

Unveiling the embodied carbon emission hidden in equity portfolios held by leading global asset managers

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Abstract

Institutional investors play a central role in global value chains but remain largely excluded from emissions accounting frameworks due to their negligible direct emissions. This omission obscures their substantial responsibility for the carbon embedded in their investment activities. Here, we uncover the embodied carbon in equity portfolios held by 380 leading global asset managers by integrating macro-level sectoral emissions with micro-level firm financial data. In 2019, these portfolios were responsible for an estimated 636.97–875.88 MtCO₂-equivalent, with over 90% of emissions concentrated among the top 20 managers, predominantly based in North America and Europe. Despite limited divestment from carbon-intensive sectors, portfolio-level carbon exposure—measured using weighted average carbon intensity (WACI) and carbon emissions to revenue (CETR)—showed minimal improvement over time. We further identify a nonlinear, inverted U-shaped relationship between climate policy stringency and portfolio carbon exposure, suggesting that only highly stringent policy environments induce meaningful shifts in investment behavior. By contrast, exposure to physical climate risk has no significant effect. These findings highlight the critical role of ambitious climate policy in advancing financial decarbonization and underscore the influence of major asset managers in shaping global emissions trajectories through capital allocation.

1 Introduction

Capital allocation is widely acknowledged as the "lifeblood" of efforts for achieving the ambitious target of the Paris Agreement and Sustainable Development Goals (SDGs)^{1,2}. Financial institutions play an undeniably pivotal role in the global decarbonization effort by aligning financial flows with low greenhouse gas(GHG) emissions and climate-resilient development pathways, shaping both climate risk-management and the transition to low-carbon technologies and production, thereby reinforcing global confidence in the combat against climate change^{3,4}. Over the past year, a growing number of financial institutions have made bold commitments to achieving net-zero portfolios by 2050 or earlier. However, few have systematically begun to measure the emissions associated with their investment and financing activities, largely hindered by procedural complexity, insufficient supply chain emission data, and related institutional or

technical barriers. Nevertheless, developing a comprehensive and intuitive understanding of the carbon emissions embedded in the investment activities of major global investors is essential for steering capital toward a low-carbon and sustainable future^{5,6}.

The GHG Protocol Corporate Accounting and Reporting Standard provides comprehensive requirements and guidance for companies and other organizations to prepare enterprise-level greenhouse gas (GHG) emissions inventories^{7,8}. It classifies emissions into three scopes: Scope 1 refers to direct emissions from sources owned or controlled by the entity; Scope 2 includes indirect emissions from purchased electricity, steam, heat, and cooling; and Scope 3 encompasses all other indirect emissions across the value chain, including activities such as supply chain logistics, business travel, leased assets, and importantly, financial services such as investment and lending⁹. Although Scope 3 emissions are often methodologically complex and uncertain to estimate^{10,11}, they typically represent the largest share of a company’s overall carbon footprint-exceeding 75% in many cases, particularly in the financial sector¹². Within financial institutions, Category 15 (Investments) under Scope 3 constitutes the most significant source of emissions. However, disclosure of Scope 3 emissions remains largely voluntary and inconsistent across jurisdictions¹³, impeding the ability of investors and regulators to manage GHG risks across the full investment chain. At the same time, growing interest among investors and policymakers focuses on whether emissions reductions by portfolio companies can improve expected returns and operational performance^{14,15}.

This study proposes an accounting framework for estimating equity investment-related emissions of financial institutions by integrating top-down sectoral emission data with bottom-up firm-level financial data. Given their dominance in global capital markets, asset management firms are central to this analysis. Their assets under management (AUM) are not only vast but also growing rapidly. For instance, the top 500 asset managers collectively managed USD 119.5 trillion by the end of 2020, reflecting a 14.5% increase from 2019¹⁶. Accordingly, using the proposed methodology, we quantify the carbon emissions embedded in the equity portfolios of 380 leading global asset managers from 2010 to 2019. We employ three carbon-related metrics recommended by the Task Force on Climate-related Financial Disclosures (TCFD)-Total Portfolio Emissions, Weighted Average Carbon Intensity (WACI) and Carbon Emissions to Revenue (CETR)-to assess portfolio-level carbon volume, exposure, and efficiency. These indicators serve as a useful foundation for advancing climate-related financial reporting and identifying emissions hotspots warranting further investigation. Motivated by the growing expectation that climate policy will influence capital allocation^{17–19}, we employ a fixed effects regression model to examine the effects of policy stringency and disaster exposure on WACI and CETR. Results reveal a nonlinear, inverted U-shaped relationship between national climate policy stringency and WACI. While low-level policy stringency shows little effect, medium levels significantly reduce carbon exposure, indicating that only beyond a threshold do policies meaningfully shape investment behavior. In contrast, international policy stringency exhibits limited influence. Disaster exposure, proxied by economic losses, shows no significant association

with portfolio emissions—suggesting that, during the pre-pandemic period, physical climate risks had not yet materially influenced investment carbon exposure. Among control variables, portfolio emission size is positively and significantly associated with both WACI and CETR, implying that larger institutions tend to manage portfolios with higher carbon intensity and lower emission efficiency.

In conclusion, these findings underscore the critical role of robust and well-calibrated national climate policies in promoting financial sector decarbonization. They also emphasize the importance of regulatory consistency and tailored intervention, highlighting that effective climate policy—beyond symbolic commitments—is essential for reshaping institutional investment behavior and aligning capital flows with global decarbonization goals.

2 Results

2.1 Over 90% of the embodied emissions in global equity portfolios are contributed by the portfolios of the top 20 asset managers

Over 90% of the embodied emissions in global equity portfolios are attributable to the portfolios managed by the top 20 asset managers. Between 2010 and 2019, the carbon emissions embedded in the equity holdings of 380 leading global asset managers increased significantly—rising by over 50%, from 351.35–533.44 MtCO₂-eq to 626.97–878.88 MtCO₂-eq (Fig. 1). On average, these embedded emissions were more than 700 times higher than the direct emissions reported per institution, underscoring the outsized climate impact of financial capital allocation relative to operational footprints. This rapid increase in investment-related emissions was primarily concentrated in two major regions: North America and Europe. In North America, the volume of emissions rose from 287.7–413.03 MtCO₂-eq in 2010 to 533.98–633.63 MtCO₂-eq in 2019. Similarly, Europe experienced an upward trajectory, with total emissions reaching 65.66–80.95 MtCO₂-eq by 2019. This concentration is largely driven by the presence of a high density of experienced financial institutions and active investment operations in these regions. Notably, in 2019, over one-third of the carbon emissions embodied in the equity portfolios of 162 North American asset managers were attributable to the “Big Three” firms: Vanguard, State Street, and BlackRock. Their respective contributions were 93.9–111 MtCO₂-eq, 66.8–74 MtCO₂-eq, and 57.6–72.5 MtCO₂-eq, collectively accounting for 34.7% of total embedded emissions. Over the decade, these three firms increased their investment-related emissions by 54.5 MtCO₂-eq, 17.5 MtCO₂-eq, and 8.3 MtCO₂-eq, respectively. Other leading asset managers in North America also experienced notable emission growth over this period. By contrast, asset managers based in Europe—the world’s second-largest financial market—exhibited lower levels of embedded emissions and in some cases, recorded declines. For instance, between 2010 and 2019, emissions associated with the equity portfolios of Lyxor AM and Aviva fell from 5.7 MtCO₂-eq to 3.5 MtCO₂-eq and from 2.1 MtCO₂-eq to 1.8 MtCO₂-eq, respectively. This trend may be partially attributed to the

