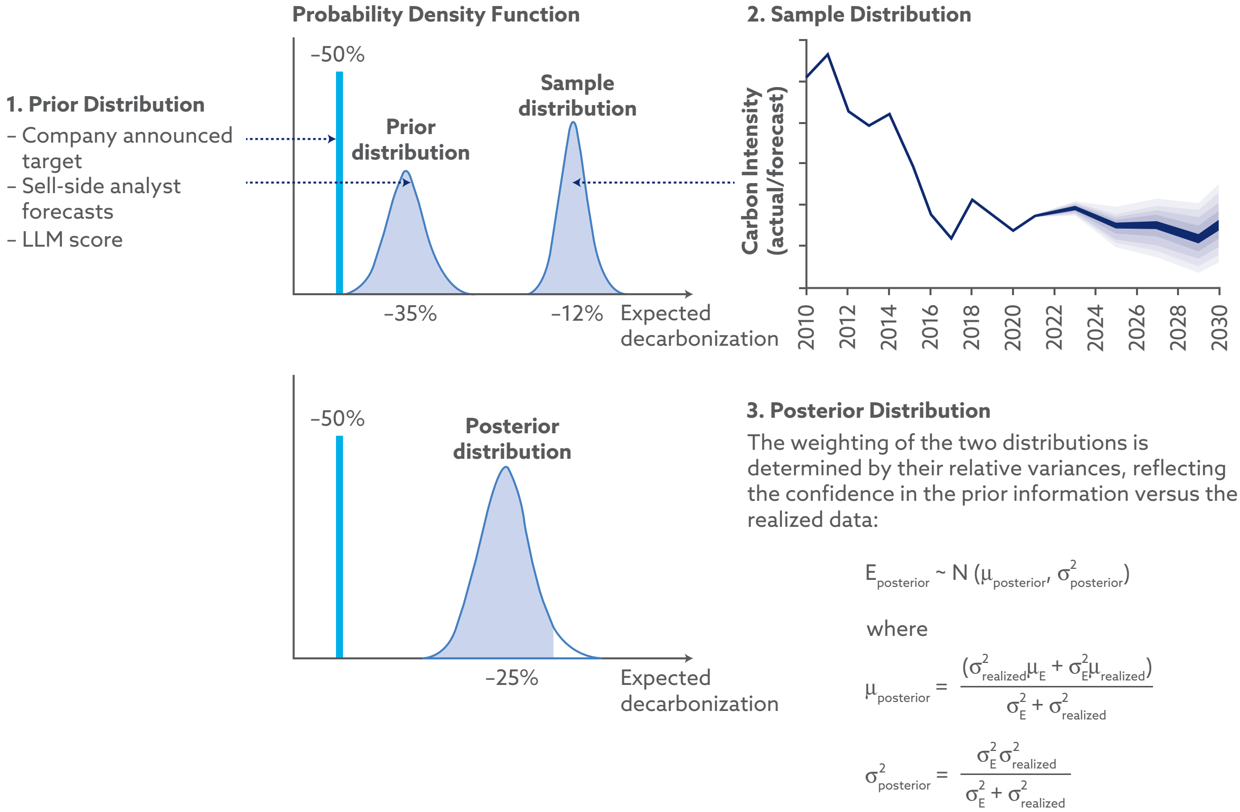
Posterior Distribution

The prior and sample distributions are combined to form the posterior distribution, providing an updated belief on a company's decarbonization alignment.

[4]We model the log ratio of a company's 2030 emissions to its latest annual emissions with a normal distribution, which is equivalent to modeling the ratio with a log normal distribution. This distribution can accommodate all possible values of a company's 2030 emissions.

[5]A company's carbon emission trajectory is modeled as the log ratio of a company's future annual emissions to its latest annual emissions.

Exhibit 4. Bayesian Updating of Carbon Emission Forecasts



When a parameter can be modeled by a prior normal distribution, Bayesian statistics show that the sample dataset from the same process can be used to update the prior to obtain a posterior normal distribution. The weighting of the two distributions is determined by their relative variances, reflecting the confidence in the prior information versus the realized data.

Exhibit 4 shows a schematic depicting the overall estimation process.

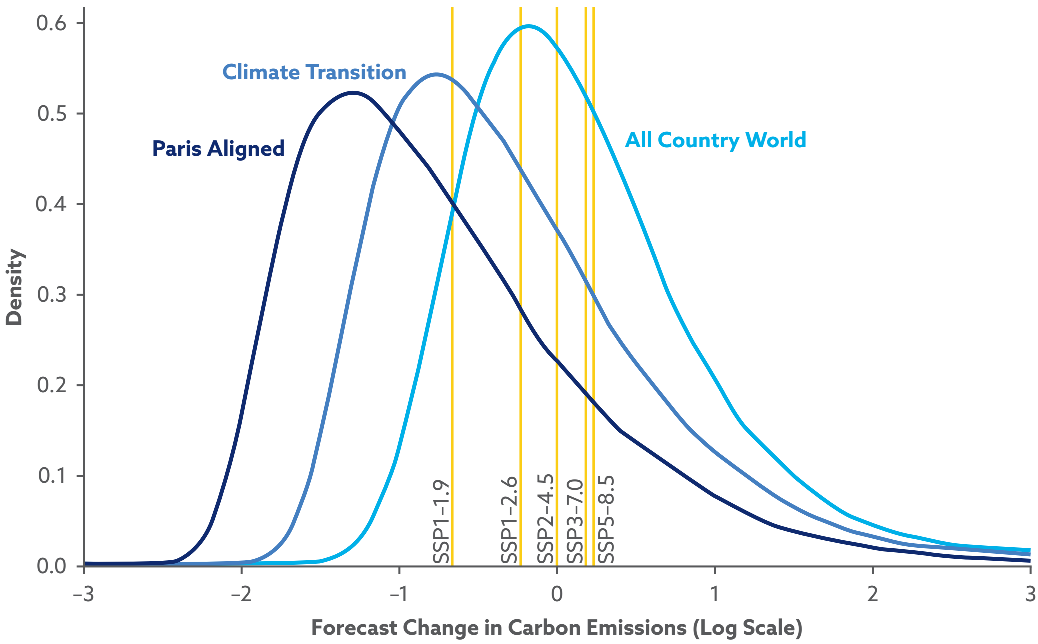
Results: Expected Decarbonization in 2030

In this section, we outline the merits of the Bayesian framework for portfolio climate analytics. In particular, we show how investors can quantify portfolio alignment to the socioeconomic pathways of the Intergovernmental Panel on Climate Change (IPCC). The five shared socioeconomic pathways (SSPs), described in the IPCC's (2021) "Sixth Assessment Report," outline representations of an uncertain future. The pathways range from a "Taking the Green Road" scenario, in which CO_2 emissions decline drastically to carbon neutrality by 2050 and are negative in the second half of the century (SSP1-1.9), to a fossil-fueled development ("Taking the Highway") scenario, in which CO_2 emissions continue to rise sharply to twice current levels in 2050 and more than three times current levels in 2100 (SSP5-8.5).

Exhibit 5 illustrates the resulting posterior probability distributions for three major benchmarks: the MSCI All Country World Index (ACWI), MSCI ACWI Climate Transition, and MSCI ACWI Paris-Aligned.[6] For each benchmark, we plot the distribution of the forecasted change in emissions. The vertical lines represent the decarbonization rates implied by each IPCC SSP. The SSP1-1.9 line implies the greatest reduction in carbon emissions, and the SSP5-8.5 line implies an increase in carbon emissions.

Exhibit 5 is based on an idea similar to the well-known MSCI Implied Temperature Rise metric. The key difference is that Exhibit 5 also gives investors information about the likely range of outcomes and allows them to quantify the risk that the portfolio might miss its climate objectives, rather than merely providing a point forecast. This is critical given the inherent uncertainty

Exhibit 5. Probability Distribution of Expected Decarbonization by 2030



Notes: The exhibit displays the posterior distribution for the MSCI ACWI, ACWI Climate Transition, and ACWI Paris-Aligned indexes as of June 2024. The vertical lines indicate the decarbonization rates under each IPCC SSP. SSP-1.9 is the IPCC's most optimistic scenario, in which global CO_2 emissions are cut to net zero around 2050, with warming reaching 1.5°C and then stabilizing to around 1.4°C by the end of the century. SSP1-2.6 is the next-best scenario, in which global CO_2 emissions are cut severely, reaching net zero after 2050. Temperatures stabilize at around 1.8°C higher by the end of the century. SSP2-4.5 is the "middle-of-the-road" scenario; CO_2 emissions start to fall mid-century but do not reach net zero by 2100, and temperatures rise 2.7°C by the end of the century. Under the SSP3-7.0 scenario, CO_2 emissions approximately double from current levels by 2100, with average temperatures rising by 3.6°C by the end of the century. The SSP5-8.5 scenario is a future to avoid at all costs: Current CO_2 emissions levels double by 2050 with economic growth fueled by exploiting fossil fuels. By 2100, the average global temperature is 4.4°C higher. The exhibit was created using the methodology described in this chapter and then bootstrapping by simulating individual securities' decarbonization paths from each security's posterior distribution.

Index source: MSCI.

[6]Index source: MSCI.

associated with climate analysis. From a top-down perspective, this includes uncertainty regarding the future direction of government and regulatory policies, technological innovation, and how consumer preferences may evolve. From a bottom-up perspective, our approach considers ongoing uncertainty associated with companies' decarbonization trajectories and willingness to follow through on their plans.

As an example application of this framework, by integrating the area under the probability distribution, we can infer alignment to a given SSP scenario. For example, Exhibit 5 shows that the core benchmark (MSCI ACWI)[7] clearly misses the mark for net-zero alignment (SSP1-1.9). The area in the left tail of the distribution up to the SSP1-1.9 vertical threshold indicates the probability that the benchmark is net-zero aligned, which is about 0.1. This suggests that this popular benchmark is highly likely to miss the climate goal of net-zero investors because the individual portfolio companies are unlikely to decarbonize promptly enough for the index to be net-zero aligned. It is more likely that the index will be aligned with the SSP2-4.5, "middle-of-the-road" scenario, but even here, we see only even odds of achieving that outcome (Exhibit 5 implies a probability of 0.46). In contrast, the two climate-oriented versions of the index, Climate Transition and especially Paris-Aligned, have a much more attractive net-zero alignment. The probability of meeting SSP1-1.9 is 0.37 for the former and 0.61 for the latter, with obviously an even higher probability of aligning with at least the SSP2-4.5 scenario (0.67 for Climate Transition and 0.81 for Paris-Aligned).

Conclusion

Climate investing and, in particular, net-zero investing are a complex but also fascinating challenge for investors. Unlike with historical carbon emissions, no company-reported, broadly comparable measures exist that could capture a firm's net-zero alignment decades from now. Instead, companies are likely to report different information, frequently in a narrative form. To process such information and to inform their broader portfolios, investors have little choice but to use ML and, in particular, NLP.

Moreover, there is no single "silver bullet" source of net-zero data, so investors must be prepared to combine different datasets and various statistical techniques in their net-zero strategies. And even then, investors will face substantial uncertainty around the estimates they produce. We believe portfolio applications should reflect this uncertainty and rely not just on our best estimate (best guess) but also on the range of possible outcomes around it—for example, through Bayesian updating. Our realistic case study showcases NLP and also highlights other important components of a holistic net-zero solution.

We conclude that while climate investing may be both art and science, there is already plenty of science investors should rely on when building net-zero portfolios.

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[7]Index source: MSCI.

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3D INVESTING: IMPLICATIONS FOR NET ZERO

Clint Howard
Quantitative Researcher, Robeco, Rotterdam, the Netherlands

Mike Chen
Head of Next Gen Research, Robeco, Rotterdam, the Netherlands

Traditional mean–variance portfolio optimization is based on the premise that investors care only about risk and return. Some investors, however, also have nonfinancial objectives, such as sustainability goals. Central to these goals, such as working toward net-zero emissions, is the question of how to incorporate such objectives into an investor's portfolio. We show how an extended mean–variance–sustainability optimization can incorporate sustainability goals into a portfolio, particularly aligning the portfolio with the net-zero transition set out in the Paris Agreement. Importantly, we compare various methods for integrating sustainability goals in investor portfolios and highlight the implications of such approaches on investor outcomes.

Introduction

Numerous approaches have challenged the standard risk-and-return portfolio framework. All of them focus on making investment decisions based on objectives that are not strictly risk or return based, such as impact investing, socially responsible investing (SRI), or environmental, social, and corporate governance (ESG) investing. Accordingly, investment practice has evolved to incorporate sustainability objectives into the investment problem, including metrics related to carbon footprint, ESG characteristics, and sustainability development goals (SDGs). In this chapter, we explore potential applications and implications of the 3D investing framework from Blitz, Chen, Howard, and Lohre (2024) in the context of net-zero transition alignment, as outlined in the Paris Agreement, adopted at the UN Climate Change Conference (COP21) in Paris on 12 December 2015.

The Paris Agreement is a landmark treaty in which 195 nations committed to limit global temperature rise this century to less than 2°C above preindustrial levels and pursue efforts to target an increase of less than 1.5°C. In 2018, the Intergovernmental Panel on Climate Change (IPCC) stated that carbon emissions need to reach net-zero neutrality by 2050 to limit global warming to 1.5°C (IPCC 2018). Achieving these ambitious climate and decarbonization

Author's note: This chapter is based on the article "3D Investing: Jointly Optimizing Return, Risk, and Sustainability" in the *Financial Analysts Journal* (Blitz, Chen, Howard, and Lohre 2024), with an extended discussion around potential net-zero implications and applications of the original article. The views expressed herein are not necessarily shared by Robeco or its subsidiaries.

goals requires investors to integrate net-zero transition objectives alongside traditional risk and return considerations, necessitating flexible portfolio construction frameworks.

Considering these ambitious climate and decarbonization goals, academics and practitioners have started developing new frameworks and toolkits to address the urgent need to decarbonize. At the center of this work is the concept of decarbonization pathways and trajectories toward net zero. These concepts can be seen as an evolution or extension of "low-carbon" portfolios, which aim to reduce exposure to assets with high carbon footprints at the moment of investment. Net-zero portfolios additionally aim to help transition the economy from "brown" to "green," which is inherently a more challenging forward-looking problem. Barahhou, Ben Slimane, Roncalli, and Oulid Azouz (2022) argue that constructing a net-zero portfolio is more complex than constructing a decarbonized portfolio because of the multi-objective nature of reducing portfolio carbon and financing the transition. At its core, the desire to construct net-zero-aligned portfolios is a multi-objective optimization problem.

Blitz et al. (2024) show how portfolio decarbonization can be achieved using both constraints and an objective function term and highlight how, for ambitious targets with low active risk budgets, the objective function term outperforms. The study's results show that for portfolios that seek to track the benchmark closely while outperforming it, ambitious sustainability goals are better implemented using a direct objective function term rather than a portfolio-level constraint. The objective function term allows for a rewarded time-varying trade-off of a stock's expected return and the stock's contribution toward the sustainability objective. It is this flexibility to decide at the portfolio construction's run time when it might be better to go for expected return vis-à-vis sustainability that gives the superior result of the objective function approach. In this chapter, we relate the concept of 3D investing to that of net-zero investing and the many-dimension problem of integrating net-zero objectives into a portfolio.

In recent years, the construction of net-zero portfolios has received considerable attention from both academics and practitioners. Bolton, Kacperczyk, and Samama (2022) propose a framework to align portfolios with a carbon budget that aims to keep global temperature rise below 1.5°C. This approach aims to maintain minimum tracking error to a market index while demonstrating the importance of time for reducing emissions. Le Guenedal and Roncalli (2022) survey how asset managers measures climate risk and constructs portfolios based on these climate risks. They highlight the importance of considering the impact of different carbon emission scopes and the challenges of integrating these objectives into the portfolio. Importantly, they highlight the nuance between portfolio decarbonization and portfolio alignment with Paris Aligned Benchmarks and net-zero carbon objectives. Jondeau, Mojon, and Pereira da Silva (2021) provide methodologies for constructing benchmark portfolios where the component companies' carbon footprint decreases over time.
In this chapter, we explore the applications and implications of a 3D investing

framework for the pressing challenge of constructing net-zero-aligned portfolios.

One of the key considerations with net-zero investing is balancing the long-term objective of reaching net zero by 2050 with the short- to medium-term objectives and incentives around balancing risk and return. Constructing net-zero portfolios is inherently a multi-objective problem, weighing decarbonization against financing the transition, risk, and return. Investors are balancing the urgency of decarbonizing the portfolio with the need to maintain the return and risk profile of the portfolios that they manage. Such a balance naturally requires a multi-faceted optimization approach that can incorporate numerous objectives alongside risk and return.

Specifically, in the context of net-zero investing, one mechanism could be to incorporate a forward-looking net-zero metric into the objective function and encourage the portfolio optimizer to take exposure to stocks based on expected returns, risk, and forward-looking net-zero expectations. If one considers incorporating Paris Aligned Benchmarks, these benchmarks effectively require a 50% carbon-intensity reduction relative to the benchmark based on current emissions, 7% year-on-year decarbonization, and adherence to several exclusions and exposure constraints. Meeting such objectives can naturally be achieved with both constraints and objective function terms. Blitz et al. (2024) show that for more ambitious carbon footprint reductions and lower tracking error targets, the objective function term helps reduce turnover and increase expected net outperformance.

Given the strict requirements of Paris Aligned Benchmarks, one could apply a portfolio construction paradigm that consists of portfolio-level constraints on current emissions, an objective function term on current emissions, and an objective function term on expected future emissions. Such an approach could allow for meeting the immediate-term requirements while also allowing the portfolio to take on greater exposure to decarbonization when it is "cheap" from an expected return or risk perspective. For example, if investors' expected return forecasts about highly emitting stocks are currently very negative, then they may be willing to take a larger underweight in such stocks if they also derive additional "net-zero utility" from such a position. Given that reducing current emissions is more valuable from a net-zero perspective than reducing future emissions, as shown by Daniel, Litterman, and Wagner (2019) and Fearnside, Lashof, and Moura-Costa (2000),[1] having a portfolio construction framework that can dynamically trade off return, risk, and net-zero objectives may lead to superior after-cost performance while meeting all stated objectives for integrating net-zero goals into the portfolio.

The question of how to integrate environmental objectives into an investment decision has been studied extensively. Repetto and Austin (2000) propose a

[1]This is the so-called time value of carbon. See the Wikipedia page on the topic: https://en.wikipedia.org/wiki/Time_value_of_carbon.

methodology to integrate environmental issues into the analysis of individual companies, using a scenario-based approach to evaluate the impact of emerging environmental issues on a company's operations. Barber, Morse, and Yasuda (2021) show how, in recent years, investors have begun to derive nonpecuniary utility when investing in dual-objective venture capital impact funds. They argue that investors are willing to sacrifice returns in pursuit of these alternative objectives.

Many approaches that strive to incorporate more general sustainability objectives into a portfolio have been proposed in the literature. These include excluding undesirable stocks from the investment universe (Diltz 1995; Kinder and Domini 1997; Naber 2001), constraining the portfolio's exposure to such objectives (Boudt, Cornelissen, and Croux 2013), and incorporating sustainable targets into the return/alpha component of the objective function (Steuer, Qi, and Hirschberger 2007; Bilbao-Terol, Arenas-Parra, and Cañal-Fernández 2012; Hirschberger, Steuer, Utz, Wimmer, and Qi 2013; Utz, Wimmer, Hirschberger, and Steuer 2014; Chen and Mussalli 2020).

The key tension of net-zero portfolio construction is the desired urgency of decarbonizing while meeting core risk and return objectives. All portfolio construction methods have different positives and negatives in considering these specific tensions. For example, divesting from high-carbon-emitting companies may significantly improve the immediate carbon profile of a portfolio, yet these companies may be best positioned to help develop and implement transitional technologies. Similarly, excluding a substantial portion of stocks may introduce significant added risk to a portfolio that is not within the risk budget. The investor's core focus is to balance these dimensions, and toolkits such as 3D investing can provide insights into how these dimensions interact in a portfolio.

In this chapter, we explore how a 3D investing framework could be applied to the challenge of constructing investment portfolios aligned with net-zero emission goals. Building on the work of Blitz et al. (2024), we show how integrating forward-looking climate metrics and emission pathway constraints into a multi-objective portfolio optimization could help investors navigate the complex trade-offs between decarbonization, performance, and risk. A 3D investing framework can allow for dynamic exposure to climate leaders and laggards based on return expectations and sustainability characteristics while adhering to decarbonization pathways. As investors grapple with the urgency of the net-zero transition, frameworks such as 3D investing will be useful tools for helping align portfolios on multiple dimensions.

The remainder of this chapter is organized as follows: In the next two sections, we outline the general multi-objective optimization framework and illustrate the use of 3D investing for climate objectives. Then, we explore the implications and applications for net-zero portfolios. Finally, we provide concluding remarks.

Multi-Objective Optimization Framework

We begin by introducing the portfolio optimization framework that we work with. First, we specify the common mean-variance optimization framework, where the investor trades off maximizing expected returns while jointly minimizing risk. We then expand this optimization paradigm to a multi-objective optimization framework.

Standard Mean–Variance Optimization

Equation 1 shows the standard mean–variance optimization formula:

$$\begin{aligned} &\max_{\mathbf{w}} \circ \lambda \mathbf{w}'\boldsymbol{\mu} - \frac{\gamma}{2}\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w}, \\ &\text{s.t. } \mathbf{w}'\mathbf{e} = 1, \end{aligned} \tag{1}$$

where

$\mathbf{w}$ is an $N \times 1$ vector of asset weights

$\boldsymbol{\mu}$ is an $N \times 1$ vector of expected returns

$\boldsymbol{\Sigma}$ is the $N \times N$ variance–covariance matrix

$\mathbf{e}$ is an $N \times 1$ vector of ones

λ and γ are scalar coefficients

Portfolios generated under Equation 1 are mean–variance optimal in that they achieve the maximum expected return for a given level of risk. This framework can be extended to include additional dimensions, such as constraining the portfolio relative to some benchmark (Jorion 2003), incorporating transaction cost penalties (Taksar, Klass, and Assaf 1988; Ledoit and Wolf 2022), penalizing turnover (Hautsch and Voigt 2019), or enforcing positive asset weights (Jagannathan and Ma 2003). Ibbotson, Idzorek, Kaplan, and Xiong (2018) explore a popularity asset pricing model (PAPM) where they introduce additional "popularity" characteristics into the standard CAPM framework. Such an approach generalizes the standard mean–variance optimization problem to any number of alternative objectives. Steuer, Qi, and Hirschberger (2007) derive analytical solutions for an efficient portfolio surface with three criteria, using portfolio liquidity as an example. They extend the classical two-mutual-fund theorem to a three-mutual-fund theorem and show how the obtained three-dimensional efficient surface has paraboloidal/hyperboloidal structures.

A Multi-Objective Optimization Framework

It is straightforward to extend the mean–variance optimizer from Equation 1 to construct portfolios on an efficient frontier surface in three (or more) dimensions. In the case of additional sustainability considerations, Equation 1 can be extended to three dimensions as follows:

$$\max_{\mathbf{w}} \circ \lambda \mathbf{w}'\boldsymbol{\mu} + (1-\lambda)\mathbf{w}'\boldsymbol{\mu}_{SI} - \frac{\gamma}{2}\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w}, \quad \text{s.t. } \mathbf{w}'\mathbf{e} = 1, \mathbf{w} \in \Omega, \tag{2}$$

where $\boldsymbol{\mu}_{SI}$ is an $N \times 1$ vector of any (discrete or continuous) sustainability metric, λ becomes the relative preference between the return and sustainability objectives, and Ω is the set of feasible solutions, which includes any portfolio constraints. This formulation is general and can accommodate the incorporation of common sustainability characteristics. These include commercial ESG metrics from vendors, such as MSCI and Sustainalytics; carbon footprint; SDG scores; and climate transition scores. The only requirement here is that the sustainability metric is ordinal.[2]

Targeting a Climate Traffic Light

To illustrate how the 3D investing framework can easily integrate forward-looking climate measures, we use the simulation framework of Blitz et al. (2024) with the Robeco Climate Traffic Light (CTL) scores (Robeco 2022).[3] To summarize, we use an MSCI World Index developed markets universe alongside a simple expected returns model and variance–covariance matrix to conduct benchmark-relative portfolio optimization exercises.[4] Our sample consists of MSCI World constituents at the end of every month from December 1989 to December 2022.[5] We source stock returns and fundamental data from Refinitiv.

We use a portfolio optimization setting that mimics the construction of a real-life investment portfolio applying realistic portfolio constraints and settings. We construct portfolios with tracking errors of 0.5% because it represents the challenging multi-objective scenario of delivering high expected returns and sustainability goals with a limited risk budget. The portfolio exposure to regions (defined as North America, Europe, and Asia Pacific) and Global Industry Classification Standard (GICS) first-level sectors are restricted to ±0.5% of the benchmark market-capitalization-weighted value. Portfolios must be long only. The maximum trade size is limited to 25% of a stock's average daily volume over the past 65 trading days (ADV). The maximum stock weight relative to

[2]For practical considerations on the sustainability metric, $\boldsymbol{\mu}_{SI}$, see Chen and Mussalli (2020).

[3]We additionally use the data simulation approach of Blitz and Hoogteijling (2022) to produce a longer history of carbon footprint data and SDG data. Note that any potential forward information leakage is of little concern because we are comparing two portfolio construction approaches using the same data. We aim to illustrate the broad application of our methodology on a representative set of sustainability data.

[4]For full details on the portfolio implementation, see Blitz et al. (2024).

[5]Prior to 2001, we use constituents of the FTSE Developed Markets index as a proxy for MSCI World constituents.

the benchmark (i.e., active weight) is ±0.5%. The maximum active share of the portfolio is 40%. The portfolio must be fully invested. We assume that the funds under management grow with the realized market return, and we design the simulations such that the final fund size at the end of 2022 is EUR4 billion. We incorporate a turnover penalty into the objective function, which is the sum of the squared absolute trade sizes.

As we target specific tracking errors, we transform the weight vector of Equation 2 from absolute asset weights to benchmark-relative weights:[6]

$$\mathbf{w}_{new} = \mathbf{w}_{p} - \mathbf{w}_{bm}.$$

Our portfolio optimization problem for a single time step is then given by

$$\max_{\mathbf{w}} \circ \lambda_1 \mathbf{w}'_{new}\boldsymbol{\mu} + \lambda_2 \mathbf{w}'_{new}\boldsymbol{\mu}_{SI} - \frac{\gamma}{2}\mathbf{w}'_{new}\sum \mathbf{w}_{new} - \kappa \left\| \mathbf{w}_{new} - \mathbf{w}_{old} \right\|, \quad (3)$$

where $\mathbf{w}_{old}$ represents the portfolio weights immediately before the rebalance, κ is a scaling parameter for the turnover penalty (we set $\kappa = 1$), and we incorporate the previously described constraints. We use a base set of portfolio construction constraints and settings across our simulations, and then we permute the expected return coefficient (λ_1), the risk aversion coefficient (γ), and the sustainability coefficient (λ_2) in each different optimization. Lastly, we introduce an additional optional constraint on either carbon footprint or SDG scores (e.g., the portfolio carbon footprint must be less than or equal to the benchmark carbon footprint.)

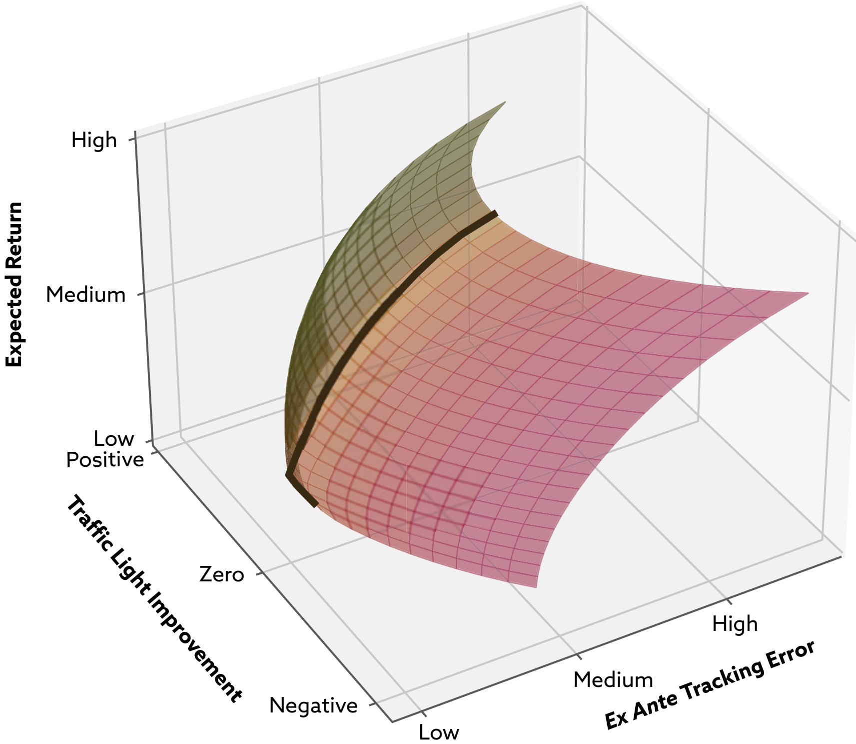
As inputs of expected returns μ, we use a simple equal-weighted multifactor score (denoted QMV) consisting of value, quality, and momentum signals. For value, we use an equal-weighted combination of book to price and 12-month forward earnings to price, ranked within GICS sectors. For quality, we use an equal-weighted combination of return on equity and debt to assets. For momentum, we use the previous 12-minus-1-month return. Each of the four underlying signals is first rank standardized between –1 and +1. The signals are then combined into a single multifactor score. We aim not to construct the best multifactor score but rather to construct a simplified score that represents common choices and implementations of multifactor investment strategies.

As for expected risk, we use a standard variance–covariance (VCV) matrix (Σ) that follows a latent factor model approach where we apply principal component analysis (PCA) with 20 components to the sample VCV matrix estimated using 60 months of daily return data. We use five-day overlapping returns to account for market asynchronicity (Burns, Engle, and Mezrich 1998).

Exhibit 1 shows the *ex ante* view of expected returns, *ex ante* tracking error, and CTL improvement over the benchmark as of December 2023. By mapping out a 3D surface of these elements, we can see how the objective of taking on more

[6]We use the same benchmark, the MSCI World, when constructing portfolios and evaluating financial and sustainability objectives.

Exhibit 1. Climate Traffic Light Efficient Surface

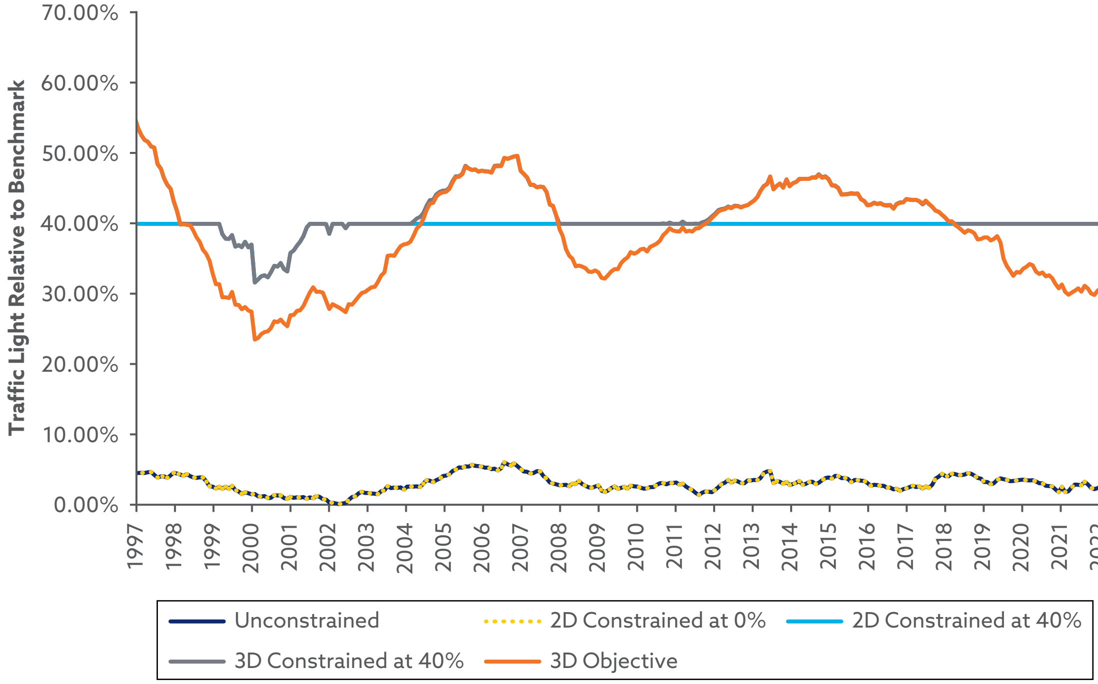


Note: This graph plots the *ex ante* expected return/tracking error/sustainability surface for Robeco's climate traffic light. The solid black line corresponds to the *ex ante* expected return/tracking error efficient frontier (i.e., the traditional case where only risk and return are considered). The surface is shaded based on the *y*-axis variable (climate traffic light relative to the benchmark), where green corresponds to a higher improvement and magenta corresponds to a lower improvement. This surface was calculated using data as of December 2023.

exposure to positive forward-looking climate stocks affects the risk and return characteristics of the optimal portfolios. In line with expectations, as the desire to integrate an alternative objective (which is not necessarily correlated with expected returns) into the portfolio increases, this integration requires either increasing tracking error or reducing expected returns.

Exhibit 2 compares the historical CTL profiles of portfolios constructed using different optimization approaches. It illustrates how the time-varying nature of a 3D investing approach can vary in comparison to a strict constraint. The dark blue line at the bottom represents an unconstrained portfolio that seeks to maximize expected excess returns without any consideration of CTL scores. This exposure is identical to the CTL improvement that is at least as good as the benchmark ("2D Constrained at 0%" yellow dotted line), suggesting that this constraint is not binding at any time. The "2D Constrained at 40%" bright blue line represents a portfolio that targets a minimum 40% CTL improvement relative to the benchmark at each rebalancing date, using a 2D optimization approach with a hard constraint on the minimum CTL score. The "3D Objective" orange line represents a CTL improvement using a 3D optimization approach. The "3D Constrained at 40%" gray line represents a portfolio that targets a minimum 40%

Exhibit 2. Climate Traffic Light Improvement to MSCI World under Various Optimization Scenarios



Note: This figure plots the percentage improvement of the portfolio's climate traffic light exposure over the MSCI World climate traffic light exposure using different 2D and 3D portfolio construction approaches. We report results for a portfolio with a tracking error target of 0.5%.

CTL improvement using a 3D optimization approach. This approach allows for a flexible trade-off between the competing objectives because the optimizer can choose to exceed the 40% minimum CTL improvement if doing so is expected to enhance returns or reduce risk. Further, in the 1999–2000 period, we can see what happens when a constraint cannot be satisfied. At this point, the "2D Constrained at 40%" bright blue line is unable to meet the 40% constraint and thus is forced to deviate to find a portfolio that satisfies this constraint.

These illustrative examples show how one can simply model the incorporation of an alternative objective into portfolio optimization. This outcome can be achieved by changing the expected return forecast for a stock or simply adding the term into the objective function with a prespecified parameter. As shown in Exhibit 2, both the 2D and 3D approaches that target a minimum 40% CTL improvement achieve this objective consistently over time. The 3D approach, however, exhibits greater variability in its CTL profile, occasionally exceeding the 40% minimum by a significant margin, because the 3D approach allows the optimizer to prioritize CTL improvement more heavily when it is expected to be beneficial from a risk-return perspective. The results presented in Exhibits 1 and 2 demonstrate the flexibility and effectiveness of the 3D investing framework in incorporating forward-looking climate metrics into the portfolio construction process.

