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A Framework for Attributing Changes in Portfolio Carbon Footprint

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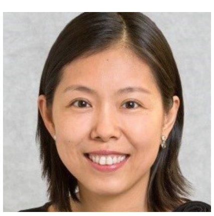

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KEY FINDINGS

- While tracking portfolios' carbon footprint is a key requirement for setting and tracking net-zero targets, it is challenging in practice because changes in carbon footprints may be driven by changes in climate-related variables, portfolio rebalancing, or financial variables.
- A framework is proposed that attributes changes in portfolio-level emissions to their primary drivers, including changes in the portfolio composition, changes in issuers' emissions, as well as changes in ownership and financing structure.
- The framework proposed allows investors to understand to what extent changes in a portfolio's carbon footprint are due to companies' real-world decarbonization efforts, a portfolio manager's investment decisions, or changes in companies' financing.

ABSTRACT

Tracking a portfolio's emissions profile over time is a key requirement for any type of climate-aware investment strategy. The challenge in tracking those profiles is that climate metrics are influenced by not only the emissions of companies in the portfolio but also portfolio managers' decisions, as well as other financial variables such as weights in the portfolio or companies' enterprise values. In this article, the authors develop an attribution framework that allows investors to disentangle these effects. They focus on financed emissions, which aggregate greenhouse gas emissions "owned" by a portfolio's holdings, and financed-emissions intensity, which adjusts financed emissions by dividing it by portfolio value. Their approach is to first calculate contributions by looking at changes in a specific input variable while keeping all other input variables constant. Next, they account for effects of simultaneous changes. The results are organized in an attribution tree that allows for a systematic drill-down into the different effects.

A range of climate metrics have been proposed by different industry organizations to track a portfolio's emission profile. All of them are based on a company's greenhouse-gas (GHG) emissions data but use slightly different methodologies to normalize emissions for company size and aggregate emissions data at a portfolio level.

Our focus in this article is on two climate indicators: financed emissions (FE), which aggregate GHG emissions "owned" by a portfolio's holdings and are therefore not size-adjusted, and financed-emissions intensity (FEI), which adjusts FE by dividing it by portfolio value. The challenge for portfolio managers in tracking emissions profiles over time is that climate metrics are influenced not only by the actual emissions of companies in the portfolio but by portfolio managers' decisions, as well as other financial variables, such as weights in the portfolio or companies' enterprise values.

In this article, we develop an attribution framework that allows investors to disentangle these effects. The basic premise is simple: For each variable influencing the respective climate metrics, we calculate first-order contributions by looking at changes in a specific input variable while keeping all other input variables constant. The nonlinear, higher-order effects arising from simultaneous change of several input variables are collected in interaction terms.

We define an attribution tree that illustrates the different contributions in several layers that allow for a drill-down into the different effects. We observe that FE is a less volatile indicator within the MSCI ACWI Investable Market Index (IMI) than emissions-intensity measures, because intensities are influenced by the quantity that is used for size adjustment (enterprise values or revenues) and thus adds significant levels of volatility. The tree attribution in this study allows users to understand how much of the change in intensities come from this so-called "denominator effect."

Our approach is also flexible enough to accommodate for variants of climate metrics that slightly differ from the ones used in this article, such as revenue-based emission intensity or a weighted-average intensity. Overall, the tree attribution that we present in this article can be used to understand whether a portfolio's carbon footprint has improved over time and what has been driving these changes.

DEFINING THE EMISSIONS OF A PORTFOLIO

Policymakers and regulators have taken a deep interest in the evolution of the climate-investing landscape. Tracking a portfolio's GHG-emissions profile over time is a key element of any climate-related investment strategy. Industry bodies, such as the Glasgow Financial Alliance for Net Zero (GFANZ),[1] the UN-convened Net Zero Asset Owner Alliance (NZAOA), the Partnership for Carbon Accounting Financials (PCAF),[2] or the Task Force on Climate-Related Financial Disclosures (TCFD),[3] have proposed several climate metrics to measure and monitor companies' emissions in investment portfolios. These are listed in Exhibit 1.

It is important to mention that FE and FEI, as defined by PCAF, are the multi-asset-class equivalents (i.e., they attribute company emissions to both equity and debt holders) of TCFD's total emissions and carbon footprint, which attribute emissions to equity owners only. In the following, we focus on the more general multi-asset-class approaches: FE and FEI.

ROBUSTNESS OF CLIMATE INDICATORS

Climate indicators can fluctuate over time due to reasons other than changes in companies' emissions. For instance, both intensity measures, FEI and WACI, in Exhibit 1 are defined as or equivalent to a weighted-average of a company's emissions

[1] See "Financial Institution Net-Zero Transition Plans: Recommendations and Guidance." GFANZ, June 2022, https://assets.bbhub.io/company/sites/63/2022/06/GFANZ_Recommendations-and-Guidance-on-Net-zero-Transition-Plans-for-the-Financial-Sector_June2022.pdf.

[2] See "The Global GHG Accounting & Reporting Standard for the Financial Industry." PCAF, November 2020, https://carbonaccountingfinancials.com/files/downloads/PCAF-Global-GHG-Standard.pdf.

[3] See "Implementing the Recommendations of the Task Force on Climate-Related Financial Disclosures." TCFD, June 2017, https://assets.bbhub.io/company/sites/60/2021/07/2021-TCFD-Implementing_Guidance.pdf.

EXHIBIT 1

Overview of Different Climate Metrics Proposed by Climate Initiatives

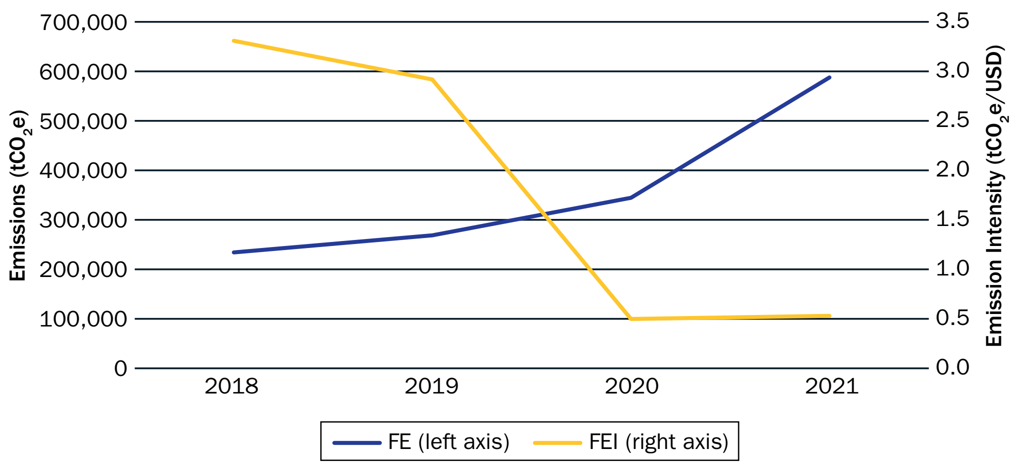
Indicator	Supported	Calculation
Financed Emissions (FE)	PCAF, GFANZ	Emissions “owned” by (multi-asset-class) portfolio
Financed-Emissions Intensity (FEI)	PCAF, GFANZ	FE/Current portfolio value = Weighted average of (Emissions/EVIC)[a]
Inflation-Adjusted FEI	EU delegated act,[b] PCAF	FEI, adjusted for the change in average EVIC
Total Emissions	TCFD	Emissions owned by portfolio through equity ownership
Carbon Footprint	TCFD	Weighted average of emissions/market capitalization
Weighted Average Carbon Intensity (WACI)	TCFD	Weighted average of emissions/Revenues

NOTES: [a]Weights are adjusted position weights. EVIC = enterprise value including cash. For unlisted companies, we use the sum of total equity and debt instead of EVIC. Other definitions may also make sense, for example, dividing by portfolio value on the reference date or using bond par values instead of market value. [b]“Commission Delegated Regulation (EU) 2020/1818.” EU Commission, July 2020.

SOURCE: MSCI ESG Research.

EXHIBIT 2

FE versus FEI of an Automobile Manufacturer



NOTE: Scope 1 + 2 FE are measured in tons of CO_2 equivalent (tCO_2e), FEI in tCO_2e/USD.

SOURCE: MSCI ESG Research.

intensity. Therefore, they can be influenced by changes in market weights as well as changes in the quantity used for the size-adjustment (EVIC or sales revenues).