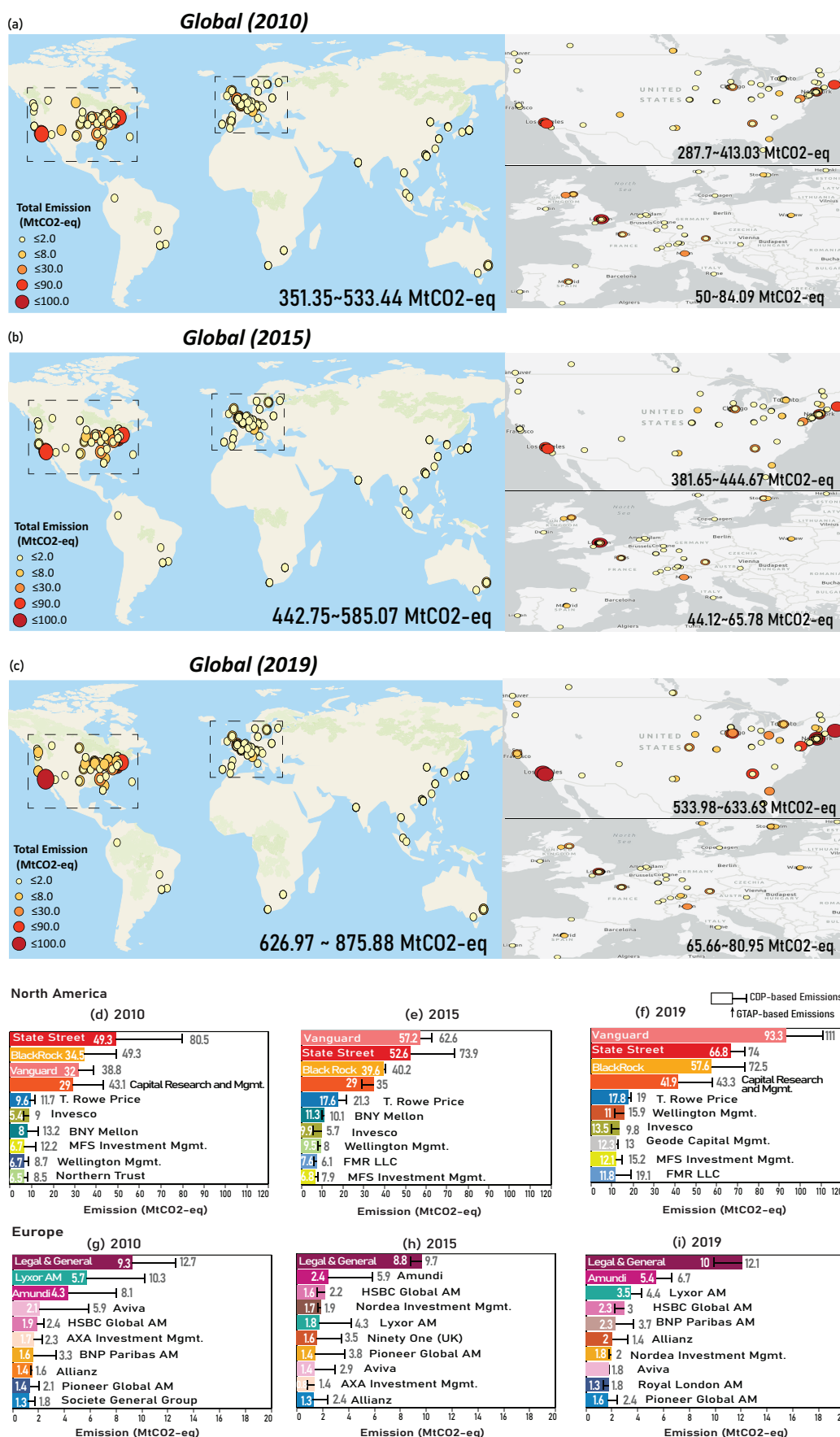


Fig. 1 Trends in carbon emissions embodied in the equity portfolios of the leading global 380 asset managers, based on GTAP and CDP data sources. In 2010 (a), 2015 (b), and 2019 (c); the top 10 emitters in North America (d–f) and Europe (g–i), respectively. The circles in the maps represent the size of the asset managers' investment carbon emissions, with darker colors and larger ones indicating larger values. The values on the maps represent the total financed carbon emissions of 380 asset managers; we also show two reference emissions types based on GTAP and CDP data sources in the bar chart (d–i).

early adoption of climate neutrality targets and legally binding climate legislation within the European Union, such as those initiated in the UK and the Netherlands.

Additionally, from a global investment embodied emissions flow perspective, analysis of investment portfolios from 2010 to 2019 reveals how carbon emissions are transferred across regions through international financial linkages (see Supplementary Information Fig. 1). North America, especially the United States, consistently emerges as the largest source of embedded emissions in cross-border investments. Europe functions as both a major emitter and recipient of financial carbon flows. Meanwhile, China and the Asia-Pacific region are increasingly becoming prominent recipients of carbon-intensive investments during this period. Although South America, India, and Africa currently play smaller roles in terms of absolute embedded emissions, they show signs of growing participation through steady investment connections. These regional patterns highlight the hypothesis that urgent need for policymakers—particularly in regions with high investment emissions—to develop enforceable sustainable finance standards. Legal mandates requiring enhanced climate-related financial disclosures by both corporations and financial institutions are critical to curbing the carbon footprint of investment flows.