It is important to note that the specific results presented here are based on a particular set of assumptions and data inputs and may not be representative of all scenarios. The appropriate trade-off between expected returns, risk, and climate alignment will depend on an investor's specific preferences, constraints, and investment horizon. Nevertheless, the 3D investing framework provides a useful tool for exploring these trade-offs in a systematic and transparent manner and can be adapted to incorporate a wide range of forward-looking climate metrics and optimization objectives.

Implications and Applications of 3D Investing for Net-Zero Portfolios

The CTL example is a simple application of the 3D investing framework of Blitz et al. (2024) but does not present anything new. Rather, it demonstrates how incorporating a simple forward-looking climate measure into the objective function is a trivial process, and the decision one must make concerns the relative risk–return cost of integrating this objective. Naturally, the question that someone using such a framework must answer is, What forward-looking climate measure do I want to target? This is a key challenge of the net-zero framework: The required forward-looking nature of both financing the transition and decarbonizing means that there is uncertainty around how to measure and model the required decarbonization pathway. Nevertheless, in this section, we elaborate on some of the implications of net zero for portfolio construction and present potential mechanisms for integrating net-zero goals into the portfolio construction problem.

Implications of Net Zero for Portfolio Construction

The transition to a net-zero economy has significant implications for portfolio construction because investors must navigate the complex trade-offs between achieving long-term climate goals and maintaining short-term financial performance. Traditional portfolio optimization frameworks, which focus solely on expected returns and risk, must be extended to handle the multi-objective nature of net-zero investing. One of the key challenges in constructing net-zero portfolios is balancing the need to reduce portfolio emissions in the short term with the objective of financing the transition to a low-carbon economy in the longer term. It requires investors to consider not only the current carbon footprint of their holdings but also the forward-looking emission trajectories and transition plans of the companies in which they invest.

The 3D investing framework provides a tool for navigating these trade-offs by allowing investors to explicitly incorporate both short-term emission reduction targets and long-term net-zero alignment objectives into the portfolio construction process. By including a term in the objective function that minimizes the portfolio's current carbon footprint, investors can ensure that their portfolios are aligned with the urgent need to reduce emissions in the near term. At the same time, by incorporating forward-looking metrics such as Implied Temperature Rise or transition readiness scores, investors can position their portfolios for the long-term transition to a net-zero economy. This forward-looking perspective is important for identifying companies that are well positioned to thrive in a low-carbon future and avoiding those with elevated risks of being left behind.

Another key implication of net-zero investing is the need to consider the real-world impact of portfolio allocation decisions. Although traditional portfolio optimization focuses solely on the financial outcomes for the investor, net-zero investing requires a broader perspective that considers the impact of investment decisions on the overall decarbonization of the economy. The 3D investing framework can accommodate this broader perspective by incorporating metrics that capture the alignment of portfolio companies with science-based emission reduction targets or the contribution of portfolio holdings to the financing of low-carbon solutions. By explicitly considering these real-world impact metrics alongside financial objectives, investors can ensure that their portfolios not only are aligned with net-zero goals but also support the transition to a low-carbon economy.

Constructing net-zero portfolios using a 3D investing framework presents some challenges, however. One key issue is the need to specify the relative weights of the various objectives in the optimization process, which can be a complex and subjective exercise. Investors must consider their own preferences and constraints when setting these weights, as well as the potential trade-offs between short-term and long-term objectives. Another challenge is the need for robust and reliable data on the emission trajectories and transition plans of portfolio companies. Although a growing number of companies are disclosing this information, the quality and comparability of these disclosures vary, making it difficult for investors to accurately assess the net-zero alignment of their portfolios. Naturally, any portfolio construction technique will grapple with similar challenges around data quality.

Despite these challenges, a 3D investing framework provides a valuable starting point for investors seeking to align their portfolios with net-zero objectives. By explicitly incorporating emission reduction targets and forward-looking transition metrics into the portfolio construction process, this approach enables investors to navigate the complex trade-offs between short-term and long-term objectives while also considering the real-world impact of their investment decisions. As the data and methodologies for net-zero investing continue to evolve, the 3D investing framework can serve as a foundation for further innovation and refinement in this critical area of sustainable finance. Although 3D investing provides a useful toolkit, investors face complex decisions around how to appropriately weight different objectives, which will require careful consideration of their specific constraints and objectives.

Incorporating Forward-Looking Net-Zero Metrics

Forward-looking metrics go beyond simple measures of current carbon footprint and aim to capture a company's alignment with future net-zero trajectories. By incorporating such forward-looking measures, investors can construct portfolios that may be better positioned for the transition to a low-carbon economy. The quality of the forward-looking measure and what it aims to capture specifically will influence the characteristics of any portfolio that integrates such a measure.

The climate traffic light we discussed is one example of a forward-looking climate metric. Investors may have a preference for other metrics, however, and our proposed framework accommodates any ordinal measure. The following are other examples of forward-looking net-zero metrics that could be integrated into a 3D investing framework:

- **Implied Temperature Rise:** This metric estimates the global temperature rise associated with a company's emission trajectory, providing an indication of its alignment with the Paris Agreement goals. A company with an Implied Temperature Rise below 2°C would be considered aligned with net-zero objectives.
- **Science Based Targets initiative (SBTi) portfolio coverage:** This metric estimates the percentage of a portfolio's holdings that have set emission reduction targets validated by the SBTi as consistent with the Paris Agreement goals.
- **Transition readiness scores:** These scores assess a company's preparedness for the low-carbon transition based on such factors as its decarbonization strategy, capital allocation plans, and climate governance. Higher scores indicate better positioning for the net-zero transition.

To incorporate these metrics into a 3D investing framework, an investor could modify the objective function in Equation 2 as follows:

$$\lambda_1 \mathbf{w}'\boldsymbol{\mu} + \lambda_2 \mathbf{w}'\boldsymbol{\mu}_{ITR} + \lambda_3 \mathbf{w}'\boldsymbol{\mu}_{SBTi} + \lambda_4 \mathbf{w}'\boldsymbol{\mu}_{CTL} - \frac{\gamma}{2}\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w},$$

where $\boldsymbol{\mu}_{ITR}$, $\boldsymbol{\mu}_{SBTi}$, and $\boldsymbol{\mu}_{CTL}$ are vectors of the chosen forward-looking net-zero metrics for each asset. The λ_i parameters control the relative importance of each forward-looking metric alongside expected returns ($\boldsymbol{\mu}$) and risk (Σ) in the optimization process. The choice of values for the λ_i parameters will depend on an investor's specific net-zero goals and risk–return preferences. One approach could be to set these weights based on each metric's perceived importance and potential financial materiality. Alternatively, investors could use optimization techniques to identify the combination of weights that best aligns with their overall objectives, subject to tracking error and other constraints. As with any optimization input, sensitivity analysis will be important to understanding the impact of these choices.

By incorporating forward-looking net-zero metrics in this way, the 3D investing framework allows investors to construct portfolios that are not only aligned with current carbon reduction goals but also positioned for the long-term transition to net zero. This forward-looking perspective is crucial for investors seeking to manage the risks and opportunities associated with the low-carbon transition while still achieving their financial objectives.

Implementing Net-Zero Pathways

The 3D investing framework can also be used to construct portfolios that align with specific net-zero emission pathways or glidepaths over time. For instance, an investor could modify Equation 2 to include an additional constraint: $E_{actual}(t) \leq E_{target}(t)$, where $E_{actual}(t)$ is the portfolio emissions at time t and $E_{target}(t)$ is the target emissions level at time t prescribed by a net-zero pathway. The 3D optimization would then produce the portfolio that maximizes alpha and sustainability objectives and minimizes risk while also satisfying the net-zero glide path constraint. This approach ensures alignment with a long-term net-zero trajectory while allowing time-varying exposures based on expected returns and sustainability characteristics. Such a constraint could also trivially be added to any portfolio optimization problem and is not unique to a multi-objective framework.

Bolton et al. (2022) demonstrate how it is possible to achieve a net-zero portfolio that tracks major indexes[7] with limited tracking error, even if the underlying reference benchmark's carbon emission stays at the 2020 level. The authors did not consider the potential for alpha generation in such a portfolio. We use their portfolio construction as a starting point but now consider how one may incorporate alpha considerations in such a portfolio.

Following Bolton et al. (2022), we consider the total cumulative carbon budget of 268.5 gigatons (Gt) of carbon dioxide (CO_2) as of 2021 to meet the 1.5°C target by 2050. With this starting point of total emission, different pathways to the 1.5°C target exist, dependent on both the start date and level of decarbonization.[8] Regardless of the pathway chosen, we define the following:

- The net-zero investor's chosen target pathway portfolio emission at year t is $E_{target}(t)$.
- The actual portfolio emission at year t is $E_{actual}(t)$.
- The cumulative target pathway emission as of year t is $C_{target}(t) = \sum_{i=0}^{t} E_{target}(i)$.
- The cumulative actual emission as of year t is $C_{actual}(t) = \sum_{i=0}^{t} E_{actual}(i)$.

[7]Bolton et al. (2022) considered the MSCI All Country World, MSCI Europe, and MSCI Emerging Markets indexes.

[8]Bolton et al. (2022) explicitly state "starting in 2021, with a geometrical rate of emission reduction, the path can be either an immediate 25% reduction in carbon footprint, followed by an 85% decrease, or a constant annual 10% reduction. With a linear rate, the pathway can be either a 25% initial reduction, followed by an annual 3.2% reduction, or a constant annual 4.6% reduction. All these paths are structured so that the entire carbon budget of 268.5 Gt CO_2 is spent."

The problem of jointly optimizing alpha and risk and satisfying a net-zero path becomes

$$\begin{aligned}&\max_{\mathbf{w}}\ \lambda\mathbf{w}'\boldsymbol{\mu}+(1-\lambda)E_{actual}^{-1}(t)-\frac{\gamma}{2}\mathbf{w}'\boldsymbol{\Sigma}\mathbf{w},\\&\text{s.t. } \mathbf{w}'\mathbf{e}=1, \mathbf{w}\in\Omega, C_{actual}(t)\le C_{target}(t).\end{aligned} \tag{4}$$

The objective function in Equation 4 is set up to jointly optimize alpha, risk, and actual annual carbon emission. The objective function will aim to minimize the actual carbon emission, but it is allowed to go *above* the target pathway emission, $E_{target}(t)$, if doing so will yield more attractive expected return or risk profiles. At the same time, the cumulative actual emission, $C_{actual}(t)$, is constrained to stay below the target pathway emission, $C_{target}(t)$, at each point in time. That is to say, the optimization problem will allow the actual annual emission to go above the target pathway annual emission only if there have been excess emissions "saved up" in previous years. We know that there is a temporal dimension to the impact of emissions on climate change (see Daniel et al. 2019; Fearnside et al. 2000). A ton of CO_2 does more damage to climate if released into the atmosphere now compared with the same ton of CO_2 released into the atmosphere later, all else equal. This means that with the constraint $C_{actual}(t) \le C_{target}(t)$, the optimized portfolio will strictly follow a net-zero path presented in Bolton et al. (2022) while jointly optimizing the immediate alpha, risk, and emissions considerations.

This formulation also has some limitations. One key drawback is that it requires specifying the net-zero pathway, $C_{target}(t)$, *ex ante*, which may not be optimal if new information emerges over time that suggests a different pathway would be more appropriate. Additionally, the use of a hard cumulative emission constraint may lead to suboptimal portfolios in some cases because it does not allow for any trade-off between emissions and other objectives once the constraint is binding. Thus, there is an element of path dependency, which any portfolio construction approach targeting a pathway will be exposed to. It is important to understand the implications of such constraints on the risk and return objectives.

To address these limitations, investors could consider several extensions to the formulation in Equation 4. For example, the cumulative emission constraint could be complemented with a penalty term in the objective function that imposes a cost on deviations from the target pathway. This situation could allow for a more flexible trade-off between current emissions, cumulative emissions, and other objectives while still ensuring alignment with the net-zero pathway.

It is important to note that the emission pathway constraint in Equation 4 operates independently of any other sustainability metrics in the objective function. In some cases, these objectives may be in tension—for example, favoring companies with strong transition plans could lead to short-term deviations from the desired pathway. Investors will need to carefully balance these considerations and may wish to fine-tune the relative weights in the objective function over time as new information becomes available. The 3D framework provides the flexibility to explore this balance, but the onus remains on investors to define their priorities and manage these trade-offs.

Finally, although a 3D investing framework provides a conceptual toolkit for navigating the complexities of net-zero portfolio construction, its practical implementation (and that of any portfolio construction approach) depends on the availability of high-quality, consistent, and comprehensive data. Investors seeking to incorporate forward-looking metrics such as Implied Temperature Rise, science-based targets, and transition readiness into their portfolio optimization face continuing data challenges. Many companies still do not disclose their full Scope 1, 2, and 3 emissions, let alone more granular information on their decarbonization strategies and capital allocation plans. Even among firms that do report this information, many methodologies and metrics lack standardization, making comparisons difficult. Moreover, the reliability of self-reported data can be questionable, highlighting the need for more robust auditing and verification processes. An important area is the continued development of comprehensive, standardized, and reliable datasets on corporate climate performance and risk management. Progress on this front will require a concerted effort from regulators, standard setters, investors, and companies to improve the quality and comparability of climate-related disclosures.

Conclusion

As the world grapples with the urgent need to decarbonize the global economy and achieve net-zero emissions by 2050, investors face the challenge of how to construct portfolios that align with these ambitious climate goals while still delivering on risk and return objectives. This chapter explores the value of the 3D investing framework as a tool for constructing net-zero-aligned portfolios. By explicitly incorporating sustainability metrics into the portfolio optimization objective function, 3D investing allows for dynamic trade-offs between expected returns, risk, and climate outcomes based on an investor's unique preferences and constraints. We show how the framework can be extended to incorporate forward-looking climate metrics and emission pathway constraints, enabling investors to pursue short-term decarbonization while preserving long-term alignment with net-zero targets. We also acknowledge, however, the inherent tensions in net-zero investing, such as balancing short-term performance with long-term climate goals, and the need for investor discretion in navigating these trade-offs.

Our analysis provides insights into applications of portfolio construction paradigms, but we recognize several limitations and areas for future research. A 3D net-zero investing framework must assume a forward-looking climate metric that captures the nuances of companies' decarbonization trajectories and potential contributions to real-world emission reductions. Future work could also explore how 3D investing could be adapted to optimize for climate impact beyond individual portfolio alignment, although quantifying this impact remains challenging.

Ultimately, translating these research insights into implementable net-zero investment solutions will require close collaboration between academics and practitioners. As climate goals evolve and data availability improves over time, investors will need to continually adapt and refine their approaches to net-zero portfolio construction. A 3D investing framework provides a framework for this ongoing innovation, offering the flexibility and rigor needed to face the challenge of aligning investment portfolios with the net-zero future.

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CARBON EMISSIONS, NET-ZERO TRANSITION, AND IMPLICATIONS FOR EQUITY PORTFOLIO RISK

Gregoire Campos
Portfolio Analyst, Systematic Core Equity, Allspring Global Investments, Charlotte, North Carolina

Harindra de Silva, CFA
Senior Portfolio Manager, Co-Head of Alternative Equity, Allspring Global Investments, Los Angeles

Megan Miller, CFA
Senior Portfolio Manager, Head of Options Solutions, Allspring Global Investments, San Francisco

We quantify the relationship between a company's carbon emissions footprint, its transition to net zero, and the expected distribution of its future stock returns as reflected in listed option prices. Option prices on high carbon emitters reflect their differential risk profile as measured by industry-relative carbon intensity. The strength of the relationship between option-implied risk and emissions changed after the 2016 adoption of the Paris Agreement. The relationship is weaker for companies that have committed to 2°C alignment goals. The undiversifiable nature of this risk is evident in the behavior of equity portfolios with high relative exposure to carbon emissions. Using a factor-based framework, we quantify the bias in the risk forecasts associated with reported carbon emissions exposure. Investors can use this framework to both measure and manage carbon emissions–related risk.

Climate change will affect every industry, region, and company in the global financial sector. In assessing this impact and the associated risk to companies, it is essential to recognize the differing implications based on whether the risk is associated with changes in physical conditions or modifications related to transitioning economies.

As climate change leads to more severe weather events, such as flooding, droughts, and storms, the physical conditions under which companies operate will inevitably change. This physical risk and associated changes will not be homogeneous across regions and industries, and companies will be affected regardless of their contribution to climate change or individual carbon emissions footprint. For example, even a company in an industry with minimal emissions will be affected by physical threats based on its geographical location.

Transition risk is separate and distinct from physical risk. It refers to the consequences businesses and investors face as countries accelerate the adoption and implementation of policies to cut carbon emissions. A company's emissions footprint relates directly to its exposure to this transition risk, with the expectation that those companies with higher emissions have higher exposure to this type of risk. While climate mitigation policies will asymmetrically affect companies based on their operating region or industry, a company's emission profile will determine whether it might benefit or suffer potential losses from the policies.

The public and private pledges to reduce emissions already require drastic cuts in corporate emissions. Henceforth, companies with higher emissions face increased scrutiny, leading to potential reputational risk. Furthermore, the Climate Change 2023 Synthesis Report (IPCC 2023) affirmed that the "current mitigation and adaptation actions and policies are not sufficient" (p. 57) To inflect emissions, public administrations have been tightening regulations. In the EU, for instance, the European Green Deal created an emissions trading system, carbon pricing on imported goods, and captured carbon through carbon sinks, amongst other elements. In this constantly evolving environment, business models relying on carbon emissions are at risk. But are investors considering this risk in their decisions? In other words, are financial markets pricing carbon risk?

We attempt to shed light on this question by evaluating the impact of emissions intensity on security prices in options and equity markets. The risk-based approach used in this chapter is designed to provide practitioners with a framework to evaluate the potential impact of emissions on the investment risk, at both the security and the portfolio level. Following a summary of prior relevant research, we document the extent to which a company's emissions intensity affects its future distribution of returns as predicted by options markets. We then evaluate how emissions intensity affects portfolio risk by quantifying the bias in the portfolio risk forecasts associated with systematic carbon emissions exposure.

Prior Research and Motivation

Research on the impact of emissions on financial markets falls into at least three broad categories. The first includes studies that attempt to measure the presence of a carbon-related risk premium (Bolton and Kacperczyk 2021). Risk premia are ideally estimated over a long period with accurate data on the underlying factor. Given the limited data availability and time period of carbon-related data, however, as well as the rapidly changing dynamics of emissions-related regulation, the results of these studies are questionable. Furthermore, the way transition risk is incorporated into asset prices has distinct phases. Changes in regulation imply the existence of a transition stage, during which prices of assets with low emissions are bid up while prices of assets with high emissions are bid down, in response to changing investor beliefs. The different repricing phases are difficult to identify empirically because individual asset prices may transition at various times and different speeds. In addition, allocating credits to higher-emitting companies in certain countries can result in windfall economic gains and abnormal stock returns. Oestreich and Tsiakas (2015) document the abnormally higher returns of companies that received free carbon emission allowances. Despite these challenges, these studies support the idea that carbon emissions provide power in explaining the cross section of stock returns and motivate emissions as a risk factor in both portfolio construction and performance measurement.

The second strand of research relates to the quality of the carbon-related data and measurement issues. Aswani, Raghunandan, and Rajgopal (2024) argue that reliance on estimates of carbon emissions (in this case, data from Trucost) instead of the actual emissions disclosed by the companies themselves causes the performance differential between high and low emitters. When they narrowed their sample to US companies that disclosed their emissions between 2005 and 2019, Aswani et al. found no relation between actual emissions and stock returns, concluding that the documented "carbon premium" must be driven by biases in the estimates. The second criticism the authors raised is the possibility of a critical missing variable—namely, a potential link amongst high emissions, high productivity, and stock returns that, to the extent it could be demonstrated, would be misconstrued as evidence of a carbon risk premium. This raises the question of whether high carbon emitters' high stock returns simply reflect these companies' greater economic activity and operating efficiency instead of a carbon risk premium. Another aspect of the missing variable critique is the correlation between emissions and other systematic drivers of risk and return. For example, Ardia, Bluteau, Lortie-Cloutier, and Tran (2023) document this systematic difference in factor exposure between high and low emitters. Ardia et al. find a statistically meaningful difference in value and momentum exposure in portfolios formed based on greenhouse gas emissions. In this chapter, we explicitly control for a wide array of such measures so that the impact of emissions intensity can be isolated.

The third strand of research focuses on the relationship between climate-related policy uncertainty and the option prices on issuers' equity securities. These studies, such as Ilhan, Sautner, and Vilkov (2021), have primarily focused on a limited universe of stocks or sectors to demonstrate that prices of short-term (i.e., one-month) options reflect the elevated risk associated with higher-emitting industries or sectors. These studies have not explicitly focused on company-related intensity, so they offer limited insight to practitioners looking to make company-specific investment decisions or seeking to identify opportunities in a particular industry.

This chapter contributes to this existing literature on two dimensions. First, we focus on the risk associated with emissions, similar to the consideration of common risk factors such as momentum, growth, and earnings quality. Focusing on the risk dimension allows investors to quantify the impact of emissions on their risk assessment of a single company and portfolio. Given our focus on the risk implication, we define a company's carbon intensity as the ratio of Scope 1 and 2 emissions to total revenue. Because companies with higher carbon-intensive revenues will likely face more exposure to carbon-related market and regulatory risk, this metric can proxy for a portfolio's exposure to potential climate change–related risks relative to other portfolios or a benchmark. This measure is also applicable across asset classes, and it is a simple and intuitive measure of the emission intensity of a security or portfolio.

Carbon intensity, as we define it, does not use company market capitalization or the size of the investor's position relative to the market, and therefore, it does not capture any measure of investor responsibility. Our measure of carbon intensity is especially relevant for an investor looking to manage the risk implications of emissions in investment portfolios rather than taking an activist position with respect to the emissions of their investment. Thus, the decision to accept positive or negative exposure to this risk factor will be based on the investor's view—whether that investor believes in a carbon risk premium or believes that the market has underestimated the risk associated with higher emissions. The higher the emission-related risk, the greater the necessity to actively measure and manage this risk exposure.

The second dimension this chapter contributes to existing literature is the focus on the incremental risk of carbon emissions in the context of other common risk factors used by financial practitioners to quantify the risk exposures. Most institutional investors in equity markets use a factor-based risk model, and we explicitly measure the incremental impact of increased carbon exposure in such a risk model. If traditional risk factors adequately capture the impact of emissions on portfolio risk, investors do not need to explicitly measure and monitor emissions-related exposure. In contrast, if emissions-related exposure is incremental to risk as measured using traditional risk models, investors could gain a clear benefit to managing this risk exposure.

In this chapter, we evaluate the impact of emissions on the risk profile of individual securities using data from options markets. Options data provide a unique perspective to measure investor expectations of the future risk of higher emitters and quantify how that risk has changed over time.

The adoption of the Paris Agreement, a legally binding international treaty on climate change, presents an opportunity to measure the change in investor expectations associated with the economic costs of carbon emissions. Adopted by 195 parties at the UN Climate Change Conference (COP21) in Paris, France on 12 December 2015, the treaty took effect on 4 November 2016. This change in the regulatory environment likely impacted the perceived operating risk faced by high emitters, and as such, one would expect a shift in their perceived risk profile.

Adopting the treaty also raised awareness amongst investors about the potential risks associated with high carbon emissions. Although others have documented the impact at an industry or regional level (see Ilhan, Sautner, and Vilkov 2021), to date there have been no studies on the impact at a company-specific level. We supplement our analysis by evaluating the effects of a company's committed climate transition pathway on the relationship between options prices and emissions.

Having demonstrated that carbon is priced at the individual security level, we evaluate whether this risk can be diversified away in a portfolio context. To the extent that carbon risk is idiosyncratic to a company's business strategy and geographical operating footprint, this risk may not be material in a portfolio context. By building portfolios with companies that have explicit exposure to carbon intensity but are neutral to other risk factors, we demonstrate that these portfolios have systematically higher risk than expected.

Data Description

The data used in this chapter represent a combination of carbon data and financial data. The carbon intensity data for individual companies are drawn from Trucost. The financial data are drawn from Barra's Global Total Market Equity Model for Long-Term Investors (GEMLT). Our study is based exclusively on data from companies listed on US exchanges.

The choice of Trucost as the source of carbon emissions and net-zero emission commitments was based on our desire to use a sole source with the most extensive coverage. The data reflect a combination of the actual company-reported data and estimated data from a broad universe of companies. This approach allows us to use the most extensive universe to measure the impact of emissions on risk and evaluate the effect of the combination of Scope 1 and 2 emissions.[1] The data are produced annually, and we used the reported carbon measure for all the months of the corresponding year in our analysis.

We calculate carbon intensity for each company using the ratio of emissions to revenues at each point in time. This metric is one of the more commonly used measures of carbon intensity because it scales a company's emissions by a measure of its contemporaneous output and is also the recommended metric of the Task Force on Climate-related Financial Disclosures (TCFD 2021). Both revenues and emissions have high levels of autocorrelation, so the lag associated with reporting carbon data does not significantly impact the calculated intensity measure. This measure is also widely used as a statistic to estimate the carbon intensity of a portfolio, computed as a portfolio's weighted average carbon intensity (WACI). Because of the focus on revenues, as opposed to market capitalization, we can use this measure to estimate the carbon intensity of both equity and fixed-income portfolios.

Carbon intensity data measured using this metric are susceptible to outliers for companies with little to no revenue, so we make standard adjustments to ease interpretation of results. For example, our carbon intensity measure is Winsorized to the 5th and 95th percentiles and standardized every month.

[1]Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy.

Exhibit 1. Selected Industry-Level Carbon Intensities

Industry	Industry Average	Residuals Average	Residuals Std. Dev.	10%	25%	50%	75%	90%
Thrifts	−1.69	−0.10	0.57	−0.72	−0.48	−0.18	0.30	0.61
Insurance	−1.40	−0.06	0.45	−0.59	−0.37	−0.10	0.21	0.51
Regional banks	−1.35	−0.06	0.47	−0.56	−0.36	−0.11	0.15	0.54
Capital markets	−0.87	−0.08	0.49	−0.74	−0.36	−0.04	0.25	0.46
Diversified financials	−0.68	−0.07	0.47	−0.56	−0.32	−0.03	0.19	0.45
Oil exploration	1.29	0.06	0.48	−0.42	−0.20	0.04	0.36	0.67
Utility	1.35	0.03	0.67	−0.79	−0.38	0.16	0.44	0.74
Oil and gas	1.38	0.06	0.79	−0.81	−0.48	0.13	0.64	1.00
Airlines	1.51	0.17	0.61	−0.64	−0.29	0.21	0.55	0.87
Diversified metals	1.51	0.23	0.61	−0.45	−0.23	0.27	0.63	1.06

To control for the impact of industries on carbon intensity, we estimate a residual carbon intensity metric by adjusting each stock's carbon intensity for the average intensity in its industry.[2] As shown in **Exhibit 1**, the average intensity of industries differs widely, so it is impossible to appropriately compare a company's emissions intensity absent such an adjustment. In this framework, a company is a low emitter only if it has low emissions relative to others in its industry peer group. We define the residual measure as company-specific carbon intensity (CSCI) to reflect a company's carbon intensity relative to others in its industry grouping at each point in time. Because of the industry-relative comparison, the emissions footprint of those companies in high-emission industries can be compared with those in low-emission industries.

The CSCI framework also acknowledges the fact that production process and production inputs per dollar revenue differ across industries. Because the adjustment is industry relative, however, we assume the processes are similar across industry. Therefore, if two companies in the same industry have the same revenue, the one with the more significant carbon emissions will have the higher intensity.

Exhibit 2 illustrates CSCI for companies in the energy equipment and services industry and the diversified financials industry. Each company's industry membership is based on its risk model exposure. In the GEMLT framework, industry exposure is not constrained to be a binary indicator variable.

[2]Specifically, intensity is the residual from a regression model where the dependent variables represent each company's industry exposure. Industries are based on Barra's GEMLT industries, and companies are permitted to have exposure to more than one industry. For robustness, we replicated the analysis presented in this chapter using simple indicator variables for industry exposures with substantially similar results.

Exhibit 2. Industry Carbon Intensity and CSCI, Focus on Energy and Diversified Financials

Rank, Industry	Company	Company Carbon Intensity	Industry Carbon Intensity	GEMLT Industry Exposure	CSCI
Bottom 5, Energy Equipment & Services	KLX Energy Services Holdings, Inc.	0.08	0.72	1.50	−1.01
	Expro Group Holdings N.V.	−0.09	0.72	1.23	−0.98
	RPC, Inc.	0.05	0.72	1.35	−0.92
	Oceaneering International, Inc.	0.22	0.72	1.46	−0.83
	Newpark Resources, Inc.	0.02	0.72	1.15	−0.81
Bottom 5, Diversified Financials	Payoneer Global Inc.	−2.19	−0.71	1.04	−1.44
	PagSeguro Digital Ltd. Class A	−2.26	−0.71	1.20	−1.40
	Block, Inc. Class A	−2.07	−0.71	1.54	−0.97
	Visa Inc. Class A	−1.35	−0.71	0.66	−0.88
	Mastercard Incorporated Class A	−1.28	−0.71	0.65	−0.82
Top 5, Diversified Financials	Acacia Research Corporation	0.08	−0.71	0.56	0.48
	Toast, Inc. Class A	−0.53	−0.71	1.44	0.51
	Upstart Holdings, Inc.	−0.56	−0.71	1.61	0.59
	OneMain Holdings, Inc.	−0.74	−0.71	1.88	0.60
	Affirm Holdings, Inc. Class A	−0.53	−0.71	1.85	0.79
Top 5, Energy Equipment & Services	Helmerich & Payne, Inc.	1.88	0.72	1.17	1.03
	Noble Corporation PLC Class A	2.02	0.72	0.93	1.34
	Tidewater Inc.	2.40	0.72	1.30	1.46
	SEACOR Marine Holdings Inc.	2.33	0.72	0.97	1.63
	Bristow Group Inc.	2.32	0.72	0.77	1.77

As expected, the carbon intensity of the energy equipment and services industry is positive, whereas that of the diversified financials industry is negative by a similar magnitude. After accounting for industries, however, the CSCI measure is comparable for the top and bottom five emitters across these two industries. As illustrated with the two industries in Exhibit 2, this adjustment makes it possible to compare the emissions footprint of companies across industries.

In **Exhibit 3**, we show the distribution of the CSCI measure over time. The distribution is stable and consistent with standardizing the exposure to make it comparable across periods. The standard deviation is also stable because of the Winsorization process used to manage carbon intensity outliers. Note that the distribution, although stable over time, is not symmetric. Even on an industry-adjusted basis, a few companies are enormous emitters.

Data on options are from OptionMetrics' IvyDB US database. All analyses related to options are based only on equity securities in the US market because of data availability. We estimate the option implied volatility skew as the difference between an out-of-money option (defined by having a delta of 0.10) and a near-the-money option (defined by having a delta of 0.50). Using both calls and puts allows us to evaluate risk on an asymmetric basis and differentiate between the forecasted risk associated with left skew using put options and right skew using call options. We consider both options with 30 days to maturity (one month) and options with 365 days to maturity (one year).

In **Exhibit 4**, we summarize data related to the option skew. The table shows the distribution of the four measures of volatility skew computed from the underlying option prices. As has been well documented for equity options, the average values of implied volatility are higher for the left skew than for

Exhibit 3. Standard Deviation of CSCI

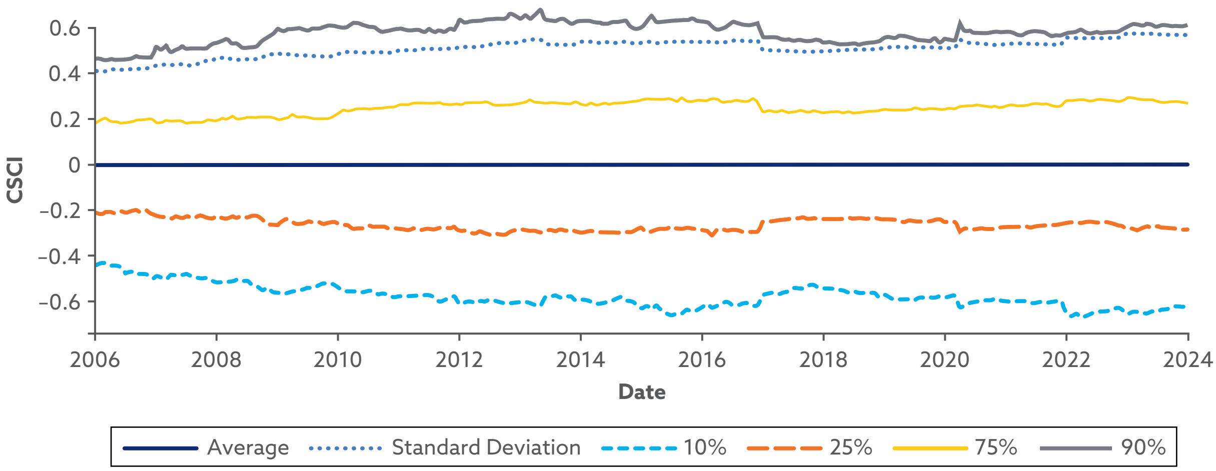


Exhibit 4. Summary Statistics for Option Skew

Implied Volatility Skew						
	No. of Obs.	Average	Std. Dev.	0.25	0.5	0.75
365 days left skew	300,952	0.14	0.17	0.07	0.10	0.16
30 days left skew	300,952	0.33	0.41	0.10	0.20	0.42
30 days right skew	300,952	0.13	0.32	0.01	0.08	0.22
365 days right skew	300,952	0.00	0.09	−0.03	−0.01	0.02
Standardized Scores						
	No. of Obs.	Average	Std. Dev.	25%	50%	75%
365 days left skew	300,951	−0.00	1.00	−0.67	−0.24	0.61
30 days left skew	300,951	−0.00	1.00	−0.76	−0.29	0.62
30 days right skew	300,951	0.00	1.00	−0.73	−0.25	0.62
365 days right skew	300,951	0.00	1.00	−0.65	−0.21	0.60

the right skew. We then standardized the skew to have a mean of zero and a standard deviation of 1 before inputting into the following regression analysis.[3] The summary statistics for the standardized data are shown in the lower half of Exhibit 4. Standardizing the skew makes it appropriate to compare the economic importance of regression statistics across different skew measures.

Exhibit 5 summarizes the financial data used in this chapter. Also shown are the factors used to control for systematic factor-related risk. We selected these factors, sourced from Barra's GEMLT for the universe of securities used in the study,[4] because of their widespread use in the risk measurement of equity portfolios. These risk factor exposures are associated with the specific date they each became available. This approach allows us to avoid the perennial look-ahead bias associated with financial data. Because global accounting reports follow different periodicity, we can use the contemporaneous exposure available for each security without imposing an arbitrary fixed period to account for reporting-related lags. We standardized all factor data by period so that the coefficient estimates directly reflect the economic significance of each variable.

[3]The use of standardized dependent variables is particularly important because we are pooling data from different time periods in our analysis, with the underlying assumption that the variance of the error term is constant over time.

[4]Although these factors are specific to the Barra GEMLT, most commercial risk models used by practitioners incorporate similar factors. The use of these factors and the accompanying risk forecast should be viewed as neither endorsement nor criticism of this particular risk model.