Both EVIC and revenue numbers can be quite volatile. In addition, EVIC and revenues within a benchmark universe can grow (or fall) over time, which results in a systematic drift in intensity numbers. As an example, Exhibit 2 shows the emissions and FEI of an automobile manufacturer from 2018 to 2021. The issuer’s absolute emissions have increased over the years. However, its EVIC has increased at a much faster pace during the observation period. As a result, the firm’s FEI has decreased. Therefore, because of changes in market conditions, FE and FEI can move in opposite directions. To adjust for this denominator effect in EVIC or revenues, the EU delegated act proposes the calculation of an inflation-adjusted FEI.

In practical terms, this means we use the average growth rate of EVIC among portfolio companies to adjust enterprise values used at the end of the period. For example, if the EVIC on average grows by 3% in a given year, then the FEI of every position is

EXHIBIT 3

Volatility of Indicators Divided by Their Mean

Indicator	Average Volatility (annual %)
FE	5%
FEI	18%
Inflation-Adjusted FEI	6%
WACI	14%
Inflation-Adjusted WACI	7%

NOTE: Based on monthly data in MSCI ACWI IMI from December 2016 to May 2022.

SOURCE: MSCI ESG Research.

scaled upward by 3%. If the EVIC of all positions in the portfolio grew by the same average rate (which is rarely the case), this adjustment would eliminate the reduction in FEI caused by EVIC growth. An analogous adjustment can be calculated for WACI, using the average revenue growth as the adjustment factor.

To illustrate how stable the different indicators are over time and to what extent the inflation adjustment reduces volatility of climate indicators, we calculate the monthly aggregate values of various climate metrics. We then look at each indicator's volatility over the same time period and divide it by the average value of the metric over time. This brought all metrics to the same scale and allowed for a more meaningful comparison (see Exhibit 3).

FE was the least volatile indicator because it is not influenced by a denominator effect in the way that FEI or WACI is. We also observed that the inflation adjustment reduced the volatility of both carbon-intensity measures by more than half.

Investors who want to track the emissions profile of their portfolio over time have two options:

1. Track the absolute amount of financed emissions, measured in tons of CO_2 equivalent, or
2. Track an emissions intensity measured either as emissions over EVIC (FEI) or as emissions over revenues (WACI).

While FEI and WACI are clearly correlated (they use position values and emissions per company), there is a conceptual difference between them in terms of the investor questions they address:

- FEI measures the emissions owned by the portfolio per dollar invested and is therefore a size-adjusted measure of a portfolio's climate impact.
- WACI measures how carbon-intense portfolio companies' business models are, which is a measure of the portfolio's transition-risk exposure.

The fact that the recommendations of PCAF, the EU delegated act and GFANZ center around FE or FEI means they propose investors focus on the impact of their portfolio. One of the conceptual advantages of the EVIC-based intensity (compared with WACI, which uses revenues to size-adjust intensities) is that it is also equivalent to dividing portfolio FE by portfolio value, which means it is the size-adjusted equivalent of FE.[4]

In the following section, we therefore focus on FE and FEI. The attribution framework proposed can, however, be transferred to WACI without major changes.

Both a portfolio's FE and FEI are influenced by companies' emissions and other non-climate-related factors, as illustrated in Exhibit 4. To summarize, FE as an absolute measure is influenced by

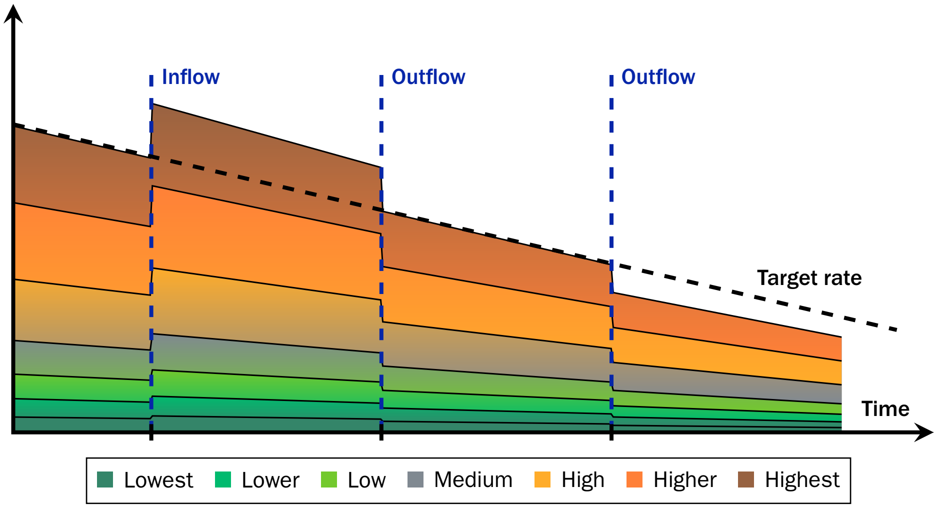
- portfolio inflows and outflows;
- changes in ownership in each portfolio company;
- changes in financing structure (equity/debt) for each company;
- changes in companies' emissions.

[4] Depending on the specific methodology, the portfolio value and FE could be evaluated at different times, leading to a slight asynchronicity between the two metrics.

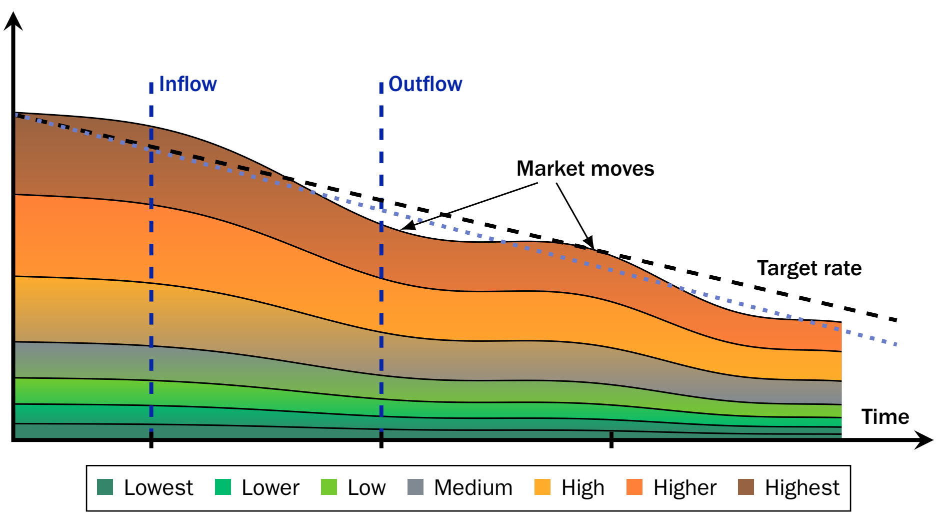
EXHIBIT 4

Comparing Portfolio FE and FEI

Panel A: Portfolio FE (tons CO_2e)



Panel B: Portfolio FEI (tons/USD)



NOTES: The charts illustrate the emissions profile (FE and FEI) of investment portfolios of securities with different levels of emissions (lowest to highest) over time. The target rate illustrates the target pathway of a portfolio manager who wants to reduce the portfolio's emissions profile over time. The effect of EV inflation illustrates the decrease of emissions intensity due to a continuous increase in the market's enterprise value, which is an undesired effect and needs to be controlled for when measuring progress against a target.

SOURCE: MSCI ESG Research.

By contrast, FEI is not influenced by inflows or outflows (because it is adjusted for size). It is, however, influenced by

- weight changes, which introduces market volatility into the calculation;
- changes in EVIC (in particular, EVIC inflation), as discussed earlier;
- changes in companies' emissions.

It is therefore critical to be able to disentangle the different drivers of change in climate metrics.

FINANCED EMISSIONS

According to reporting standards, GHG emissions from loans and investments should be allocated to the reporting financial institutions based on the proportional share of lending or investment in the borrower or investee.[5] By doing so, the FE metric measures the emissions "owned" by a portfolio through investments in equity, debt, or other securities and represents the total climate impact an investor is responsible for via any kind of financing in the invested companies, projects or other economic entities.

The general methodology proposed by PCAF calls the share of emissions of the borrower or investee allocated to an investor an attribution factor. For listed equities and corporate debt, the attribution factor is calculated as the ratio of the position value over the enterprise value including cash, or EVIC. Note that in the PCAF definition of companies' emissions, EVIC and investment value are not current values, but measured at a reference date, usually as of fiscal year-end.

For other asset classes, where EVIC is hard to define or not meaningful, the attribution factor is calculated as the ratio of the outstanding amount of financing provided by the investor via their portfolio position (numerator) and the total value of the financed entity, project, or asset (denominator).