2.2 Embodied emissions performance in top asset managers' equity portfolios and sectoral concentration in high-Carbon industries

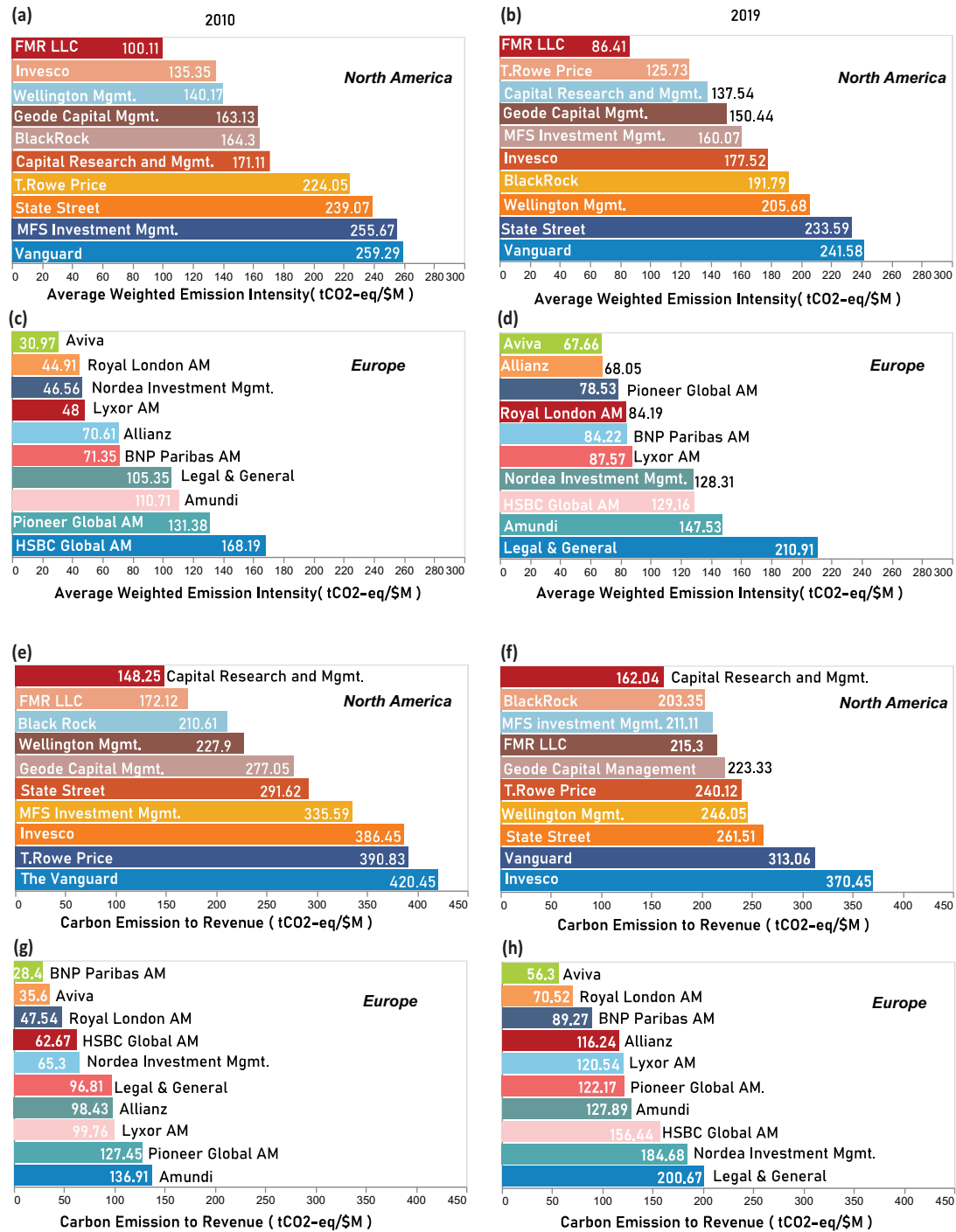


Fig. 2 Weighted Average Carbon Intensity (WACI) and Carbon Emission to Revenue (CETR) for the industrial equity portfolios of the top 10 selected asset managers in North America in 2010(a, e), 2019(b, f) and Europe in 2010(c, g), and 2019(d, h). Specifically, according to equation (3), WACI is the average carbon emission intensity calculated using the weight of sectoral investment holdings, and according to equation (4), CETR is the average carbon emission intensity calculated by using the weight of sectoral investment returns.

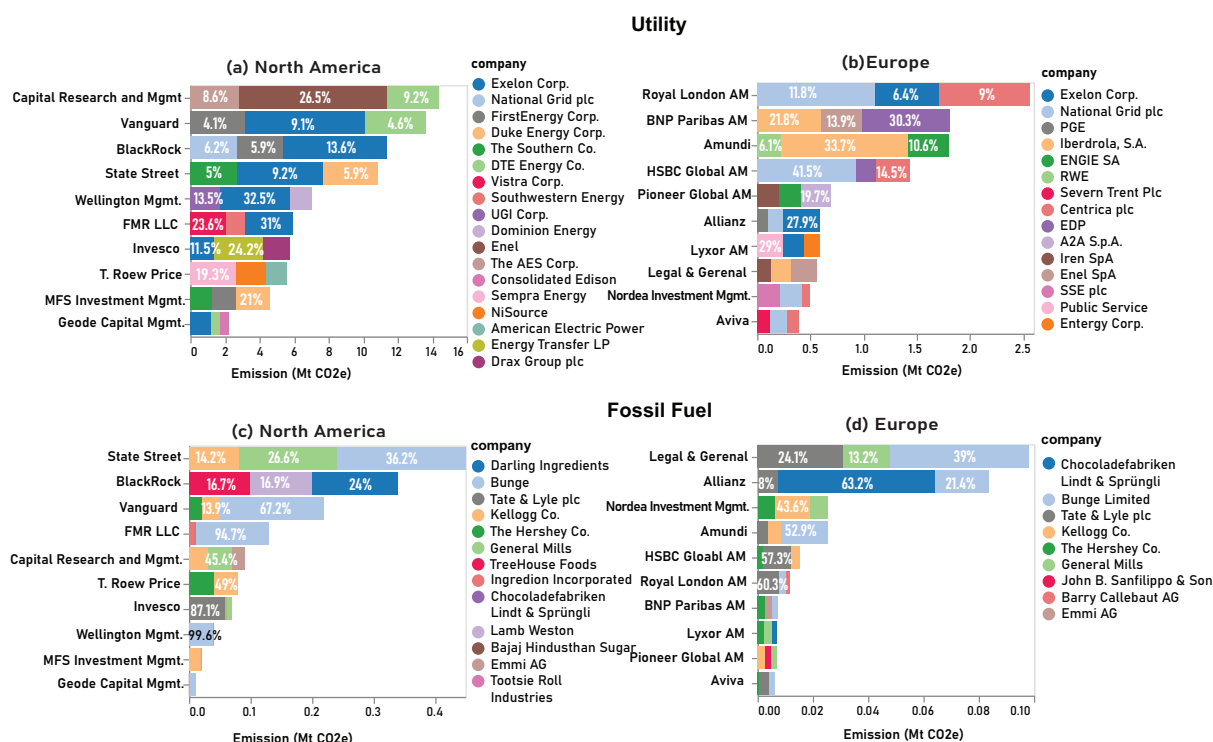


Fig. 3 Financial emissions allocated through the international equity portfolios are concentrated in leading companies in the utility (a, b), and fossil fuel (c, d) sectors. The percentage in the bar charts indicates the share of emissions from this investee in the total sectoral emissions. Figure 3 shows the volume of the embodied carbon emissions for two highly carbon-intensive sectors. The stacked bar represents the top three carbon emissions (in terms of volume) embodied in sectoral equity portfolios of an asset manager. For each subfigure, we calculate the share of carbon emissions embodied in the investment in these three firms.