Exhibit 5. Summary Statistics for Financial Factors and CSCI

	No. of Obs.	Average	Std. Dev.	25%	50%	75%
CSCI	300,951	−0.00	0.52	−0.26	0.01	0.25
Beta	300,951	0.00	1.00	−0.71	−0.06	0.65
Book-to-price ratio	300,951	−0.00	1.00	−0.76	−0.21	0.60
Dividend yield	300,951	−0.00	1.00	−0.91	−0.27	0.97
Earnings quality	300,951	0.00	1.00	−0.67	−0.10	0.58
Earnings variability	300,951	0.00	1.00	−0.80	−0.26	0.62
Earnings yield	300,951	0.00	1.00	−0.52	0.05	0.60
Growth	300,951	−0.00	1.00	−0.57	−0.03	0.54
Investment quality	300,951	−0.00	1.00	−0.57	0.19	0.68
Leverage	300,951	0.00	1.00	−0.79	−0.12	0.67
Liquidity	300,951	−0.00	1.00	−0.64	−0.04	0.62
Long-term reversal	300,951	0.00	1.00	−0.62	−0.04	0.59
Mid cap	300,951	0.00	1.00	−0.98	0.38	0.89
Momentum	300,951	−0.00	1.00	−0.59	0.06	0.64
Profitability	300,951	−0.00	1.00	−0.68	−0.11	0.62
Residual volatility	300,951	0.00	1.00	−0.75	−0.19	0.59
Size	300,951	0.00	1.00	−0.72	−0.08	0.64

The scope of this chapter is to quantify the impact of carbon emissions on risk, so we decided to be overly broad in the variable selection process. The variables used, listed in Exhibit 5, reflect a combination of risk-related variables, valuation factors, profitability factors, and technical (i.e., historical return) factors.[5] From an econometric standpoint, this approach reflects the decision to potentially overspecify the model instead of being susceptible to an omitted variable bias. The potential overspecification can reduce the statistical power of the tests.

Finally, **Exhibit 6** shows the correlation between the financial risk measures and the CSCI measure. In general, the CSCI variable has a low correlation with economic variables. The low correlation indicates that other variables cannot be used as proxies to capture carbon-related effects.

[5]This list reflects the complete list of risk factors used in the Barra GEMLT risk model.

Exhibit 6. Correlation of CSCI and Financial Variables

	CSCI
Beta	−0.11
Book-to-price ratio	0.07
Dividend yield	0.13
Earnings quality	0.11
Earnings variability	0.01
Earnings yield	0.03
Growth	−0.10
Investment quality	0.04
Leverage	0.13
Liquidity	−0.01
Long-term reversal	0.01
Mid cap	0.07
Momentum	0.02
Profitability	−0.08
Residual volatility	−0.04
Size	0.07

Methodology and Results

We separately examined carbon intensity as a risk factor in the options market and the equity market.

Carbon Pricing in the Options Market

We evaluate the relationship between the carbon intensity measure and option skew in terms of left skew and right skew for both one-month and one-year options. We examined this separately before and after the implementation of the Paris Agreement in November 2016. The pre-2016 period uses data from February 2006 to November 2016, and the post-2016 period reflects the data through January 2024. **Exhibit 7** summarizes the regression results for the four option skew metrics.

The results represent a pooled regression using each month's CSCI variable, financial variables, and fixed effects for each month. The left skew measurement pre- and post-2016 have similar explanatory power, with *R*-squares of 0.23 for

Exhibit 7. Impact of Emissions on Option Skew

	Left Skew: 365 days				Left Skew: 30 days				Right Skew: 30 days				Right Skew: 365 days			
	Pre-2016		Post-2016		Pre-2016		Post-2016		Pre-2016		Post-2016		Pre-2016		Post-2016	
CSCI	−0.04**	*−6.59*	0.00	*1.06*	−0.02**	*−4.14*	0.02**	*4.13*	−0.02**	*−4.16*	0.01	*1.83*	−0.03**	*−5.21*	−0.01**	*−2.43*
Beta	0.13**	*36.36*	0.02**	*9.34*	0.03**	*9.62*	−0.00	*−0.62*	−0.13**	*−39.47*	−0.02**	*−8.87*	−0.23**	*−65.86*	−0.11**	*−45.66*
Book-to-price ratio	0.09**	*19.18*	0.10**	*36.19*	0.08**	*18.04*	0.07**	*25.13*	0.04**	*9.07*	0.08**	*26.37*	0.01	*1.40*	0.07**	*24.83*
Dividend yield	0.05**	*12.78*	0.07**	*26.41*	0.07**	*20.89*	0.04**	*17.63*	0.07**	*22.65*	0.04**	*17.20*	0.09**	*24.78*	0.08**	*32.19*
Earnings quality	−0.03**	*−9.70*	0.01**	*4.06*	−0.01**	*−4.56*	0.01**	*3.38*	0.02**	*8.33*	0.02**	*8.07*	0.03**	*9.57*	0.00	*0.14*
Earnings variability	0.08**	*20.76*	0.04**	*13.80*	0.07**	*18.85*	0.06**	*20.85*	0.12**	*31.15*	0.03**	*10.42*	0.06**	*16.04*	0.03**	*9.86*
Earnings yield	−0.07**	*−20.54*	−0.02**	*−5.43*	−0.08**	*−22.90*	−0.01**	*−5.24*	−0.02**	*−6.37*	0.00	*0.91*	−0.01**	*−2.92*	−0.04**	*−14.06*
Growth	−0.03**	*−6.84*	−0.00	*−1.76*	−0.03**	*−8.09*	−0.01**	*−5.18*	−0.03**	*−7.68*	−0.00	*−0.60*	−0.04**	*−10.95*	0.00	*0.70*
Investment quality	0.04**	*13.01*	−0.04**	*−14.50*	0.04**	*11.90*	−0.05**	*−22.08*	0.01**	*2.76*	−0.03**	*−11.31*	−0.02**	*−6.10*	−0.05**	*−19.54*
Leverage	0.07**	*22.91*	0.08**	*34.12*	0.03**	*9.07*	0.06**	*25.11*	0.01**	*3.59*	0.05**	*20.17*	−0.01**	*−4.81*	0.02**	*8.61*
Liquidity	0.03**	*9.17*	−0.09**	*−39.80*	−0.14**	*−42.26*	−0.09**	*−38.11*	−0.16**	*−50.89*	−0.07**	*−29.05*	−0.20**	*−59.58*	−0.10**	*−40.86*
Long-term reversal	0.08**	*23.24*	0.03**	*14.18*	0.08**	*27.13*	0.04**	*18.29*	0.05**	*17.48*	−0.00	*−1.23*	−0.02**	*−5.91*	0.01**	*2.97*
Mid cap	−0.03**	*−8.26*	−0.11**	*−32.00*	0.03**	*9.07*	−0.11**	*−32.55*	0.01**	*2.43*	−0.07**	*−20.29*	−0.01**	*−3.90*	−0.01	*−1.55*
Momentum	0.01**	*3.18*	0.05**	*20.02*	−0.01**	*−3.97*	0.04**	*17.83*	−0.19**	*−62.09*	−0.09**	*−38.40*	0.00	*0.74*	−0.04**	*−16.09*
Profitability	−0.02**	*−5.52*	0.00	*1.40*	−0.03**	*−8.74*	−0.01**	*−4.02*	−0.02**	*−6.14*	−0.00	*−0.09*	−0.02**	*−5.51*	−0.02**	*−9.27*
Residual volatility	0.07**	*19.68*	−0.09**	*−32.60*	0.07**	*19.33*	−0.07**	*−25.24*	−0.01**	*−2.83*	−0.05**	*−17.69*	−0.11**	*−32.20*	−0.13**	*−46.98*
Size	−0.07**	*−18.86*	−0.25**	*−72.34*	−0.38**	*−109.60*	−0.34**	*−104.26*	−0.40**	*−119.71*	−0.27**	*−79.39*	−0.32**	*−91.81*	−0.27**	*−77.13*
No. of Obs.	102,803		198,148		102,803		198,148		102,803		198,148		102,803		198,148	
R^2	12%		16%		23%		23%		27%		17%		21%		14%	

Note: **\|*t*-stat.\| > 2.

one-month options and *R*-squares of 0.12 and 0.16 for the one-year horizon. The results indicate a change in the perception of downside risk associated with CSCI after the passage of the climate treaty.

Before the agreement, carbon intensity was statistically significantly negatively related to downside risk over one-month and one-year horizons. A negative relationship between emissions and left skew indicates that companies with lower emissions have higher downside risk, reflecting a greater chance of a left-tail event. After the agreement's passage, the relationship changes sign: Higher emitters have significantly more downside risk, although no relationship exists at the longer one-year horizon.

This finding is consistent with the notion that after the Paris Agreement took effect, the stock prices of high emitters adjusted to reflect the potential downside scenarios. The coefficient on the CSCI variable can be compared with the coefficients of the other variables because of the standardization process used in the analysis. Over a one-month horizon, as reflected in the 30-day left skew post-2016, the impact of a 1-standard-deviation increase in emissions exposure is 0.0155. This impact is similar in economic magnitude to that of the earnings yield factor, with similar statistical significance indicated by their respective *t*-statistics.

The right skew represents the "upside" opportunity, and with increased regulation, we would expect higher-carbon-intensity companies to have less opportunity. We show the results for the right skew also in Exhibit 7. As expected, the coefficient on carbon intensity is significantly negative before and after 2016 using 365-day option prices. The negative coefficient is 0.0293 in the first period and declines to 0.0093 in the second, with less statistical significance. In the case of right-tail skewness, the passage of agreement appears to have decreased the importance of emission intensity.

Since the Paris Agreement, it has become increasingly common to analyze companies' approaches to managing their carbon emissions relative to the target of reducing emissions by 45% by 2030, with the goal of reaching net zero by 2050. Companies' emissions commitments to net zero are characterized by a temperature reduction goal and a base year—for example, 2°C by 2030. Comprehensive data on companies' commitments have been available since 2019, and we use this data to further evaluate the relationship between option implied volatility skew and emissions. Carbon emissions reflect the company's point-in-time behavior. In contrast, a commitment to a particular net-zero pathway demonstrates the company's overall emission-related goal and provides a clear signal of the company's intent. We expect emissions intensity to matter less for companies with more ambitious commitments.

We evaluate this hypothesis by categorizing companies into three groups for the commitment year of 2030: those with a commitment to a 2°C reduction or less (the most ambitious), those with a commitment greater than 2°C, and those with no commitment. We show the CSCI measure for each of these groups

Exhibit 8. CSCI and Emissions Commitments for 2030

	N	Average	Std. Dev.	25%	50%	75%
CSCI, no target	8,542	0.01	0.56	−0.23	0.01	0.22
CSCI, target >2°C	93,152.00	0.06	0.49	−0.19	0.06	0.29
CSCI, target ≤2°C	44,284.00	−0.13	0.61	−0.45	−0.06	0.23

in **Exhibit 8**. The average CSCI for companies committed to 2°C alignment is lowest amongst the categories at −0.13, as is the 25th percentile score at −0.45. However, the average CSCI for companies that announced a transition target above 2°C is higher than for those that have not committed. The standard deviation of the scores is similar amongst the three categories. From the standpoint of carbon intensity, there is little differentiation amongst these three categories.

We then estimate a regression of option skew in which the coefficient on emissions intensity can vary based on the 2030 commitment level over the period of available data. We show the results of the regression in **Exhibit 9**. The most informative comparison is between the companies that have committed to a target of less than 2°C and those with a commitment greater than 2°C. The skew of companies with an announced target of less than 2°C have overall sensitivity to the current emissions. In contrast, those with some commitment show a robust systematic relationship to left skew over one year and one month. The companies with no announced commitment have the highest sensitivity amongst the three categories, especially with respect to the sensitivity to the right skew over a one-year horizon. These results support the notion that the markets look beyond current emissions and to net-zero emissions commitments in assessing future risk as reflected in option prices.

Although this reflects the behavior of markets in the United States for companies that are primarily US based, it is significant evidence that the options market does pay attention to companies' climate behavior. Despite some resolution of uncertainty in the post-2016 period, a systematic relationship remains between implied skew, as priced by options, and emissions. As measured in this chapter, the emissions are on an industry-related basis, so even portfolios managed on an industry or sector-neutral basis can potentially be exposed to this factor. The company-specific risk impact of emissions does not mean it cannot be diversified away, however. To the extent that business strategies and regulatory policies are industry specific, this risk may be irrelevant in a well-diversified portfolio. We next assess this notion by evaluating the performance of an equity portfolio.

Exhibit 9. Impact of Emissions Commitment for 2030 on Option Skew

	Post-2019							
	365 Days Left Skew		30 Days Left Skew		30 Days Right Skew		365 Days Right Skew	
	Beta	*t*-Stat.	Beta	*t*-Stat.	Beta	*t*-Stat.	Beta	*t*-Stat.
CSCI, no target	−0.02	*−1.19*	−0.04**	*−2.26*	−0.06**	*−3.21*	−0.07**	*−4.11*
CSCI, target >2°C	0.02**	*3.36*	0.03**	*5.23*	0.02**	*4.02*	0.01	*0.83*
CSCI, target ≤2°C	0.00	*0.01*	0.02**	*2.70*	−0.01	*−0.85*	−0.01	*−1.95*
Beta	0.03**	*10.49*	0.01**	*2.15*	−0.02**	*−6.97*	−0.11**	*−37.96*
Book-to-price ratio	0.10**	*29.61*	0.06**	*18.93*	0.07**	*19.31*	0.06**	*17.82*
Dividend yield	0.06**	*19.82*	0.04**	*12.48*	0.04**	*13.28*	0.07**	*21.10*
Earnings quality	0.01**	*3.69*	0.01**	*3.30*	0.02**	*8.27*	0.00	*0.86*
Earnings variability	0.03**	*8.89*	0.05**	*15.50*	0.02**	*5.59*	0.02**	*5.30*
Earnings yield	−0.00	*−0.51*	0.01**	*2.56*	0.03**	*8.32*	−0.02**	*−6.31*
Growth	−0.02**	*−6.45*	−0.03**	*−9.76*	−0.01**	*−3.28*	−0.00	*−0.82*
Investment quality	−0.03**	*−10.29*	−0.05**	*−17.24*	−0.02**	*−8.61*	−0.05**	*−16.84*
Leverage	0.08**	*28.90*	0.05**	*19.58*	0.04**	*14.09*	0.01**	*4.67*
Liquidity	−0.09**	*−32.55*	−0.07**	*−26.01*	−0.04**	*−14.97*	−0.07**	*−23.31*
Long-term reversal	0.03**	*9.57*	0.04**	*16.95*	−0.00	*−0.67*	0.02**	*8.72*
Mid cap	−0.11**	*−28.32*	−0.13**	*−34.24*	−0.09**	*−21.22*	−0.02**	*−4.79*
Momentum	0.04**	*14.62*	0.04**	*13.22*	−0.09**	*−31.44*	−0.05**	*−16.52*
Profitability	0.00	*0.74*	−0.02**	*−7.04*	−0.01**	*−3.65*	−0.03**	*−7.92*
Residual volatility	−0.10**	*−31.57*	−0.07**	*−23.64*	−0.05**	*−15.46*	−0.11**	*−35.05*
Size	−0.24**	*−59.32*	−0.31**	*−78.11*	−0.24**	*−59.13*	−0.24**	*−57.75*
No. of obs.	145,978		145,978		145,978		145,978	
R^2	16%		22%		15%		12%	

Note: **|*t*-stat.| > 2.

Carbon Intensity in Equity Portfolios

Well-diversified portfolios allow investors to limit their exposure to the idiosyncratic variation associated with a particular company's actions and strategies, which is especially important when company decisions are only loosely related to economic performance. Before the Paris Agreement, most companies had yet to integrate management of carbon emissions into their business strategy. After the treaty's implementation in 2016, however, there is certainly anecdotal evidence to corroborate our statistical analysis that companies and investors pay attention to this dimension. If we assume, for example, that the risk associated with emissions intensity reflects an undiversifiable or systematic risk, then a portfolio exposed to this factor will experience higher-than-expected volatility resulting from the comovement of stocks in the portfolio. To the extent that emissions risk reflects a transition risk exposure, we would expect the returns of companies with similar emissions to have a nonzero correlation.

In this section, we build multiple portfolios with systematically different exposures to carbon intensity (as measured by the portfolio CSCI, which is simply the weighted average CSCI of each stock in the portfolio) and evaluate their performance and risk. The portfolios are constructed to minimize risk, measured by the tracking error relative to the Russell 1000 Index, although incrementally increasing exposure to company-specific carbon intensity. The exposure to CSCI varies from –3 standard deviations to +3 standard deviations. Absolute active exposure is constrained to 0.6% for each security. This set of constraints, combined with the incremental approach to increasing CSCI, allows us to isolate the impact of carbon emissions on the portfolios' risk profile.[6] We compare the portfolio results with the Russell 1000, a common equity benchmark in institutional equity portfolio management. If exposure to carbon reflects a systematic undiversifiable risk, the risk forecasts for portfolios should be biased downward because the risk forecasts are missing the common carbon-related risk. The extent of the bias will be a function of the portfolio's carbon exposure, either positive or negative. A portfolio with negative exposure to carbon as measured by CSCI will have the "greenest" stocks in every industry, and if carbon intensity is systematically priced as a risk factor, the covariance of these stocks will be higher than expected.

In conducting these tests, we build the carbon-related portfolio using GEMLT combined with a quadratic optimization process.[7] The portfolios are constructed to achieve the lowest possible level of tracking error with the Russell 1000, given the desired target exposure to CSCI. The monthly expected tracking error serves as

[6]See the appendix for more details on the risk factors' exposures between 2015 and 2024 (Exhibit A1), the forecasted active risk using GEMLT (Exhibit A2), the *ex post* active risk (Exhibit A3), and the bias statistic (Exhibit A4).

[7]Barra's GEMLT uses the same financial risk factors that we use throughout this study, along with an idiosyncratic risk forecast for each security. To our knowledge, no current risk model directly incorporates the use of carbon or emissions-related risk factors. The results presented on the bias in the risk forecast are consistent with this variable's omission in the portfolio risk estimation. The GEMLT is aligned with an investment horizon of six months. By limiting our sample to US firms, we limit the potential impact of nonsynchronous trading (caused by differing time zones) on correlations and risk estimates.

the forecasted active risk of the portfolio. If the risk forecast is accurate, the ratio of the portfolio excess return (relative to the benchmark) to the forecasted active risk will have a unit standard deviation when measured over multiple periods.

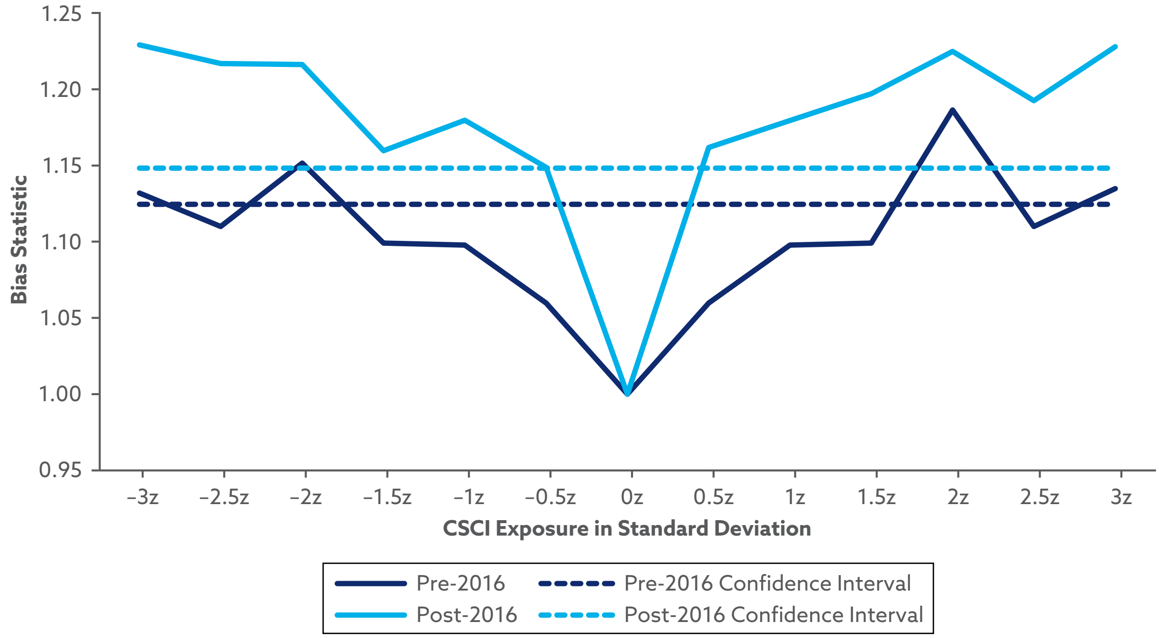
We recognize that risk forecasts are unbiased only over long periods. For example, if measured in periods in which the market is devoid of shocks, the bias statistic will be less than 1. If measured over a period in which the market has been subject to surprises, such as during the COVID-19 pandemic, the bias statistic will be greater than 1. We attempt to address this deficiency by comparing bias statistics of portfolios with varying emissions exposure over the same time period. As such, each portfolio's bias statistic reflects the unique characteristics of the time period. It is possible, however, that high emissions assets were "stranded" and left worthless, which may have been incorporated into asset prices during the period in question. Such a phenomenon could have an impact on our results, but our findings appear to be robust to different time periods.

We reconstruct the portfolio monthly, using the prevailing CSCI exposure and the corresponding risk model. The optimization process aims to identify a set of portfolio weights that minimize tracking error to the benchmark subject to constraints on the targeted CSCI exposure and neutrality to risk factors and industries. Because of the risk factor neutrality, the only potential source of bias in the risk forecast is associated with the CSCI exposure that is explicitly targeted in the optimization. Intuitively, the correlations between stocks with similar CSCI exposure are understated because the risk factor is missing from the covariance matrix. So, by targeting a specific level of CSCI exposure in the portfolio, we are increasing the correlation between the stocks (if the CSCI factor is systematic). The degree of CSCI exposure varies in standard deviation units from –3.00 to +3.00 in increments of 0.50. Note that because of the slight variation in CSCI exposure, using a specific standard deviation target ensures constant portfolio exposure over time.

The test spans February 2006 to January 2024, representing the most extended period over which carbon emissions data are available for a broad universe of equity securities. We measure the forecast bias separately over the pre– and post–Paris Agreement periods. We hypothesize that the latter period will show more significant bias, reflecting a period in which investment professionals have become increasingly climate aware. This latter period is also likely more representative of the environment that investment professionals will face in future years.

Exhibit 10 illustrates the results of the bias test. A portfolio bias statistic greater than 1 indicates a significant risk understatement. This is the case for both periods. The greater the absolute value of CSCI exposure, the greater the bias in the tracking error forecast. The bias statistic follows the V-shaped pattern consistent with risk model misspecification in each period considered. We also show the 95% confidence interval for an unbiased estimate with the appropriate correction for the number of periods used in the estimation in the chart. Notably, the bias is systematically more significant in the post-agreement period, indicating that emissions intensity as measured by CSCI represents

Exhibit 10. Bias Statistic for Forecast Tracking Error vs. CSCI Exposures



a priced factor. As Exhibit 10 shows, the bias is also generally statistically significant, even at modest levels of exposure.

For active equity managers who consider tracking error a critical risk measure, measuring and managing CSCI exposure has become increasingly important since the passage of the Paris Agreement. This importance holds even if the portfolio is not exposed to polluting industries, because the risk factor used here measures exposure on an industry-relative basis. Absent a risk model that explicitly incorporates such a factor, this bias can be approximated by measuring the CSCI of the portfolio relative to the benchmark. The higher the "active" CSCI exposure, the greater the bias. For example, a portfolio with a tracking error of 4% and an active CSCI of 1 standard deviation will have a realized tracking error close to 5% because of the associated bias. This bias could also increase as investors become more aware of high carbon emitters' physical and transition risks.

Conclusion

From these findings, the primary implication for investors is that carbon intensity, specifically measured by the ratio of carbon emissions to revenue, should be treated as a risk factor. The intensity measure used in this chapter has risk implications in terms of economic and statistical significance similar in magnitude to other financial risk factors widely used in the investment industry. Furthermore, using variables related to quality, profitability, or a broad group of other commonly used financial factors does not subsume the power of the carbon intensity variable. Failure to measure and manage this exposure will result in biased estimates of portfolio risk for portfolios exposed to the factor, regardless of whether the exposure is positive or negative.

Although this study focuses on the US equity market, other markets and asset classes can use this framework. We would expect significantly greater bias from this risk factor in regions more susceptible to transition risk or regulatory uncertainty. Although this study used emissions as a risk factor, using companies' net-zero transition commitments could further enhance the equity risk modeling process. Such an approach is similar to using historical and forecast earnings in risk models.

As with most other factors, such as the growth or momentum factor, the return on the carbon intensity factor is uncertain. More importantly, and unlike the other factors, the carbon factor is exposed to regulatory uncertainty and technological innovations. Advances such as carbon capture or the development of alternative energies such as fusion would significantly impact the return and future volatility of the carbon intensity factor, suggesting that this factor could be a substantial source of alpha for those with forecasting ability on this dimension.

Lastly, exposure to carbon intensity should be an active decision incorporated directly into the investment process. Appropriately, investors with different time horizons and risk appetites might make varying decisions based on the results of this study. Some shorter-term investors might see these results as an arbitrage opportunity, choosing to hold stock or option positions that other longer-term investors may avoid. Regardless of the time horizon or risk appetite, investors should consider their portfolio's increased covariance associated with active carbon exposure.

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Appendix

These additional tables highlight the opportunity for the investor to manage their carbon emissions exposure. As illustrated in **Exhibit A1**, we believe it is instructive to see the various statistics by industry to guide improved risk management and portfolio construction. **Exhibits A2** and **A3** highlight that the relationship we described in the chapter is consistent over time, by comparing year-by-year results to the overall results we shared in the chapter.

The exhibits are referenced in footnote 6.

Exhibit A1. CSCI, Summary Statistics by Industry

Industry	Industry Avg.	Residuals Avg.	Std. Dev.	10%	25%	50%	75%	90%
THRIFTS	−1.69	−0.10	0.57	−0.72	−0.48	−0.18	0.30	0.61
INSURNCE	−1.40	−0.06	0.45	−0.59	−0.37	−0.10	0.21	0.51
RGNLBNKS	−1.35	−0.06	0.47	−0.56	−0.36	−0.11	0.15	0.54
CAPMRKTS	−0.87	−0.08	0.49	−0.74	−0.36	−0.04	0.25	0.46
DIVFIN	−0.68	−0.07	0.47	−0.56	−0.32	−0.03	0.19	0.45
BANKS	−0.62	0.20	0.50	−0.23	0.00	0.21	0.43	0.72
SOFTWARE	−0.59	−0.05	0.35	−0.42	−0.24	−0.07	0.15	0.32
INTERNET	−0.55	0.00	0.44	−0.32	−0.22	−0.07	0.16	0.56
MEDIA	−0.53	−0.02	0.43	−0.47	−0.27	−0.02	0.25	0.41
HLTHSVC	−0.39	0.04	0.69	−1.05	−0.38	0.29	0.51	0.77
COMMUNIC	−0.26	0.00	0.48	−0.51	−0.24	−0.04	0.30	0.52
TELECOM	−0.11	0.00	0.41	−0.37	−0.23	−0.09	0.26	0.51
HLTHEQP	−0.06	0.00	0.33	−0.34	−0.14	0.07	0.16	0.29
RLESTMNG	−0.05	0.01	0.77	−1.18	−0.57	0.41	0.53	0.72
COMPUTER	−0.04	−0.01	0.59	−0.70	−0.22	0.04	0.35	0.62

(*continued*)

Exhibit A1. CSCI, Summary Statistics by Industry (*continued*)

Industry	Industry Avg.	Residuals Avg.	Std. Dev.	10%	25%	50%	75%	90%
BIOTECH	−0.03	−0.01	0.29	−0.12	−0.01	0.03	0.11	0.17
AEROSPACE	−0.02	0.03	0.40	−0.45	−0.24	0.03	0.26	0.46
CONSDUR	−0.01	0.03	0.52	−0.59	−0.12	0.05	0.25	0.53
PHARMA	−0.01	−0.03	0.34	−0.42	−0.11	0.02	0.13	0.26
COMMSVCS	0.04	0.03	0.84	−0.88	−0.48	−0.13	0.33	1.12
SMICNDEQ	0.07	0.00	0.57	−0.63	−0.36	−0.05	0.41	0.69
RETAIL	0.10	0.01	0.37	−0.52	−0.07	0.10	0.22	0.34
AUTO COMP	0.11	0.03	0.46	−0.40	−0.21	−0.07	0.19	0.68
FOODRETL	0.11	0.03	0.41	−0.46	−0.17	0.06	0.23	0.36
MACHINRY	0.14	0.01	0.48	−0.46	−0.24	−0.04	0.19	0.49
HSHLDPRD	0.15	0.07	0.64	−0.77	−0.25	0.01	0.36	1.00
BLDCNSTR	0.26	−0.03	0.67	−0.76	−0.36	−0.07	0.40	0.79
SEMICOND	0.30	0.02	0.64	−0.91	−0.41	0.17	0.38	0.67
REALEST	0.34	0.03	0.48	−0.29	−0.10	0.01	0.19	0.52
FOODPRD	0.38	0.04	0.62	−0.66	−0.24	0.02	0.25	0.69
ENERGY	0.44	0.04	0.73	−0.64	−0.48	−0.23	0.44	1.09
CONSVCS	0.46	0.00	0.56	−0.56	−0.28	−0.02	0.23	0.70
PRECMETL	0.56	0.19	0.87	−0.35	−0.11	−0.02	0.78	1.94
TRNSPORT	0.72	0.06	0.94	−1.19	−0.42	0.12	0.74	1.21
GOLD	1.00	0.10	0.85	−0.90	−0.78	0.24	0.82	1.07
STEEL	1.10	−0.02	0.61	−0.80	−0.36	−0.05	0.40	0.80
CHEMICAL	1.11	0.01	0.67	−0.80	−0.50	0.00	0.53	0.93
CONSTPP	1.17	0.07	0.58	−0.60	−0.31	0.05	0.47	0.82
INOILGAS	1.20	0.40	0.54	−0.37	−0.01	0.32	0.64	0.93
AGROCHEM	1.22	0.23	0.88	−0.73	−0.51	0.01	0.75	1.70
OILEXPL	1.29	0.06	0.48	−0.42	−0.20	0.04	0.36	0.67
UTILITY	1.35	0.03	0.67	−0.79	−0.38	0.16	0.44	0.74
OILGAS	1.38	0.06	0.79	−0.81	−0.48	0.13	0.64	1.00
AIRLINES	1.51	0.17	0.61	−0.64	−0.29	0.21	0.55	0.87
DIVMETAL	1.51	0.23	0.61	−0.45	−0.23	0.27	0.63	1.06

Exhibit A2. *Ex Ante* Active Risk: GEMLT

	-3z	-2.5z	-2z	-1.5z	-1z	-0.5z	0z	0.5z	1z	1.5z	2z	2.5z	3z
2006	3.11%	3.11%	2.21%	1.39%	0.73%	0.36%	0.00%	0.36%	0.73%	1.39%	2.02%	3.11%	3.11%
2007	3.04%	2.96%	1.57%	1.12%	0.61%	0.30%	0.00%	0.30%	0.61%	1.12%	1.58%	2.96%	3.04%
2008	4.45%	3.49%	2.22%	1.64%	0.90%	0.45%	0.00%	0.45%	0.90%	1.64%	2.12%	3.49%	5.02%
2009	4.88%	3.86%	2.62%	1.97%	1.09%	0.54%	0.00%	0.54%	1.09%	1.97%	2.86%	3.86%	5.55%
2010	2.51%	2.21%	1.52%	1.14%	0.63%	0.31%	0.00%	0.31%	0.63%	1.14%	1.43%	2.21%	2.88%
2011	1.79%	1.59%	1.10%	0.83%	0.46%	0.23%	0.00%	0.23%	0.46%	0.83%	1.10%	1.59%	2.03%
2012	1.84%	1.50%	1.06%	0.80%	0.46%	0.23%	0.00%	0.23%	0.46%	0.80%	1.07%	1.50%	1.89%
2013	1.70%	1.52%	1.07%	0.82%	0.46%	0.23%	0.00%	0.23%	0.46%	0.82%	1.08%	1.52%	1.91%
2014	1.50%	1.35%	0.96%	0.73%	0.41%	0.21%	0.00%	0.21%	0.41%	0.73%	0.96%	1.35%	1.67%
2015	1.54%	1.27%	0.91%	0.69%	0.39%	0.19%	0.00%	0.19%	0.39%	0.69%	0.99%	1.27%	1.57%
2016	1.63%	1.47%	1.05%	0.80%	0.44%	0.22%	0.00%	0.22%	0.44%	0.80%	0.97%	1.47%	1.81%
2017	1.33%	1.21%	0.87%	0.66%	0.37%	0.18%	0.00%	0.18%	0.37%	0.66%	0.88%	1.21%	1.47%
2018	1.39%	1.15%	0.83%	0.64%	0.36%	0.18%	0.00%	0.18%	0.36%	0.64%	0.82%	1.15%	1.39%
2019	1.45%	1.32%	0.95%	0.73%	0.41%	0.20%	0.00%	0.20%	0.41%	0.73%	0.96%	1.32%	1.58%
2020	1.98%	1.66%	1.21%	0.93%	0.52%	0.26%	0.00%	0.26%	0.52%	0.93%	1.29%	1.66%	1.98%
2021	1.77%	1.62%	1.19%	0.91%	0.51%	0.25%	0.00%	0.25%	0.51%	0.91%	1.11%	1.62%	1.92%
2022	1.48%	1.35%	0.99%	0.76%	0.43%	0.21%	0.00%	0.21%	0.43%	0.76%	1.00%	1.35%	1.60%
2023	1.40%	1.28%	0.94%	0.72%	0.40%	0.20%	0.00%	0.20%	0.40%	0.72%	0.94%	1.28%	1.52%
Pre–2016 Avg.	2.54%	2.21%	1.48%	1.09%	0.60%	0.30%	0.00%	0.30%	0.60%	1.09%	1.47%	2.21%	2.77%
Post-2016 Avg.	1.54%	1.37%	1.00%	0.77%	0.43%	0.21%	0.00%	0.21%	0.43%	0.77%	1.00%	1.37%	1.64%

Exhibit A3. *Ex Post* Active Risk: Standard Deviation of Monthly Active Returns

	–3z	–2.5z	–2z	–1.5z	–1z	–0.5z	0z	0.5z	1z	1.5z	2z	2.5z	3z
2006	4.13%	4.13%	3.40%	1.91%	0.94%	0.41%	0.00%	0.41%	0.94%	1.91%	3.40%	4.13%	4.13%
2007	2.76%	2.76%	2.20%	1.49%	0.64%	0.31%	0.00%	0.31%	0.64%	1.49%	2.21%	2.76%	2.76%
2008	3.27%	2.87%	1.86%	1.31%	0.67%	0.32%	0.00%	0.32%	0.67%	1.31%	1.86%	2.87%	3.19%
2009	1.57%	1.26%	1.18%	1.03%	0.61%	0.29%	0.00%	0.29%	0.61%	1.03%	1.18%	1.26%	2.83%
2010	1.82%	1.79%	1.63%	1.21%	0.64%	0.32%	0.00%	0.32%	0.64%	1.21%	1.63%	1.79%	2.05%
2011	1.98%	1.76%	1.23%	1.00%	0.60%	0.30%	0.00%	0.30%	0.60%	1.00%	1.23%	1.76%	2.30%
2012	1.86%	1.63%	1.04%	0.71%	0.42%	0.21%	0.00%	0.21%	0.42%	0.71%	1.04%	1.63%	2.18%
2013	1.85%	1.50%	0.96%	0.80%	0.47%	0.23%	0.00%	0.23%	0.47%	0.80%	0.96%	1.50%	2.21%
2014	2.14%	1.93%	1.25%	0.94%	0.52%	0.26%	0.00%	0.26%	0.52%	0.94%	1.25%	1.93%	2.31%
2015	2.57%	2.29%	1.55%	1.14%	0.61%	0.31%	0.00%	0.31%	0.61%	1.14%	1.55%	2.29%	2.83%
2016	1.70%	1.52%	1.05%	0.74%	0.40%	0.20%	0.00%	0.20%	0.40%	0.74%	1.05%	1.52%	1.93%
2017	2.04%	1.84%	1.29%	0.97%	0.52%	0.25%	0.00%	0.25%	0.52%	0.97%	1.29%	1.84%	2.24%
2018	2.17%	1.97%	1.38%	0.98%	0.55%	0.27%	0.00%	0.27%	0.55%	0.98%	1.38%	1.97%	2.33%
2019	1.86%	1.67%	1.15%	0.84%	0.44%	0.21%	0.00%	0.21%	0.44%	0.84%	1.15%	1.67%	2.06%
2020	3.07%	2.79%	1.99%	1.49%	0.80%	0.39%	0.00%	0.39%	0.80%	1.49%	1.99%	2.79%	3.39%
2021	1.41%	1.28%	0.94%	0.74%	0.43%	0.22%	0.00%	0.22%	0.43%	0.74%	0.94%	1.28%	1.54%
2022	1.18%	1.13%	0.92%	0.74%	0.45%	0.23%	0.00%	0.23%	0.45%	0.74%	0.92%	1.13%	1.25%
2023	1.53%	1.42%	1.10%	0.84%	0.49%	0.24%	0.00%	0.24%	0.49%	0.84%	1.10%	1.42%	1.62%
Pre-2016 Avg.	2.33%	2.13%	1.58%	1.12%	0.59%	0.29%	0.00%	0.29%	0.59%	1.12%	1.58%	2.13%	2.61%
Post-2016 Avg.	1.89%	1.73%	1.25%	0.94%	0.52%	0.26%	0.00%	0.26%	0.52%	0.94%	1.25%	1.73%	2.06%

Exhibit A4. Bias Statistic: GEMLT

	-3z	-2.5z	-2z	-1.5z	-1z	-0.5z	0z	0.5z	1z	1.5z	2z	2.5z	3z
2006	1.33	1.33	1.54	1.37	1.30	1.14	1.00	1.14	1.30	1.37	1.68	1.33	1.33
2007	0.91	0.93	1.40	1.33	1.05	1.02	1.00	1.02	1.05	1.33	1.40	0.93	0.91
2008	0.73	0.82	0.84	0.80	0.74	0.71	1.00	0.71	0.74	0.80	0.88	0.82	0.63
2009	0.32	0.33	0.45	0.53	0.56	0.54	1.00	0.54	0.56	0.53	0.41	0.33	0.51
2010	0.73	0.81	1.07	1.06	1.02	1.02	1.00	1.02	1.02	1.06	1.14	0.81	0.71
2011	1.11	1.11	1.12	1.20	1.29	1.28	1.00	1.28	1.29	1.20	1.12	1.11	1.13
2012	1.01	1.08	0.98	0.89	0.93	0.93	1.00	0.93	0.93	0.89	0.97	1.08	1.15
2013	1.09	0.99	0.89	0.98	1.02	1.01	1.00	1.01	1.02	0.98	0.89	0.99	1.16
2014	1.42	1.43	1.31	1.29	1.26	1.27	1.00	1.27	1.26	1.29	1.31	1.43	1.38
2015	1.66	1.79	1.71	1.65	1.57	1.58	1.00	1.58	1.57	1.65	1.57	1.79	1.79
2016	1.04	1.03	1.00	0.93	0.90	0.89	1.00	0.89	0.90	0.93	1.08	1.03	1.06
2017	1.53	1.53	1.48	1.46	1.41	1.38	1.00	1.38	1.41	1.46	1.47	1.53	1.53
2018	1.56	1.71	1.66	1.54	1.53	1.54	1.00	1.54	1.53	1.54	1.68	1.71	1.68
2019	1.29	1.27	1.20	1.15	1.08	1.05	1.00	1.05	1.08	1.15	1.19	1.27	1.30
2020	1.55	1.68	1.64	1.60	1.54	1.50	1.00	1.50	1.54	1.60	1.54	1.68	1.71
2021	0.80	0.79	0.79	0.81	0.84	0.87	1.00	0.87	0.84	0.81	0.85	0.79	0.80
2022	0.80	0.84	0.93	0.97	1.06	1.08	1.00	1.08	1.06	0.97	0.92	0.84	0.78
2023	1.09	1.12	1.17	1.17	1.21	1.20	1.00	1.19	1.21	1.17	1.16	1.12	1.07
Pre-2016 Avg.	1.03	1.06	1.12	1.09	1.06	1.04	1.00	1.04	1.06	1.09	1.13	1.06	1.07
Post-2016 Avg.	1.23	1.27	1.27	1.24	1.24	1.23	1.00	1.23	1.24	1.24	1.26	1.27	1.27

Notes: The bias statistic is computed by dividing the active return by the forecasted tracking error as measured by the GEMLT. This calculation creates a monthly bias metric. Computing the standard deviation of this monthly metric over the year creates an annual bias metric.