In the development of our methodology, we focus on portfolios containing equity and corporate bonds where the attribution factor is clearly related to enterprise value. We also briefly touch on the differences in the treatment of other asset classes. The examples presented here are equity-only portfolios to keep focus on the high-level, generally applicable approach to attribution, not the technical details.

For an equity or debt position in a portfolio, we have the following:

$$\begin{aligned} FE &= Company\ GHG\ emissions \times Attribution\ factor \\ &= Company\ GHG\ emissions \times \frac{Position\ value\,(Reference\ date)}{EVIC\,(Reference\ date)} \end{aligned}$$

This approach ensures that each dollar invested in a security of a company—whether equity or debt—finances the same amount of GHG emissions and that FE don't fluctuate intra-year because of fluctuations in market values.

Conversely, FE as defined by PCAF lags by several months the changes in the capital structure caused by large market movements or the issuance/retirement of securities. Certain practitioners may prefer a metric that reflects these changes in a timelier manner, even at the expense of higher volatility. A more frequent update of the EVIC data would help achieve that goal. It is important to remember that the essence and underlying logic of our attribution framework would be unaffected by this choice. In the examples in the next section, we will use daily updates to the equity part of the EVIC data.

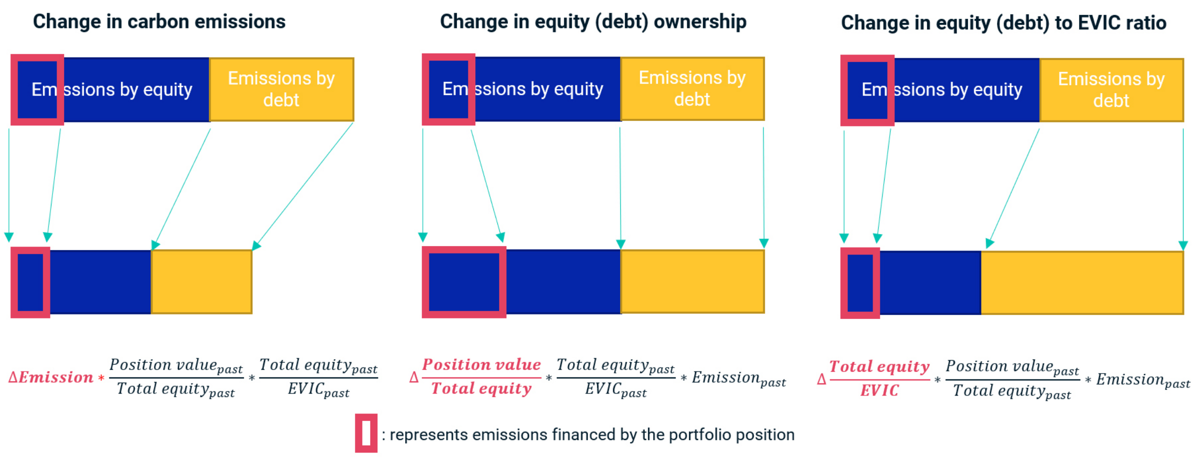
ATTRIBUTION FRAMEWORK

The objective of our attribution framework is to understand the drivers of a portfolio's change in FE over time. To be precise, we want to disentangle changes due to portfolio managers' decisions, changes driven by the market, and actual changes in companies' GHG emissions.

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

EXHIBIT 5

Separating the Three Main Drivers for Changes in FE



NOTE: The red boxes indicate an investor’s share in a company’s equity or debt.

SOURCE: MSCI ESG Research.

Because a portfolio’s FE is just the sum of position-level financed emissions, we can follow a bottom-up approach. Therefore, we start attributing changes at a position level and then sum changes from position to the portfolio level.

In Exhibit 5, we start with an example company whose assets, liabilities, and the emissions it is financing are represented by a bar. We illustrate the types of changes over a certain period of time that can influence the FE of a portfolio position. Our analysis isolates the effect of the change in one driver at a time, while keeping everything else constant.

First, there can be a change in the total amount of emissions of the company. In the example in Exhibit 5 (first panel), company emissions shrink, all other factors remain constant, leading to a decrease in FE. Second, the investor can buy or sell securities of the firm, while emissions and all other factors remain constant (center panel). In this example, more equity is bought, which contributes to an increase in FE. Third, the financing structure of the firm can change either with new issuance or buybacks of securities, or because of market movements in the equity part (third panel). In this example, the share of equity financing drops, while all other factors remain constant, leading to lower FE.

These three main effects are related to real-world emission changes, investor decisions and market movements, or a company’s financing decisions. As our approach dictates, we presented the effects in isolation, but in reality, several drivers can simultaneously contribute to the change in FE, so their interaction cannot be ignored. Our proposed approach is able to handle several changes at the same time, at the cost of introducing specific contributions describing “interactions” between various drivers.

Finally, because our approach is bottom-up, we get the same decomposition at a portfolio level for changes in FE by simply summing up the changes for each portfolio position. At a portfolio level, however, there is an additional fourth driver for change in FE—a change in the investment universe: Securities of new companies may be added to the portfolio or existing securities can be dropped. Our proposed framework is also able to logically incorporate these effects.

Note that for a portfolio position where the underlying entity is not a corporation with a combination of equity- and debt-type financing but rather has only one type of financing (e.g., a vehicle loan or a government bond), only the first two drivers can be meaningfully defined.

BUILDING AN ATTRIBUTION-TREE MODEL

The effect that the different drivers have on FE could be shown in a simple table structure. However, portfolio attributions are often shown in the shape of a tree that allows users to zoom in on the details of a top-level effect.

This type of tree model is a preferred option for portfolio managers who would like to assess portfolio changes at different aggregation levels. Typically, there are multiple ways to disentangle different effects into a tree. From a practitioner's perspective, the guiding principle when defining the tree is that every level of it should show variables that are of interest to portfolio managers and that are worth disentangling into subcomponents.

For FE, we build a tree with three layers, based on the calculation in the following formula:

$$FE = \sum_{i \in Universe} GHG\ Emissions_i \times Attribution\ factor_i$$

where changes in the asset universe over which the sum is taken represent the first layer of attribution. The changes in companies' greenhouse-gas emissions and changes in investor stakes—described by the attribution factors—represent the second and third layers of attribution. The calculation formulas for the different fields are shown in the Appendix.

The hierarchical tree format is shown in Exhibit 6. This format also has the flexibility to zoom in or out according to the level of detail needed.

The first layer shows effects of the changes in the investment universe; that is, the impact of adding or deleting names from the portfolio. In addition, a change in coverage term is added to isolate the effect of FE change merely due to the appearance/disappearance of emission-data coverage. For example, if data coverage was below 100%, but it increased over time, this term would be a positive contribution arising from the freshly covered emissions. The second layer disentangles real-world emission changes from ownership changes. Finally, the third layer disentangles ownership changes into market movements and financing changes on the one hand and buy/sell decisions on the other hand.

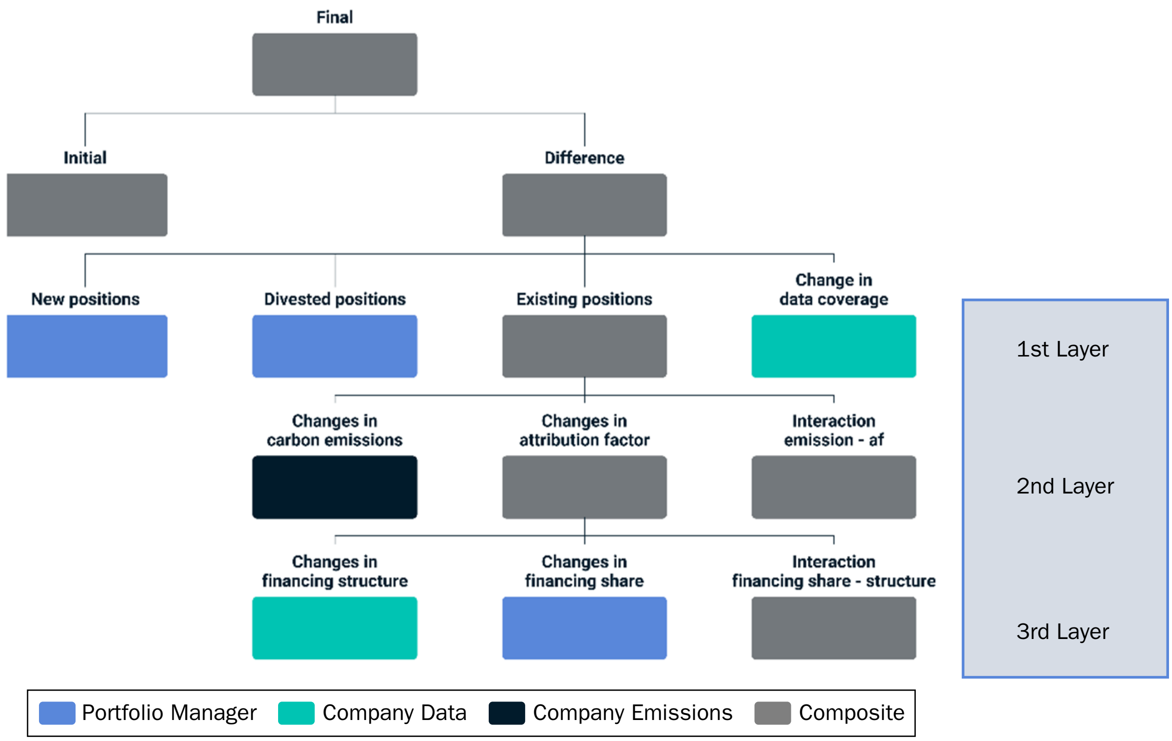
Besides the effects described previously, so called interaction terms also appear in the final decomposition due to several input variables changing at the same time. Although there would be gaps in the attribution without these terms, some practitioners do not like the complications caused by them. To simplify the presentation, they can be systematically absorbed into other terms while keeping the hierarchical approach intact.