Most of the top 20 asset managers' equity portfolios exhibit varying degrees of carbon exposure and emission efficiency. Two key indicators are employed to assess these characteristics. The Weighted Average Carbon Intensity (WACI) reflects the degree to which a portfolio is exposed to high- or low-carbon-intensity companies from a financial risk perspective, while Carbon Emissions to Revenue (CETR) measures how efficiently portfolio companies generate revenue per ton of carbon emitted. Between 2010 and 2019, WACI for the majority of the top 10 asset managers based in North America and Europe declined only marginally, with some institutions even experiencing increases. This trend indicates that, despite growing awareness and increased regulatory attention to climate-related financial risks, the overall carbon exposure of these portfolios has not significantly diminished over the past decade (Fig. 2). Notably, WACI is highly sensitive to sectoral investment composition. During this period, many asset managers appeared to reduce their holdings in traditionally carbon-intensive sectors—such as utilities, ferrous metals, and processed products—while maintaining or increasing allocations to sectors like equipment and machinery (Supplementary Information Fig. 2). This reallocation suggests to some extent a partial divestment from high-emission industries. However, it also underscores a persistent structural exposure to carbon-intensive activities, as remaining investments often involve sectors with stagnant or rising carbon intensity levels.

Importantly, the persistently high WACI is largely driven by rising carbon intensities within certain sectors—particularly the utility sector—and by individual high-emitting companies. A similar pattern is observed in CETR, which also reflects sectoral revenue performance. In the case of over 10 institutions, the utility sector’s share of portfolio revenue was consistently lower than its share of portfolio holdings from 2010 to 2019, reflecting the underperformance of utility companies in terms of revenue over the decade. Moreover, the top 10 European institutions consistently exhibited a lower ratio of portfolio revenue to holdings compared to their North American counterparts, suggesting relatively weaker revenue efficiency in carbon-intensive sectors. Regarding regional heterogeneity, both WACI and CETR values for the top 10 European asset managers were significantly lower than those of North American firms. This disparity reflects the relatively lower carbon intensity of the companies targeted by European portfolios, as well as differences in investment strategy, sectoral focus, and regulatory environments across regions.

Building upon the above findings, we further investigate the downstream sources of embedded emissions within equity portfolios (Fig. 3). The analysis reveals that substantial portions of carbon emissions originate from investments in downstream leaders in carbon-intensive sectors. Within the utility sector, Exelon Corporation, the largest energy provider in the United States, was the dominant source of embedded emissions in the portfolios of Vanguard, State Street, BlackRock, Wellington Management, FMR, and Invesco, accounting for 9.1%, 13.6%, 9.2%, 32.5%, 31%, and 11.5% of utility-related portfolio emissions, respectively. Other major contributors include DTE Energy and Duke Energy, which significantly influenced the emissions profile of Capital Research, Vanguard, State Street, and MFS. Among the top 10 European asset managers, leading industrial players such as National Grid, Iberdrola, Centrica, and ENGIE SA were primary sources of embedded emissions. A similar pattern is observable in the fossil fuel sector, where Bunge Limited emerged as the largest contributor to the embodied emissions of several North American and European equity portfolios.

Importantly, these top 20 asset managers have recently committed to aligning their portfolios with net-zero targets by 2050 or earlier. As influential capital allocators, they play a critical role in redirecting financial flows toward low-carbon pathways. For example, State Street, a member of the Net Zero Asset Managers Initiative, has set interim decarbonization targets for 2030 in pursuit of net-zero portfolio emissions by 2050. BlackRock has also pledged to align its portfolios with net-zero objectives, while Allianz has established a near-term decarbonization target through 2025 and aims for full portfolio neutrality by 2050.

2.3 Assessment of regional climate policy stringency and disaster exposure effects on asset managers' portfolio-level carbon performance