INTEGRATING FORWARD-LOOKING CLIMATE METRICS IN CORPORATE FIXED-INCOME INDEX PORTFOLIOS

Kushal Shah
Climate Specialist, Vice President, State Street Global Advisors, London

Alexis Royer, CFA
Fixed Income Portfolio Manager, Vice President, State Street Global Advisors, London

Rupert Cadbury
Sustainable Investing Strategist, Vice President, State Street Global Advisors, London

Existing climate investment approaches primarily incorporate screening or target backward-looking climate metrics, such as carbon intensity and brown revenues. In recent years, however, several forward-looking data metrics, such as temperature alignment and climate risk ratings, have become widely available. Investors that seek to manage risk and return from climate factors have increasingly expressed interest in these forward-looking metrics. While the effects of using such metrics in portfolio construction are understood in equity index universes, there remains a gap in understanding their effects in fixed-income index universes. We help fill this gap by analyzing the characteristics of forward-looking climate data metrics in commonly used fixed-income investment benchmarks, including the Global, US, and Europe investment grade (IG) and high yield corporations. In the Global IG USD universe, we also explore the effects of including these metrics on portfolio characteristics like diversification and tracking error. We then explore the effects of incorporating both forward-looking and backward-looking climate metrics on various representative portfolios.

Introduction

Investor allocation to climate-themed funds and strategies has increased sharply in recent years. Bioy, Wang, Pucci, and Biddappa (2024) study of global investment trends in climate funds identified a total of 1,506 mutual funds and exchange-traded funds (ETFs) as of December 2023, compared to fewer than 200 in 2018. Similarly, the assets under management (AUM) increased to about $540 billion in 2023, relative to about $40 billion in 2018. Although much interest has focused on equity strategies, fixed-income strategies accounted for about 13.5% of the AUM in climate-themed funds.

The drivers for investor interest in such strategies are manifold. Advances in scientific research—in particular, reports published periodically by the Intergovernmental Panel on Climate Change (IPCC), the International Energy

Agency (IEA), and the Network for Greening the Financial System (NGFS)—have highlighted the potential harmful impacts of climate change on global economies. Countries around the world have recognized the potential risks that climate change poses, resulting in international agreements to curtail the emissions of greenhouse gases (GHGs). Most notably, the Paris Agreement (signed in 2016) sets long-term goals to hold global temperature increase to well below 2°C above preindustrial levels and to pursue efforts to limit it to 1.5°C above preindustrial levels. More recently, countries represented at the 28th UN Climate Change Conference (COP28) at the end of 2023 reached an agreement to call on parties to triple renewables capacity and double energy efficiency improvements globally by 2030, while transitioning away from fossil fuels in a just, orderly, and equitable manner.[1] Similarly, global governmental policies and regulation have accelerated support for an energy transition, including the passage of the Inflation Reduction Act (IRA) in the United States in 2022 and the Net Zero Industry Act (NZIA) in the European Union (EU) in 2024.

Additionally, in recent years, investors with a variety of climate-related objectives (such as risk management, alpha generation, values alignment, or real-world impact) have signed on to various industry-led voluntary climate initiatives (for example, the Net-Zero Asset Owner Alliance, or NZAOA). The signatories to these voluntary initiatives are expected to adhere to certain requirements or, in certain cases, follow a net-zero framework. These frameworks include the Institutional Investors Group on Climate Change's Net Zero Investment Framework (IIGCC 2024b), the Science Based Targets initiative's framework for financial institutions (SBTi 2024), and the NZAOA's Target-Setting Protocol (NZAOA 2024). These frameworks, in turn, recommend that investors set targets broadly related to engagement (primarily with companies) and capital allocation within investment portfolios (portfolio decarbonization, climate solutions, etc.).

Another driver is the increased availability of company disclosures and data related to climate change. The Task Force on Climate-related Financial Disclosures (TCFD) established voluntary guidance around effective disclosure of climate-related risks and opportunities by companies in various industries. This guidance framework has been adopted by several markets around the world, notably the United Kingdom, Singapore, and Hong Kong. In the EU, disclosure requirements, such as the Corporate Sustainability Reporting Directive (CSRD), will come into force in a phased manner over 2025–2027, whereas investment fund–related sustainability disclosures under the Sustainable Finance Disclosure Regulation (SFDR) have been in force since 2021. International efforts to standardize sustainability-related data have also accelerated in recent years, most notably with the establishment of the International Sustainability Standards Board (ISSB) under the International Financial Reporting Standards (IFRS) Foundation. The ISSB builds on work previously done by the TCFD and the Sustainability Accounting Standards Board (SASB), among others, and in 2023 released two sustainability standards

[1]See www.cop28.com/en/the-uae-consensus-foreword.

for companies (called IFRS S1 and IFRS S2). For investors, regulators in certain jurisdictions—for example, the United Kingdom[2] and Switzerland (State Secretariat for International Finance 2023)—encourage the disclosure of various climate-related metrics for investment portfolios, including forward-looking measures, such as the climate value at risk and implied temperature rise. Concurrent with these developments, climate- and sustainability-related data have become available from several third-party data vendors, such as MSCI, ISS ESG, S&P Trucost, and FTSE.

Company-level climate data are broadly classified into two main types: backward-looking data and forward-looking data. As the name suggests, backward-looking data refer to a company's activities in the past and cover such metrics as a company's carbon or GHG emissions, ownership of fossil-fuel reserves, revenues derived from fossil-fuel-related activities, and involvement in certain business activities. Such metrics have been available for several years and have an established data history, running five years or more. However, these backward-looking metrics may miss key information related to a company's future plans, innovation, or potential future risks and opportunities arising from climate change. Forward-looking metrics seek to measure such plans, risks, or opportunities and have recently become available in the market. These include such metrics as company emission reduction targets and temperature ratings, climate scenario–based "value at risk" estimates, and transition or physical risk ratings. We will cover these metrics in more detail in later sections.

For fixed-income investors, climate-related factors can be incorporated within their strategies in three main ways: screening-based approaches, green bonds, and tilts based on climate metrics. Previously, screening-based approaches (for example, based on business or product involvement screens) were the primary method, but in recent years, green bonds and tilts based on climate metrics have become more prominent. For instance, the EU adopted minimum standards for the Climate Transition Benchmarks (CTBs) and the Paris Aligned Benchmarks,[3] which set minimum requirements on business activity screens, portfolio-level carbon intensity and related annual improvements, and green-to-brown ratios, among others. We note that these regulatory benchmarks primarily focus on backward-looking climate elements, and recent investor-led guidance on net-zero benchmarks (IIGCC 2023; NZAOA 2022b) suggests an increased focus and preference for forward-looking elements. In this chapter, we seek to study the effects of incorporating such forward-looking climate data in fixed-income index universes.

The remainder of the chapter is organized as follows. In the next section, we provide an overview of existing literature and articulate the contribution of this chapter. Then, we describe the data used, including definitions, sources, and mapping procedures. In the subsequent section, we analyze the distribution in several universes, as well as the relationship between the metrics. Finally, we

[2]See www.handbook.fca.org.uk/handbook/ESG/2/3.html.

[3]See https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R1818.

analyze the impact of incorporating climate metrics in a global investment-grade universe and provide concluding remarks.

Literature Review

While interest in the body of research covering climate-related impacts on companies' financial performance and investment portfolio returns has increased in the years following the Paris Agreement, the area is still nascent and emerging in nature. This is very likely due to the short data history available (less than 10 years in most cases), generally low consistency among various datasets, and differing methodological approaches. As a result, the lessons in this literature review are appropriately caveated.

According to the TCFD (2017), companies may be impacted by climate change due to two main categories of risks and opportunities: those that are transition related and those that are physical related. Transition-related risks and opportunities could be driven by changes in government policy and regulation, litigation, development of new technologies, and changes in consumer behavior or preferences. Physical-related risks and opportunities are divided into chronic effects (e.g., temperature rise, sea level rise, precipitation) or acute effects (e.g., heatwaves, floods, cyclones).

The NGFS (2023, p. 12) examined the potential channels by which these transition and physical risks may be transmitted to the broader economy and the financial system. The study found climate change may affect businesses and households at the microeconomic level through property damage, loss of income, stranded assets, and so on, and at the macroeconomic level through shifts in prices, productivity changes, and socioeconomic changes, among others. These economic effects may, in turn, be transmitted to the financial system as, for example, credit risk (e.g., loan defaults), market risk (e.g., repricing of securities), or underwriting risk (e.g., insurance losses).

Institutional investors broadly consider these climate-related risks to be financially material, and some believe such risks are not fully priced (Krueger, Sautner, and Starks 2020). In the equity markets, several research articles have been published in recent years that try to tackle this question, with mixed results. For example, Bolton and Kacperczyk (2021, 2023) find a positive relationship between companies (US and global) with high emissions and expected returns, consistent with an interpretation that investors are demanding greater compensation for exposure to emission risk. However, Bauer, Huber, Rudebusch, and Wilms (2022) find that green stocks generally outperformed brown stocks over their study period in G7 countries. We note that these studies mainly focus on backward-looking data elements.

Beyond equities, Campiglio, Daumas, Monnin, and von Jagow (2023) conducted a broad literature study covering various asset classes and distinguished between research using backward-looking methodologies and forward-looking methodologies. We refer readers to the full study for a complete overview;

however, we highlight some of their key findings: (1) Climate-related risks may predominantly lead to negative effects on financial performance, (2) climate-related risks may not be fully reflected in asset prices, and (3) it is challenging to compare forward-looking methodologies due to heterogeneity in approaches and scope.

Several key studies focus on the fixed-income market. There is some evidence that green bonds may provide a hedge against transition and physical risks (Cepni, Demirer, and Rognone 2022). In the municipal bond market, counties that are more exposed to climate risks may pay more in underwriting fees and initial yields for long-term bonds (Painter 2020). Firms with poor environmental performance or high emissions may have lower credit ratings and higher yield spreads (Seltzer, Starks, and Zhu 2022) and may be perceived by the market as more likely to default (Capasso, Gianfrate, and Spinelli 2020). Further, Huynh and Xia (2021) find that bonds with a higher climate news beta may earn lower future returns. However, Mastouri, Mendirotta, and Giese (2022) suggest that although broader credit market and bond spreads do not yet incorporate potential climate risks, these risks may still have a material impact on the asset value of firms. Moreover, the magnitude of these risks can have an adverse impact on bond investors and other creditors.

Looking at physical risks, there is some evidence that firms exposed to higher sea-level rise pay a premium when issuing bonds (Allman 2022) and those in locations with higher climate exposure pay higher spreads on their bank loans (Javadi and Masum 2021).

Lastly, as it relates to forward-looking climate data in particular, there is some evidence that such metrics may contain information about future carbon emissions (Fang-Klingler, Stroh, and Wisser 2022). Additionally, firms with traditionally poor sustainability or climate performance (e.g., power generation, oil, and gas) may produce more and higher-quality green innovation (Cohen, Gurun, and Nguyen 2020). This finding further supports the idea that forward-looking metrics may capture information that is not contained in backward-looking data.

In addition, the practitioner literature on the incorporation of climate factors in investment management has evolved over the years. Andersson, Bolton, and Samama (2016) demonstrate the construction of reduced-carbon portfolios for passive equity investors at low levels of tracking error. Bender, Bridges, and Shah (2019) adopt a mitigation and adaption approach to equity index portfolios and demonstrate the incorporation of multiple climate metrics in the portfolio construction process. Kolle, Lohre, Radatz, and Rother (2022) construct climate-aware portfolios that also seek to harvest traditional return factors, such as value, momentum, and quality. More recently, Bender, He, and Sun (2024) study the incorporation of forward-looking climate metrics in equity index portfolios.

In addition to financial materiality and risk and return considerations, investors may have other drivers when considering the inclusion of climate-related factors in their investment strategies. These may include influencing real-world decarbonization, moral considerations, and reputation risk (NZAOA 2022a; Krueger et al. 2020). Studying the impacts of all the aforementioned drivers is out of scope for this chapter, but we offer some views on the question of real-world decarbonization. Existing literature (Kölbel, Heeb, Paetzold, and Busch 2020) has outlined the main mechanisms of investor impact as (1) shareholder engagement (e.g., dialogue with company boards and management), (2) capital allocation decisions (e.g., shifting portfolio allocations toward greener companies), and (3) indirect impacts (e.g., endorsement and benchmarking). Making definitive conclusions is not possible due to the nascent area of study, but the findings suggest that the impact of engagement approaches is well supported while capital allocation approaches are only partially supported. More recent work (Quigley 2023) covering various asset classes suggests that investors may be able to have a higher degree of impact in fixed-income investments relative to equities; however, the volume and quality of supporting evidence is still low. Therefore, while it is theoretically possible for investors to influence real-world decarbonization by making investments in climate-aware strategies, this claim is uncertain, and further research needs to be conducted to verify and substantiate it.

In summary, the potential effects of climate change on the financial performance of companies and investment portfolios have been studied along many dimensions (transition versus physical, backward versus forward looking, return performance, equity index portfolio construction, loan spreads, bond yields, etc.). While equity index strategies that use climate metrics have been studied previously in the academic and practitioner literature, a gap in the research exists concerning the practical implications of incorporating forward-looking climate measures in corporate bond index universes. This chapter seeks to fill that gap.

Data Description

In this section, we describe the various datasets used in our analysis, including the climate-related metrics and benchmark index data.

Climate Metrics

In recent years, a variety of climate-related metrics have become available from public sources and third-party data vendors. These sources include the CDP, S&P Trucost, MSCI, ISS ESG, and Bloomberg. We refer readers to Bender et al. (2024) for a complete overview of such datasets and the lenses through which they can be interpreted. In summary, these metrics can be viewed as (1) decarbonization versus climate solutions, (2) mitigation versus adaptation, and (3) risks versus opportunities.

Without going into too much detail, in general, climate-related datasets are nascent and have relatively short data histories compared to company fundamental data. Data histories for forward-looking metrics in particular are even shorter, and methodologies are both complex and nonstandardized with wide variation among different data providers. In our study, we omit several underlying details of the metrics' calculation methodology, but we refer readers to Shakdwipee, Giese, and Nagy (2023) for an overview of the MSCI datasets.[4]

In our study, we use a combination of backward- and forward-looking climate data supplied by MSCI ESG Research and ISS ESG. Note that we do not differentiate between green and nongreen bonds that are issued by the same company. Therefore, green bonds are treated the same; the primary driver is a lack of security-specific data for green bonds. An overview of the various input metrics is provided in **Exhibit 1**. In the following subsections, we describe the various metrics we use in more detail.

Backward-Looking Climate Metrics

We utilize three commonly used backward-looking metrics: carbon intensity (CI), potential emissions (PE), and brown revenues (BR). Next, we describe these metrics.

Carbon Intensity (CI)

The GHG Protocol recommends standards for company-level Scope 1, Scope 2, and Scope 3 emissions. Data vendors collect emission data that are disclosed by companies via various methods (company sustainability reports, annual reports, CDP disclosures, etc.) and supplement these data with their own proprietary estimation models to improve coverage for wide investment universes.

- *Scope 1* emissions are direct emissions from sources that are owned or controlled by a company. They include, for example, on-site fossil-fuel combustion and fleet fuel consumption.
- *Scope 2* emissions are indirect emissions from sources that are owned or controlled by a company. They include emissions that result from the generation of electricity, heat, or steam purchased from a utility provider.
- *Scope 3* emissions are from sources not owned or directly controlled by a company that are nonetheless related to the company's activities or the use of its products. They include emissions generated by a company's nonelectricity supply chain, employee travel and commuting, and emissions associated with contracted solid waste disposal and wastewater treatment. Scope 3 is often divided into "upstream" and "downstream" emissions.

Although Scope 3 emissions can be a large part of a company's carbon footprint, there are several challenges associated with using these data for investment use cases (Fouret, Haalebos, Olesiewicz, Simmons, Jain, and Kooroshy 2024;

[4]An overview of the single ISS ESG dataset can be found at www.issgovernance.com/esg/climate-solutions/carbon-risk-rating/.

Exhibit 1. Overview of Climate Metrics Used in This Study (as of August 2024)

Metric Name	Abbr.	Definition	Units	Data Source	History Available	Range	Interpretation[a]
Carbon Intensity	CI	Scope 1 and Scope 2 emissions per $1 million revenue	Tons of CO_2 equivalent per $1 million	MSCI	2012	Positive values	Lower is better
Potential Emissions	PE	Potential emissions related to fossil-fuel reserve ownership	Million tons of CO_2 equivalent	MSCI	2017	Positive values	Lower is better
Brown Revenues	BR	Percentage of revenues derived from fossil-fuel-related activities	% of revenues	MSCI	2017	0%–100%	Lower is better
Implied Temperature Rise	ITR	The global temperature rise (in the year 2100) if the whole economy had the same carbon budget over-/undershoot level as the company analyzed	°C	MSCI	2022	1.3–10	Lower is better
Carbon Risk Rating	CRR	Rating that measures a company's preparedness for a low-carbon economy	NA	ISS ESG	2016	0–100	Higher is better
Policy Climate Value at Risk	Pol-CVaR	A company's aggregated downside policy risk exposure	% of market value	MSCI	2022	−100% to 0%	Higher (less negative) is better
Technology Climate Value at Risk	Tec-CVaR	A company's upside technology opportunity exposure	% of market value	MSCI	2022	0%–100%	Higher (more positive) is better
Physical Value at Risk	Phy-CVaR	A company's expected downside or upside potential from physical climate events	% of market value	MSCI	2022	−100% to 100%	Higher (less negative) is better

[a]The interpretation is provided for readers viewing these metrics from a risk/opportunity lens. For example, assuming CI as a proxy for climate risk, a lower value is better (considered to be less risky).

Sources: State Street Global Advisors; MSCI ESG Research; ISS ESG.

IIGCC 2024a). As a result, we use Scope 1 and Scope 2 emissions in our research. To make the metric comparable across companies of different sizes, we normalize the emission figures with a company's annual sales.

Potential Emissions (PE)

This metric is based on fossil-fuel reserves that are owned by companies and disclosed in their public reporting. PE sources can be various types of coal (metallurgical and thermal), oil (conventional, shale, or tar sands), and gas (natural or shale). MSCI provides proven and probable reserves (2P) for coal and proven reserves (1P) for oil and natural gas. In some cases, they also consider 2P values for oil and natural gas if a company does not disclose its 1P. The reserve values are then converted to equivalent potential carbon emissions estimated using various factors (net calorific value of the fuel, carbon content of the fuel, etc.), under the assumption that all reserves are combusted.

Brown Revenues (BR)

Similar to the PE metric, BR measure the proportion of revenues that a company derives in any given year from fossil-fuel-related sources and activities. These include fossil-fuel power generation, extraction, processing, transportation, and other supporting activities.

Forward-Looking Climate Metrics

We use three types of forward-looking metrics in our study: implied temperature rise (ITR), carbon risk rating (CRR), and climate value at risk (CVaR). CVaR is, in turn, divided into three components: policy, technology, and physical CVaR. Next, we describe these metrics.

Implied Temperature Rise (ITR)

Temperature alignment data for corporate issuers have become available in the sustainability data market in recent years. Companies around the world have started setting emission reduction targets over the past several years. According to the SBTi, as of 21 July 2024, over 8,500 companies have either set emission reduction targets validated by the SBTi or committed to do so.[5] In addition, companies may set targets voluntarily as well, without SBTi validation.

However, these emission targets vary widely in terms of target date, level of improvement, scope of emissions, and exact emission metric being targeted (economic intensity, physical intensity, or absolute emissions), among other factors. As a result, comparing such targets across companies can be quite challenging, especially when adding in considerations of regional and sectoral differences.

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[5]See https://sciencebasedtargets.org/companies-taking-action.

Temperature alignment scores assess the myriad company emission reduction targets and assign companies a "temperature score," making them more easily comparable and interpretable. Such temperature scores are known by various names—for example, ITR, temperature alignment, and Paris alignment. We provide a brief overview of MSCI's methodology next.

Several steps are involved in the estimation of MSCI's ITR. First, companies are assigned a carbon budget based on the projections of the NGFS REMIND Net Zero 2050 scenario. Next, companies' future emissions are projected according to their stated targets and are adjusted based on a credibility assessment. Third, the company's projected emissions are compared with its carbon budget, and an overshoot or undershoot factor is calculated. Last, this over-/undershoot is converted into a temperature figure based on an estimated relationship between carbon emissions and temperature outcomes.

Note that such methodologies are inherently complex and involve several assumptions and modeling choices made by data vendors. In addition, calculation of ITR scores at the portfolio level is recommended to be done using an "aggregate budget method." We omit technical detail here and simply note that this measure differs from the weighted average method that is typically used to calculate portfolio-level statistics. In our analysis, we specify whether ITR calculations are presented using a portfolio-weighted average or an aggregate budget method, but in general, the takeaways do not differ materially when using either method.

Carbon Risk Rating (CRR)

The CRR is a climate transition risk assessment created by ISS ESG. It is composed of two main parts:

1. *Carbon Risk Classification*, which assesses a company's exposure to carbon-related transition risks by estimating its emission intensity in the company's value chain, based on its industry and business activities
2. *Carbon Performance Score*, which evaluates the current carbon-related performance of a company, as well as a company's risk management and measures to reduce its CI in the future

ISS ESG combines the two components and rescales such that each company can obtain a score between 0 and 100, where 0 is considered high risk (worst score) and 100 is considered low risk (best score). Effectively, the CRR is a metric that assigns a risk rating to every company based on its sector and business activities, as well as its efforts to manage potential transition risks.

Climate Value at Risk (CVaR)

MSCI's CVaR metric seeks to quantify the potential effects of climate change into a dollar value impact on a company's valuation, typically expressed as a percentage of company value at risk over a 15-year time horizon under various climate scenarios. MSCI calculates the CVaR for its coverage universe under a variety of climate scenarios (orderly transition, disorderly transition, hothouse world, and temperature outcomes ranging from 1.5°C to 3°C). The CVaR metric is also further broken down into three components: Policy CVaR (Pol-CVaR), Technology CVaR (Tec-CVaR), and Physical CVaR (Phy-CVaR). These loosely correlate to transition risks, transition opportunities, and physical risks.

Pol-CVaR is estimated by modeling the potential negative impacts to company financials under future policies (proxied using carbon prices) projected under various climate scenarios.

Tec-CVaR is estimated by modeling the potential positive impacts of low-carbon patents on company financials under various climate scenarios.

Phy-CVaR is estimated by modeling the potential positive or negative impacts of various physical climate events (extreme cold, extreme heat, extreme precipitation, heavy snowfall, extreme wind, coastal flooding, fluvial flooding, tropical cyclones, river low flow, and wildfires) under various climate scenarios.

In our study, we use CVaR estimates under the NGFS REMIND Net Zero 2050 scenario and examine each subcomponent separately.

Index Data

Indexes are selected by market participants for a variety of reasons, but the key features investors typically seek when choosing a benchmark include the breadth of the fixed-income market captured, standardization of an index's security inclusion/exclusion criteria, pricing transparency of the underlying holdings, supporting analytics available on portfolio management systems, and flexibility to disaggregate particular segments of the covered universe.

In this chapter, we study the climate data characteristics of the following six indexes:

- Bloomberg Global Investment Grade Corporate Aggregate Index (Global IG)
- Bloomberg Global Investment Grade Corporate USD Aggregate Index (Global IG USD)
- Bloomberg US Investment Grade Corporate Aggregate Index (US IG)
- Bloomberg Pan Euro Investment Grade Corporate Aggregate Index (EUR IG)
- Bloomberg US High Yield Corporate Aggregate Index (US HY)
- Bloomberg Pan-European High Yield Corporate Aggregate Index (EUR HY)

Note that portfolio analysis is conducted only for the Global IG USD. All data are as of 31 May 2024.

Exhibit 2. Descriptive Statistics for Corporate Bond Indexes (as of 31 May 2024)

	Global IG	Global IG USD	US IG	EUR IG	US HY	EUR HY
No. Securities	16,393	10,165	8,000	3,704	1,949	664
No. Issuers	2,484	1,803	969	791	750	285
Total Market Value ($ billions)	12,040.31	8,109.29	6,621.09	2,855.65	1,283.98	360.41
Option-Adjusted Duration (OAD)	5.97	6.55	6.92	4.51	3.19	2.85
Option-Adjusted Spread (OAS)	94.56	87.87	84.64	107.87	308.21	321.81
Yield to Worst	5.10	5.56	5.52	3.88	8.00	6.31
Index Rating Number	8.20	8.18	8.18	8.34	15.06	13.98

Sources: State Street Global Advisors; Bloomberg.

All holdings and index weight data are sourced from Bloomberg. Additionally, relevant fundamental indicators, such as yield to worst, option-adjusted spread, option-adjusted duration, sector classifications, and market capitalization, are also sourced from Bloomberg. Some descriptive data on these indexes are provided in **Exhibit 2**.

Mapping Index Data to Climate Metrics

Climate data providers typically provide identifiers, such as an International Securities Identification Number (ISIN) or a ticker, to reference the securities that they cover and provide climate data for. Often, however, even if a company issues many securities, only one such security is referenced by the climate data provider. In such instances and particularly in corporate bond universes, it can be challenging to map climate data because of poor identifier matching. To overcome this challenge, we use a company- or issuer-level identifier system provided by Bloomberg. We map ISINs to their issuer, as well as to the issuer's parent and ultimate parent using this system.

As the first step in our mapping process, we join our index holdings to climate metrics using the security-level ISINs supplied by the providers. Next, for securities that are not mapped, we use Bloomberg's issuer-level identifier to map climate data to our index universes. If data for a particular issuer are not available, we next consider data related to the parent company. If data are still not available, we consider data related to the ultimate parent company. If data are not available even after all these steps, then we assume data are not available for that security.

Data Distribution and Relationships

In this section, we study the characteristics of the climate-related metrics in our selected index universes, including coverage, descriptive statistics, sectoral distribution, and data relationships in various universes. We also provide a short overview of our approach to missing data treatment, which is necessary where full coverage is not available.

Coverage in Selected Index Universes

First, we provide coverage statistics for our chosen climate metrics in the aforementioned index investment universes. The statistics are provided along two dimensions—by number of securities and by index weight.

We make the following observations based on **Exhibit 3**:

- Coverage of the metric for PE appears to be poor; in reality, however, this is a quirk of the data. Given most companies do not own fossil-fuel reserves, these are reported as null even if the company is assessed for other metrics. In this case, it is more representative to consider the coverage of fossil fuels to be the same as that of CI and BR.
- Within investment-grade universes, coverage is strong for backward-looking metrics (over 90%), while it is a bit varied for forward-looking data. Among these, CRR and ITR have good coverage (over 85%), while that for CVaR metrics is slightly weaker across the board.
- Within high-yield universes, a similar trend is apparent vis-à-vis backward- versus forward-looking metrics; however, we observe that the coverage is weaker across all data points relative to investment-grade universes.
- Sustainability datasets tend to be based on public financial disclosures by companies; therefore, they overwhelmingly focus on publicly listed companies. The credit space is composed of both public and private companies, the latter of which are not subject to the same public disclosure reporting requirements. As a result, coverage of private companies (which form a meaningful proportion of the universe) tends to be poor in comparison.

Missing Data Treatment

While using climate data metrics for practical portfolio construction use cases, missing data can be treated in two main ways: (1) excluding securities that are not covered and (2) missing value imputation or gap filling. The main drawback with the first option is that it can lead to high tracking error impact due to blunt exclusion, and it is usually not the preferred approach in practice. A gap-filling approach is typically preferred; however, note that the selection of an optimal method can be a separate research study of its own. As a result, for this study, we use an approach based on the observation that climate data metrics typically

Exhibit 3. Coverage of Climate Metrics in Various Index Universes (as of 31 May 2024)

Metric	Global IG		Global IG USD		US IG		EUR IG		US HY		EUR HY	
	By Number	By Weight	By Number	By Weight	By Number	By Weight	By Number	By Weight	By Number	By Weight	By Number	By Weight
CI	90.2	93.0	95.8	97.4	91.6	94.5	93.3	94.5	75.8	74.7	73.3	74.1
PE	4.2	4.4	6.7	6.1	4.2	4.2	4.8	5.1	3.6	3.2	0.5	0.7
BR	90.2	93.0	95.8	97.4	91.6	94.5	93.3	94.5	75.8	74.7	73.3	74.1
ITR	87.2	91.2	93.2	95.8	89.5	93.4	90.8	92.7	72.8	71.5	67.0	67.7
CRR	79.7	85.0	85.3	89.5	84.0	89.2	85.4	87.0	63.4	62.5	62.0	62.9
Pol-CVaR	67.4	75.1	72.7	80.0	73.4	81.7	71.5	74.3	48.7	48.8	41.3	44.1
Tec-CVaR	67.4	75.1	72.7	80.0	73.4	81.7	71.5	74.3	48.7	48.8	41.3	44.1
Phy-CVaR	67.4	75.1	72.7	80.0	73.4	81.7	71.5	74.3	48.7	48.8	41.3	44.1

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

display a strong dependence on the economic sector a company operates in (see **Exhibit 6**). Second, given that most sustainability data are based on publicly listed companies and commonly used sector classifications differ between equity and fixed-income universes, we prioritize the NACE classification,[6] which is recommended under the EU's Climate Benchmark regulation and can be used for both types of asset classes. Therefore, we fill in missing values for our climate metrics using the medians calculated by (in order of availability) NACE sectors and Bloomberg Class 3 sectors. Hereafter, all statistics and inferences are presented using climate data that are "gap filled" by the process described here.

Descriptive Statistics

To better understand the climate data characteristics, we present descriptive statistics in the combined universe of Global IG, US HY, and EUR HY in **Exhibit 4**. To avoid multiple counting, this calculation is based on unique issuers in the index, rather than individual securities.

Exhibit 4. Descriptive Statistics of Climate Data in the Combined Global IG, US HY, and EUR HY Universe (as of 31 May 2024)

Statistics	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Count	3,519	3,519	3,519	3,519	3,519	3,519	3,519	3,519
Count (nonzero)	3,517	136	584	3,519	3,518	3,519	1,643	3,511
Mean	257.0	37.8	9.37	2.63	49.79	−15.03	2.17	−1.64
Std. Deviation	867.1	321.2	25.97	1.64	13.94	24.31	8.54	4.50
Kurtosis	168.69	186.06	6.25	9.68	0.47	4.85	62.38	196.82
Skewness	9.85	12.39	2.78	2.95	0.15	−2.32	7.12	−11.76
Min.	0.0	0.0	0.00	1.30	0.00	−100.00	0.00	−100.00
5%	0.8	0.0	0.00	1.30	26.00	−82.03	0.00	−5.10
25%	5.4	0.0	0.00	1.70	42.00	−18.53	0.00	−1.40
50%	28.7	0.0	0.00	2.20	49.00	−3.86	0.00	−0.61
75%	134.6	0.0	0.00	2.90	58.00	−0.90	0.14	−0.31
95%	1,051.5	0.0	95.46	5.80	73.00	−0.51	10.24	−0.06
Max.	22,680.8	7,415.2	100.00	10.00	100.00	−0.08	100.00	6.21

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

[6]According to Eurostat, "The 'statistical classification of economic activities' in the European Community, abbreviated as NACE, is the classification of economic activities in the EU. The term NACE is derived from the French title: Nomenclature statistique des activités économiques dans la Communauté européenne." See https://ec.europa.eu/eurostat/web/nace/overview.