Another way to reduce interaction effects is to divide the interval between the two dates into several subintervals and calculate the attribution for each subinterval and then sum them up through time.[6] More technical details on these approaches can be found under "Elimination or reduction of interaction terms" in the Appendix.

The color scheme of the tree shown in Exhibit 6 illustrates another important aspect—it shows the variables a portfolio manager can influence (blue)—that is, the universe of the portfolio (by adding or deleting names) and the number of securities owned in each company. By contrast, changes in companies' real-world emissions (black) and market-valuation effects (turquoise) are outside of the portfolio manager's control.

[6] Reducing the length of the intervals reduces interaction terms disproportionately more because those terms are of second order. Hence, after summing them up, one still ends up with a smaller total interaction term.

EXHIBIT 6
FE Attribution Tree



SOURCE: MSCI ESG Research.

Note that for the part of the portfolio where the underlying entities are not corporations with a combination of equity- and debt-type financing, the third layer representing financing-structure change cannot be calculated; here, the attribution stops at the second layer, and no further drill-down is possible.

COVERAGE-ADJUSTED FINANCED EMISSIONS

The challenge of incomplete and changing data coverage over time was treated with the addition of an explicit "change in data coverage" term in the attribution tree. This term shows the change in FE solely due to the increase or decrease in data coverage between the initial and final portfolio and allows for better comparison over time.

Another way to mitigate this issue is to calculate a coverage-adjusted FE metric to put portfolios with different asset–coverage ratios on the same footing. In this adjustment, we treat out-of-coverage positions as if they have the same FE intensity as the covered portion of the portfolio. Thus, the coverage-adjusted FE represents the estimated tons of CO_2 equivalent the investor has financed based on the full value of the portfolio.

Technically, the coverage-adjusted FE is calculated by scaling up the portfolio FE by the coverage ratio, but it could also be viewed as the addition of a correction term:

$$Coverage - Adjusted\ \ FE = \frac{FE}{FE\ \ coverage\ \ ratio} = FE + Coverage\ \ correction$$

where

$$FE\ coverage\ ratio = \frac{\sum_{Covered\ assets} Current\ market\ value_i}{Portfolio\ value\ (AuM)}$$

A limitation of this approach is that the uncovered portion may not share the carbon-emission characteristics of the covered portion. We expect this limitation to be mitigated as data quality and coverage improve over time.

The attribution of the coverage-adjusted FE can be treated in various ways. One possibility is to consider the uncovered assets as if they were covered assets with the average emission intensity imputed from the covered portion of the portfolio. In this case the "change in data coverage" term would be strictly zero, because all positions in the portfolio would be assigned a (possibly imputed) FE number. We do not recommend this treatment, however, as it would not give any information on the size of the coverage adjustment. Instead, we suggest calculating a term equal to the change in the coverage-correction term and adding it to the tree as either a separate node or a node under the "change in data coverage" term.

FINANCED-EMISSIONS INTENSITY

FEI is a size-adjusted measure and therefore allows a direct comparison of companies and portfolios with different sizes. It is also immune to portfolio inflows or outflows as shown in Exhibit 4. It is defined as follows:

$$FEI = \frac{FE}{Portfolio\ value}$$

With a little effort, for a portfolio containing only equities and corporate bonds, this expression can be formally rewritten as a weighted sum of emission intensities:

$$\begin{aligned}\frac{FE}{Portfolio\ value} &= \sum_i \frac{Position\ value\ (ref.\ date)_i}{Portfolio\ value} \times \frac{GHG\ emission_i}{EVIC\ (ref.\ date)_i} \\ &= \sum_i Weight_i \times \frac{GHG\ emission_i}{EVIC\ (ref.\ date)_i}\end{aligned}$$

Note that because of the misalignment in the valuation date of positions and the total portfolio, the weights can differ from position weights and may not sum to 1.[7]

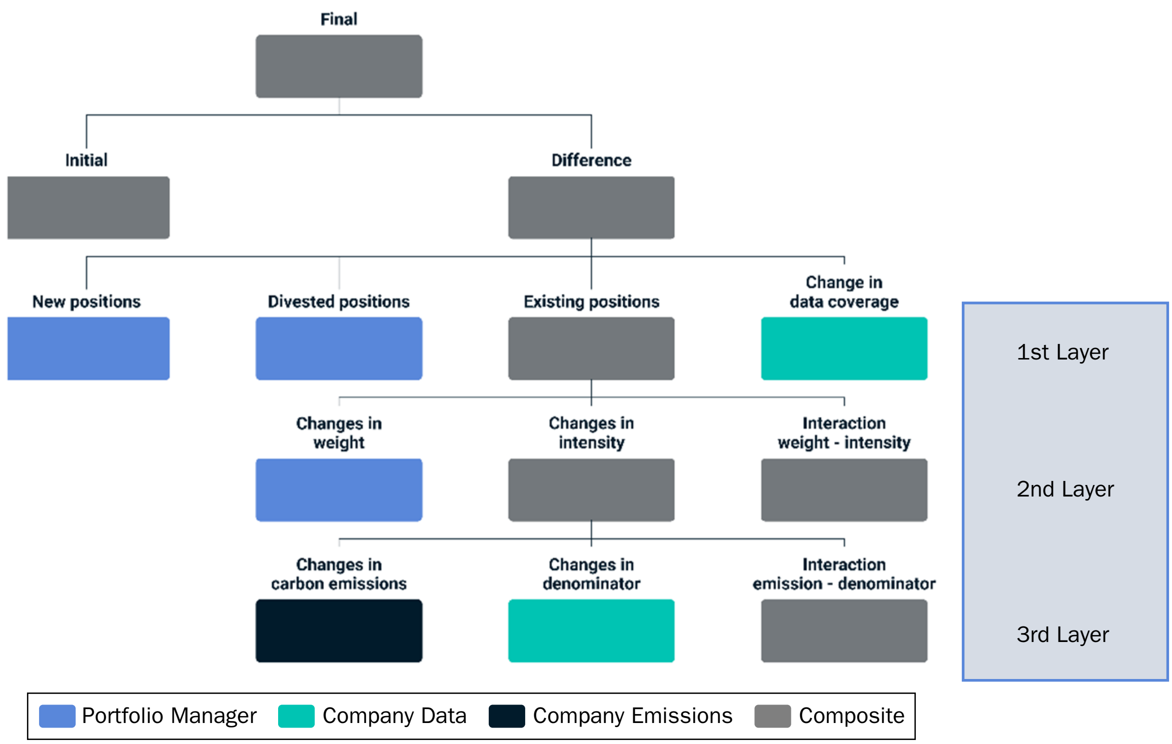
ATTRIBUTION FRAMEWORK

We can develop an attribution framework for emissions intensities based on the same fundamental principle: Calculate the impact of the change in one input variable while keeping all other inputs constant. So-called interaction terms will appear to show the effect of several input variables changing at the same time. Because there are three main variables (portfolio weights, GHG emissions, and EVIC) we again have three main terms. In addition, we have changes in the universe as an additional driver at the portfolio level.

[7] To simplify the presentation, we aligned the reference date here with current portfolio-evaluation date. It leads to a weighted average with weights summing to 1. The more general case of misaligned dates that leads to the appearance of an extra term, "Weight Fluctuation" in layer 1, is treated in the Appendix.

EXHIBIT 7

Emissions-Intensity Attribution Tree



SOURCE: MSCI ESG Research.