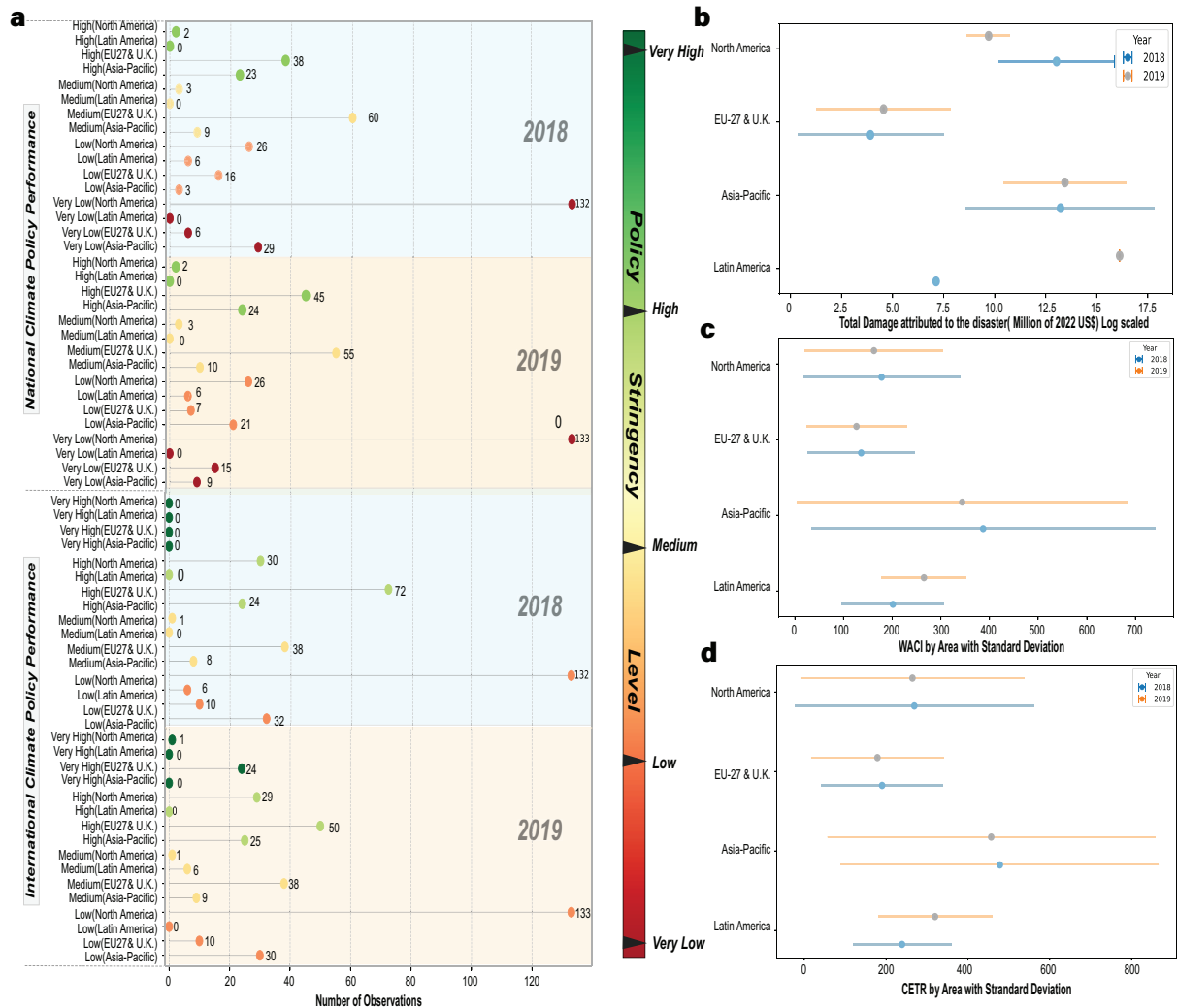


Fig. 4 Regional climate policy stringency and Asset Managers' Portfolio-Level Carbon Performance. Number of observations by region and policy stringency levels for National (Very Low, Low, Medium, High) and International Climate Policy Performance (Low, Medium, High, Very High) in 2018 and 2019 (a). Total Damage (log-scaled, thousands of US dollars) refers to the value of all economic losses directly or indirectly due to the disaster (b), Weighted Average Carbon Intensity (WACI) (c), and Carbon Emissions to Revenue (CETR) (d) by region, with standard deviations. WACI and CETR reflect portfolio-level carbon exposure and efficiency based on sectoral investment weights and returns, respectively.

Table 1 | Linear panel regression models shwowing the effects of policy stringency and damage expoure on Weighted Average Carbon Intensity (WACI) and Carbon Emssion to Revenue (CETR)

	Dependent Variables:			
	WACI		CETR	
	(1)	(2)	(3)	(4)
National Climate Policy: Low	17.464** (6.925)	8.789*** (8.330)	0.098 (17.968)	1.183 (17.867)
National Climate Policy: Medium	-84.617* (47.568)	-84.208* (50.330)	-377.644*** (34.080)	-378.950*** (42.655)
International Climate Policy: Medium	81.881*** (27.265)	86.291*** (32.029)	95.400*** (27.811)	100.865** (43.078)
International Climate Policy: High	0.300 (9.267)	-2.942 (9.400)	8.814 (9.881)	5.985 (11.412)
Log Total Affected		-0.118 (1.596)		-0.269 (2.697)
Emission	24.872* (13.246)	24.422* (13.466)	39.901* (22.794)	39.294* (23.362)
Observations	545	513	545	513
R ²	0.069	0.081	0.179	0.187
F Statistic	3.882***	3.437***	11.368***	8.968***
<i>Note:</i>			* p<0.1; ** p<0.05; *** p<0.01	

In the recent decade, a growing consensus has emerged on the necessity of more stringent government regulations to mitigate the potentially catastrophic consequences of climate change²⁰. Climate policies and physical climate risks are widely recognized as downside risks for carbon-intensive firms^{21,22}, directly influencing institutional investors' portfolio-level carbon exposure and performance.

To explore the economic implications of climate policy stringency and disaster exposure, Figure 4 provides a descriptive overview of regional variations in policy strength and climate-related metrics. Figure 4 provides a descriptive overview of regional variations in policy strength and climate-related metrics. Subfigure (a) shows clear regional differences in climate policy performance. The EU-27 & U.K. stand out, having the largest number of agencies situated in areas with high national climate policy stringency or very high international climate policy stringency, compared to other regions like North America, Asia-Pacific, and Latin America. Subfigure (b) highlights regional disparities in value of all economic losses directly or indirectly due to the disaster, with North America and Asia-Pacific experiencing the most impact, and Latin America the least. Subfigures (c) and (d) show high variance in both WACI and CETR across regions, indicating significant heterogeneity in carbon exposure and emission efficiency, likely influenced by differing policy regimes.

Using the fixed effects regression models described in the Methods, the findings reveal a nonlinear, inverted U-shaped relationship between national climate policy stringency and asset managers’ equity portfolios’ carbon exposure and performance. Transitioning from *very low* (the base category) to *low* national policy stringency is associated with a significant increase in *WACI* (17.464; $p < 0.05$), as shown in Model (1), suggesting that marginal policy tightening may initially lead to increased exposure. once national policy stringency reaches a *medium* level, the effect becomes significantly negative. In Models (1) and (2), medium national policy stringency is associated with a reduction in *WACI* by approximately 84.6 and 84.2 units, respectively ($p < 0.1$ and $p < 0.05$). A similar effect is observed for *CETR* in Models (3) and (4), with a reduction of around 378.9 units ($p < 0.01$). These results suggest that only after a meaningful threshold is crossed do national policies begin to drive substantive reductions in portfolio carbon intensity, validating the hypothesis of an inverted U-shaped effect. For international climate policy (from low to very high), a similar pattern emerges. from low to *Medium* international stringency is associated with a significant *increase* in both *WACI* and *CETR*—rising by 81.9 to 86.3 units and 95.4 to 100.9 units, respectively ($p < 0.01$ and $p < 0.05$). Conversely, *high* international climate policy stringency does not have a statistically significant effect in any model, possibly reflecting weaker enforcement or inconsistency in cross-border climate policy implementation.

Among the control variables, emission size is consistently and positively associated with both *WACI* and *CETR*, suggesting that institutions with larger emission volumes tend to maintain portfolios with higher carbon intensity and lower carbon efficiency. In contrast, disaster exposure, proxied by the logarithm of the total number of people affected, does not exhibit a statistically significant association with either dependent variable. This implies that, during the pre-pandemic period, the experience of climate-related disasters had not materially influenced institutional investment decisions.