We make the following observations:

- CI, PE, and BR are all significantly right-tailed metrics, with medians much lower than the 95th percentile and their respective maximums. Pol-CVaR and Phy-CVaR are both left-tailed.
- PE and BR are predominantly zero values, with a small proportion of nonzero values (about 4% of issuers and 16% of issuers, respectively). Similarly, Tec-CVaR is also dominated by zero values, although the proportion of nonzero values is higher (about 47%).
- CRR is the only metric that appears to be somewhat normally distributed; all the other metrics display nonnormality and a high degree of skewness.

In **Exhibit 5**, we look at the overall climate data scores for each of the selected index universes in our study. In general, the US IG and US HY have higher climate exposures in the majority of metrics considered here, relative to EUR IG and EUR HY. Additionally, relative to their investment-grade counterparts, the two high-yield universes (US HY and EUR HY) tend to have more exposure along some metrics (ITR, CRR, Pol-CVaR) while having lower or comparable exposure along some other metrics (PE, CI, Tec-CVaR).

Exhibit 5. Climate Data Scores for Selected Index Universes (as of 31 May 2024)

Metric	Global IG	Global IG USD	US IG	EUR IG	US HY	EUR HY
CI	181.07	241.25	247.96	95.75	223.30	104.24
PE	83.35	89.13	92.75	94.50	11.69	2.78
BR	8.8	9.5	10.7	5.6	12.5	2.3
ITR (weighted average)	2.41	2.51	2.47	2.32	2.93	2.31
ITR (agg. budget)	2.35	2.48	2.58	2.09	3.30	2.21
CRR	56.69	55.74	56.18	59.73	45.32	54.29
Pol-CVaR	−11.97	−11.87	−11.73	−12.75	−15.29	−13.83
Tec-CVaR	1.76	1.22	1.15	3.45	0.89	3.80
Phy-CVaR	−1.31	−1.30	−1.14	−1.38	−1.54	−1.40

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Exhibit 6. Climate Metrics' Weighted Averages in Global IG by Bloomberg Class 3 Sector (as of 31 May 2024)

Bloomberg Class 3 Sector	Index Weight	No. of Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Banking	26.5%	3,029	3.9	0.0	0.0	2.42	65.28	−0.67	0.00	−0.43
Basic Industry	2.9%	556	442.9	279.1	3.2	4.69	46.25	−46.78	5.52	−2.92
Brokerage, Asset Managers, Exchanges	1.6%	316	2.8	0.0	0.8	2.18	56.58	−0.75	0.12	−0.36
Capital Goods	4.9%	902	182.6	0.3	0.7	3.22	47.71	−13.01	3.44	−0.77
Communications	7.3%	951	28.0	1.8	0.0	1.66	65.60	−2.64	0.04	−1.07
Consumer Cyclical	7.9%	1,303	27.8	0.1	1.4	2.60	49.20	−16.55	0.82	−1.81
Consumer Non-Cyclical	13.4%	2,069	31.6	0.0	0.0	1.93	64.39	−5.48	0.13	−1.24
Electric Utility	7.1%	1,714	1,467.3	2.3	32.2	2.64	41.54	−36.16	8.60	−1.51
Energy	5.8%	951	401.2	1,267.4	92.7	3.15	28.24	−59.85	7.86	−3.55
Finance Companies	1.0%	206	7.2	0.0	0.0	2.99	45.18	−0.93	0.00	−6.15
Other Financials	1.4%	389	59.0	0.0	0.0	3.09	45.79	−1.58	0.11	−2.18
Other Industrials	0.6%	188	126.7	231.7	3.3	2.50	49.07	−10.04	2.29	−3.60
Insurance	5.9%	1,155	12.2	1.6	0.2	1.69	59.08	−1.75	0.00	−0.79
Natural Gas Utility	1.3%	325	497.4	8.4	63.0	1.98	43.15	−34.54	6.93	−1.87
Other Utility	0.6%	146	433.4	0.0	2.9	2.18	50.64	−28.61	22.50	−2.50
REITs	2.6%	703	66.7	0.0	0.0	2.40	54.52	−0.92	0.06	−1.03
Technology	6.4%	855	28.4	0.0	0.0	1.92	66.65	−2.37	0.38	−0.98
Transportation	2.9%	635	259.1	0.0	2.0	2.74	53.81	−19.56	0.84	−2.90

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Sector Distributions

To better understand the distribution of climate data across sectors, we now present sector-weighted averages for the climate metrics within the broad Global IG universe (see Exhibit 6). We make the following observations:

- There is significant variation among sectors, and climate data tend to be concentrated in certain sectors.
- Notably, Electric Utility, Natural Gas Utility, Energy, and Basic Industry generally have high exposure to the climate metrics considered here but also tend to have greater opportunities as measured by Tec-CVaR, corroborating previous research (Cohen et al. 2020).
- Companies in the Other Utility sector also score well on Tec-CVaR but may still be exposed to higher Pol-CVaR on an aggregate basis.

Data Relationships

We now seek to understand the relationships between the various climate metrics we use.

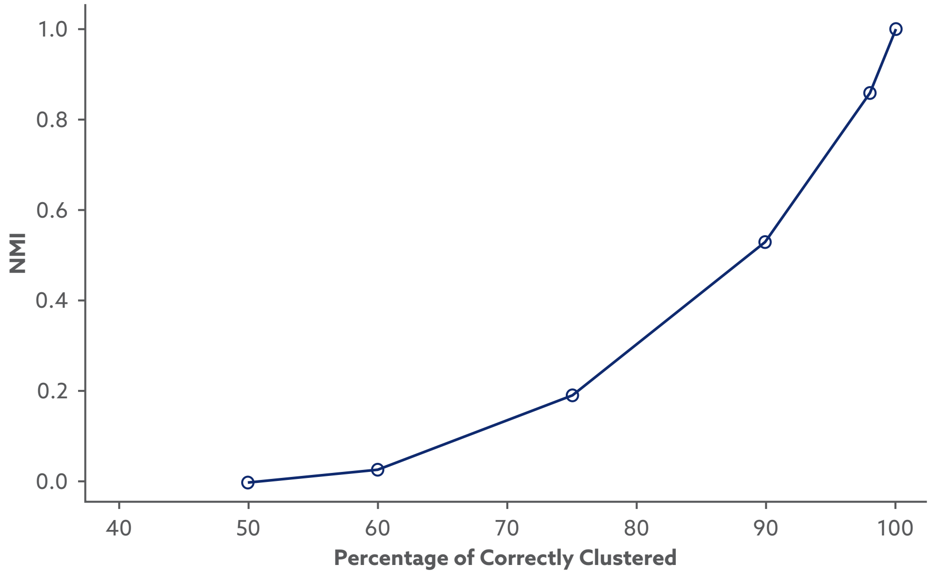
Methods

Pearson correlations are typically used to understand the linear correlations or relationships between datasets. As noted previously, however, climate metrics are quite concentrated and skewed (with the exception of CRR), making some relationships nonlinear in nature and challenging to understand and model. As a result, while correlation statistics for Global IG are reported in the appendix for the interested reader, we prefer to use alternative methods to understand the relationships. For this, we use the normalized mutual information (NMI) metric and decile-weighted averages.

The NMI is a clustering-based method that is commonly used to understand data relationships in machine learning applications and typically performs well at modeling nonlinear relationships. NMI can be interpreted as the decrease in uncertainty in *X* that results from knowing the value of *Y*. Details of the calculation methodology are provided in the appendix; however, we provide some helpful notes on interpretation of the metric, reproduced from Kachouie and Shutaywi (2020):

> NMI values close to one indicate that most of identified cluster labels agree with the true class labels. That is, most of the objects that belong to the same class are clustered in the same cluster. NMI value ranges from zero to one, but we should point out that it is a non-linear criterion for the clustering performance. For example, if in the clustering result, half of the data is correctly clustered, a linear criterion will score 0.5, while NMI score is zero. [**Exhibit 7**] shows NMI values with regard to

Exhibit 7. NMI Score versus Clustering Performance



Source: Kachouie and Shutaywi (2020).

clustering performance. It shows that NMI has a value of zero when 50% of the elements are correctly clustered, a value of about 0.5 when 88% of the elements are correctly clustered, a value of 0.6 when 93% of the elements are correctly clustered, and a value of one when 100% of the elements are correctly clustered.

In addition to the NMI, we also report decile-weighted averages by dividing the index universe into deciles based on selected climate metrics. We report these statistics as an additional robustness check; this method additionally accounts for index weights of various issuers, while the NMI weights all issuers equally.

Summary of Data Relationships

We first present our observations based on the NMI and decile calculations, and the detailed results are presented in the following two sections. We make the following observations:

- As may be expected, the three backward-looking metrics appear to have a relationship with each other: Companies with high CI also tend to have high BR or PE.
- CI also appears to be related to the forward-looking metrics: Companies with high CI also have poor CRR and Pol-CVaR. Interestingly, companies with high CI also tend to have higher Tec-CVaR, which further supports the findings from the sector analysis in the previous section.

- CRR and Pol-CVaR also appear to have a relationship with the backward-looking metrics. Companies that have high exposure to these two dimensions also have higher exposure to CI, PE, and BR. The relationship of these metrics with Tec-CVaR is also similar to that of CI: Higher-risk companies also have higher Tec-CVaR.
- Regarding ITR, the relationship among different metrics is weaker in comparison, although directionally similar.
- Phy-CVaR may have a weak relationship with Pol-CVaR and Tec-CVaR but not with the other metrics in consideration.

In summary, it appears that CRR and Pol-CVaR capture a lot of information contained in backward-looking data points, while ITR, Tec-CVaR, and Phy-CVaR appear to contain additional complementary information. In addition, these broad relationships appear to hold across the six universes we studied.

NMI Ratio

We present the NMI statistics in our selected index universes in **Exhibit 8**. Similar to before, these statistics are presented at the level of issuers rather than securities to avoid multiple counting.

Exhibit 8. NMI Ratio (as of 31 May 2024)

A. Global IG

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.41	0.01	0.24	0.25	0.34	0.03	0.02
BR	0.41	1.00	0.37	0.08	0.19	0.27	0.11	0.05
PE	0.01	0.37	1.00	0.18	0.41	0.42	0.15	0.10
ITR	0.24	0.08	0.18	1.00	0.07	0.07	0.07	0.05
CRR	0.25	0.19	0.41	0.07	1.00	0.15	0.11	0.09
Pol-CVaR	0.34	0.27	0.42	0.07	0.15	1.00	0.26	0.31
Tec-CVaR	0.03	0.11	0.15	0.07	0.11	0.26	1.00	0.05
Phy-CVaR	0.02	0.05	0.10	0.05	0.09	0.31	0.05	1.00

B. Global IG USD

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.44	0.01	0.26	0.23	0.37	0.02	0.02
BR	0.44	1.00	0.34	0.09	0.22	0.28	0.13	0.04
PE	0.01	0.34	1.00	0.19	0.38	0.39	0.13	0.06
ITR	0.26	0.09	0.19	1.00	0.07	0.09	0.10	0.06
CRR	0.23	0.22	0.38	0.07	1.00	0.18	0.10	0.10
Pol-CVaR	0.37	0.28	0.39	0.09	0.18	1.00	0.25	0.13
Tec-CVaR	0.02	0.13	0.13	0.10	0.10	0.25	1.00	0.07
Phy-CVaR	0.02	0.04	0.06	0.06	0.10	0.13	0.07	1.00

Exhibit 8. NMI Ratio (as of 31 May 2024) (*continued*)

C. US IG

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.46	0.01	0.27	0.16	0.39	0.04	0.02
BR	0.46	1.00	0.39	0.12	0.21	0.31	0.11	0.09
PE	0.01	0.39	1.00	0.26	0.46	0.39	0.21	0.16
ITR	0.27	0.12	0.26	1.00	0.08	0.09	0.12	0.07
CRR	0.16	0.21	0.46	0.08	1.00	0.16	0.11	0.09
Pol-CVaR	0.39	0.31	0.39	0.09	0.16	1.00	0.23	0.24
Tec-CVaR	0.04	0.11	0.21	0.12	0.11	0.23	1.00	0.11
Phy-CVaR	0.02	0.09	0.16	0.07	0.09	0.24	0.11	1.00

D. EUR IG

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.16	0.01	0.18	0.18	0.35	0.08	0.09
BR	0.16	1.00	0.45	0.06	0.26	0.39	0.14	0.12
PE	0.01	0.45	1.00	0.11	0.52	0.50	0.38	0.34
ITR	0.18	0.06	0.11	1.00	0.07	0.05	0.05	0.05
CRR	0.18	0.26	0.52	0.07	1.00	0.18	0.19	0.11
Pol-CVaR	0.35	0.39	0.50	0.05	0.18	1.00	0.37	0.29
Tec-CVaR	0.08	0.14	0.38	0.05	0.19	0.37	1.00	0.16
Phy-CVaR	0.09	0.12	0.34	0.05	0.11	0.29	0.16	1.00

E. US HY

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.15	0.06	0.20	0.12	0.32	0.04	0.01
BR	0.15	1.00	0.31	0.15	0.21	0.29	0.04	0.07
PE	0.06	0.31	1.00	0.41	0.33	0.38	0.01	0.00
ITR	0.20	0.15	0.41	1.00	0.07	0.14	0.08	0.14
CRR	0.12	0.21	0.33	0.07	1.00	0.11	0.07	0.07
Pol-CVaR	0.32	0.29	0.38	0.14	0.11	1.00	0.20	0.17
Tec-CVaR	0.04	0.04	0.01	0.08	0.07	0.20	1.00	0.07
Phy-CVaR	0.01	0.07	0.00	0.14	0.07	0.17	0.07	1.00

F. EUR HY

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.14	0.00	0.21	0.30	0.43	0.01	0.06
BR	0.14	1.00	0.86	0.20	0.20	0.34	0.01	0.02
PE	0.00	0.86	1.00	0.40	0.32	0.48	0.01	0.01
ITR	0.21	0.20	0.40	1.00	0.13	0.11	0.04	0.05
CRR	0.30	0.20	0.32	0.13	1.00	0.08	0.11	0.09
Pol-CVaR	0.43	0.34	0.48	0.11	0.08	1.00	0.35	0.17
Tec-CVaR	0.01	0.01	0.01	0.04	0.11	0.35	1.00	0.04
Phy-CVaR	0.06	0.02	0.01	0.05	0.09	0.17	0.04	1.00

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Decile-Weighted Averages

We now present weighted averages by dividing the Global IG index universe into deciles based on ranking index constituents by a number of climate metrics (see **Exhibit 9**). Note that each decile is very close to but not exactly 10% of total weight. We do not present deciles based on PE, BR, and Tec-CVaR due to the low number of nonzero values available, meaning that decile comparisons are not sensible.

In our view, deciles are useful to examine because portfolio statistics are calculated based on index weights as a starting point and target portfolio-level-weighted average improvements for the most part (except for ITR), while also providing a robustness check for any observations made using correlations or NMI.

Exhibit 9. Weighted Averages within Deciles Created by Ranking Securities Based on Climate Metrics within the Global IG Universe (as of 31 May 2024)

A. Deciles Based on CI

Decile	Index Weight	No. Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
1	10.0%	1,702	0.8	0.0	0.1	2.24	65.24	−1.60	0.03	−0.81
2	10.0%	1,421	2.2	0.0	0.0	1.92	63.30	−0.88	0.11	−0.51
3	10.0%	1,297	3.7	0.0	0.0	2.50	64.88	−1.79	0.04	−0.82
4	10.0%	1,183	5.8	0.7	0.0	2.24	62.88	−1.32	0.38	−0.49
5	10.0%	1,337	10.6	0.0	0.6	2.14	64.30	−3.09	0.18	−0.80
6	10.0%	1,588	20.6	0.8	0.5	2.49	54.35	−9.32	0.66	−1.95
7	10.0%	1,669	31.3	0.0	1.2	2.06	57.98	−7.50	0.93	−1.16
8	10.0%	2,044	63.0	57.0	4.6	2.29	52.14	−8.98	1.42	−1.75
9	10.0%	1,968	242.6	679.4	41.1	2.69	40.54	−41.48	8.02	−2.88
10	10.0%	2,184	1429.9	95.6	40.1	3.55	41.33	−43.74	5.86	−1.97

(continued)

Exhibit 9. Weighted Averages within Deciles Created by Ranking Securities Based on Climate Metrics within the Global IG Universe (as of 31 May 2024) (*continued*)

B. Deciles Based on ITR

Decile	Index Weight	No. Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
1	10.0%	1,505	58.4	0.0	2.5	1.30	65.41	−7.29	3.30	−1.15
2	10.0%	1,514	51.8	0.0	2.6	1.45	64.92	−5.35	0.58	−0.88
3	10.0%	1,567	47.7	0.3	4.4	1.58	61.51	−5.96	0.86	−1.01
4	10.0%	1,851	63.3	1.0	3.7	1.75	59.13	−7.56	1.00	−1.16
5	10.0%	1,672	134.5	201.2	11.9	1.94	51.95	−15.14	2.80	−1.95
6	10.0%	1,679	76.0	107.8	6.1	2.13	55.19	−10.07	1.73	−0.99
7	10.0%	1,615	158.7	88.1	11.0	2.34	52.55	−13.69	1.37	−1.24
8	10.0%	1,477	178.2	81.0	12.7	2.63	55.34	−13.79	2.27	−1.40
9	10.0%	1,841	319.8	48.2	11.9	3.21	53.16	−13.25	0.94	−1.15
10	10.0%	1,672	722.2	305.7	21.4	5.81	47.75	−27.59	2.80	−2.22

C. Deciles Based on CRR

Decile	Index Weight	No. Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
1	10.0%	1,301	22.6	0.0	0.3	1.70	79.53	−2.82	0.82	−1.13
2	10.0%	1,305	33.5	0.0	0.3	2.43	71.50	−2.63	0.15	−0.88
3	10.0%	1,351	10.3	0.0	0.0	1.97	67.66	−1.53	0.02	−0.60
4	10.0%	1,057	20.4	0.0	0.4	2.15	64.66	−1.84	0.12	−0.64
5	10.0%	1,491	89.1	0.0	2.1	2.34	61.99	−5.38	1.09	−0.86
6	10.0%	1,777	76.4	5.6	2.4	2.25	56.24	−5.29	1.00	−1.07
7	10.0%	2,036	89.8	5.7	1.3	2.60	51.11	−8.66	1.96	−0.96
8	10.0%	2,090	131.4	1.4	4.6	2.64	45.90	−14.30	2.59	−1.58
9	10.0%	2,069	727.7	4.2	25.4	3.00	40.33	−27.39	3.91	−2.72
10	10.0%	1,916	609.8	816.6	51.4	3.05	27.97	−49.87	6.00	−2.69

(*continued*)

Exhibit 9. Weighted Averages within Deciles Created by Ranking Securities Based on Climate Metrics within the Global IG Universe (as of 31 May 2024) (*continued*)

D. Deciles Based on Pol-CVaR

Decile	Index Weight	No. Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
1	10.0%	1,278	7.0	0.0	0.0	2.22	66.06	−0.33	0.01	−0.39
2	10.0%	1,080	12.4	0.0	0.0	2.31	64.56	−0.58	0.01	−0.51
3	10.0%	1,427	5.9	0.0	0.0	2.15	63.14	−0.81	0.03	−0.44
4	10.0%	1,824	12.0	0.0	0.0	2.30	59.48	−0.91	0.01	−0.64
5	10.0%	1,672	24.2	0.0	0.0	1.91	62.47	−1.34	0.44	−1.58
6	10.0%	1,575	34.5	0.0	0.5	2.08	63.09	−2.61	0.44	−0.83
7	10.0%	1,634	42.0	2.1	2.8	2.20	60.07	−5.22	0.60	−1.31
8	10.0%	1,867	145.1	9.7	8.1	2.90	50.03	−11.41	1.83	−1.57
9	10.0%	2,302	872.2	18.5	29.6	2.67	43.21	−28.61	4.48	−2.53
10	10.0%	1,734	655.7	803.7	47.3	3.39	34.80	−67.91	9.80	−3.33

E. Deciles Based on Phy-CVaR

Decile	Index Weight	No. Securities	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
1	10.0%	1,511	123.7	38.7	4.5	2.21	61.56	−4.87	0.88	0.05
2	10.0%	1,385	70.7	0.0	1.4	2.62	61.54	−2.68	0.62	−0.20
3	10.0%	1,594	18.0	0.0	0.1	2.07	61.44	−1.22	0.07	−0.30
4	10.0%	1,422	36.5	0.4	1.6	2.27	61.02	−2.91	0.17	−0.34
5	10.0%	1,662	120.4	2.6	3.4	2.69	55.96	−5.12	0.87	−0.48
6	10.0%	1,814	87.3	56.5	5.0	2.18	59.96	−6.71	0.85	−0.65
7	10.0%	1,515	132.1	32.5	5.6	2.48	54.01	−13.76	1.73	−0.88
8	10.0%	2,111	802.1	55.8	24.7	2.62	49.75	−24.82	3.53	−1.23
9	10.0%	1,694	177.0	96.2	14.2	2.45	54.39	−21.54	1.06	−2.32
10	10.0%	1,685	242.8	551.0	27.8	2.55	47.29	−36.10	7.85	−6.79

Note: The deciles are created for each metric by ranking securities based on perceived risk exposure (low risk = Decile 1; high risk = Decile 10).

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Portfolio Analysis

In this section, we restrict our analysis to the Global IG USD universe for three main reasons: (1) We want to maintain a global universe but remove the effects of currency, (2) the findings are generalizable to other regional-focused universes, and (3) coverage is marginally better relative to other universes studied (e.g., Global High Yield) and hence minimizes any impact from missing value treatments.

Portfolio Construction Approach

In order to construct portfolios that seek to improve the climate profile relative to the index, we chose to select simple portfolio-weighted averages as the target metric (except for ITR, which we will explain). Securities are ranked based on the target metric (e.g., CI), and the companies scoring the worst are screened out one by one (weight is reallocated to the remaining names proportionally) until the target objective is achieved (e.g., 20% reduction in weighted average CI). For ITR, a similar approach is followed; however, the target objective is calculated using the aggregated budget method (rather than weighted average). When multiple securities are tied, we screen out the one with the lowest index weight first and proceed as before. We construct the following portfolios and note that there is a certain level of subjectivity to choosing the level of improvements for various targets; however, we believe that the range in **Exhibit 10** covers commonly used targets by investors seeking to incorporate climate-themed investment objectives into their portfolios.

Exhibit 10. Details of Portfolio Target Metrics and Objectives Relative to the Standard Market-Capitalization-Weighted Index

Target Metric	Calc. Method	Target Type	Target Objective				
CI	Weighted average	Relative reduction	−20%	−40%	−60%	−80%	
PE	Weighted average	Relative reduction	−20%	−40%	−60%	−80%	−100%
BR	Weighted average	Relative reduction	−20%	−40%	−60%	−80%	−100%
ITR	Aggregated budget	Absolute level target (°C)	2.25	2.00	1.75	1.50	
CRR	Weighted average	Relative improvement	10%	20%	30%		
Pol-CVaR	Weighted average	Relative reduction	−20%	−40%	−60%	−80%	
Tec-CVaR	Weighted average	Relative improvement	10%	20%	30%	40%	
Phy-CVaR	Weighted average	Relative reduction	−20%	−40%	−60%	−80%	

For simplicity, the data presented in the following section include only the weighted average ITR; however, the interpretation and directionality are quite similar regardless of the approach selected.

We use this simple approach since we are constructing portfolios based on a single target metric. When there are a large number of sustainability objectives to consider in a portfolio's construction, an optimizer may be used to define the initial eligible opportunity set from which the portfolio will then seek to replicate. We do not explore this approach in our study, but it may be a suitable topic for future study.

For the construction of portfolios holding physical bonds, due to the large number of securities in broad credit market indexes, liquidity characteristics and transaction costs may render full replication of the index either impossible or not economically attractive. Hence, almost all credit strategies that cannot be fully replicated will usually be managed based on an approach called stratified sampling. We do not explain this approach further, but note that the impact of climate metric incorporation in practical portfolio management may have a slight difference relative to the research here. However, we believe the findings very much apply regardless.

Impact Analysis

In this section, we present the impacts of these sets of portfolios targeting improvement in a single climate metric along three dimensions.

Impact on Other Climate Metrics

First, in **Exhibit 11**, we demonstrate the effects on other climate metrics (e.g., portfolios that reduce CI are also studied for improvements in Pol-CVaR, PE, and all other metrics).

Exhibit 11. Improvements in Climate Metrics Relative to the Benchmark (as of 31 May 2024)

A. Portfolios Targeting Improvement in CI

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	−20%	−9%	−6%	−3%	1%	−4%	2%	2%
Portfolio 2	−40%	−8%	−12%	−4%	2%	−8%	−3%	2%
Portfolio 3	−60%	−6%	−20%	−5%	2%	−14%	−8%	2%
Portfolio 4	−80%	−13%	−45%	−9%	4%	−33%	−17%	−5%

B. Portfolios Targeting Improvement in Fossil-Fuel Reserves

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	7%	−31%	−4%	−1%	1%	−3%	6%	1%
Portfolio 2	7%	−42%	−6%	−2%	1%	−4%	6%	1%
Portfolio 3	7%	−61%	−10%	−2%	1%	−7%	−6%	0%
Portfolio 4	7%	−81%	−16%	−2%	2%	−11%	−18%	−2%
Portfolio 5	4%	−100%	−27%	−4%	3%	−19%	−19%	−4%

C. Portfolios Targeting Improvement in BR

	CI	FF	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	5%	−13%	−21%	−2%	1%	−5%	7%	0%
Portfolio 2	4%	−60%	−41%	−2%	3%	−14%	−3%	−3%
Portfolio 3	−7%	−90%	−60%	−5%	4%	−24%	−20%	−7%
Portfolio 4	−38%	−92%	−80%	−7%	5%	−32%	−26%	−7%
Portfolio 5	−70%	−99%	−100%	−8%	7%	−52%	−53%	−15%

D. Portfolios Targeting Improvement in ITR

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	−29%	−26%	−17%	−14%	2%	−16%	−5%	−9%
Portfolio 2	−45%	−52%	−35%	−20%	4%	−29%	−12%	−14%
Portfolio 3	−68%	−67%	−49%	−28%	5%	−36%	−21%	−15%
Portfolio 4	−72%	−95%	−57%	−32%	9%	−46%	−41%	−18%

(*continued*)

Exhibit 11. Improvements in Climate Metrics Relative to the Benchmark (as of 31 May 2024) (*continued*)

E. Portfolios Targeting Improvement in CRR

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	−64%	−99%	−78%	−8%	10%	−54%	−50%	−13%
Portfolio 2	−80%	−99%	−90%	−14%	20%	−74%	−75%	−33%
Portfolio 3	−88%	−100%	−98%	−19%	30%	−80%	−90%	−35%

F. Portfolios Targeting Improvement in Pol-CVaR

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	−6%	−52%	−15%	−4%	2%	−20%	−22%	−5%
Portfolio 2	−21%	−87%	−35%	−6%	4%	−40%	−35%	−8%
Portfolio 3	−64%	−95%	−56%	−10%	6%	−61%	−62%	−13%
Portfolio 4	−85%	−98%	−85%	−11%	10%	−80%	−82%	−29%

G. Portfolios Targeting Improvement in Tec-CVaR

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	9%	−1%	7%	−2%	0%	5%	16%	7%
Portfolio 2	15%	6%	11%	0%	−1%	9%	25%	11%
Portfolio 3	22%	7%	16%	1%	−2%	14%	35%	15%
Portfolio 4	31%	15%	25%	−1%	−4%	22%	44%	19%

H. Portfolios Targeting Improvement in Phy-CVaR

	CI	PE	BR	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
Index level	241.3	89.1	9.54%	2.51	55.74	−11.87	1.22	−1.30
Portfolio 1	8%	−11%	−3%	−2%	1%	−4%	2%	−20%
Portfolio 2	6%	−51%	−22%	−3%	2%	−16%	−20%	−40%
Portfolio 3	−5%	−71%	−33%	−4%	3%	−32%	−31%	−60%
Portfolio 4	−57%	−87%	−74%	−7%	7%	−68%	−65%	−80%

Notes: All statistics are reported using simple weighted averages. For Panel D, the ITR target by aggregated budget method is 2.25°C, 2°C, 1.75°C, and 1.5°C.

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Portfolio Characteristics

Second, in **Exhibit 12**, we demonstrate the effects on fundamental portfolio characteristics, such as tracking error, duration, and yield.

Exhibit 12. Fundamental Portfolio Characteristics of Climate Improvement Portfolios (as of 31 May 2024)

A. Tracking Error

Tracking Error (in bps)					
Target	−20%	−40%	−60%	−80%	
CI	8.1	12.3	15.6	19.9	
Target	−20%	−40%	−60%	−80%	−100%
PE	5.2	5.0	6.2	7.1	9.0
Target	−20%	−40%	−60%	−80%	−100%
BR	6.3	8.7	11.8	15.5	31.3
Target	2.25	2	1.75	1.5	
ITR	9.0	7.4	17.7	37.4	
Target	10%	20%	30%		
CRR	17.6	24.0	38.4		
Target	−20%	−40%	−60%	−80%	
Pol-CVaR	9.7	12.2	19.8	25.4	
Target	10%	20%	30%	40%	
Tec-CVaR	9.4	16.4	13.1	16.1	
Target	−20%	−40%	−60%	−80%	
Phy-CVaR	4.0	6.4	10.6	49.9	

B. Option-Adjusted Duration

OAD (reference level = 6.55)					
Target	−20%	−40%	−60%	−80%	
CI	−1.0%	−1.6%	−2.1%	−2.7%	
Target	−20%	−40%	−60%	−80%	−100%
PE	−0.5%	−0.4%	−0.7%	−0.8%	−1.1%
Target	−20%	−40%	−60%	−80%	−100%
BR	−0.6%	−1.0%	−1.4%	−2.1%	−4.5%
Target	2.25	2	1.75	1.5	
ITR	−1.1%	−0.5%	2.0%	5.4%	
Target	10%	20%	30%		
CRR	−2.2%	−2.3%	3.1%		
Target	−20%	−40%	−60%	−80%	
Pol-CVaR	−1.3%	−1.7%	−2.7%	−3.3%	
Target	10%	20%	30%	40%	
Tec-CVaR	−0.7%	−1.7%	−0.4%	1.3%	
Target	−20%	−40%	−60%	−80%	
Phy-CVaR	−0.1%	−0.5%	−1.1%	−7.1%	

Exhibit 12. Fundamental Portfolio Characteristics of Climate Improvement Portfolios (as of 31 May 2024) (*continued*)

C. Option-Adjusted Spread

OAS (reference level = 87.87)					
Target	−20%	−40%	−60%	−80%	
CI	−0.6%	−0.6%	−0.9%	−2.0%	
Target	−20%	−40%	−60%	−80%	−100%
PE	−0.4%	−0.3%	−0.2%	−0.1%	−0.4%
Target	−20%	−40%	−60%	−80%	−100%
BR	−0.7%	−0.7%	−1.0%	−1.3%	−1.5%
Target	2.25	2	1.75	1.5	
ITR	−0.6%	−1.3%	−0.4%	−1.0%	
Target	10%	20%	30%		
CRR	−2.4%	−7.7%	−10.6%		
Target	−20%	40%	−60%	−80%	
Pol-CVaR	−0.5%	−0.8%	−1.4%	−2.8%	
Target	10%	20%	30%	40%	
Tec-CVaR	0.3%	0.9%	0.7%	0.1%	
Target	−20%	−40%	−60%	−80%	
Phy-CVaR	−0.7%	−0.7%	−1.0%	−1.9%	

D. Yield to Worst

Yield (reference level = 5.56)					
Target	−20%	−40%	−60%	−80%	
CI	−0.1%	−0.1%	−0.1%	−0.3%	
Target	−20%	−40%	−60%	−80%	−100%
PE	−0.1%	−0.1%	0.0%	0.0%	0.0%
Target	−20%	−40%	−60%	−80%	−100%
BR	−0.1%	−0.1%	−0.1%	−0.2%	−0.2%
Target	2.25	2	1.75	1.5	
ITR	−0.1%	−0.2%	0.0%	−0.2%	
Target	10%	20%	30%		
CRR	−0.4%	−1.2%	−1.6%		
Target	−20%	−40%	−60%	−80%	
Pol-CVaR	−0.1%	−0.1%	−0.2%	−0.4%	
Target	10%	20%	30%	40%	
Tec-CVaR	0.1%	0.2%	0.1%	0.0%	
Target	−20%	−40%	−60%	−80%	
Phy-CVaR	−0.1%	−0.1%	−0.2%	−0.2%	

Exhibit 12. Fundamental Portfolio Characteristics of Climate Improvement Portfolios (as of 31 May 2024) (*continued*)

E. Index Rating: Numeric Representation of Credit Ratings (AAA = 2, BAA3 = 11)

Index Rating (reference level = 8.18)					
Target	−20%	−40%	−60%	−80%	
CI	0.0%	0.2%	0.0%	−1.0%	
Target	−20%	−40%	−60%	−80%	−100%
PE	0.0%	0.0%	0.1%	0.3%	0.1%
Target	−20%	−40%	−60%	−80%	−100%
BR	−0.5%	−0.5%	−0.6%	−0.7%	−0.8%
Target	2.25	2	1.75	1.5	
ITR	−0.1%	−1.1%	−0.4%	−1.2%	
Target	10%	20%	30%		
CRR	−1.2%	−4.8%	−5.8%		
Target	−20%	−40%	−60%	−80%	
Pol-CVaR	0.0%	−0.4%	−0.6%	−2.0%	
Target	10%	20%	30%	40%	
Tec-CVaR	0.6%	0.6%	0.4%	0.9%	
Target	−20%	−40%	−60%	−80%	
Phy-CVaR	−0.3%	−0.4%	−0.9%	−3.4%	

Note: The tracking error statistics in Panel A represent *ex ante* one-year tracking error based on the Bloomberg MAC3 Model and are relative to the Global IG USD index.