As for FE, the different effects can be disentangled in a tree model, where the intermediate tree levels are chosen to allow for a drill-down into variables that may be of interest to portfolio managers. This leads to the following general tree structure. The first layer is analogous to FE showing the impact on emissions intensity of adding or deleting names from the portfolio. In addition, a change in coverage is again included. The second layer captures the effect of changes in portfolio composition or company emissions intensities. Finally, the third layer disentangles emissions-intensity effects into changes in the numerator (emissions) and denominator. The denominator is EVIC for equity or corporate debt, but can be other data for other asset classes; that is, GDP for government bonds, as per the PCAF standard.

The resulting tree model is shown in Exhibit 7.

Interaction terms indicate nonlinear effects where several input variables change at the same time. If interaction terms are not preferred by the practitioner, they can be eliminated or reduced in much the same way as for FE. (See the section "Elimination or Reduction of Interaction Terms" in the Appendix for more details.)

The color scheme again indicates which variables were due to portfolio changes by the portfolio manager (blue), changes in companies' emissions (black), or changes in a company's other financial variables (turquoise).

It is worth noting that the same tree structure can be used for emissions intensity using revenues: In this case, the term "changes in denominator" will denote changes in companies' revenues instead of changes in companies' EVIC.

EVIC-FLUCTUATION ADJUSTMENT

As mentioned previously, both the EU delegated act as well as PCAF propose a so-called inflation adjustment to control for the market's overall change in EVICs in the calculation of FEI.[8] We analyze the effectiveness of this adjustment in the following section. To illustrate the effect, we use the MSCI ACWI IMI Index as a benchmark universe and look at emission changes from March 2020 to March 2022. In Exhibit 8, we calculate two emission attribution trees: one for FE intensities and one for inflation-adjusted intensities.

The tree without EVIC adjustment (Panel A) showed a 38.49% decrease in FEI, while the tree with EVIC adjustment (Panel B) reduced it significantly, to a 15.8% decrease. Both trees showed the exact same reduction in companies' real-world emissions of 9.9% due to the change of issuers' GHG emissions.

This supports the finding from Exhibit 3 and shows that adjusting company EVIC by the change in average EVIC in the portfolio is a crude way to control for market shifts in company values that works quite well for large, diversified portfolios. For more concentrated portfolios, however, using average EVIC change may not be precise enough. Using the attribution model described in this article provides a more accurate understanding of the effects of individual—not average—EVIC changes on portfolio-level emissions intensity. In such a scenario, a full tree attribution that shows the exact contribution from EVIC growth for every position in the portfolio is a more precise way of controlling for EVIC fluctuations.

TECHNICAL IMPLEMENTATION OF THE ATTRIBUTION FRAMEWORK

According to PCAF, the calculation of FE is based on position values, EVIC, and emissions as per fiscal year-end or calendar year-end. The attribution examples in this article for FE and FEI are aligned with a daily update cycle (concerning the equity part only).

A yearly reporting cycle (advocated by PCAF) may suffice for regulatory reporting purposes. However, for portfolio construction and management use cases, or to track portfolio carbon emission more frequently than annually, investors need to update the relevant data (especially EVIC data) more frequently. According to the definition of PCAF, companies' EVIC data aggregates the value of equity at market prices and the value of debt at nominal values. More frequent updates of EVIC, therefore, help investors more accurately reflect equity-price movements as well as changes in companies' size of debt.

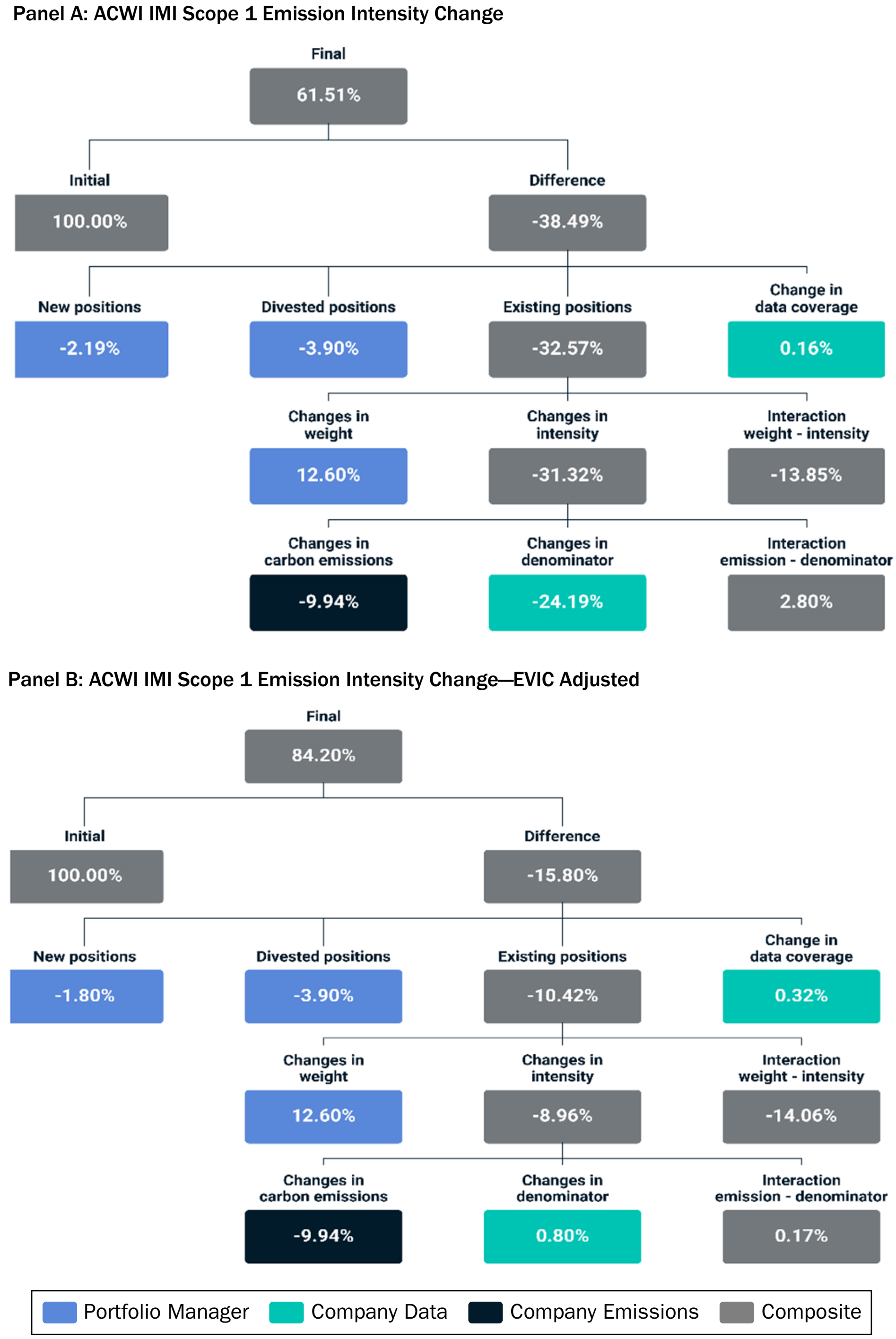
ATTRIBUTION EXAMPLE

As an example for our attribution analysis, we looked at a US minimum-volatility exchange-traded fund (ETF), for the period December 31, 2019, to December 31, 2022. This particular ETF was chosen for two reasons. First, the underlying minimum-volatility index has much higher turnover than a standard market-capitalization-weighted benchmark, which makes an attribution analysis more challenging and more interesting. Second, the inflows and outflows of the ETF allow us to analyze changes in the attribution for FE (which changes due to these flows) and emissions intensity (which is size-adjusted and therefore does not change with these flows).

[8] Calculation details are included in the Appendix.

EXHIBIT 8

Comparison of FEI with and without Inflation Adjustment for the MSCI ACWI Investable Market Index



NOTES: The tree in Panel A shows FEI for Scope 1 emissions; the tree in Panel B shows FEI adjusted for the growth in EVIC of the MSCI ACWI IMI. Data for the period from March 31, 2020, to March 31, 2022.

SOURCE: MSCI ESG Research.

EXHIBIT 9
FE of the Minimum-Volatility ETF

Date	12/31/2019	12/31/2021	Change	% Change
Market cap (USD billions)	37.3	30.5	–6.8	–18%
FE (scope 1, million metric tons CO_2e)	2.6	1.4	–1.0	–44%

SOURCE: Lipper.