Overall, these results underscore the importance of well-calibrated climate policy design and effective enforcement, showing that proper stringency of national climate policy is most effective in driving asset managers’ equity portfolio-level carbon intensity, while poorly enforced or inconsistent international policies may be less impactful. Furthermore, the strong positive association between emission size and portfolio-level carbon metrics may indicate structural inertia among large asset management institutions. This could be due to path dependency or scale-related constraints, whereby larger firms-functioning as substantial ”emitters” through their investment allocations-encounter greater challenges in divesting from carbon-intensive holdings and shifting their investment strategies, capturing the notion of ”too big to pivot.”

3 Discussion

Capital flows remain central to the objectives of the Paris Agreement. In particular, Article 2.1(c) redefines the role of finance by emphasizing the need to make all financial flows consistent with the Agreement’s goals for mitigation and adaptation²³. However, financial institutions face substantial challenges in the collection, benchmarking, and evaluation of Scope 3 emissions data—particularly in navigating the complexity and fragmentation of available methodologies. Rather than waiting for the establishment of a unified global measurement standard, financial institutions must proactively begin preparing emissions data across their entire value chains. This includes quantifying financed emissions and translating long-term net-zero pledges into actionable, near-term targets. This study investigates the carbon emissions embodied in the equity portfolios of leading global asset managers—an area that offers a pragmatic starting point for addressing climate-related financial risks. The findings indicate that over 90% of the total carbon emissions embedded in equity portfolios are attributable to the top 20 asset managers, predominantly located in North America and Europe. As such, the investment behavior of these institutions has the potential to shape the global carbon landscape through capital allocation decisions.

As investors increasingly incorporate carbon emissions data into their decision-making processes, capital markets are emerging as a significant force in addressing emission-related issues. Our analysis further reveals that a large share of portfolio-level emissions stems from investments in high-emission sectors, particularly through equity holdings in dominant firms. Given that institutional investors are partial owners of these firms, there is empirical evidence that institutional ownership is positively correlated with future environmental and social performance²⁴. Therefore, mitigating embodied emissions in equity portfolios necessitates that institutional investors actively engage in corporate governance to encourage improved emissions management practices^{25,26}. Such stewardship not only enhances corporate climate accountability but also contributes to reducing long-term emissions risk within the portfolios. In addition, there is growing interest among institutional investors in understanding whether carbon risks are already priced into current firm valuations, and how carbon emissions affect stock returns^{27,28}. Krueger et al. (2018) found, through a global investor survey, that while most respondents recognized the materialization of climate risks, equity valuations did not fully reflect these risks²⁹. This aligns with our empirical findings, which show that WACI and CETR have not significantly declined in the pre-pandemic period, further supporting the assertion that climate-related risks are not yet fully internalized in financial markets.

Moreover, institutional investors around the world are increasingly attentive to the implications of climate-related risks, particularly transition risks—such as policy uncertainty—and physical risks, both of which have the potential to significantly affect portfolio performance³⁰. Among these risks, the stringency of climate policy has emerged as a pivotal instrument for signaling a nation’s commitment to sustainability and for managing environmental risk at the systemic level³¹. A growing body of empirical literature

indicates that uncertainty surrounding climate policy can exert broad effects on macroeconomic conditions and firm-level financial behavior. Specifically, it has been shown to lead to higher financing costs, reduced access to capital markets, and increased precautionary cash holdings, as firms attempt to hedge against potential regulatory shocks^{32,33}. This study identifies a nonlinear, inverted U-shaped relationship between the stringency of national climate policy and asset managers' equity portfolio-level carbon exposure. This concave association implies that only beyond a certain threshold does policy stringency begin to influence asset managers' carbon exposure and investment behavior. These results hold important implications for financial policy design, highlighting the need for a calibrated approach where climate policy is sufficiently stringent to drive financial decarbonization without inducing disproportionate market distortions.

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Methods

1) Accounting boundary, attribution factor, and the embodied carbon emissions of equity portfolios

The Greenhouse Gas Protocol (GHG Protocol) defines carbon emissions across three scopes to avoid double-counting. Scope 1 includes direct emissions from owned or controlled sources; Scope 2 covers indirect emissions from purchased electricity, steam, and heating; Scope 3 includes all other indirect emissions along the value chain, including those from investments. The Partnership for Carbon Accounting Financials (PCAF) classifies investment activities under Scope 3 into six types: listed equity, business loans, unlisted equity, project finance, commercial real estate, and vehicle loans.

This study focuses on equity portfolios, which have substantial carbon impacts. Carbon attribution is based on the Attribution Factor (AF), which is defined as:

$$\text{Attribution Factor (AF)} = \frac{\text{Outstanding Amount}}{\text{Total Market Value}} \quad (1)$$

The outstanding amount is the value of equity held by a financial institution, while the total market value equals the product of the share price and total shares outstanding.

Given limited company-level Scope 1 and 2 disclosures, we estimate emissions using sector-average carbon intensity and revenue:

$$\text{Total Financial Carbon Emissions} = \sum_i \left(AF_i \times \frac{\text{Scope 1\&2 Emissions}_s}{\text{Total Output}_s} \times \text{Revenue}_i \right) \quad (2)$$

This yields an estimate of total carbon emissions embodied in industrial portfolios, consistent with GHG Protocol investment accounting.

2) Quantifying carbon performance of equity portfolios

Equation (2) provides absolute emissions but is unsuitable for comparing portfolios of different sizes. Following the TCFD framework, we use two performance indicators: WACI and CETR.

Weighted Average Carbon Intensity (WACI) measures carbon exposure per unit of enterprise value:

$$\begin{aligned} \text{WACI} &= \sum_i \left(\frac{EV_i}{EV} \times \frac{\text{Scope 1\&2 Emissions}_s}{\text{Total Output}_s} \right) \\ &= \sum_s \text{Share of Holding}_s \times \text{Sectoral Carbon Intensity}_s \end{aligned} \quad (2)$$

Carbon Emissions to Revenue (CETR) evaluates productivity-adjusted emissions:

$$\begin{aligned} \text{CETR} &= \frac{\sum_i \left(AF_i \times \frac{\text{Scope 1\&2 Emissions}_s}{\text{Total Output}_s} \times \text{Revenue}_i \right)}{\sum_i \text{Revenue}_i} \\ &= \sum_s \text{Share of Revenue}_s \times \text{Sectoral Carbon Intensity}_s \end{aligned} \quad (3)$$

These metrics enable cross-portfolio and cross-sector comparisons of carbon performance and highlight key investment exposures.

3) Fixed effects regression framework

To assess the empirical relationship of how national and international climate policy performance shapes institutional-level carbon exposure, we estimate a series of linear panel regression models using two dependent variables: *Weighted Average Carbon Intensity (WACI)* and *Carbon Emission to Revenue (CETR)*.