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

Sector Weights

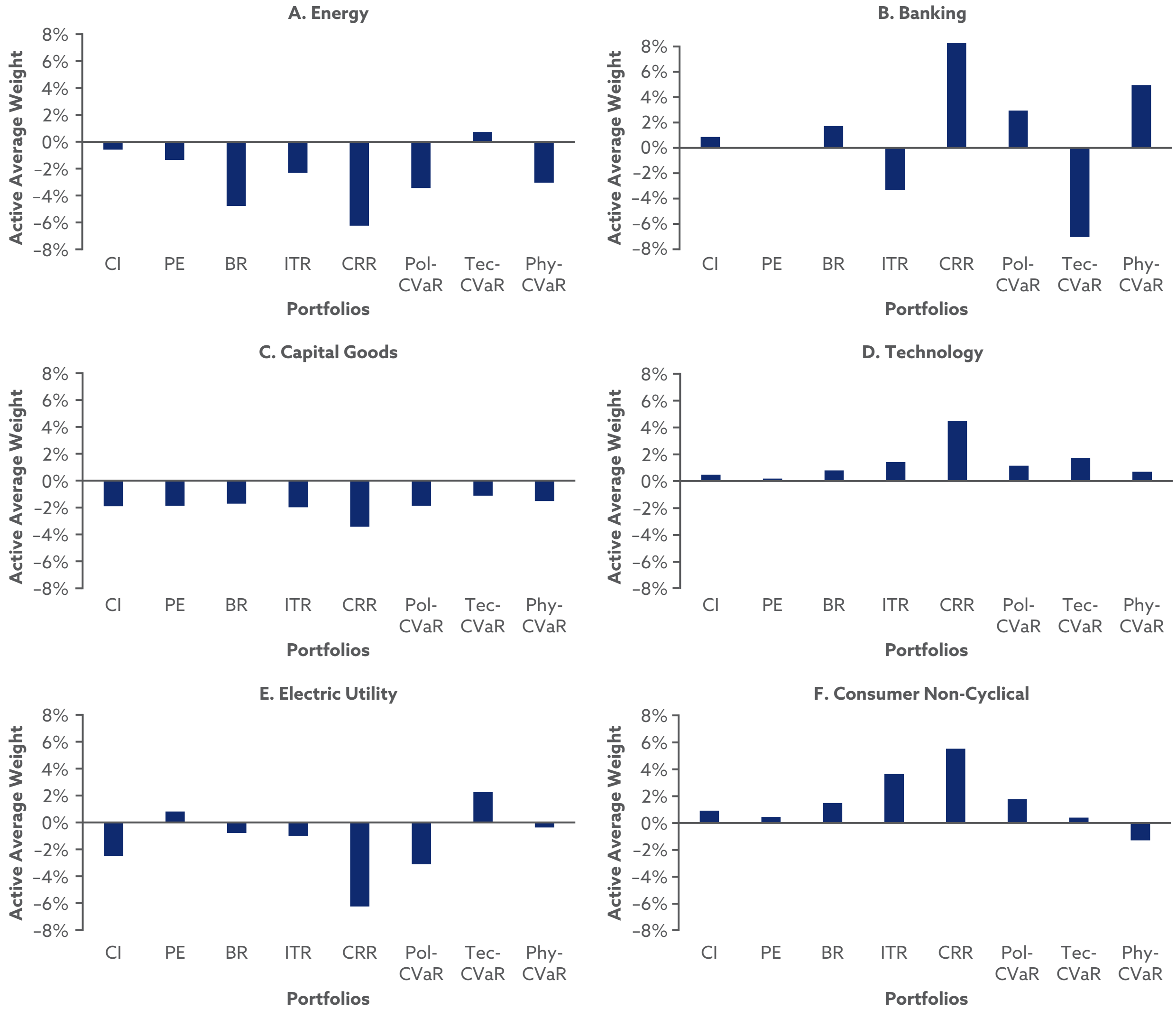
Third, we present the average active weights of certain sectors. The sectors are selected based on the average active weights across various metrics, as well as relative size in the index. For each target metric, we report the average active weight across the portfolios targeting improvement in that metric. For example, in Panel A of **Exhibit 13**, CI represents the average active weight to the Energy sector across the four CI improvement portfolios (−20%, −40%, −60%, and −80%).

Discussion

Based on the portfolios and analysis, we make several observations:

- It may be possible to target improvements in multiple metrics simultaneously without taking on too much additional risk. Due to the correlated nature of the underlying climate metrics, portfolios that target improvements in climate metric exposure also often result in improvements in other climate metrics. Notably, portfolios that target improvements in CI, PE, BR, ITR, or Pol-CVaR also concurrently result in improvement in the other metrics, though the level of improvement varies.

Exhibit 13. Average Active Sector Weights across Selected Sectors (Bloomberg Class 3; as of 31 May 2024)



Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

- However, a side effect of such portfolios is that they also result in a worsening of the exposure to the Tec-CVaR metric. This finding is further borne out by the results of the portfolios targeting an increase in Tec-CVaR, which results in a worsening for all the other climate metrics. This result indicates that it may be challenging to obtain simultaneous improvements in Tec-CVaR and the other metrics.
- An interesting finding is that improvement in CRR appears to improve the other metrics significantly as well (except for Tec-CVaR); however, this comes at the cost of a relatively higher tracking error and deviation in sector allocations.

- In general, the sector takeaways are not surprising and are consistent with previous research. Carbon-intensive sectors, such as Energy, Utilities, and Capital Goods, tend to be underweighted by such portfolios, while Banking, Technology, and Consumer Non-Cyclical tend to be overweighted. There does seem to be a nuance related to Tec-CVaR in which the effects appear to be reversed (underweights to Banking and overweights to Energy and Electric Utility).
- Regarding the *ex ante* tracking error impact of the portfolios that incorporate climate improvements versus the standard market-weighted index, in general, achieving higher improvement leads to higher tracking error. However, there does appear to be an "inflection point" for portfolio improvements in most metrics, where achieving the next level of improvement costs a lot more relative to the previous level. This is most visible for BR (moving from −80% to −100%), Phy-CVaR (going from −60% to −80%), ITR (going from 1.75°C to 1.5°C), and CRR (going from 20% to 30%). Regarding the level of tracking error itself, note that portfolios investing in investment-grade-rated bonds with *ex ante* tracking error above the 50 bp threshold are generally considered to be active investment strategies. For index investors in credit universes, the level of tracking error is typically constrained well below this threshold, and as a result, many of the portfolios we tested may prove to be impractical. Therefore, while small levels of improvement are possible at the lower end of the tracking error spectrum, larger and simultaneous improvements in the sustainability targets relative to the benchmark (particularly for Tec-CVaR) may prove to be challenging to achieve.
- Looking at the other portfolio characteristics, there are similar findings for the OAD, OAS, and index rating, while the impact on yield appears to be relatively muted.

Conclusion

Given the increasing prevalence and availability of forward-looking climate data metrics in investment management, we studied a selection of the various types of datasets available in the market. We found that coverage in common fixed-income universes is good in investment-grade credits but slightly lacking in high-yield universes, necessitating missing value treatments.

We found that although the classification would suggest otherwise, some types of forward- and backward-looking metrics are closely related to each other (notably, CI, PE, BR, ITR, and Pol-CVaR). At the same time, some forward-looking metrics (Phy-CVaR and Tec-CVaR) appear to have a weaker or an opposite relationship with backward-looking metrics and may contain complementary information.

We further found that portfolios that seek to improve against the index's climate profile may be able to achieve simultaneous improvements in multiple transition risk-related metrics while also losing exposure to transition opportunities. This finding suggests that the opportunity exposure may need to be controlled separately. We conclude by suggesting the study of simultaneous improvements in risk and opportunity as an area for future research.

Appendix

In this section, we review some key information theory concepts and provide Pearson correlation statistics of climate metrics in the Global IG universe.

Information Theory Concepts Review

In this section, we will use the entropy definition and notation from López de Prado (2018).

Let X be a discrete random variable that takes a value x from the set S_x with probability $p(x)$. The entropy of X is defined as

$$H(X) = -\sum_{x \in S_x} p(x) \ln[p(x)].$$

Throughout this section, we will follow the convention that $\ln(e) = 1$, $0 \ln(0) = 0$, since $\lim_{p \to 0^+} p \ln(p) = 0$. Entropy can be interpreted as the amount of uncertainty associated with X. Entropy is zero when all probability is concentrated in a single element of S_x. Entropy reaches a maximum at $\ln\left(\|S_x\|\right)$ when X is distributed uniformly, $p(x) = 1/\|S_x\|$, $\forall x \in S_x$.

Let Y be a discrete random variable that takes a value y from the set S_y with probability $p(y)$. The joined entropy of X and Y is defined as

$$H(X,Y) = -\sum_{x,y \in S_x \times S_y} p(x,y) \ln[p(x,y)].$$

Mutual information is defined as the decrease in uncertainty (or informational gain) in X that results from knowing the value of Y:

$$I(X,Y) = H(X) + H(Y) - H(X,Y).$$

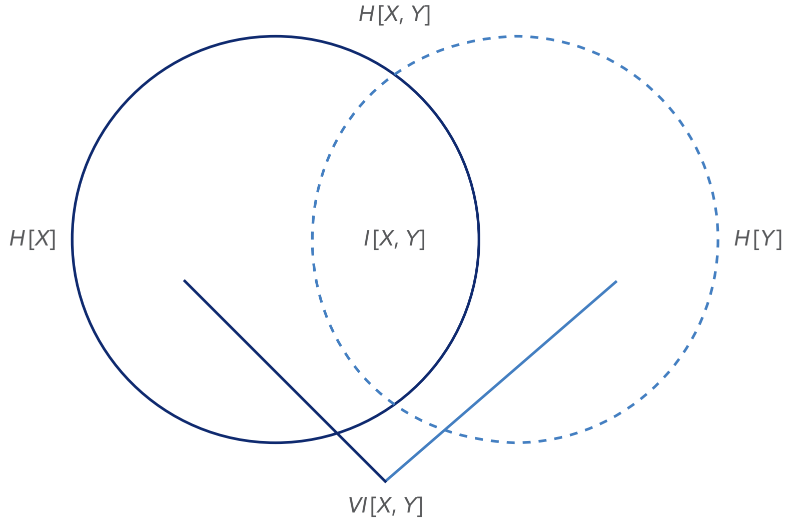
Variation of information is defined as

$$VI(X,Y) = H(X,Y) - I(X,Y).$$

It can be interpreted as the uncertainty one expects in one variable if told the value of other. **Exhibit A1** shows a pictorial depiction of these concepts.

It is important to recognize that that this definition of entropy is finite only for discrete random variables. In the continuous case, one can discretize the random variables. We adopt the methodologies from Hacine-Gharbi, Ravier, Harba, and Mohamadi (2012), Hacine-Gharbi and Ravier (2018), and López de Prado (2018).

Exhibit A1. Correspondence between Joint Entropy, Marginal Entropies, Mutual Information, and Variation of Information



Note: Readers familiar with these concepts will notice that the conditional entropies definition was not included to keep the graph clearer.

Pearson Correlation

For interested readers, **Exhibit A2** shows the Pearson correlation of climate metrics in the Global IG universe.

Exhibit A2. Pearson Correlation of Climate Metrics in Global IG (as of 31 May 2024)

	CI	BR	PE	ITR	CRR	Pol-CVaR	Tec-CVaR	Phy-CVaR
CI	1.00	0.39	0.00	0.38	–0.28	–0.42	0.11	–0.06
BR	0.39	1.00	0.34	0.23	–0.43	–0.48	0.17	–0.07
PE	0.00	0.34	1.00	0.09	–0.24	–0.33	0.17	–0.07
ITR	0.38	0.23	0.09	1.00	–0.27	–0.32	0.08	–0.08
CRR	–0.28	–0.43	–0.24	–0.27	1.00	0.46	–0.07	0.09
Pol-CVaR	–0.42	–0.48	–0.33	–0.32	0.46	1.00	–0.37	0.23
Tec-CVaR	0.11	0.17	0.17	0.08	–0.07	–0.37	1.00	–0.10
Phy-CVaR	–0.06	–0.07	–0.07	–0.08	0.09	0.23	–0.10	1.00

Sources: State Street Global Advisors; Bloomberg; MSCI ESG Research; ISS ESG.

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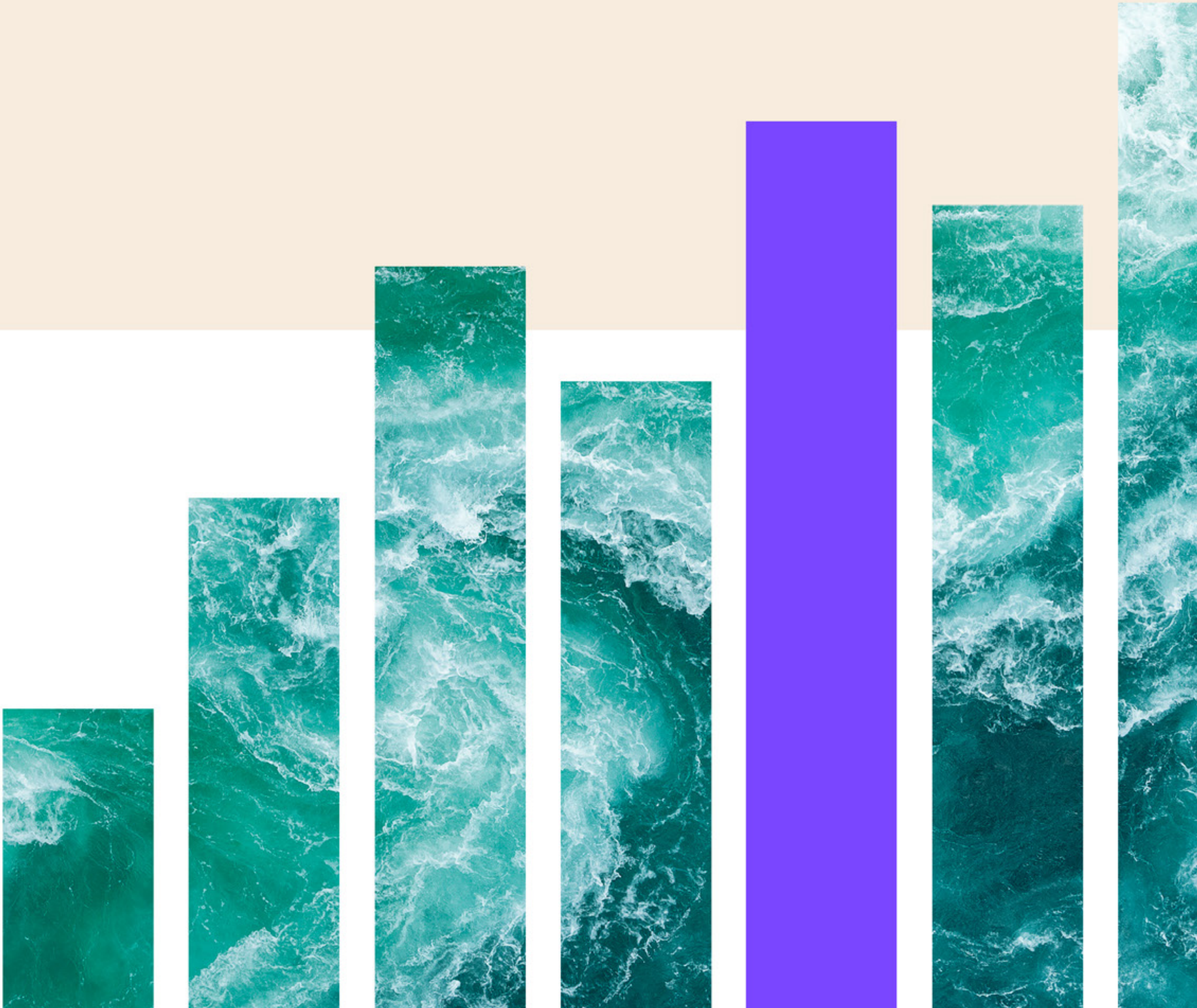
Investment Innovations Toward Achieving Net Zero: Voices of Influence

III. Case Studies



RECONCILING PORTFOLIO DIVERSIFICATION WITH A SHRINKING CARBON FOOTPRINT

Patrick Bolton
Professor of Finance, Columbia University, New York City, and Imperial College, London

Marcin Kacperczyk
Professor of Finance, Imperial College, London

Henrik Lorin Rasmussen
Chief Portfolio Manager, PenSam, Farum, Denmark

Frédéric Samama
Adjunct Professor of International and Public Affairs, Sciences Po, Paris, and Columbia University, New York City

Net-zero-aligned portfolios (NZPs) aim to reduce the portfolio carbon footprint over time along a pathway of decarbonization that is consistent with science-based decarbonization pathways for the global economy. One of the goals of this portfolio strategy is to reward companies that engage in emission reduction by including them in NZPs and to penalize the others while keeping a low portfolio sector deviation. NZPs have grown increasingly popular among institutional investors. The first part of this chapter provides a methodology to construct NZPs. The second part discusses a case study of the Danish Pension Fund (PenSam), which recently adopted an NZP methodology with the goal of minimizing market risk. Our results indicate that NZPs are feasible investment tools that deliver good diversification properties while simultaneously offering a significant reduction in the carbon footprint of the portfolio.

Net-zero-aligned portfolios (NZPs) are dynamically constructed so that their carbon footprint—defined as the market share of the carbon footprint of constituent stocks in the portfolio—is shrinking over time to achieve a net-zero (NZ) footprint by a target date (typically 2050). The basic aim of NZP construction is to reduce the carbon footprint over time in line with the prescribed, science-based Intergovernmental Panel on Climate Change (IPCC) decarbonization pathway for the global economy. Thus, the NZ-aligned decarbonization pathway prescribes a rate of reduction of the portfolio carbon footprint greater than or equal to the rate at which the IPCC estimated global carbon budget is shrinking.

One fundamental reason for aligning portfolio decarbonization with the recommended decarbonization of the global economy is to mitigate carbon transition risk for investors. Indeed, a portfolio aligned with this pathway is protected against policy shocks (whose timing and size are always difficult to predict) that aim to lower carbon emissions to set the decarbonization of the economy on an NZ trajectory. A decarbonization of the economy that is consistent with a maximum 2°C, preferably 1.5°C, global average temperature increase necessarily involves stranded assets and regulatory constraints on the use of fossil fuels. Thus, this portfolio decarbonization approach provides a hedge against costly future climate-related regulations.

The automobile industry provides a salient illustration of the massive disruptions that such anticipated regulations can give rise to, even if no assets are necessarily stranded. When policy interventions result in asset stranding, investors take a hit. A portfolio that is less exposed to assets with high carbon footprints (i.e., those at greater risk of asset stranding) provides a hedge to investors against carbon transition risk relative to a market benchmark.

Deviations from market indexes, however, inevitably involve diversification risk. A portfolio that already has an NZ footprint today can be straightforwardly constructed. It would contain stocks of only green companies that have an NZ footprint. But the problem with such a portfolio is obviously the lack of idiosyncratic risk diversification: This portfolio would expose investors to major undiversified risk without adequate compensation for holding that risk. Thus, the goal of NZP construction is to reduce carbon transition risk exposure while maintaining maximum diversification to maximally reduce the tracking error of NZP expected returns with expected returns of a market index.

The tension between the conflicting goals of portfolio diversification and carbon transition risk hedging is resolved by decarbonizing a well-diversified portfolio gradually along a decarbonization pathway that is aligned with NZ targets and implementing portfolio construction rules minimizing sector deviations. Indeed, if the global economy and all companies are on an NZ trajectory, then a market portfolio will be too, reducing carbon transition risk for investors even if no further portfolio decarbonization is undertaken. Also, the higher the carbon transition risk, the bigger the gap between carbon emissions from a global economy operating on a business-as-usual (BAU) pathway and those from a global economy on an NZ pathway. We take this gap to be a measure of the macro carbon transition risk investors are exposed to if they do not reduce the carbon footprint of their portfolio. An NZP that gradually reduces the portfolio carbon footprint along an NZ trajectory essentially hedges investors against this macro carbon transition risk, which may grow over time the longer the global economy remains on a BAU pathway. Meanwhile, diversification risk remains limited.

The popularity of NZ investing goals among institutional investors has grown rapidly, with more than USD130 trillion of global assets under management currently covered by various NZ investment initiatives. The NZP principle has also shaped policy debates around sustainable finance. For instance, the EU Climate Transition Benchmarks Regulation established uniform rules for low-carbon investment benchmark indexes and set their required decarbonization trajectories.

Even though investment in NZPs does not imply the decarbonization of the global economy, at scale it does provide incentives for companies to decarbonize. If a large investor base is invested in NZPs, companies will worry about being excluded from their portfolios. Companies that undertake emission reductions will be rewarded by being included in NZPs. Companies that lag behind their peers risk being penalized by being excluded from NZPs. A growing fraction of companies, however, are on a carbon-neutral trajectory or already have a low-carbon footprint.

The methodology behind constructing NZPs that we describe in this chapter is built around two key concepts. The first is that investors apply a dynamic carbon budget in their portfolio decisions. This budget is informed by scientific projections about climate scenarios and determines the maximum amount of emissions an NZP can be exposed to at each point in time. The second key concept is the rule by which investors select companies into NZPs.

For our illustration, we have chosen the 2021 IPCC pathway, which is consistent with the 1.5°C scenario being achieved with 83% probability (see IPCC 2021, Table SPM.2). Our selection rule is based on firm-level emissions that comprise both direct and indirect emissions. Notably, our framework is flexible enough to accommodate deviations from either of these two assumptions. The main optimization problem we solve is that of minimizing the portfolio tracking error with respect to the benchmark market index by reweighting active share holdings, conditional on the pre-selected set of companies fitting in the (shrinking) portfolio carbon budget. To ensure that tracking error remains limited, we also impose a penalty on sectoral and country deviations from the benchmark market index for the NZP.

Interestingly, it is possible to obtain major reductions in portfolio carbon footprints while maintaining a similar overall sectoral exposure as the market index. This dynamic portfolio decarbonization is achievable because of the substantial heterogeneity in company carbon footprints within each sector (Bolton and Kacperczyk 2021a; 2023). Our analysis is best understood as a methodology suited for passive investors who seek diversification by investing in a market index, and who also seek to reduce their exposure to carbon transition risk (or prefer investments with a lower carbon footprint, other things equal).

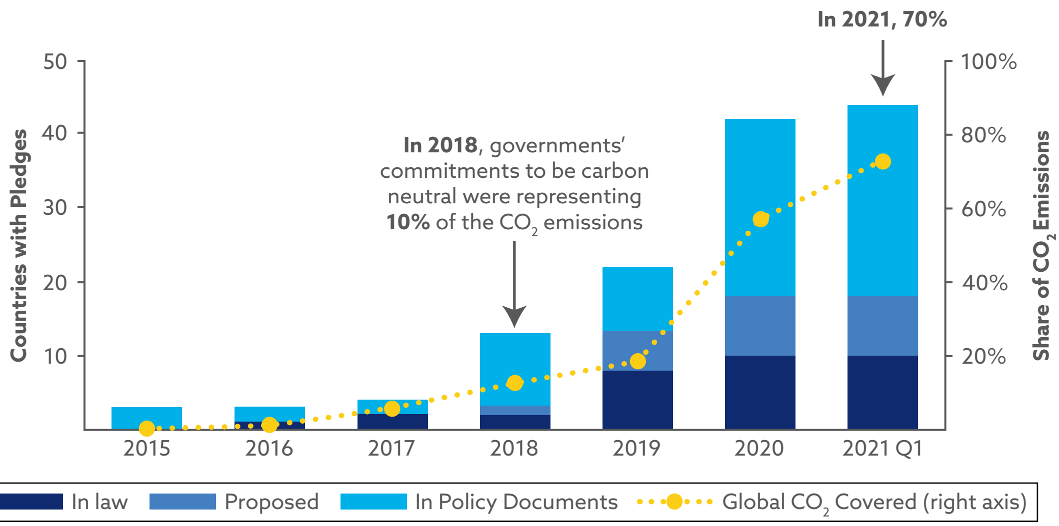
Later in this chapter, we illustrate how this approach has been implemented by one of the largest Danish pension funds, PenSam. The results from PenSam's portfolio decarbonization indicate that one can achieve a portfolio that is aligned with an NZ target and at the same time does not deviate much from the market benchmark. Moreover, the portfolio is scalable to large amounts of assets under management and therefore provides a realistic decarbonization model in the current investment environment.

The Global Context: Net-Zero Commitments and Macro-Regulatory Risk

Portfolio decarbonization has risen to the forefront of investor challenges in recent years, to a large extent because of the changing context of a global policy shift on climate mitigation and the decarbonization of the economy. Ever since the landmark 2015 Paris Agreement on climate change, the number of countries and other actors that have pledged to reduce greenhouse gas (GHG) emissions has increased sharply. The most salient pledges have taken the form of NZ targets. Currently, more than 130 countries have pledged to become carbon neutral by 2050, with China setting its NZ target by 2060 and India by 2070.[1] A few countries have pledged to reach their NZ targets before 2050, and some have even made legally binding commitments. As **Exhibit 1** highlights, all these commitments now represent more than 70% of global emissions.

These commitments have not yet materialized in the form of lower global GHG emissions, however (Bolton and Kacperczyk 2021b). According to the International Energy Agency (IEA 2023), global GHG emissions are estimated to peak by 2025, which means that the gap between the current level of emissions and emissions compatible with a 2050 NZ pathway is still rising. As this gap begins to close, it will represent a huge global carbon transition risk for investors—especially for passive investors holding market indexes, which are skewed toward well-established companies that depend heavily on fossil fuels.

Exhibit 1. Global Commitments and Carbon Emissions, 2015–2021



Source: International Energy Agency (IEA 2021, p. 33); authors.

[1]See https://unfccc.int/NDCREG for further details.

This exposure to legacy brown assets contains two main risks. The first is regulatory risk for brown companies. Inevitably, the decarbonization of the global economy over the next quarter-century necessitates extensive policy interventions to push these companies to transform their operations. Some of these interventions will fundamentally disrupt major sectors of the economy. A particularly salient example is the auto industry and the phaseout of thermal cars, with sales of new models scheduled to be banned starting in 2035 in Europe. This ban means that 65% of total automobile production in 2022 will be phased out in the next decade. Such a momentous disruption translates into major transition risk for investors holding stocks in the current major auto companies. The second is technological risk with respect to competition from the entry of new green companies and the expansion of green operations, which are likely to benefit from subsidies, tariff protections, and other incentives similar to those introduced by the Inflation Reduction Act of 2022 in the United States.

Investors holding market indexes today can reduce their exposure to this global transition risk by essentially underweighting their holdings of brown assets and overweighting stocks of green companies, in anticipation of the energy transition that must happen but has not yet taken place. By aligning their portfolios with the direction of future policy and the future reallocation of the economy, investors can hedge the carbon transition risk embedded in current market benchmarks. All the available evidence suggests that the corporate sector is not decarbonizing fast enough. The longer the necessary decarbonization is delayed, the more carbon transition risk accumulates. All the climate stress tests that have been conducted to date agree that a delayed and disorderly transition will cost more and subject the economy to sudden, large shocks (Network for Greening the Financial System 2023). From a pure prudence perspective, therefore, it is desirable to reduce investors' exposure to these shocks.

Of course, not all investors can hedge this risk at the same time; someone must be left holding the bag. To the extent that long-term-oriented investors (e.g., pensioners) can offload this risk to others before it is too late, this is desirable. Currently, passive investors that hold the market portfolio are most at risk of being left holding the bag, as more nimble active investors are likely to be more proactive in anticipating transition shocks when they begin to materialize. Slow-moving capital is most exposed to carbon transition risk. Portfolio decarbonization, especially passive portfolio decarbonization, can be seen as a structural response to the risks associated with the coming energy transition by bringing forward the movement of capital away from declining legacy assets and toward the new investment opportunities.

Low-Carbon Indexes

All major index providers now offer low-carbon indexes, but with the exception of Standard & Poor's (S&P), they do not offer low-carbon indexes that are built around a shrinking carbon budget and an NZ target. The key differences in the construction of these low-carbon indexes essentially boil down to four design choices: objective, exclusions, weighting, and constraints. We summarize the parameter choices for these four dimensions in **Exhibit 2**. The design of some of these low-carbon indexes has also been shaped by the EU Climate Transition Benchmarks Regulation, which is based on two different climate benchmarks: the Paris Aligned Benchmarks (PABs) and the Climate Transition Benchmarks (CTBs). Combinations of these four parameters can lead to many different low-carbon index designs, but we can distinguish between two broad families of climate indexes.

The main purpose of the first family of indexes was to reduce the carbon footprint while having a low tracking error. This family was initiated with the S&P 500 Carbon Efficient Select Index (Andersson, Bolton, and Samama 2016b). It became clear only later that this technology was a way to address the main challenge for investors at the time: "the tragedy of the horizon" for climate change action (Carney 2015). When this index and later the MSCI ESG Leaders Indexes and MSCI Factor ESG Target Indexes were introduced, there was still little climate policy action in most countries and little awareness of carbon transition risk. Accordingly, for investors concerned about climate change, it was a matter of hedging a still somewhat distant risk. Therefore, by investing in a low tracking error, low-carbon index, investors would be able to buy time for free on a still mispriced risk. Framing the climate investment solution as a "free option" on carbon transition risk made it easier to create a market for low-carbon indexes and to mobilize investors to engage with the rising climate risk (Andersson, Bolton, and Samama 2016a).

The second and more recent family of low-carbon indexes is more explicitly tied to achieving an NZ objective. This family has two archetypes. The first is

Exhibit 2. Parameter Choices in Low-Carbon Indexes

Parameter	Typical Parameter Setting
Objective	Reduction target Scope 1 + 2 or Scope 1 + 2 + 3 Inclusion of other targets, such as green revenue
Exclusions	PAB exclusions CTB exclusions Fossil fuel exclusions
Weighting	Simple rebalancing Optimized approach based on reducing tracking error Best-in-class approach Adjustment factor
Constraints	Sector constraints Country constraints Turnover

essentially a static design, selecting corporations that are aligned with an NZ objective. The second is a dynamic design, reshuffling portfolios regularly over time to keep the carbon footprint of the portfolio on an NZ trajectory. The two approaches can be evaluated based on scalability, portfolio construction risk, and impact.

The first model's strength is that it builds on real decarbonization of the constituents, which is taken to count as real impact. This approach resembles investing in green companies, with a broader universe if one also includes companies that are about to become green. The main challenge for this static model, however, is that it is constrained by the still-limited number of corporations that have made NZ commitments. Moreover, even these companies can only truly commit to reduce their direct emissions. They may still be dependent on an ecosystem responsible for indirect (scope 3) emissions that is not aligned with an NZ target. The main challenges for this model are scalability (WWF 2022) and tracking error (portfolio construction risk).

The strength of the second (dynamic) model is that a well-diversified portfolio can have a carbon footprint that is on a trajectory to NZ that is consistent with what the IPCC prescribes. The EU PAB/CTB benchmarks fit into this category. Based on simulations for a large portfolio (up to USD1 trillion in value), Bolton, Kacperczyk, and Samama (2022) have shown that this approach is scalable and has a low tracking error. The reason is that the NZP only gradually reduces the weight of brown companies over time to be on an NZ trajectory and includes low-carbon emitters in each sector. This approach allows for a portfolio construction that can be close to sector neutral relative to the market benchmark by shifting portfolio weights over time toward the companies in the sector with lower emissions. Preserving such sector neutrality is an important step in limiting tracking error. An additional benefit of this approach is that it, in effect, creates competition among corporations within each sector to reduce carbon emissions to be able to maintain their position in a decarbonizing portfolio.

Constructing Net-Zero-Aligned Portfolios

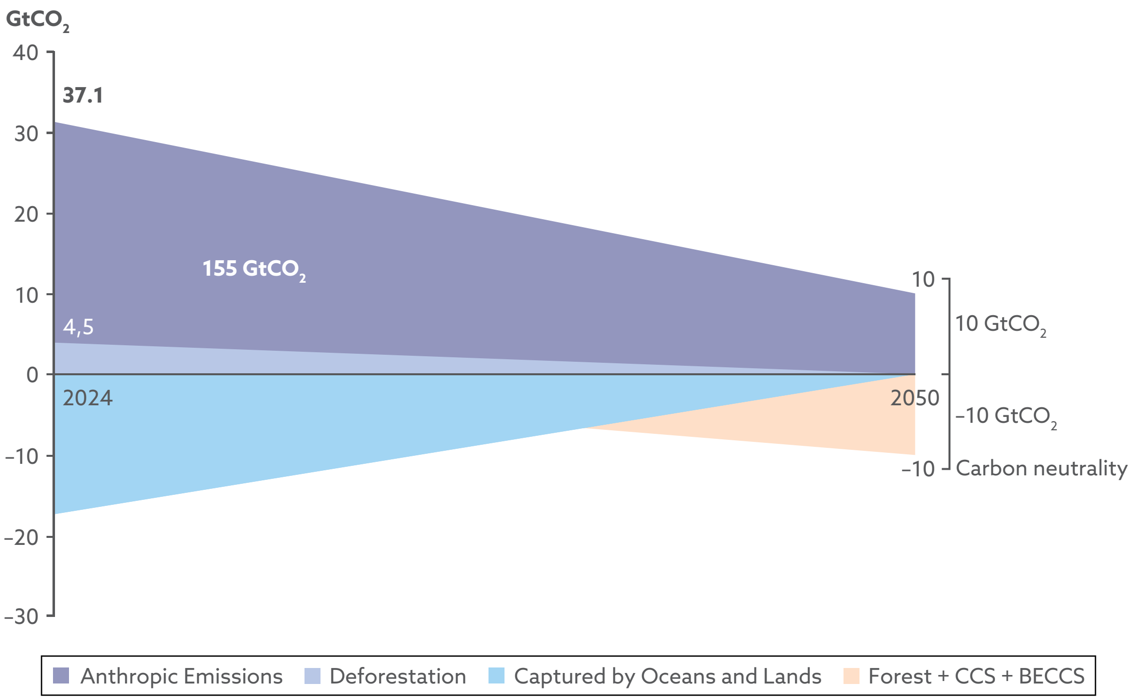
The starting point in constructing an NZP is a market index. The task is to reweight or exclude constituents of this index on a periodic basis to keep the carbon footprint of the reweighted portfolio on an NZ trajectory, while minimizing the tracking error with respect to the benchmark index. The portfolio's carbon footprint is taken to be the direct and indirect emissions of the constituent companies multiplied by the respective market-cap-based ownership of the individual stocks in the portfolio. The portfolio is dynamically constructed so that all the capital remains invested, while the portfolio carbon footprint is constrained to stay on an NZ trajectory.

Having chosen the reference index and calculated the carbon footprint of that index, the next step is to define the NZ trajectory, which can be done in multiple ways. The end goal is, of course, an NZP by the target date. This date is typically

2050, but other dates can be chosen. The simplest trajectory would be to keep the carbon footprint on a straight line from the initial point at the start date (say, 2024) to zero in 2050. Such a trajectory, however, would be incompatible with the prescribed decarbonization of the economy of the IPCC to avoid warming of the planet greater than 1.5°C or 2°C. In its 2021 report, the IPCC determined that a 300 $GtCO_2$ carbon budget is left to deplete if temperature increases are to remain below 1.5°C with an 83% probability. Bolton et al. (2022) take this to be the carbon budget that would serve to anchor the NZ trajectory of the portfolio (see **Exhibit 3**). Other budgets, with a higher temperature limit than 1.5°C or a lower probability than 83%, can of course be used to tie down the decarbonization pathway of the economy. The pathway to decarbonize the economy is determined by the rate at which it is necessary to reduce GHG emissions to remain within the carbon budget. In the last few years, total yearly GHG emissions from human activity have been around 40 $GtCO_2$ according to the IEA (2022). This means that the carbon budget has been shrinking every year by this amount, so that in 2024, the remaining budget is around 155 $GtCO_2$.

The fundamental takeaway from this analysis of NZ pathways based on a shrinking carbon budget is that any delayed decarbonization necessarily translates into a steeper decarbonization rate in the future to remain within the carbon budget. The carbon budget does not remain constant—rather, it shrinks every year, which means that delay in decarbonization itself becomes a transition risk factor (Network for Greening the Financial System 2024).

Exhibit 3. Constant Rate Decarbonization Pathway as of 2024



Source: Bolton et al. (2022); authors.