The ETF returned 27.1% during the observation period, while the MSCI USA IMI Index returned 52.7%. During this period of underperformance, the ETF experienced USD 4.5 billion and USD 7.9 billion of outflows in 2020 and 2021, respectively.

FINANCED-EMISSIONS ATTRIBUTION

Exhibit 9 shows the market capitalization and FE of the ETF for the observation period. To find the drivers of these changes, we decompose the change in FE, as shown in Exhibit 10. The initial level of FE has been scaled to 100% to allow for an easier comparison.

Portfolio-level FE decreased by 44% relative to the beginning of the period. The addition of new positions increased emissions by 2.8%, while divesting from certain securities reduced emissions by 8.9%.

The bulk of the decrease, 38%, was due to stocks present in both the initial and final portfolio. Looking at the main drivers, we found a 33% reduction from a change in financing share (for equities, this is simply the change in the ownership percentage, or in other words, the trading of existing companies) and a 7% reduction from lower carbon emissions by issuers. Note that the attribution factor can also change because of the change in the financing structure, or the equity/EVIC ratio (i.e., the share of portfolio emissions that are financed through equity), which in this case removed 2% from overall FE.

FINANCED-EMISSIONS-INTENSITY ATTRIBUTION

In Exhibit 11, we examine the FEI attribution of the same ETF over the same observation period. To find the drivers of these changes, we decompose the change in FEI, as shown in Exhibit 12. The initial level of FEI has been scaled to 100% to allow for an easier comparison.

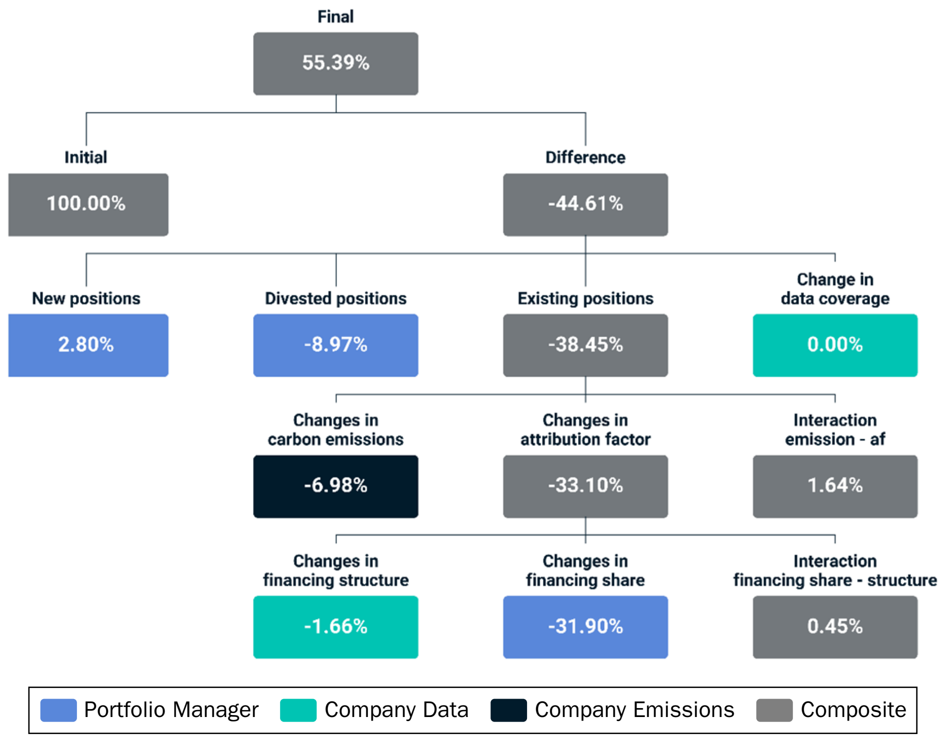
Overall, portfolio-level FEI decreased by 32% relative to the beginning of the period. The addition of new positions in the ETF detracted 18% from the initial intensity, while divestment increased intensity by 19%. The overall effect from stocks that were included in both the initial and final portfolio was a 33% reduction.

The main driver of this decrease was a 16% reduction due to an increase in EVIC, followed by a 7% reduction in issuer carbon emissions and an 11% reduction from changes in weights (either market movements or rebalancing).

ELIMINATION OF INTERACTION TERMS

If interaction terms are not preferred by practitioners, they can be eliminated from the tree by a small change in the methodology and interpretation of the terms.

EXHIBIT 10
FE Drivers



NOTE: Data for the period December 31, 2019, to December 31, 2021.

SOURCES: Lipper, MSCI.

EXHIBIT 11
FEI of the Minimum-Volatility ETF

Date	12/31/2019	12/31/2021	Change	% Change
Market cap (USD billion)	37.3	30.5	–6.8	–18%
FEI (Scope 1, tons / USD million EVIC)	68.7	46.5	–22.2	–32%

SOURCES: Lipper, MSCI.

Because interaction terms are generally larger in the emissions-intensity attribution tree, we illustrate the method in the emissions-intensity example, but the same logic applies to FE as well.

The original methodology consists of measuring the effect of changing one variable while keeping all else constant. Instead of this approach, one can apply an "average" methodology that combines the change in one variable with average values of the other variables. This slight modification still explains the total headline change along the same variables and same layers but systematically absorbs interaction effects into other terms.[9]

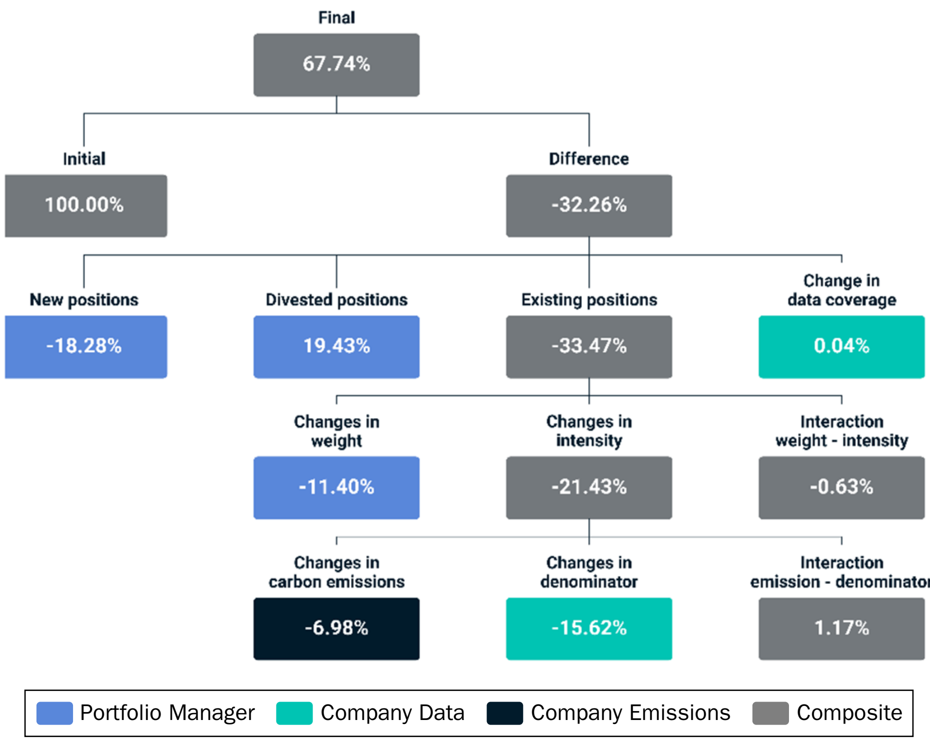
For our ETF example, the comparison is shown in Exhibit 13.

From Exhibit 12, the roughly –0.6% contribution from intensity-weight interaction gets redistributed into changes in intensity and weight, with both increasing by

[9] For calculation details, see "Elimination or Reduction of Interaction Terms" in the Appendix.

EXHIBIT 12

FEI Drivers



NOTE: Data for the period December 31, 2019, to December 31, 2021.

SOURCES: Lipper, MSCI.

around 0.3% each. Contributions at the higher layers and headline numbers remain the same, but contributions in lower layers change slightly as consistency is kept between parent and child nodes.