These metrics serve as proxies for an institution’s exposure to carbon-intensive investments and the carbon efficiency of its equity portfolio, respectively. Specifically, the primary explanatory variables capture the *stringency of climate policy* in both domestic and international contexts. We include: (1) National Climate Policy Performance (NCPP), categorized as *Very Low* (reference), *Low*, *Medium*, and *High* and (2) International Climate Policy Performance (ICPP): categorized as *Low* (reference), *Medium*, *High*, and *Very High*. Dummy variables are constructed for all non-reference categories. To control for heterogeneity in baseline emissions across institutions, we include *Emission Size* ($Emission_{it}$) as a continuous control variable. In an extended specification, we examine the potential influence of *climate-related physical risk* by incorporating the logarithm of the total economic loss affected by climate-related disasters ($\log(\text{Total Affected}_{it})$). This variable serves as a proxy for the intensity of physical climate risk faced by institutions headquartered in more vulnerable regions.

All models are estimated using a *two-way fixed effects panel regression*, controlling for unobserved time-invariant institutional effects (α_i) and year-specific shocks (λ_t). Robust standard errors are computed using the heteroskedasticity-consistent *HC1 estimator*.

The baseline model is specified as follows:

Model 1:

$$\begin{aligned} Y_{it} = & \beta_1 \cdot \text{NCPP_Low}_{it} + \beta_2 \cdot \text{NCPP_Medium}_{it} + \beta_3 \cdot \text{NCPP_High}_{it} \\ & + \beta_4 \cdot \text{ICPP_Medium}_{it} + \beta_5 \cdot \text{ICPP_High}_{it} + \beta_6 \cdot \text{ICPP_VeryHigh}_{it} \\ & + \beta_7 \cdot \text{EmissionSize}_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

The extended model, which incorporates disaster-related exposure, is expressed as:

Model 2:

$$\begin{aligned} Y_{it} = & \beta_1 \cdot \text{NCPP_Low}_{it} + \beta_2 \cdot \text{NCPP_Medium}_{it} + \beta_3 \cdot \text{NCPP_High}_{it} \\ & + \beta_4 \cdot \text{ICPP_Medium}_{it} + \beta_5 \cdot \text{ICPP_High}_{it} + \beta_6 \cdot \text{ICPP_VeryHigh}_{it} \\ & + \beta_7 \cdot \log(\text{TotalAffected}_{it}) + \beta_8 \cdot \text{EmissionSize}_{it} + \alpha_i + \lambda_t + \varepsilon_{it} \end{aligned}$$

Data sources

To estimate sector-level average carbon intensity, we use data from the *Global Trade Analysis Project* (GTAP), which provides harmonized economic output data by sector. The GTAP database is updated quadrennially and includes data for the years 2011, 2014, and 2017. To fill gaps for intermediate years, we adopt an interpolation strategy: GTAP9 (2011) is applied to 2010–2012, GTAP10 (2014) to 2013–2015, and GTAP11 (2017) to 2016–2020: <https://www.gtap.agecon.purdue.edu/databases/default.asp>

Scope 1 emissions by sector and region are sourced from the *International Energy Agency* (IEA: <https://www.iea.org/data-and-statistics>), which reports data for 191 countries and 34 economic sectors. Scope 2 emissions are drawn from the *GTAP-E* database, which provides electricity consumption by energy type

across 140 countries. To ensure consistency with GTAP classifications, all emissions data are aggregated into 141 regions and 14 sectors.

To assess the robustness of emissions estimates, we also incorporate firm-level Scope 1 data from the *Carbon Disclosure Project* (CDP:<https://data.cdp.net/>), which includes reported emissions from over 5,000 companies worldwide. These data are used to generate alternative sectoral carbon intensity estimates for sensitivity analysis.

Equity investment and financial data are obtained from *S&P Capital IQ*:<https://www.capitaliq.com/CIQDotNet/Login-okta.aspx>, which offers quarterly updated information on institutional holdings in publicly traded firms. The dataset includes variables such as total revenue, market capitalization, geographic location, and industry classification codes. Market capitalization is standardized to year-end values to mitigate volatility effects, while revenue figures are adjusted to reflect annual earnings from January 1 to December 31, accounting for variations in reporting practices across exchanges. The country of each investee firm is used to map the geographic distribution of financial assets.

Climate policy performance data are sourced from *Germanwatch's Climate Change Performance Index (CCPI)*, which annually publishes national-level climate policy indicators, including qualitative assessments of both national and international climate policy frameworks. These data are derived from expert assessments and capture recent policy developments not available in quantitative datasets. All policy indicators are publicly available via the CCPI platform: <https://ccpi.org/downloads/>.

Disaster exposure data, specifically total economic losses from climate-related extreme events, are sourced from the *EM-DAT International Disaster Database*: <https://www.emdat.be/>.

Supplementary Information

Supplementary Table 1 · The aggregated 14 economic sectors

No.	Sector	No.	Sector
1	Grains & Crops	8	Mineral products necessity
2	Fuel	9	Ferrous metals
3	Other extraction	10	Metal necessity
4	Processed products	11	Metal products
5	Textile and clothes	12	Equipment and machinery
6	Wood and paper	13	Utility
7	Chemical products	14	Other