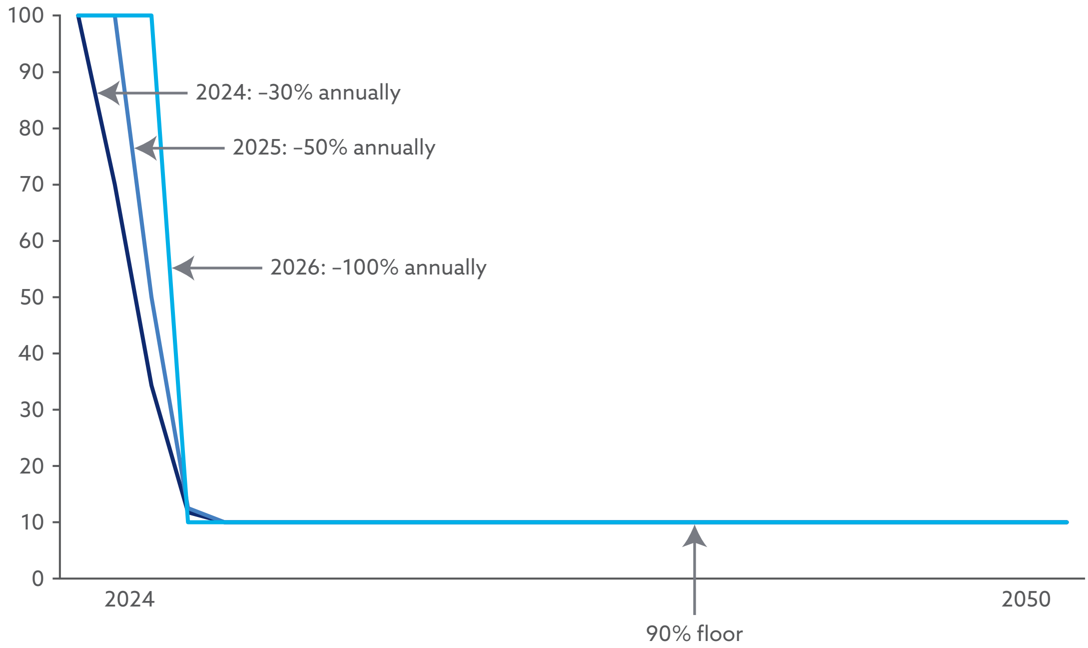
The more the carbon budget is depleted before the carbon transition takes place, the more abrupt and disruptive the transition will have to be.

Bolton et al. (2022) derive the NZ pathway for the portfolio by assuming that the remaining carbon budget will be fully depleted by 2050, with a 90% floor for emissions and the 10% residual emissions being captured. This projection maps into a 30% annual reduction rate for the portfolio carbon footprint or an initial 70% carbon haircut in 2024, followed by a 7% annual rate of decline until 2050. If decarbonization were to be postponed by one year, then this 30% annual reduction rate would increase to 50% annually the following year (see **Exhibit 4**).

The inclusion of scope 3 emissions is important because in some industries, a disproportionate amount of emissions is indirect (see **Exhibit 5**); this is the case in particular for the energy sector. If scope 3 emissions were to be excluded in the definition of the carbon footprint, then mechanically greater weight would be put in the NZP on fossil fuel energy companies, which would be inconsistent with hedging carbon transition risk. One inevitable consequence of including scope 3 emissions in the calculation of the carbon footprint is double counting of emissions. Double counting is not a problem, however, because what matters for NZPs is the rate at which the portfolio must be decarbonized. This rate is the same whether or not double counting occurs.

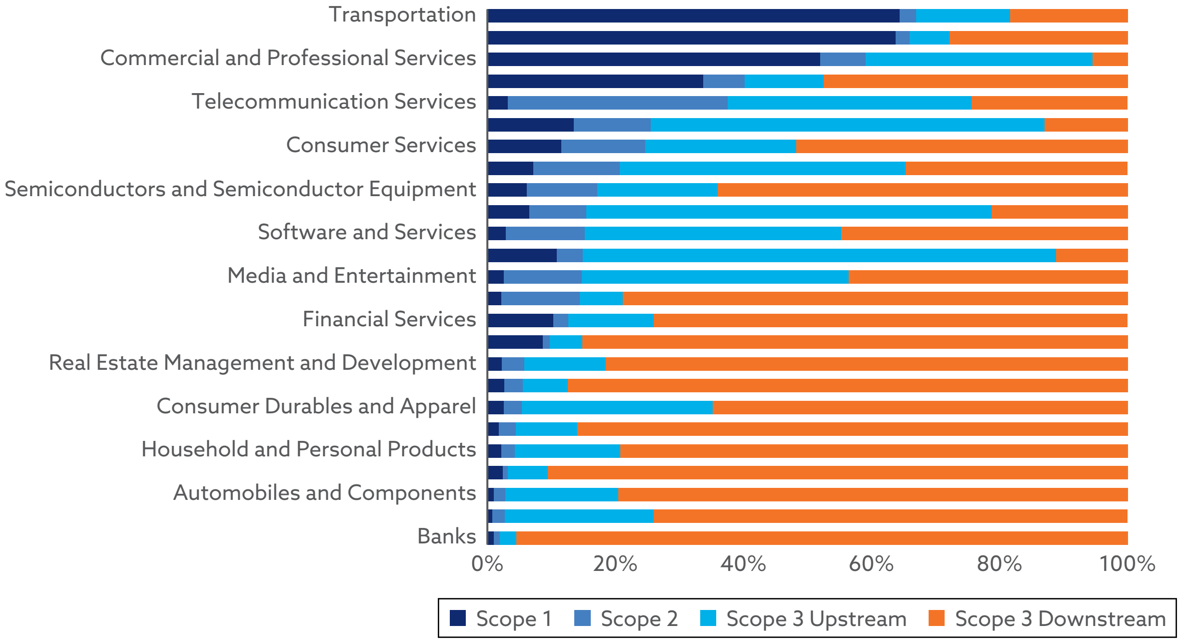
The carbon footprint of the NZP can shrink only through reweighting or exclusion if constituent companies themselves do not decarbonize their

Exhibit 4. Impact of Delay on Decarbonization Rate



Source: Bolton et al. (2022); authors.

Exhibit 5. S&P Global Broad Market Index (BMI) Carbon Footprint



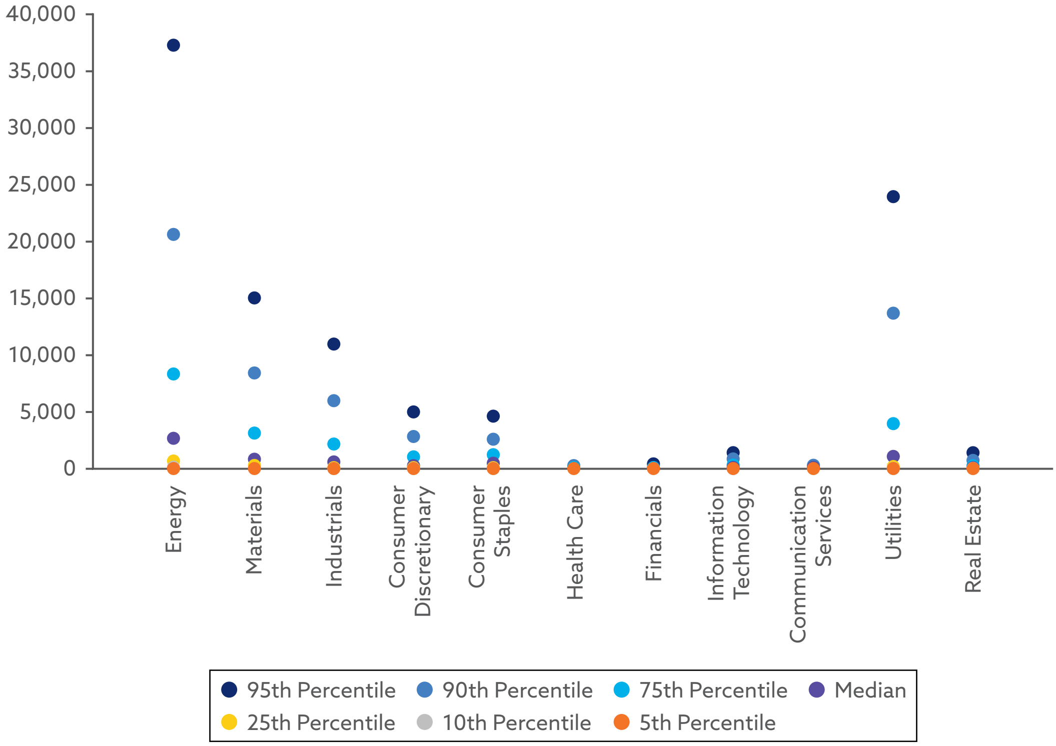
Source: S1, S&P Global for PenSam.

operations fast enough. One might expect that the reweighting and exclusion would result in an imbalanced portfolio in terms of sectoral representation, with the highest-emitting sectors gradually shrinking relatively to other sectors in the NZP. It turns out, however, that within most sectors, there is a wide dispersion of companies' carbon footprints (see **Exhibit 6**). As a result, sectoral balance can be maintained by underweighting (or excluding) the highest emitters within each sector. This selective underweighting in each sector is an important reason why the NZP can be constructed so as to have a low tracking error with respect to the market benchmark.

After determining the market benchmark, calculating that benchmark's carbon footprint, and setting the NZ trajectory constraint, the next task is minimizing the tracking error of the NZP over time. This is done, approximately, at each rebalancing date by determining the portfolio weights of each constituent, w_i, by minimizing the following objective function:

$$Objective = \sum \frac{1}{n}\frac{(w_i - w_{ui})^2}{w_{ui}} + \sum \frac{1}{l}\frac{(w_i - w_{uki})^2}{w_{uki}} + \sum \frac{1}{m}\frac{(w_i - w_{usi})^2}{w_{usi}} + \sum \frac{1}{q}\frac{(w_i - w_{uci})^2}{w_{uci}}$$

Exhibit 6. Carbon Intensity (Scopes 1–3 Emissions/Market Cap) for S&P Global BMI



Source: Trucost for PenSam.

where

n = number of stocks selected

I = number of Global Industry Classification Standard (GICS) industries in the underlying index

m = number of GICS sectors in the underlying index

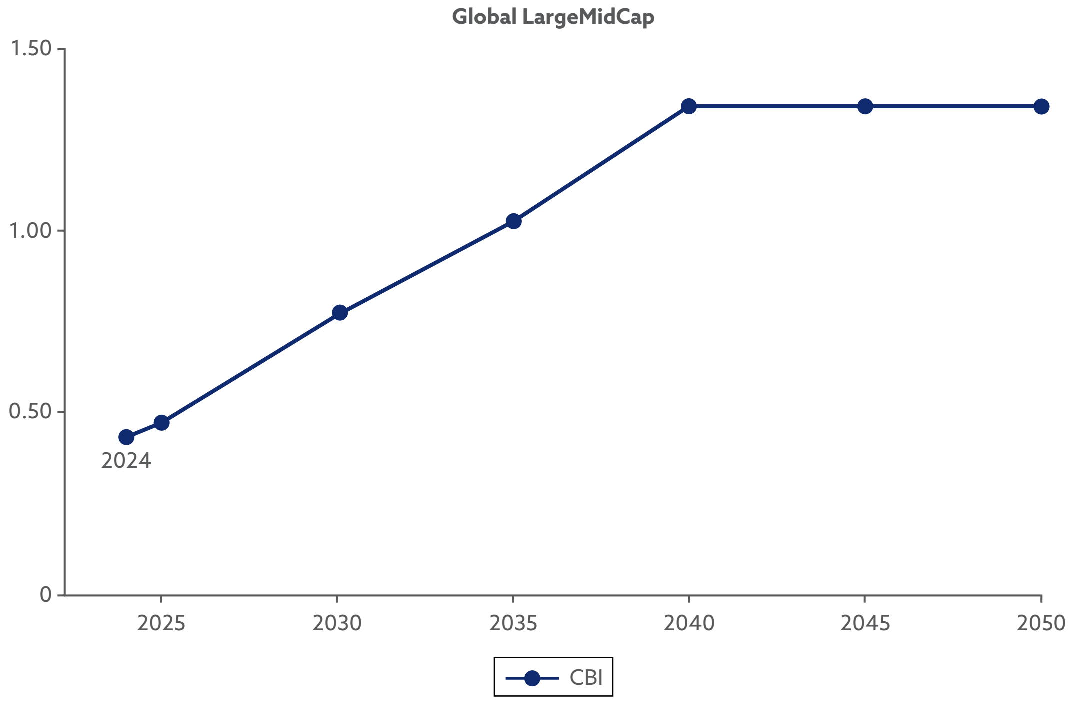
q = number of countries of domicile in the underlying index

That is, the portfolio weights are set to minimize the differences in constituent, sector, and country representation relative to the S&P Global LargeMidCap Index. In each term, *u* refers to the underlying weights of each stock *i* in the portfolio. The main constraint is given by the imposed rate of decarbonization of the portfolio. To simulate the tracking error of the portfolio, we used a fundamental risk factor model from AXIOMA. Notably, the factor returns are based on standard style characteristics, including size, value, momentum, and quality. The AXIOMA covariance matrix used to predict the tracking error can be found by looking at the exposures to those factors of the constituents in our index basket.

In calculating our tracking error, we made a few assumptions. Mainly, (i) the forward-looking analysis assumes that carbon emissions in the parent universe remain unchanged over time (i.e., there is no upward or downward trend), (ii) the market risk environment remains the same (i.e., the covariance matrix remains the same), and (iii) the parent index composition remains unchanged in terms of its constituents and its weights (including sector and country composition).[2] As **Exhibit 7** highlights, the NZP can be constructed in such a way that tracking error remains very small. These calculations are for the tracking error of the S&P Global LargeMidCap Carbon Budget Climate Index, which PenSam has adopted.

A robust way of keeping diversification risk low is to have sector weights that are close to those in the real economy. **Exhibit 8** shows how sector deviations in the S&P Global LargeMidCap Carbon Budget Climate Index are limited, especially in the early years. Indeed, in 2024—the first year of the index—the only significant deviation is for the consumer staples sectors, which is underweighted relative to the market benchmark (there is also a slight overweighting of the information technology sector). By 2035, the three main sectors that are overweighted are information technology, health care, and financials—but with an overweighting

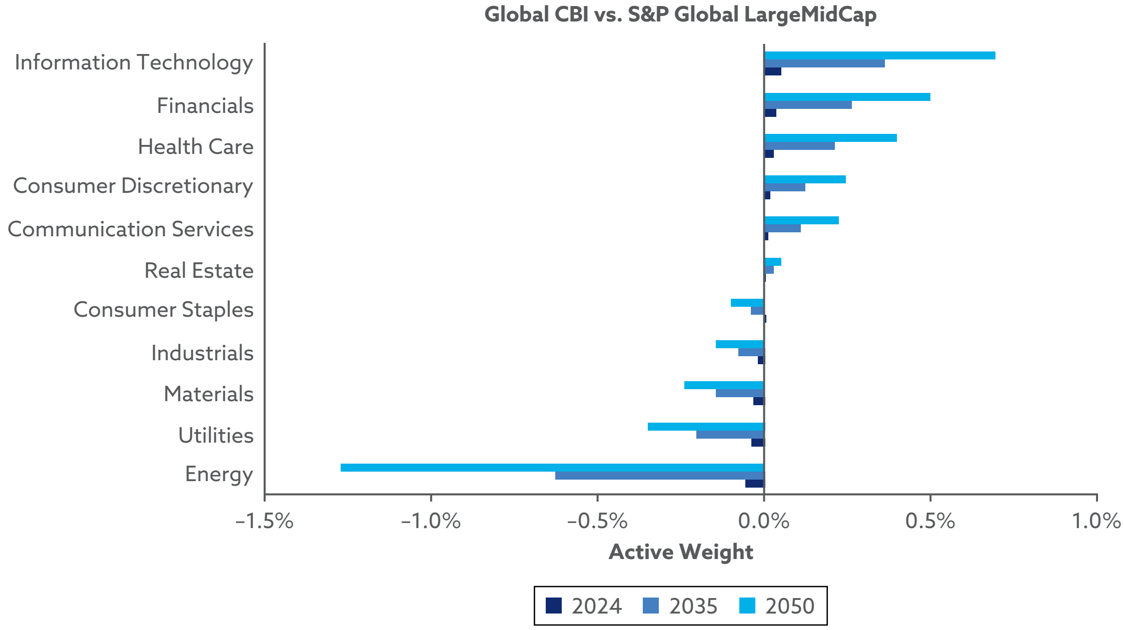
Exhibit 7. Tracking Error of NZPs



Source: S&P Dow Jones Indices (S&P DJI) for PenSam 2024 vintage (S&P DJI 2024).

[2]One could extend this model to take into account forward-looking emission pathways. But Bolton et al. (2022) and Cenedese, Han, and Kacperczyk (2024) argue that incorporating such information into the NZP does not materially change its tracking error properties.

Exhibit 8. Sector Deviations of the NZ Index



Source: S&P DJI for PenSam 2024 vintage (S&P DJI 2024).

of no more than 0.5%. The main sector that is underweighted is energy, with an underweighting of around 0.6%. Finally, by 2050, the S&P Global LargeMidCap Carbon Budget Climate Index is expected to indeed have greater sector deviations but still limited under- and overexposure of sectors, the main one being the underweighting of the energy sector by around 1.5%.

These estimates are all based on the very conservative assumption that constituent stocks keep their emissions unchanged. It is reasonable to expect, however, that the decarbonization of the economy will pick up speed as we enter the last two decades of the carbon transition, in which case even better sectoral balance will be achievable.

Indeed, it is possible to better integrate and anticipate the expected decarbonization of the constituents themselves by looking at corporate commitments to decarbonize their operations and at capital expenditures. This approach is particularly useful if one does not want to exclude companies that can be pivotal in the transition period even if their emissions today are higher than those of their peers.

Exclusion criteria built around corporate ambition to decarbonize have been introduced in Cenedese, Han, and Kacperczyk (2024). Their NZP construction sorts companies based on a Misalignment Score, which is a weighted average of three elements: (1) current emission levels and their growth rates, (2) current emission intensity measures and their growth rates, and (3) forward-looking climate-related activity metrics. Carbon emission levels and their growth rates are useful to be able to extrapolate future emissions. Intensity-level metrics add an additional dimension of energy efficiency not directly linked to company size. Finally, forward-looking metrics summarize all the commitments made by a company that relate to its ambition to reduce future emissions.

Besides offering a balanced approach to both diversification and carbon transition risk, NZ-aligned indexes can also serve as a tool for systematic engagement (Bolton et al. 2022). Given that it is possible to simulate the future composition of the portfolio, an NZ-aligned index can serve as a communication tool with corporations, indicating which companies are expected to remain in the NZP and which ones will exit if their emissions do not decline fast enough. One simple way of conveying this information is the distance-to-exit proxy (DTE), which measures the number of years a company is projected to remain in the portfolio, proposed by Cenedese et al. (2024). Communicating this information is a form of systematic and active engagement: It gives a clear escalation forecast to corporations based on their current and projected carbon footprint relative to their peers if they do not decarbonize their operations faster. Notably, Cenedese et al. (2024) show that companies with a lower DTE are associated with higher expected stock returns and lower equity values.

Danish Pension Fund PenSam's Choice of NZP

PenSam, a Danish labor market pension fund, manages the pensions of employees of Danish municipalities, regions, and private companies in service sectors such as eldercare, cleaning services, and pedagogical care. As it affirms on its website, PenSam "takes a clear ethical approach when investing pension funds, and our code of ethics is based on a number of international conventions."[3] Accordingly, PenSam is committed to a responsible investment approach that is cognizant of the environmental and social impact of its investments while ensuring a good risk-adjusted return to its pensioners. The fund seeks to implement the responsible investment principles of the UN Global Compact and to follow the OECD guidelines for multinational enterprises on consumer rights and competition behavior, as well as the UN Principles for Responsible Investment.

Consistent with this investment stance, PenSam imposes exclusionary screens for its portfolio construction to avoid companies that do not adequately protect labor and human rights, armaments companies dealing controversial weapons, tobacco companies, and companies subject to international sanctions or that have been found in violation of business ethics. It also imposes climate and environmental exclusionary screens—for example, avoiding investments in coal companies (where more than 5% of revenue is related to coal), unless these companies have committed to concrete and short-term plans for transitioning away from coal. Oil companies extracting tar sands are also excluded. Its exclusion policy extends to investments in government bonds of countries with

[3]See www.pensam.dk/in-english.

a poor human and labor rights record and countries on the EU blacklist of tax havens. Finally, these exclusionary screens extend to the mandates of PenSam with its external asset managers.

Beyond these exclusionary policies, PenSam is committed to supporting the green transition in investment management and seeks to reduce its exposure to fossil fuels beyond what a representative investor does. It is committed to doing so not only through divestment but also through engagement with companies that have high CO_2 emissions. PenSam has joined the Paris Aligned Investment Initiative, with an NZ target by 2050 and interim targets for its equity and credit portfolios and Danish real estate portfolio of a 55% reduction in carbon emissions relative to 2019 by 2025.

Based on its purpose and mission, PenSam has the right investor profile to consider an NZP strategy. Its responsible investment stance naturally invites climate and environmental considerations besides purely financial performance ones in its portfolio construction. It is thus not completely surprising that PenSam has chosen to anchor its portfolio construction around low-carbon market indexes. What is notable, however, is PenSam's recent strategic decision to adopt the S&P Global Carbon Budget Index approach. As announced on 30 January 2024 (S&P Global 2024), PenSam has embraced S&P Dow Jones Indices (S&P DJI) as the provider of an NZ benchmark for its equity portfolio, with the immediate consequence of "throttling technology stocks" in the new benchmark (Madsen 2024). PenSam's decision was motivated by its fundamental concern of balancing diversification risk and carbon transition risk. The previous climate benchmark that PenSam favored was significantly reducing its exposure to high-carbon-footprint stocks but also exposing PenSam to diversification risk by substituting high-carbon-footprint stocks with technology stocks. As a result, the previous climate benchmark had a large tracking error with respect to the market index and was loading up the PenSam equity portfolio to Big Tech risk. As the head of ESG (environmental, social, and governance) at PenSam, Mikael Bek explained about the previous climate benchmark PenSam relied on:

> We have been challenged by tilting the portfolio towards technology stocks. Last year, we had a preponderance of 10 percentage points in that sector. After all, it was excellent in 2023 because of the magnificent seven, and we had a really good return. But we do not want so much sector overweight. We want to be more sector neutral.

In its analysis of the pros and cons of the different low-carbon indexes on offer by index providers, PenSam concluded that the S&P Global Carbon Budget benchmark has a satisfactory level of integration of climate parameters. At the same time, the sectoral weight restrictions imposed on the S&P Carbon Budget benchmark and other portfolio rebalancing would ensure that this benchmark would avoid pronounced sector and company concentration.

The Investment Challenge for PenSam

Since 2020, PenSam has used the MSCI ACWI Climate Change benchmark. This benchmark uses the MSCI Low Carbon Transition score to increase the weight of constituents of the parent benchmark that are pursuing climate transition opportunities and decrease the weight of constituents that remain more exposed to carbon transition risk. This reweighting has resulted in significant overweighting of the information technology sector relative to the broad market (MSCI ACWI) index because many of the climate transition opportunities that MSCI has identified with its methodology are in this sector. This overweighting has materialized in a negative excess return of −3.3% in 2022 and a positive excess return of 5.5% in 2023 (see **Exhibit 9**). That is, the overweighting of the information technology sector has given rise to significant tracking error, exposing PenSam to important diversification risk.

From a prudent investment perspective, the Climate Change benchmark has induced both excessive sector concentration—especially toward the highly volatile information technology sector (the overweight was 8% relative to the broad market index, see **Exhibit 10**)—and too much concentration in individual companies in this sector. Moreover, this sector overweight, and the resulting tracking error relative to the broad market index, have increased significantly since implementation in 2020.

Assessment of Alternatives to the Existing Benchmark

PenSam explored various other climate benchmarks that may better reduce its diversification risk. Following an initial analysis of the available options, the PenSam team focused on the S&P benchmark as a possible alternative, given that the concern over sector concentration seemed less pronounced. Extensive further analysis confirmed the initial assessment that the S&P benchmark

Exhibit 9. Return of MSCI ACWI (Gross, DKK) and PenSam's MSCI ACWI Climate Change (Gross, DKK, corrected for exclusions list), in Percentages

Year	MSCI ACWI	MSCI ACWI Climate Change (corrected for exclusions list)	Excess Performance
2021	28.0	28.5	+0.5
2022	−12.6	−15.9	−3.3
2023	18.9	24.4	+5.5

Note: Exhibit 9 shows the returns for the broad market index (MSCI ACWI) and MSCI ACWI Climate Change Index. The exhibit shows that the performance of PenSam's climate benchmark has varied substantially compared with the performance of the broad market index.

Exhibit 10. Sector Distribution in MSCI ACWI Climate Change (corrected for exclusions list) and MSCI ACWI, as of June 2023, in Percentages

Sector	MSCI ACWI Climate Change (corrected for exclusions list)	MSCI ACWI	Difference
Information Technology	31.1	22.3	+8.4
Financials	13.7	13.9	−0.2
Health Care	14.6	12.6	+2.0
Consumer Discretionary	9.9	11.0	−1.1
Industrials	9.4	10.1	−0.7
Consumer Staples	6.4	7.6	−1.2
Communication Services	7.2	7.5	−0.3
Energy	0.3	4.8	−4.5
Materials	2.6	4.7	−2.1
Utilities	1.8	3.0	−1.2
Real Estate	3.0	2.4	+0.3
Total	100.0	100.0	

offered PenSam the best compromise. A key consideration was that the S&P methodology penalized excessive country or sector weight deviations relative to the broad market benchmark. This feature was considered an essential requirement in light of the fact that the data used to construct climate benchmarks can vary substantially and that the label "green" may have multiple definitions. The robust sectoral construction of the benchmark substantially mitigates the risk with respect to errors and changes in the different underlying climate data being used. The climate area is currently undergoing major changes both in terms of legislation and data. PenSam will therefore continuously reassess the benchmark to ensure that it is using the best and most up-to-date benchmark.

Exhibit 10 shows the sector distribution in MSCI ACWI and MSCI ACWI Climate Change (corrected for exclusions list). The exhibit shows in particular that PenSam had increased its exposure to the information technology sector.

The S&P Carbon Budget Indices primarily focus on reducing the carbon footprint of the index and on increasing exposure to revenue from climate impact solutions.

Overlaying PenSam's Impact Objectives onto the S&P Carbon Budget Indices

The structure and methodology of the S&P Carbon Budget Indices provided important assurances to PenSam on the diversification risk front. The indexes also provided a good balance of carbon transition risk exposure and diversification risk. PenSam wanted to go further in meeting its impact objectives, however, and sought a more aggressive reduction of the carbon footprint than that of the S&P climate benchmark of 2023. Note that there is no additional reduction relative to the 2024 vintage. PenSam was prepared to accept a higher tracking error if it could implement a more aggressive reduction in the carbon footprint of its portfolio. It sought a 70% reduction in the carbon footprint of its equity portfolio to avoid compromising its overall goals.

Indeed, PenSam's past stated aim was to reduce its carbon footprint by 44% by 2025 compared with 2019. PenSam's carbon footprint is based on a weighted average carbon intensity metric, where CO_2 emissions are measured relative to the constituent company's revenue. The overall carbon footprint reduction target was for its entire holdings of listed equities, liquid credit, and real estate. This target was increased in 2023 to 55%. Also, under the MSCI ACWI Climate Change benchmark, PenSam had been able to reduce the carbon footprint of its equity portfolio by about 70% compared with the MSCI ACWI. Using the PenSam 2024 vintage version of the S&P index would lead to the same carbon footprint reduction and would also allow PenSam to keep the tracking error at an acceptable level. **Exhibit 11** reports the overweighting of the information technology sector in, respectively, the MSCI and S&P benchmarks. As can be seen, the MSCI ACWI Climate Change benchmark gives rise to a 10-percentage point overweight in the information technology sector relative to the MSCI ACWI. This compares with an overweighting of only 1.2 percentage points for the S&P Global LargeMidCap Carbon Budget Climate benchmark.

In sum, under the S&P Global LargeMidCap Carbon Budget Climate benchmark, PenSam can substantially limit its overexposure to the cyclical information technology sector. The fund will also be able to underweight the energy sector, with a weighting of energy stocks of 0.5% compared with a weight of over 5% for the S&P Global LargeMidCap benchmark.

PenSam is applying this S&P Global LargeMidCap Carbon Budget Climate benchmark to its entire listed equity portfolio of DKK45 billion (USD6.5 billion). Management of the equity portfolio will be split between two asset managers:

Exhibit 11. Overweight in the Information Technology Sector (in percentage points)

	MSCI ACWI Climate Change	S&P Carbon Budget Climate
Information Technology	+10.0	+1.2

Amundi, which will manage a passive fund of the S&P Global LargeMidCap Carbon Budget Climate Index, and Nordea, which will manage an active version of the fund with greater discretion but also greater tracking error.

Conclusion

NZPs allow investors to reduce the carbon footprint of their portfolios over time, thereby reducing exposure to carbon transition risk while maintaining a low tracking error. NZPs provide an effective and dynamic way of balancing carbon transition and diversification risk by tracking the recommended decarbonization pathway consistent with a shrinking IPCC carbon budget. They can also help better align incentives for companies to decarbonize. If companies do not shrink their carbon emissions fast enough, consistent with the recommended decarbonization pathway for the global economy, then those companies' securities may eventually be excluded from the NZ-aligned benchmark. This implied warning is an additional reason why these benchmarks are particularly suitable for green investors with a purpose of investing responsibly.

NZ-aligned benchmarks thus provide a scalable and flexible solution for the rising passive investment segment of capital markets. They should, however, not be seen as a panacea. NZ-aligned benchmarks may be necessary to help accompany investors through the carbon transition, but they are clearly not sufficient. Tilting away from high-emitting companies and toward green companies over time accomplishes little unless these companies also change their operations, with brown companies shrinking their carbon footprint and green companies scaling up their operations (Angelini 2024). The process of gradually decarbonizing portfolios must clearly be accompanied by a decarbonization of the real economy, which involves many other policy interventions and changes in how companies operate. However, the decarbonization of portfolios will help remove a potentially important obstacle: investor resistance against the energy transition. Last but not least, the index vintage approach conveys the key message of the cost of delay that had been a key IPCC message for years but had not yet been embedded in green financial products.

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GREEN AND TRANSITION FINANCE ON THE MUNICIPAL LEVEL: CASE OF HUZHOU CITY

Ma Jun
President, Institute of Finance and Sustainability, Beijing

Yunhan Chen
Research Associate, Institute of Finance and Sustainability, Beijing

Since becoming one of China's inaugural "green finance pilot zones" in 2017, Huzhou has seen its green loan balance grow eightfold to CNY338.8 billion by the end of 2023, which represents 32% of its total loan balance and is 20 percentage points higher than the national average. This success is driven by an enabling environment shaped by the local government, including clear regulatory frameworks and policy incentives that essentially reduce transaction costs. Digital platforms that integrate environmental, social, and governance assessments and green certifications have further supported the market players.

Huzhou has also pioneered transition finance, introducing a comprehensive taxonomy covering nine carbon-intensive sectors as well as guidelines for carbon accounting and just transition. By integrating digital solutions for emissions data and offering standardized templates for transition plans, Huzhou helps financial institutions, particularly small and medium-sized enterprises, initiate climate actions while allowing space for future refinements. This approach may also serve as a reference for the thousands of cities across emerging markets and developing economies to help green and transition corporations tap into local liquidity.

Introduction

Achieving net-zero emissions has become a critical global priority because of the escalating impacts of climate change. At its core, net zero relies on two essential pillars: the advancement of green industries and the systematic decarbonization of carbon-intensive sectors. Green industries show that economic growth can be maintained while providing essential goods and services in an environmentally friendly way. By accelerating investments and innovation in these sectors, countries can not only reduce emissions but also develop new economic models and create employment opportunities, thus supporting and compensating for the phaseout of traditional carbon-intensive industries.

Although all green growth requires structural changes, green finance typically supports the growth of new industries. In contrast, transition finance affects existing infrastructure and presents different risks, opportunities, and challenges to current development patterns and pathways. This process entails setting ambitious emissions reduction targets, implementing stringent regulatory frameworks, deploying advanced technologies, and fostering collaboration among governments, businesses, and civil society.

Green and transition finance can be mutually reinforcing. Although the fine details may differ, transition finance benefits from many of the same governance structures as green finance, including taxonomy, disclosure requirements, and policy incentives.

This chapter presents the case of Huzhou, a medium-sized city in coastal China. Huzhou has found a new development pathway through piloting green finance and is now paving the way for transition finance by building on its previous experiences. In analyzing this case, we illustrate the lessons for how municipalities can develop green finance and how the existing architecture of green finance can also become a lever for transition finance.

Becoming the Green Finance Pilot Zone

A city in Zhejiang province, Huzhou sits at the heart of the Yangtze River Delta, one of China's most affluent regions. In 2023, the city's total GDP reached CNY401.51 billion, a 5.8% increase from the previous year. This growth highlights the city's economic resilience and its ongoing development. Its GDP per capita in 2023 (CNY117,195) is equivalent to USD16,396 and is roughly 20% higher than that of both the national and world averages. Its economic growth relies heavily on both the secondary (49.3%) and tertiary (46.7%) sectors (People's Government of Huzhou 2024a). Like many of its Chinese peers, Huzhou's rapid expansion of heavy industry in past decades led to significant economic growth.

This growth, however, came at the cost of environmental degradation. As environmental impacts became more pronounced, public awareness for environmental protection increased. This awareness has increased demand for a greener economic development pathway. On the one hand, economic development is still the top priority, which means shutting down polluting enterprises without finding the proper alternative is not a viable option. On the other hand, such a polluting and carbon-intensive pathway has reached the point where it is no longer economically and environmentally sustainable. Economically, the added value compared with the use of resources for these industries is relatively small, reducing resource efficiency. Environmentally, the negative externalities will ultimately burden public spending.

The political momentum for green development in Huzhou can be traced back to the early 2000s, with the ideology of "Clear Waters and Green Mountains" from President Xi Jinping when he was the governor and party secretary of Zhejiang province; this momentum continued to build in the 2010s. Initially, the focus was on reducing and remediating environmental pollution and degradation in line with national environmental governance efforts. Local government actions in Huzhou included improvements to urban infrastructure, such as waste management systems, a tightened review process for projects with potential environmental impacts, and the establishment of emissions trading for pollutants (*National Business Daily of China* 2023). The trading system marked the initial steps in using market-based mechanisms to address environmental externalities at the local level, setting the stage for more advanced initiatives.

In 2015, when the concept of green finance started emerging in China, Huzhou was among the first to propose the establishment of regional green finance pilot zones. In 2016, the People's Bank of China (PBOC), alongside six other ministries, issued what is considered the founding document of China's green finance system, "Guidelines for Establishing the Green Financial System." This document (PBOC 2016) prompted local governments to develop their own plans for promoting green finance.

In 2017, Huzhou was selected as one of the first pilot zones for green finance reform and innovation. In its action plan, it aimed to build an ecosystem of green finance with regional traits, rapid growth of green financing, steady decline of financing for carbon-intensive and polluting sectors, and a relatively low nonperforming ratio for green loans. Notably, as a medium-sized city, Huzhou also emphasized how green finance should be tailored to the development needs in a small or medium-sized city context (PBOC et al. 2017).

Financing for an Eco-City

In recent years, Huzhou's overall progress in green development has been accelerating, particularly since the announcement of China's dual carbon goals in 2020. Even a year before this announcement, it had already become the first city in Zhejiang province to fully transition its public transport system to electric vehicles, with more than 2,000 electric buses in operation in 2019.