ATTRIBUTION OF FINANCED EMISSIONS VERSUS FINANCED-EMISSIONS INTENSITY

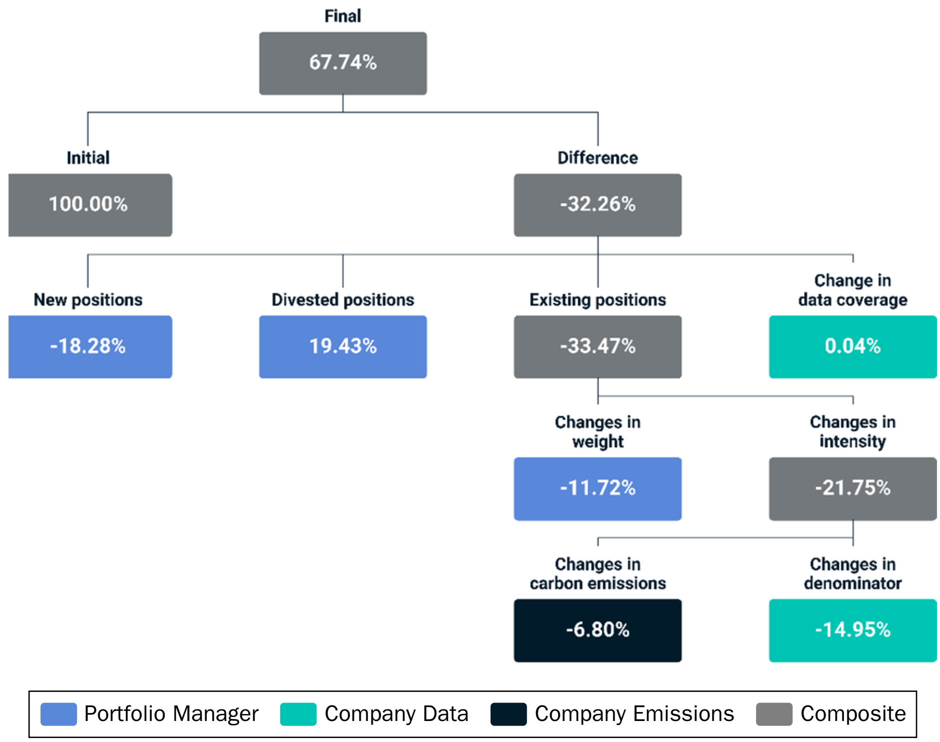
It is interesting to directly compare the emission attribution using FE and FEI to see if the conclusion drawn from them differs significantly (Exhibits 10 and 12).

While the intensity decreased by 32% over the two-year period, FE decreased by 43% due to the significant outflows from the fund. But for both metrics, the contributions from issuer carbon-emission reduction are the same in percentage terms, 6.78%. This is no accident and is due to the fact that the FEI defined in this study is consistent with the portfolio's FE and calculated by dividing it by current portfolio value. If a different definition were used (e.g., a position-value-weighted average of intensities), the two effects would somewhat differ.

It is also worth noting that additions and deletions had an opposite impact in both attributions: FE as an absolute measure always increases with additions to the portfolio and always decreases with deletions. However, for emissions intensity, this is not necessarily the case. In the previous example, additions decreased the portfolio-level intensity (i.e., companies that had an emissions intensity below the existing portfolio average were added at an index rebalancing), while deletions increased the intensity (i.e., companies that had a below-average intensity were deleted at an index rebalancing).

EXHIBIT 13

FEI Attribution without Interaction Terms



NOTE: Data for the period December 31, 2019, to December 31, 2021.

SOURCES: Lipper, MSCI.

CONCLUSION

Tracking a portfolio's emissions profile over time is a key requirement for any type of climate-aware investment strategy. Technically, this can be challenging because climate metrics proposed by different industry bodies are influenced not only by companies' emissions but by other factors—for example, portfolio managers' decisions, market variables (i.e., changes in portfolio weights), and companies' financial variables (revenues, EVIC, equity-to-debt ratio).

We observed that the financed emissions of a given portfolio are influenced by companies' real-world emissions, the portfolio manager's decision to buy or sell securities, inflows and outflows from the portfolio, and companies' EVIC and financing structure (equity-to-debt ratio).

These different effects can be displayed in a tree structure that allows the user to look at the total change in a portfolio's FE and then drill down into the specific contributions.

A similar approach can be used for emissions-intensity measures. However, these measures have an additional contribution from the variable that is used for size-adjusting companies' emissions (EVIC or revenues), which needs to be disentangled in the tree structure.

The approach proposed here is robust in the sense that slight modifications in the actual definitions of the climate metrics used by institutional investors do not alter the structure of the attribution. Our approach is anchored to the definition of FE but allows significant latitude in deriving other metrics and in the calculation details. Therefore, if an economic entity's emissions are allocated to its investors in proportion to their financing stakes, the overall structure of our attribution methodology stays the same. The tree attribution can therefore be used to understand whether a portfolio's carbon footprint has improved over time and what has been driving the changes.

APPENDIX

In this appendix we provide the mathematical formulas for the various tree attributions developed in the main section of this article. We focus on portfolios consisting of equities and corporate bonds where data availability is best and attribution factors can be calculated using EVIC.

FINANCED EMISSIONS

Exhibit A1 shows the definitions of the main variables used in the attribution framework. Note that, in general, the subscript *i* refers to the *ith* position in the portfolio, and the subscripts *1* and *2* refer to the initial and final portfolio snapshots.

The attribution factor is based on the book value of bonds and the market value of all equities (including preferred shares) and minority interests. The PCAF reporting standard requires all values (including equity prices) to be calculated on the same date—i.e., the previous fiscal-year-end date of the company. An attribution factor can also be calculated for other asset classes, describing the fraction of a company's emissions that the investment is financing. For certain practitioners, the reference date can also be more recent. For example the equity financing of listed companies can be calculated at a daily frequency. These minor changes do not affect the structure of the framework.

The attribution approach decomposes a position's FE into three factors: the position's share in the same type of financing (equity or bond) of the company, the financing mix of the company, and the company's emissions. For example, if a portfolio position holds 1% of the outstanding bonds of a company that is 60% financed by bonds and 40% by equities, then the position finances 0.6% of the company's total emissions (attribution factor of 0.006).

Financed emissions are expressed in *metric tons of* CO_2 *equivalent*. The aggregation from position to portfolio level is a simple sum. We separate certain types of summands to better showcase the effect of changes in the investment universe and data coverage, as shown in Exhibit A2.

The *existing positions* term can be further decomposed based on the general formula that is valid for the product of any two variables:

$$\Delta(A \times B) = \Delta A \times B_1 + \Delta B \times A_1 + \Delta A \times \Delta B \qquad \text{(A1)}$$

where the first two terms describe the effect of a change in one variable while all else is kept constant, and the last term is referred to as the *A-B interaction* term. Because FE is the product of three variables, Equation 1 has to be applied twice, as we detail in Exhibit A3.

The approach allows for a hierarchical decomposition that can be easily represented in a tree format (see Exhibit 8 in the main text).[10] The total effect is the sum of the individual effects shown in Exhibit A3.

[10] Note that the hierarchical grouping is not necessary, the two interaction terms can be grouped together, and the three main terms (changes in emission, equity ownership and equity/EVIC ratio) kept separately at the same hierarchical level as interaction.

EXHIBIT A1
Definition of Variables

Term	Notation	Formula
Issuer Emissions	e_i	
EVIC	$evic_i$	
Attribution Factor	af_i	$\frac{Adjusted\ position\ value_i}{evic_i}$
Financing Share	own_i	$\frac{Adjusted\ position\ value_i}{Total\ equity_i}$ or $\frac{Adjusted\ position\ value_i}{Total\ debt_i}$
Equity (debt) to EVIC Ratio or Financing Structure	fr_i	$\frac{Total\ equity_i}{evic_i}$ or $\frac{Total\ debt_i}{evic_i}$
Position-Level FE	FE_i	$af_i \times e_i = own_i \times fr_i \times e_i$
Position-Level FE Change	ΔFE_i	$\Delta(af_i \times e_i) = \Delta(own_i \times fr_i \times e_i)$
Portfolio-Level FE	FE_P	$\sum_i FE_i$
Portfolio-Level FE Change	ΔFE_P	$FE_{P,2} - FE_{P,1} = \sum_i \Delta FE_i$

EXHIBIT A2
Calculation of Layer 1 Terms

Term	Formula
New Positions	$\sum_{af_{i,1}=0} af_{i,2} \times e_{i.2}$
Deleted Positions	$-\sum_{af_{i,2}=0} af_{i,1} \times e_{i.1}$
Change in Data Coverage	$\sum_{e_{i,1}\ is\ missing} af_{i,2} \times e_{i.2} - \sum_{e_{i,2}\ is\ missing} af_{i,1} \times e_{i,1}$
Existing Positions	$\sum_{af_{i,1}>0,\ af_{i,2}>0} \Delta FE_i = \sum_{af_{i,1}>0,\ af_{i,2}>0} \Delta(own_i \times fr_i \times e_i)$

EXHIBIT A3
Calculation of Layer 2 and Layer 3 Terms

Term	Formula
Changes in Emissions	$\Delta e_i \times (own_{i,1} \times fr_{i,1})$
Changes in Financing Share	$\Delta own_i \times (e_{i,1} \times fr_{i,1})$
Changes in Financing Structure	$\Delta fr_i \times (e_{i,1} \times own_{i,1})$
Interaction Financing Share Structure	$e_{i,1} \times \Delta(own_i \times \Delta fr_i)$
Interaction Emission-AF	$\Delta e_i \times \Delta(own_i \times fr_i)$
Changes in Attribution Factor	Change in financing share + Change in financing ratio + Interaction financing share – Ratio
Existing Positions	Change in emissions + Change in attribution factor + Interaction emission-AF

NOTE: All terms must be summed over the positions such that $af_{i,1} > 0, af_{i,2} > 0$; i.e., all the existing positions.