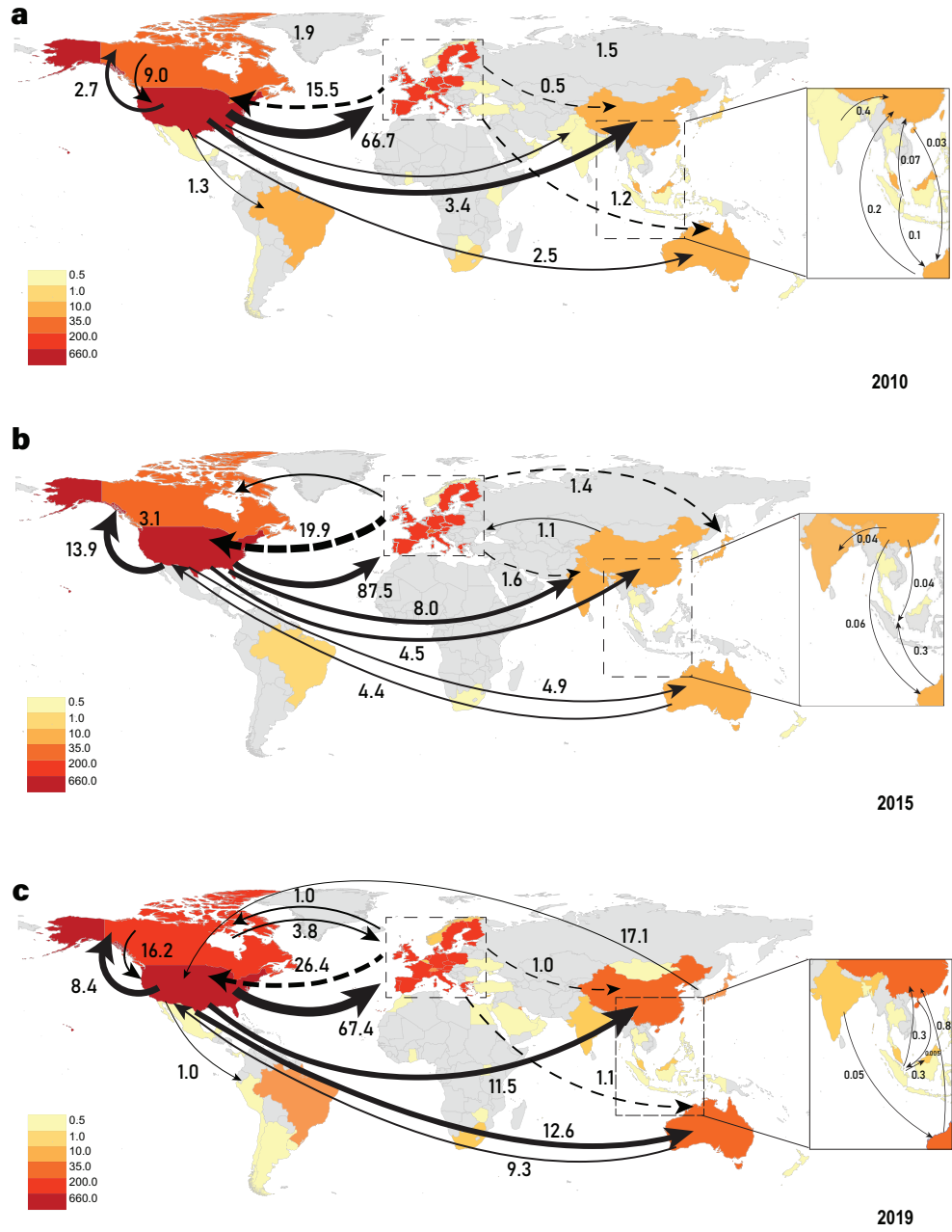


Fig. 5 Carbon flows embedded in international equity investments in 2010, 2015, and 2019((a-c)). Arrows represent the direction and magnitude of embodied carbon emissions associated with cross-border equity investments, indicating flows into recipient countries. The color gradient of each country reflects the total investment-related emissions embedded in equity portfolios managed by asset managers domiciled in that country. Insets provide magnified views of emission flows in South and Southeast Asia.

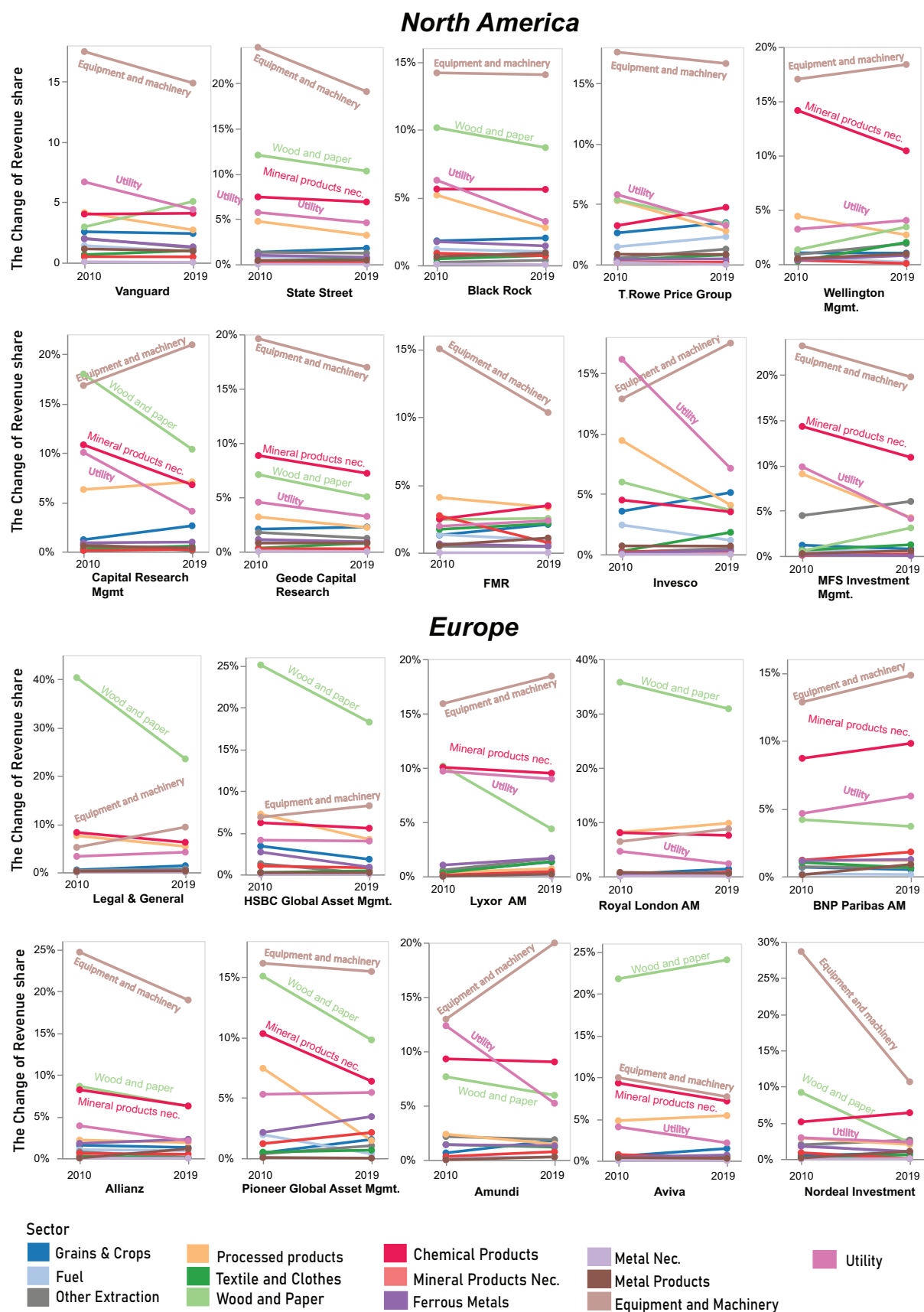


Fig. 6 Sectoral changes in portfolio holding shares between 2010 and 2019 for the top 20 selected asset managers in North America and Europe.