The development strategy used by the local government to transition its industry structure can be described in the metaphor of "emptying the cage and letting the right birds in"—in this case, meaning to clear out traditionally polluting industries and make room for green and advanced ones. Statistics show that from 2005 to 2022, the total GDP of Huzhou increased from CNY64 billion to CNY385 billion, with an average annual growth rate of 11.1% (Caixin News 2023). Meanwhile, the industry structure shifted toward higher technology and lower emissions. In 2022, the proportion of the traditional textile and building materials industries declined to 20%, compared with 50% in 2005. The number of companies in the lead battery industry decreased from 225 to 16. Overall, the value-added share of high-tech industries, strategic emerging industries, and the equipment manufacturing industry in Huzhou reached 65.7%, 38.9%, and 35.2%, respectively (Caixin News 2023).[1]

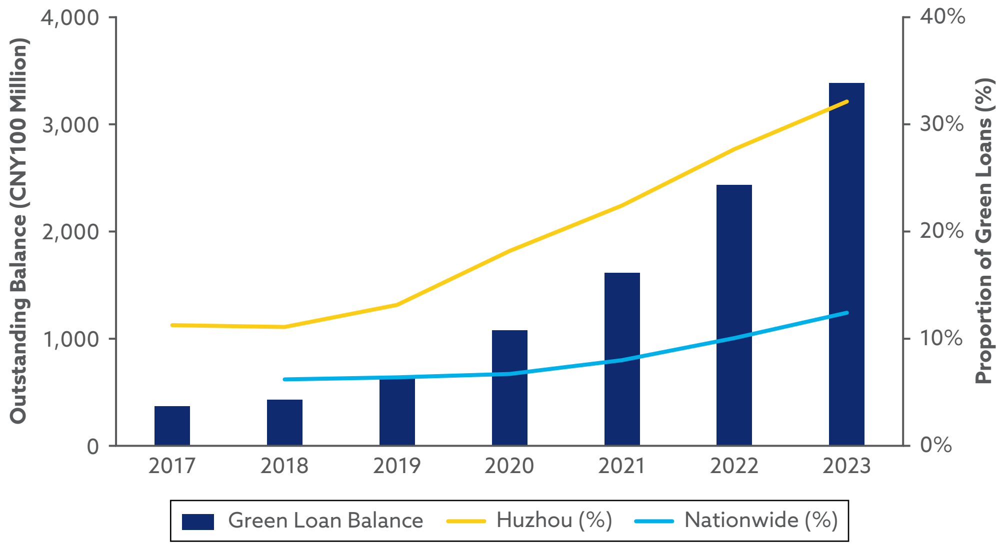
[1]These data are from the People's Government of Huzhou. These emerging industries include the manufacturing of electronic vehicles and semiconductors, smart logistics and biomed technologies, special-use materials, components for renewable energy and robotics, and geographic information system technology.

The implementation of a "carbon efficiency code" for industrial entities, in which carbon emissions and efficiency compared with their per-acre output can be traced, drove actual carbon emissions per unit of added value down by 12% in 2022, just one year after its launch.

Green finance in Huzhou has developed rapidly as the facilitator of green and transition activities. Since Huzhou became a pilot zone in 2017, its outstanding balance of green loans has increased by 45.8% annually, contributing to more than 50% of the overall loan increase. As shown in **Exhibit 1**, green loans now account for 31.3% of the total loans, 21 percentage points higher than China's average and higher than these statistics from other developing countries. As of the end of March 2023, the outstanding volume of green loans reached CNY298.4 billion (USD41 billion), 7 times higher than that of 2018 (Exhibit 1). Meanwhile, green loans are performing significantly better, with an overall nonperforming loan ratio of only 0.002%—substantially lower than the financial sector average of 0.32%.[2]

Financial institutions (FIs) have taken initiatives in innovating green financial products. There are now more than 180 varieties, ranging from loans and bonds to insurances and guarantees. These products also cover a wide range of themes, such as carbon efficiency, carbon price, electric vehicles, and green buildings, to name a few. FIs and corporations have collectively issued

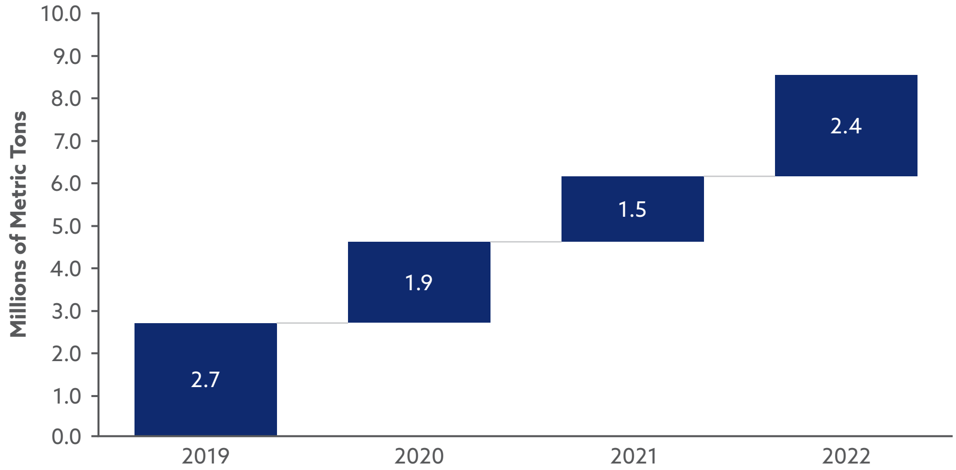
Exhibit 1. Green Loan Growth and Proportion of Green Loans, Huzhou vs. China Nationwide, 2017–2023



Source: PBOC Huzhou Branch, Institute of Finance and Sustainability (IFS).

[2]Provided by the local Huzhou government office.

Exhibit 2. CO_2 Emission Reduction Related to New Green Loans in Huzhou City, 2019–2022



Sources: Consolidated from public sources by the authors.

59 labeled green bonds, amounting to CNY39.41 billion (USD5.4 billion; Financial Regulatory Bureau of Zhejiang Province 2023). A digital platform, Green Loan Express, has been created and cumulatively has served more than 43,000 enterprises and facilitated more than CNY510 billion in credit, accelerating the matchmaking process and improving access for micro and small-sized enterprises.[3] The fast-growing green loans have also significantly contributed to avoiding millions of metric tons in carbon emissions (see **Exhibit 2**).

Creating an Enabling Environment for Green Finance

To understand Huzhou's journey in green and transition finance, it is important to understand the key components for green and transition finance as identified by the G20 Sustainable Finance Working Group (SFWG), such as in the G20 Sustainable Finance Roadmap and the G20 Transition Finance Framework. These components include an identification approach (such as a taxonomy), policy incentives, products, and information disclosure, all of which were later expanded to accommodate transition finance. In the case of Huzhou, it is therefore important to review how such a green financial ecosystem developed and how it has become an enabler for transition finance. Lessons learned from the previous years of pilots continue to inform policymaking from municipal to national levels, even contributing global dialogues and business decisions by market players.

[3]Provided by the local government.

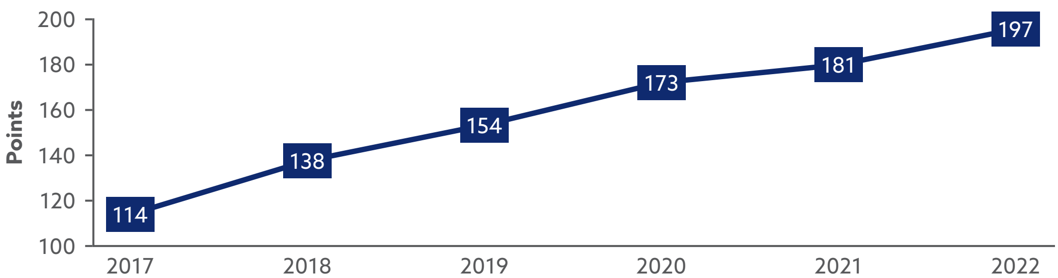
Policy and Legislative Framework

When green finance first emerged, how to define "green" activities was among the primary challenges. On top of national green taxonomies, starting in 2017, Huzhou has developed its first batch of local green finance standards to evaluate green projects, green financing enterprises, and green banks. Furthermore, Huzhou developed standards for a special set of FIs that conduct business only in green finance, named "green finance specialized institutions"; the creation of such FIs is unique to China, compared with other countries. Huzhou also created a "Green Finance Development Index" for the municipality itself, with a set of 45 quantitative indicators and corresponding methodologies to evaluate the municipal-level performance of green finance. The key indicators were grouped into three main categories: governance and policy foundation; market performance; and contribution of green finance to green, technological, and economic advancements (Huzhou Market Supervising Administration 2019). **Exhibit 3** demonstrates how the overall development environment for green finance has improved, as measured by the index.

The system of standards continues to evolve and expand, covering green building loans, green agriculture loans, green inclusive loans, and carbon-neutral banks. Huzhou's experience in standard setting also contributes to the formulation of seven national standards as well as provincial ones. In a city with a small presence of large third-party service providers and a high proportion of small and medium-sized enterprises (SMEs), government-led standard setting leads to the clarification of market expectations and reduces the costs of green certification for FIs and enterprises, which may be replicable in other developing economies.

Policy incentive is another government-led approach that has had clear impacts in shaping market expectations and giving prompts to first movers in the market. In the case of Huzhou, policy incentives usually fall into three categories: fiscal, monetary, and regulatory. At the very beginning, incentives for green policies started with "shades of green": Based on how "green" the firms are, the government would provide interest subsidies of 12%, 9%, and 6%, respectively. The policy gradually expanded to a wider range of incentives

Exhibit 3. Green Finance Development Index, 2017–2022



Source: PBOC Huzhou Branch, IFS.

targeting different objectives. Despite the recognition of pilot zones from the national level, such subsidies are provided in the local government's own fiscal and monetary capacity. **Exhibit 4** presents a non-exhaustive list of current policy incentives in Huzhou. The maximum amount of subsidy to each enterprise ranges from CNY30,000 to CNY300,000 (roughly USD4,200 to USD42,000).

To ensure consistency across different administrations over time, green finance has been written into the local legislation, incorporating key topics such as carbon finance, environmental, social, and governance (ESG) rating, and green finance performance evaluation. Local legislation of green finance has codified both incentive and punitive measures. Supportive measures for innovation in green finance fall into the fiscal mandate. There are also administrative penalties for "greenwashing" behavior, such as false disclosure of carbon emissions,

Exhibit 4. List of Current Policy Incentives in Huzhou (non-exhaustive)

Green Inclusive Loan	For green inclusive loans in the current year, interest subsidies of up to 12% of the China loan prime rate will be provided to FIs based on their green finance performance, with a maximum interest subsidy of CNY150,000 per enterprise.
Green Bank	Banks that are approved as the first batch of green finance demonstration banks within the pilot zone and achieve significant results in such areas as "carbon-neutral" banks, green loans, and transition finance will receive a one-time reward of up to CNY300,000.
Green Bonds (e.g., carbon-neutral bonds, transition bonds, sustainability-linked bonds)	Eligible enterprises and FIs issuing green bonds, carbon-neutral bonds, transition bonds, sustainability-linked bonds, and other debt financing instruments and asset securitization products (collectively referred to as "green bonds") can receive a subsidy of CNY100,000 for each successful issuance. For green bonds issued in alignment with the China–EU Common Ground Taxonomy, the subsidy per bond issuance will be increased to CNY150,000.
Green, ESG, and Transition Insurance	For enterprises that purchase environmental pollution liability insurance, a subsidy of 30% of the insurance premium will be provided, with the cap of CNY30,000 per enterprise. For enterprises that purchase ESG insurance, a subsidy of 50% of the insurance premium will be provided, with the cap of CNY50,000 per enterprise.
Government Procurement	In government procurement of services related to banking or insurance, the performance of FIs in green finance will be used as one of the criteria in the bidding process.
Standard Setting	For FIs, research institutions, and local financial organizations, participation in the formulation of national or industry-level green financial standards will be rewarded with CNY250,000 at maximum for each set of standards. Participation at the provincial level will be rewarded with CNY150,000 at maximum. Lead drafting entity (entities) in the formulation of standards at the municipal level will be rewarded CNY100,000 for each set.

Sources: Sorted by the author from publicly disclosed policy documents (People's Government of Huzhou 2023b).

fraudulent application to government subsidies, or false advertisements about green financial products.

Digitalization in Green Finance

Similar to many cities in other developing economies, Huzhou is home to numerous SMEs. According to estimates, there are 40,000–50,000 SMEs in Huzhou, ranging from manufacturing to services and making up about 99% of the business entities in the city (Paulson Institute Green Finance Center and Research Center for Green Finance Development of Tsinghua University 2020). The significant proportion of SMEs made developing SME-specific green and sustainable finance one of the municipality's top priorities.

Compared with large enterprises and FIs, SMEs tend to have more constraints on capacity and resource mobilization, such as limited knowledge about green finance and industries, difficulty finding bankable green projects, relatively high costs for green certification from professional service providers, and so on. These constraints can act as hurdles to SMEs' development of green finance. Digitalization can help address information asymmetry and lower transaction costs.

In Huzhou, a Green Finance One-Stop Service Platform (One-Stop Service Platform)[4] was built to tackle this specific issue for SMEs. Through big data, cloud computing, and other technologies, the platform focused on green lending, green financing, and green credit ratings for SMEs. As of year-end 2023, the platform has provided ESG ratings for more than 22,000 enterprises. Cumulatively, it has assisted 51,000 enterprises in accessing bank financing, with a total of CNY590 billion (USD81 billion). **Exhibit 5** presents a screenshot of the user interface on mobile phones, with buttons that direct users to loan applications, equity investments, and guarantees.

The One-Stop Service Platform main characteristics can be explained in the following three aspects:

- **Consolidation of mandated data from multiple government agencies:** Recognizing that collecting useful data remains a common challenge for the green finance market, the One-Stop Service Platform consolidates information from 31 government agencies, including the Huzhou Municipal Administration for Industry and Commerce, Huzhou Tax Bureau, and Huzhou Environmental Protection Bureau—information that is "green" and will be used in due diligence. This consolidation reduces search costs: Financiers can save efforts in profiling clients and verifying their information, while enterprises can avoid duplicating efforts of submitting the same information to multiple FIs on top of their regulatory requirements.

[4]The platform consists of subplatforms, such as Green Loan Express (mentioned previously), Green Financing Express, green regulatory data, and personal carbon accounts.

Exhibit 5. Mobile Interface of Green Loan Express

Note: *Governance loan is actually based on the performance of the Chinese Communist Party government branches within corporations.

- **Automation of standards and ratings:** The application of standards will still demand a certain level of knowledge and capacity from financiers and enterprises. But incorporating them into the online system and automating the evaluation process, such as alignment with green standards and the rating of overall ESG performances, will not only alleviate the burdens for FIs and enterprises but also enhance credibility in the process because results are backed by regulators. Results of evaluation will feed into the due diligence process and update regularly for risk management.
- **Dynamic matchmaking:** The platform is similar to e-commerce websites, where enterprises can browse the various financial products offered (both loans and equity financing) and financiers can browse the various projects seeking financing. It is estimated that the average time for matchmaking between banks and enterprises has been reduced to 1.4 days, compared with 2.7 days originally (People's Government of Huzhou 2022b). Moreover, the platform is constantly upgrading with more "smart" elements, including the evaluation of future financing demands, a recommendation algorithm, and risk monitoring.

According to the local government, the One-Stop Service Platform will be upgraded to enable automatic regulatory review based on all the data readily available (*China Economic Observer* 2022), which also alleviates the workload for regulators.

Lessons Learned

Among numerous reasons why Huzhou has stood out among green finance pilot zones, those associated with the context of developing economies—where the financial market is generally less developed and government regulation has great potential to shape the market landscape for green finance—can serve as useful reference.

One core concern for green finance from market players is the additional cost associated with "green," whether it is identification of green projects, certification of instruments, or sustainability-related disclosure. Huzhou has taken various measures to offset this cost, or even reduce it to levels below normal financing—ranging from standards to incentives to digitalization. As illustrated earlier, ESG ratings and labeling of green loans through automated platforms have saved FIs from hiring external service providers that usually charge rather high prices, particularly compared with the small volume of transactions in the city. Based on market logic, FIs were then able to supply green financial products with lower costs, contributing to the boom of green loans and bonds in recent years.

Huzhou's ability to build up such an enabling system can be attributed to a few factors:

- **Strong political will and consensus:** Local government leaders have not only demonstrated a robust commitment to prioritizing green finance but also coordinated among different agencies, laying the foundation for the digital infrastructure as well as policy alignment. Meanwhile, there is also a broad consensus among public and private players on the necessity of developing green finance.
- **The mindset of "create first, improve later":** Huzhou has adopted a pragmatic approach to green finance by focusing on solutions best available within the local capacity and development contexts, with the understanding that there will certainly be gaps between local and global best practices, because improvements in quality need to be achieved progressively. Instead of waiting for very detailed instructions or standards from the national level, Huzhou has started with what is feasible and refined it over time, in terms of both policymaking and financial product innovation. This approach allows for the testing of new ideas and models, which can then be adjusted based on feedback and results. Notably, because local governments tend to have competing development priorities, some of these priorities—such as creating rural employment opportunities, alleviating poverty, and increasing access to affordable energy—can be achieved all together through localized policy design and financial solutions.

- **Capacity building and international cooperation:** Huzhou has focused on developing the skills and capabilities of local professionals in green finance while learning from and cooperating with international entities. By partnering with global organizations such as CFA Institute and by participating in international initiatives such as the G20 SFWG, Huzhou has tapped into the abundance of best practices and innovative solutions worldwide, which can benefit local stakeholders around major and emerging topics of green finance. Notably, these international collaborations have facilitated a two-way exchange of knowledge. Huzhou not only learns from global experiences but also shares its insights and successes, thus contributing to the broader discourse on green finance in developing economies.

A Local Approach to Transition Finance

Despite its leading performance in green development, Huzhou still has a higher carbon intensity compared with the provincial average, with a relatively heavy industrial structure. The city's eight major high-energy-consuming industries account for 70.8% of the energy consumption in regulated industries, yet they represent only 37.7% of the total added value of large enterprises. The need for transitioning the carbon-intensive sectors becomes more pressing than ever with the national dual-carbon goals as well as the limited overall carbon budget, leaving insufficient room for new industries to settle in Huzhou. Meanwhile, Zhejiang is one of China's fastest-developing provinces, and there is fierce competition for new industries from other cities. Huzhou needs to act fast enough to grasp the opportunity window for green development.

However, the development of transition finance is far more difficult than that of green finance in nature, both temporally and spatially. Climate transition is inherently a long-term, dynamic process and thus requires ongoing evaluation, as opposed to green economic activities that can maintain their green status once certified. Market participants need to keep track of the transition pathways because of their evolving nature, which raises both the costs and requirements for capacity. Meanwhile, climate transition is highly constrained by local contexts and conditions, such as political systems and economic growth models. Developing countries such as China are still in the process of industrialization, with newer infrastructure and growing market demand. Therefore, delicacy is needed in designing transition pathways, policies, and financial products to ensure a credible and smooth transition while minimizing the risks of "transition washing."

In the case of Huzhou, exploration into transition finance is built on its previous experiences, policy setup, and market infrastructures. Because transition finance is considered an extension of green finance, it has shared similar pillars of development—such as taxonomies, disclosure, incentives, and products—with some unique elements, such as transition planning. In January 2022, Huzhou introduced China's first municipal-level roadmap for transition finance,

Exhibit 6. Huzhou's Approach to Transition Finance

Institutional Standards

- Transition Finance Taxonomy
- Guidelines for Transition Target Setting
- Outline of Transition Plans for Firms
- Methodology for Assessing Just Transition
- Guidelines for Calculating Carbon Emissions of Bank Loans

Products and Services

- Carbon Efficiency Loans
- Transition Loans
- Sustainability-Linked Bonds
- ESG Insurance

Policy Incentives

- Interest Subsidies for Transition Entities
- Subsidies for Carbon-Neutral Banks
- Subsidies for Standard Formulation

Digital Platform

- Platform for Carbon Accounts
- Green Financial Service Platform
- ESG Evaluation

Source: People's Government of Huzhou (2022a).

which identified seven primary tasks that include developing taxonomies, incentives, transition finance services, and digital platforms (see **Exhibit 6**).

Taxonomy

Huzhou first launched its own Transition Finance Taxonomy in 2022 and updated it in 2023 (People's Government of Huzhou 2023a). The taxonomy outlines 106 transition technology pathways for "8+1" carbon-intensive sectors locally in the form of a "whitelist," with the rationale of technological neutrality. The "8+1" refers to eight traditional key sectors: textiles, paper, chemicals, chemical fibers, nonmetal minerals, steel, nonferrous metals, and power generation. The "plus-one" is wire and cable, which is classified as a subsector in the national industry catalog. The wire and cable industry is included because of its high energy consumption and thus urgent need for transition.

The transition pathways in the taxonomy can be generalized into four categories: clustering of industries, decarbonization of production process (including reduction in source and process as well as carbon sequestration at the end), infrastructure upgrade, and purchase of third-party consultation services:

- Clustering of industries: focusing on systemic changes in the geographical layout of industries, to cut down long-distance transportation of materials and intermediate products.

- Decarbonization of production process: reduction in source materials, technical upgrade of the production process, and potential application of carbon capture, utilization, and storage technologies at the end of the process.
- Infrastructure upgrade: focusing on improving the efficiency of infrastructure related to production, such as factory buildings, charging sites, and green data centers.
- Purchase of third-party consultation services: consultation, certification, and advisory services that contribute to the low-carbon transition of the operations.

The taxonomy establishes baseline and targets of "carbon intensity" instead of energy consumption intensity, reflecting unit CO_2 emissions per CNY10,000 of industrial added value. Compared with the energy consumption intensity approach, this design is more straightforward and can avoid being impacted by the increasing proportion of renewable energy in the grid. The baseline values are provided by the local Statistics and Economic Information Bureau, based on industry data and the overall energy efficiency of production facilities. The target values are determined in line with the Paris Agreement and Huzhou's 14th Five-Year Plan for carbon reduction. Leveraging carbon targets that are readily available from government agencies supervising respective industries, the accuracy and credibility of benchmarks are assured, as is consistency across government agencies.

The taxonomy also includes instructions for four primary kinds of users: enterprises applying for transition financing, FIs, third-party agencies, and local governments. Essentially, users can benchmark the performance of transition entities against the values to determine if the entities are on track to meet the targets, which helps to mitigate the risks of transition washing. Advantages of municipal-level standards include accuracy of values (given the same statistical system), homogeneity of regulated entities, and flexibility to renew in time.

Transition Planning

Transition planning is an essential element of transition finance, which differentiates it from green finance. Transition finance is heavily reliant on the transition pathways of the financed entities. The process of developing a climate transition plan at the corporate level helps enterprises better understand climate-related risks and opportunities, clarify their business goals and strategies, and enhance their climate resilience. Lack of data and capacity remain key challenges for FIs and enterprises in this regard, however, particularly in developing countries.

Huzhou continues to follow the rationale of "create first, improve later" and emphasizes the practicality of transition planning from the perspectives of both policymakers and practitioners. The municipal government has formulated several other guidance documents in addition to the taxonomy, including guidelines on carbon accounting for banks, transition target setting for enterprises in the key sectors, assessment for just transition, developing "carbon-neutral" banks, and outlines/templates for formulating transition plans.

Carbon accounting: Carbon accounting is a common challenge for FIs in both disclosure and transition planning, particularly with financed emissions. Therefore, Huzhou issued the General Carbon Accounting Guidelines for Bank Loans, which provides formulas and emission coefficients for the use of fossil fuels and purchased electricity, as well as emissions in the production of cement, lime, steel, and desulfurization of coal power generation (Huzhou Market Supervising Administration 2022a). The financed emissions are the proportion of loans to the total assets of the enterprise, multiplied by its total emissions. This calculation is in line with the methodology from the Partnership for Carbon Accounting Financials. The emission intensity of enterprises is emissions divided by unit added value (CNY10,000). Although the coefficients may be subject to update from time to time, and may not necessarily reflect the performance of specific enterprises if they outrun or fall behind their peers, banks in Huzhou can still apply the formulas to their portfolios, generating results ready to be disclosed and compared with those of other FIs. Starting from here, FIs can determine whether they need to calculate on a more granular scale to create advantages in the market or answer investors' demands for more information.

"Carbon-neutral" banks: The guidelines for carbon-neutral banks were built on the previous guidance for green finance-specialized institutions and covered both operational and financed emissions in Scopes 1–3 (Huzhou Market Supervising Administration 2022b). Banks are encouraged to calculate their greenhouse gas (GHG) emissions based on established methodologies, such as the GHG Protocol and local guidelines. They are also encouraged to have standalone/separate credit quotas, approval channels, pricing, risk appetite, performance appraisal, products, and disclosures. In Huzhou's medium- to long-term planning for the banking sector, it provides differentiated timelines for pilot banks and others, while expecting overall neutrality by 2058 for all banks within its jurisdiction (People's Government of Huzhou 2021). **Exhibit 7** illustrates the milestones for carbon-neutral banks in Huzhou.

Target setting: For enterprises in the key sectors in the taxonomy, Huzhou developed guidelines to help them set short-, medium-, and long-term

Exhibit 7. Milestones for Carbon-Neutral Banks in Huzhou

Progress Milestone	Pilot Banks	Other Banks
Carbon peaking of operations	By 2025	By 2028
Carbon neutrality of operations	By 2030	By 2035
Overall neutrality	By 2055	By 2058

Source: People's Government of Huzhou (2021).

transition targets that are more ambitious than the targets in the taxonomy to prevent the risk of "transition washing."[5]

Transition planning: The formulation of transition plans is a complicated process. So far, net-zero transition plans published by leading FIs and enterprises globally are mostly lengthy documents of hundreds of pages, which is hard for smaller FIs to replicate. To address the capacity constraint, Huzhou prescribed outlines as well as a template of transition planning for enterprises, in the format of filling in blanks and checkboxes (Huzhou Financial Office 2023). In terms of themes, it is structurally in line with global frameworks—such as requirements from the International Sustainability Standards Board or the Task Force on Climate-Related Financial Disclosures—starting from strategic targets and descending to actions, financing plans, supporting measures, just transition/social responsibility, and disclosure. The content of each section is as follows:

- Introduction: organizational background and baseline of emissions.
- Strategy and targets: Transition entities are encouraged to provide short-term (2025), mid-term (2030), and long-term goals (year of carbon neutrality by 2045/2050/2055/2060).
- Actions: Transition entities are encouraged to provide relevant technologies and pathways, indicating whether they fall into the taxonomy.
- Financing plans: Transition entities are encouraged to provide an estimate of the overall expenditure by 2025 and how much of it is expected from external financing.
- Supporting measures: This part covers all supporting measures, including governance mechanisms, monitoring, internal incentivization, and risk management.
- Just transition/social responsibility: Transition entities are encouraged to estimate the potential impact on employment, supply chain, and commodity prices.
- Disclosure: format and content of disclosure.

Despite its simplicity in format, this template covers most elements put forward in international frameworks, such as those published by Climate Bonds Initiative, Glasgow Financial Alliance for Net Zero, and Transition Plan Taskforce. It serves as a skeleton and leaves entities the flexibility to fill in as much "flesh" (i.e., detailed reasoning or measures, as well as advanced modeling) as they see fit. For most of the enterprises seeking financing from only domestic FIs, filling in the template should give them sufficient backing to apply for transition finance. For enterprises seeking financing from international investors, they can elaborate the plan with more granularity to compete with international peers.

[5]Wanli Bian, "There Are Five Major Challenges in the Implementation of Financial Transformation. How Can We Solve Them?" *21st Century Business Herald* (30 June 2024). www.21jingji.com/article/20240630/herald/e888ae5f604165c674230aee56b21f26.html.

Right after the publication of the template, enterprises in the chemical fiber sector were selected as the first batch of transition entities. According to their commitments, their average carbon intensity will decline by 39.8% as of year-end 2025, compared with the baseline at year-end 2020 (*National Business Daily of China* 2023).

Just Transition

Just transition has received increasing attention in recent years and was included in the G20 Transition Finance Framework. Its definition or implications may vary across countries, however, as may the approaches that FIs need to take to address it. In the Chinese context, just transition is mostly associated with social stability, such as employment, income distribution, and commodity prices.

To ensure a just and equitable transition, Huzhou has also issued an assessment methodology with multiple quantitative and qualitative indicators to help firms evaluate, disclose, and mitigate the potential social impact of their transition planning. **Exhibit 8** presents a list of indicators used in the methodology.

Exhibit 8. Indicators in the Just Transition Assessment Methodology

Dimension	Indicator	Indicator Specification
Impact on Employee	Employee stability	Changes in the number of employees
	Equitable distribution of income	Changes in the income level of frontline manufacturing workers
	Employee growth plan	Status of staff training, including plans to provide training for new or upgraded skills and to support workers affected by corporate-level transition to access career opportunities and decent jobs
Impact on Supply Chain	Supply chain resilience	Impact on (the number of) small and micro firms in the upstream and downstream of the supply chain
	Price effect	Provision of affordable energy
		Provision of affordable raw materials
Sustainable Development Impact	ESG performance	A firms' own ESG score compared with that of the same period last year
		ESG score ranking compared with those of enterprises in the same industry in the city

Source: Huzhou municipal government.[6]

[6]The full table was provided by the Huzhou government in a research interview. Numeric thresholds were omitted by the author as they were not publicized. The public version can be accessed at https://custom.huzhou.gov.cn/DFS/file/2023/07/28/20230728164430854xcmln3.pdf?iid=570150.

Evaluation indicators are both quantitative and qualitative, depending on the status quo of sectors and regions. For dimensions where quantitative indicators are available, thresholds are provided as hard cutoffs. Meanwhile, some questions may not be applicable to certain enterprises and thus will be omitted. Data are extracted from the One-Stop Service Platform, other governmental agencies, and disclosure by the enterprises.

Such evaluation takes place as a component of ESG risk management before the approval of loans. It has also been included in post-loan monitoring: In the case of any deteriorating performance that triggers a risk alert, contingency plans will be activated. Banks are encouraged to actively engage with clients on the importance of just transition.

So far, in small-scale pilot tests, negative scores are mainly concentrated in small enterprises—partially because of the absence of clear employee growth plans or the presence of declining ESG scores—which may be explained by small enterprises' limited capacity for corporate governance.[7] Even though it is considered the social responsibility of enterprises to help employees grow, smaller enterprises may find doing so burdensome, particularly when they already face downward pressure from climate transition, such as income decline. Further capacity building is still needed from government agencies that oversee social welfare and employment, as well as research institutions and civil society organizations. SMEs in other economies may find this challenge relatable to their own corporate transition planning.

Incentives

In addition to the incentives for green finance, the Huzhou government has mobilized fiscal resources for transition entities. For transition entities that meet the committed progress of their transition targets, the government will provide subsidies of up to 0.5% of the entity's total loan amount in that year, with a maximum of CNY300,000 per entity. For entities that disclose transition information and achieve a just transition, the subsidy can increase by 10% (People's Government of Huzhou 2023b).

Meanwhile, banks in Huzhou have designed specialized financial products, such as "transition loans" and "carbon efficiency loans," whose lending terms are linked to transition targets and carbon efficiency performance. As of May 2024, a cumulative total of CNY56.552 billion in carbon efficiency loans has been issued (People's Government of Huzhou 2024b).

Bridging the Data Gaps

To enhance transparency and ensure measurability, reportability, and verifiability of performances, Huzhou developed a municipal-wide "carbon account" platform. Using digital technologies, the platform aggregates data from government

[7]Huzhou City Government, "Just Transition Practices in Huzhou," Presentation made by Huzhou government officials to the German Agency For International Cooperation, Huzhou, China (May 2024).

agencies, FIs, and third-party service providers to create a unified and consolidated emissions database. Through built-in algorithms, the platform can automatically draw data on the usage of electricity, oil, gas, coal, and heating and then calculate the carbon emissions, intensity, carbon efficiency ratings, and loan-associated carbon footprints, while matching the emissions within the time frame of loans, with just a few clicks. The platform not only helps enterprises keep track of their own progress but also helps FIs develop transition finance products.

To date, the carbon account platform has covered 31,000 enterprises, taking up more than 70% of the corporate clients of Huzhou's banks and accounting for 80% of the city's energy consumption and carbon emissions from the production sector (Huang 2022). It significantly reduces the costs of carbon accounting for enterprises and verification for FIs while enhancing the credibility of transition actions and financial products.

Conclusion

Reasons for Achievements

The most important reason for Huzhou's achievements is the reduction of costs for green and transition finance, given that these costs are a core challenge faced by FIs and firms worldwide. Particularly with the rise of transition finance, even more costs will be associated with data verification and labeling. In the case of Huzhou, however, a huge proportion of such costs is borne by the government through digital measures. With integrated and automated digital platforms, costs are saved in many aspects—such as data tracking, carbon accounting, and verification and certification—and market players are more incentivized to act in a green or transition-enabling manner. Whether Huzhou's achievements can be replicated in other municipalities is a hard question to answer.

Some additional reasons for Huzhou's success cannot be neglected:

- **Decent fiscal space and governance capacity:** Huzhou is located in one of the most affluent provinces in China, and its steady economic growth allows room for policy incentives, particularly fiscal subsidies. Meanwhile, the governance capacity of the local government is relatively high compared with that of average Chinese municipalities in terms of policy research, formulation, implementation, and cross-agency coordination. Plus, the Huzhou government has a high commitment to green development. In particular, cross-agency coordination has facilitated the provision of data infrastructure, while the fiscal space bears the costs of such public goods.
- **Lighter industrial structure:** Huzhou's industrial landscape, characterized by a predominance of light industries such as textiles and wooden furniture, has also made its climate transition easier. Its emission intensity may be high compared with that of its peers in the same province, but the intensity is not among the highest emissions in China. These light industry sectors face relatively lower pressures compared with heavy industries—the latter may already be challenged in terms of business sustainability and thus have

a more dire need to transition. For example, the market demand for textiles is still growing, and transition is somehow perceived as something "good to have." In other cities with higher reliance on heavy industries—such as steel, which has seen a sharp drop in demand—transitioning these industries in an orderly and just manner will be much more difficult.

- **"Learning by doing" mindset:** Notably, Huzhou's capacity to learn from global best practices and adapt them to its local context has been a cornerstone of its achievements. The city has embraced innovative approaches, especially technologies, to improve efficiency and reduce search and verification costs. It has also adopted a pragmatic rationale that prompts FIs to get started first and improve later, with the realistic expectation that it is impossible for smaller FIs to directly copy the pattern or efforts of the "big names" (i.e., global FIs) given capacity constraints and the actual demands. Starting with a small quantity, however, does not necessarily mean a compromise in quality.

Taking the example of transition planning, the brief template has covered all major aspects in global frameworks and can be further expanded when conditions allow. In such dynamic processes, FIs will be able to cultivate their unique understanding of green and transition finance in alignment with the local context and enhance their capacity gradually. The lessons learned through pilots will also feed into the provincial and national-level policymaking.

Future Challenges

Huzhou's experience with fiscal incentives illustrates its effectiveness in jump-starting green finance activities. However, fiscal incentives cannot last forever. There is an urgent need to create a self-sustaining green finance ecosystem that reduces reliance on continuous fiscal support.

Meanwhile, FIs in Huzhou have also mentioned that profitability lies at the heart of green and transition finance. In some cases, their green or transition finance products can meet the profitability criteria only with the subsidies; in other cases, FIs are willingly giving up some profitability in these products to demonstrate their responsibility. But with the downward trend in interest rates, there may be more pressure on the business sustainability of these actions. Banks interviewed during the writing of this chapter expressed their expectation that what Huzhou has accomplished will foster a culture of green preference among consumers and investors, with the hope of ensuring that financial products remain commercially viable. How soon this expectation can be achieved, however, remains a question.

Another challenge lies in the diversification of financial products. Loans have been the dominant product in Huzhou's green financial market. From an enterprise perspective, loans typically have a lower risk appetite compared with equity, making them less suitable for high-risk, high-reward ventures such as early-stage decarbonization technologies. Relying heavily on loans may increase the debt burden on businesses, limiting their financial flexibility and performance. The time frame is also an issue: Loans often come with shorter repayment periods relative to "patient capital" (e.g., pension fund or sovereign wealth funds), and these shorter time frames may not align with the long development cycles and uncertain payoffs associated with many decarbonization technologies. As the whole society continues to decarbonize, there is a growing need for more risk-tolerant and patient capital, as well as more structured financial products to cater to market demands.

Last but not least, the constant evolution of regulatory requirements, taxonomies, and standards is both a challenge and an opportunity for Huzhou and other municipalities striving to lead in green and transition finance. Although these updates can be demanding and resource intensive, they are essential for aligning financial practices with climate and sustainability goals in a rapidly evolving global landscape of regulatory requirements.

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