EXHIBIT A4

Definition of Variables

Term	Notation	Formula
Issuer Emissions	e_i	
EVIC	$evic_i$	
Adjusted Position Weight	w_i	$\frac{\text{Adjusted position value}_i}{\text{Current portfolio value}_i}$
Emissions Intensity	EI_i	$\frac{e_i}{evic_i}$
Portfolio-Level Emissions Intensity	EI_P	$\sum_i w_i \times EI_i$
Portfolio-Level Emissions-intensity Change	ΔEI_P	$EI_{P,2} - EI_{P,1} = \sum_i \Delta(w_i \times EI_i)$

EMISSIONS-INTENSITY ATTRIBUTION

Emissions intensity is a size-normalized version of company-level emissions. Normalization is achieved by dividing company emissions by something that represents the size of the company, such as revenues or EVIC. The resulting measure shows how much CO_2 equivalent is released per USD 1 of revenue or USD 1 of EVIC. It allows direct comparison of firms of various sizes.

In the following, we focus on EVIC-based intensity attribution, but the calculations are analogous for the revenue-based intensity as well. Similarly to FE, actual definitions can also vary by standard, regulatory requirements, or practitioner needs considered. It may affect the choice of reference date, or the market value update frequency, and so on. These variations do not affect the structure of the framework.

Exhibit A4 shows the definition of quantities used in the attribution framework for intensities.

The aggregation of position intensities at the portfolio level is defined as a position-weighted average, where the weight is the adjusted position value (defined by PCAF) divided by the current total portfolio value. We separate certain types of summands to better showcase the effect of changes in the investment universe and data coverage, as shown in Exhibit A5.

Note that we subtract $EI_{P,1}$, the average initial intensity, from the different attribution terms to make the interpretation more intuitive: The contribution of each term is only positive if a position of above-average intensity is added or a position of below-average intensity is removed, and vice versa.

In general, $\Sigma_i \Delta w_i \neq 0$, so this subtraction leads to an effect that is best accounted for in a separate term. For example, the PCAF-inspired definition uses different dates in the numerator and denominator of the portfolio-intensity definition. Consequently, the expression can be rewritten as a weighted-average of position-level-intensities, but with the sum of weights not equal to 1 and also fluctuating with market performance. It would lead to the appearance of the weight-fluctuation term.

The *existing positions* term can be further decomposed based on the general Equation (A1). Because emissions intensity is the product of three variables, Equation (A1) has to be applied twice, as we detail in Exhibit A6.

Exhibit A6 shows the resulting attribution into the second and third layer of the attribution tree for emissions intensities.

EXHIBIT A5

Calculation of Layer 1 Terms

Term	Formula
New Positions	$\sum_{w_{i,1}=0} w_{i,2} \times (EI_{i,2} - EI_{P,1})$
Deleted Positions	$-\sum_{w_{i,2}=0} w_{i,1} \times (EI_{i,1} - EI_{P,1})$
Change in Data Coverage	$\sum_{EI_{i,1}\text{ is missing}} w_{i,2} \times (EI_{i,2} - EI_{P,1}) - \sum_{EI_{i,2}\text{ is missing}} w_{i,1} \times (EI_{i,1} - EI_{P,1})$
Existing Positions	$\sum_{\substack{w_{i,1}>0,\\ w_{i,2}>0}} \Delta EI_i = \sum_{\substack{w_{i,1}>0,\\ w_{i,2}>0}} \Delta(w_i \times EI_i) - \Delta w_i \times EI_{P,1}$
Weight Fluctuation	$\sum_{\text{all positions}} \Delta w_i \times EI_{P,1}$

EXHIBIT A6

Calculation of Layer 2 and Layer 3 Terms

Term	Formula
Changes in Weight	$\Delta w_i \times (EI_{i,1} - EI_{P,1})$
Changes in Carbon Emissions	$\Delta e_i \times \frac{w_{i,1}}{evic_{i,1}}$
Changes in Denominator	$\Delta(\frac{1}{evic_i}) \times e_{i,1} \times w_{i,1}$
Interaction Weight – intensity	$\Delta w_i \times \Delta EI_i$
Interaction Emission-Denominator	$w_{i,1} \times \Delta e_i \times \Delta(\frac{1}{evic_i})$
Change in Intensity	Changes in carbon emissions + Changes in denominator + Interaction emission-denominator or $w_{i,1} * \Delta EI_i$
Existing Positions	Changes in weight + Changes in intensity + Interaction weight – intensity

NOTE: All terms must be summed over the positions such that $w_{i,1} > 0, w_{i,2} > 0$—i.e., all the existing positions.

ELIMINATION OR REDUCTION OF INTERACTION TERMS

Some practitioners prefer attribution models without interaction terms because their practical interpretation can be difficult.

Interaction terms can be systematically eliminated by a slight change in the calculation methodology. The basic idea is to replace Equation (A1) with the following relationship:

$$\Delta(A \times B) = \Delta A \times \bar{B} + \Delta B \times \bar{A}$$

where $\bar{A} = \frac{A_1 + A_2}{2}$ denotes the average of the initial and final value of A; thus, no interaction terms are needed.

This changes the interpretation of attribution terms slightly: The different attribution terms no longer represent the effect of the change in one variable while all else is kept constant.

Instead, we measure the effect while all other variables are kept at their average values during the observation period. For example, in the FE attribution tree the change in emissions term becomes

$$\Delta e_i \times \overline{own_i \times fr_i}$$

and at the same time, the two interaction terms in the tree disappear, while the layers of the tree remain the same.

Another way to reduce the importance of interaction terms is to increase the frequency of attribution by dividing the period of the attribution analysis into smaller subintervals. For example, instead of comparing to portfolios one year apart, one can run the attribution each month and add up the monthly attribution results.

The attribution is then calculated for each subinterval (the final portfolio of subinterval t being equal to the initial portfolio of subinterval $t+1$ and so on).

Taking the example of FE and assuming the large interval is divided into N smaller intervals, we have for interval j,

$$\Delta FE_{P,j} = FE_{P,j} - FE_{P,j-1} = \sum_{k=1}^{K} \gamma_{j,k}$$

where γ denotes all the different terms in the attribution. The change over the larger interval can then be written as

$$\Delta FE_{P} = FE_{P,N} - FE_{P,1} = \sum_{j=2}^{N} \Delta FE_{P,j} = \sum_{j=2}^{N}\sum_{k=1}^{K} \gamma_{j,k} = \sum_{k=1}^{K}\sum_{j=2}^{N} \gamma_{j,k} = \sum_{k=1}^{K} \Gamma_{k}$$

Where $\Gamma_k = \Sigma_{j=2}^{N} \gamma_{j,k}$ is the sum of the kth attribution term over time, for example the sum of all the “changes of weights” terms.

Why does this reduce the overall interaction terms? Interaction terms are of second order, for example,

$$e_{i,1} \times (\Delta own_i \times \Delta fr_i)$$

Hence, if the interval is divided into N parts, the interaction terms will change proportionally to $\frac{1}{N^2}$, and their sum over the N subintervals will change proportionally to $\frac{1}{N}$. Therefore, the more frequent the attribution over subintervals, the less relevant interaction terms become.

Finally, note that running attribution over subintervals also changes the relative importance of the layer 1 terms (new positions, deleted positions) for a portfolio that is rebalanced frequently. When comparing two distant portfolio snapshots, we measure the *net* effect of additions and deletions over a longer period. If the portfolio is rebalanced frequently, the net effect can differ significantly from the sum of the addition and deletion terms measured at a higher frequency. For example, a security can be sold and bought back at different times over a one-year period, leading to a zero addition and deletion contribution at layer 1 when comparing just the initial and final portfolios. When the attribution is calculated more frequently, the effect of each transaction appears at layer 1: once as an addition and once as a deletion.