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Quantifying Supply Chain ESG Risks:
A Flexible Framework

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Global regulations and investor demands have galvanised companies to closely scrutinise the environmental, social, and governance (ESG) profiles of their suppliers. As part of this, firms are aiming to quantify Scope 3 emissions, or those resulting from assets that are not owned by the company but are active in its supply chain (whereas Scope 1 and Scope 2 emissions result directly from the operations of a company). However, it has also long been recognised that calculating Scope 3 emissions — as outlined in the reporting frameworks for the Task Force on Climate-Related Financial Disclosures and the Greenhouse Gas (GHG) Protocol — is difficult and costly. In this article, we introduce a simple and intuitive approach to calculating the emissions resulting from a company's base of suppliers. Importantly, our framework can be generalised to evaluate other types of ESG risks embedded in a firm's value chain.

Scope 3 Emissions Disclosure: Clunky and Costly, But Crucial

By capturing all of the carbon emissions related to, but not directly associated with, a company's business activities, Scope 3 metrics can paint a more comprehensive picture of a firm's ESG profile and can ensure that companies do not hide "dirty activities" along their supply chains.[1] Scope 3 emissions can be significant; per a Citi report, companies such as food manufacturers or fertiliser producers could generate 90% of their total emissions from Scope 3 emissions.[2] And according to a McKinsey report, two-thirds of Scope 3 emissions are usually from the upstream supply chain.[3]

As a consequence of these trends, investors are requesting more supply chain emissions disclosures and a swath of regulations are requiring them. For example, the Sustainable Finance Disclosure Regulation in EMEA and the proposed SEC Names Rule and ESG Disclosure Rules in the US combat greenwashing and require companies to disclose and quantify Scope 3 emissions. The International Capital Market Association, which sets standards for green bonds, has suggested that green bond issuers should be including Scope 3 emissions within targets.

Companies have a way to go. In 2021, only 18% of Fortune 500 companies had targets on Scope 3 emissions,[4] and globally, companies have voiced concern about the burdensome implementation costs of reporting. Our approach to calculating GHG emissions in supply chains is manageable to implement and can be expanded to apply to almost any other ESG-related risk. Conceptually it is very similar to the upstream Scope 3 carbon emissions as defined by the GHG Protocol, but our framework requires much less data and uses a simpler process.[5] The essence of the framework is built upon the well-known input-output model, but we apply it at a company level.

A Hypothetical Supply Chain Carbon Emissions Calculation

Suppose our task is to estimate the total carbon emissions required to produce a company's final product. As an example, for Apple Inc.'s production of an iPhone, this encapsulates all emissions occurring as the phone makes its journey to a customer's door, including fuel extraction from the ground (or other sources of energy) to provide electricity, aluminum mined for raw materials or recycled from scrap, parts assembly overseas, final product transport to distributors, and other elements of the phone's production. Given the complexity of the value chain ecosystem, estimating Scope 3 carbon emissions in total is a difficult ask in this case and most others. However, if we home in on one supplier at a time, the goal becomes more attainable.

In a hypothetical example (Figure 1), Company A has three direct suppliers (B, C, and D), which account for $0.40, $0.30, and $0.10 of the cost of goods sold[6] (COGS) for every $1.00 of revenue of the company, respectively.

Figure 1
Calculating COGS and Value Add for Each Supplier

Suppliers		+	Company		=		
B	$0.40		Value Added	$0.20		Revenue	$1.00
C	$0.30						
D	$0.10						

Source: State Street Global Advisors, as of September 2022.
The information contained above is for illustrative purposes only.

We translate the equation in Figure 1 to apply specifically to carbon emissions. If the total upstream carbon intensity (or TUCI) of Supplier B is TUCI_B, the amount of its carbon emissions that should be allocated to Company A is TUCI_B times the COGS from Supplier B, i.e., TUCI_B x 0.40. Similarly, we can determine the emissions coming from other suppliers. To calculate total emissions from Company A, we add the emissions from all the suppliers to the company's direct carbon emission (DCI), which is direct carbon intensity times revenue, or DCI x $1.00 (Figures 2 and 3).

Figure 2
Aggregating TUCI from Company A Suppliers

Total Emissions from Suppliers			+	Direct Emissions from Company A	=	Total Upstream Carbon Intensity from Company A
TUCI_B	x	$0.40		Company DCI $1.00		
TUCI_C	x	$0.30				
TUCI_D	x	$0.10				

Source: State Street Global Advisors, as of September 2022.
The information contained above is for illustrative purposes only.

Figure 3
Company A's TUCI in Matrix Terms

$$\begin{bmatrix} 0.40 \\ 0.30 \\ 0.10 \end{bmatrix}^T \begin{bmatrix} TUCI\_B \\ TUCI\_C \\ TUCI\_D \end{bmatrix} + [DCI] = TUCI\_A$$

The information contained above is for illustrative purposes only.

If we summarise the input-output relationship between any company and its suppliers in our universe by a matrix "M," the above equation can be written in matrix terms as shown in Figure 4. In the formula in Figure 4, TUCI and DCI are the vectors of upstream carbon intensity and direct carbon intensity, respectively. Figure 3 above represents one row in this equation corresponding to Company A.

Figure 4
Company A's TUCI as a Formula

$$M * TUCI + DCI = TUCI,$$

The information contained above is for illustrative purposes only.

The equation in Figure 5 resembles the Leontief inverse matrix. Some literature has used the Leontief model to estimate upstream carbon emissions at the country or sector level.[8] What differentiates our framework from these studies is that we estimate emissions at the company level, which significantly strengthens our capabilities of measuring, monitoring and influencing climate change risks in the corporate world.

Rearranging the equation and solving for TUCI produces the equation in Figure 5.

Figure 5
General Formula for Quantifying Supplier Emissions

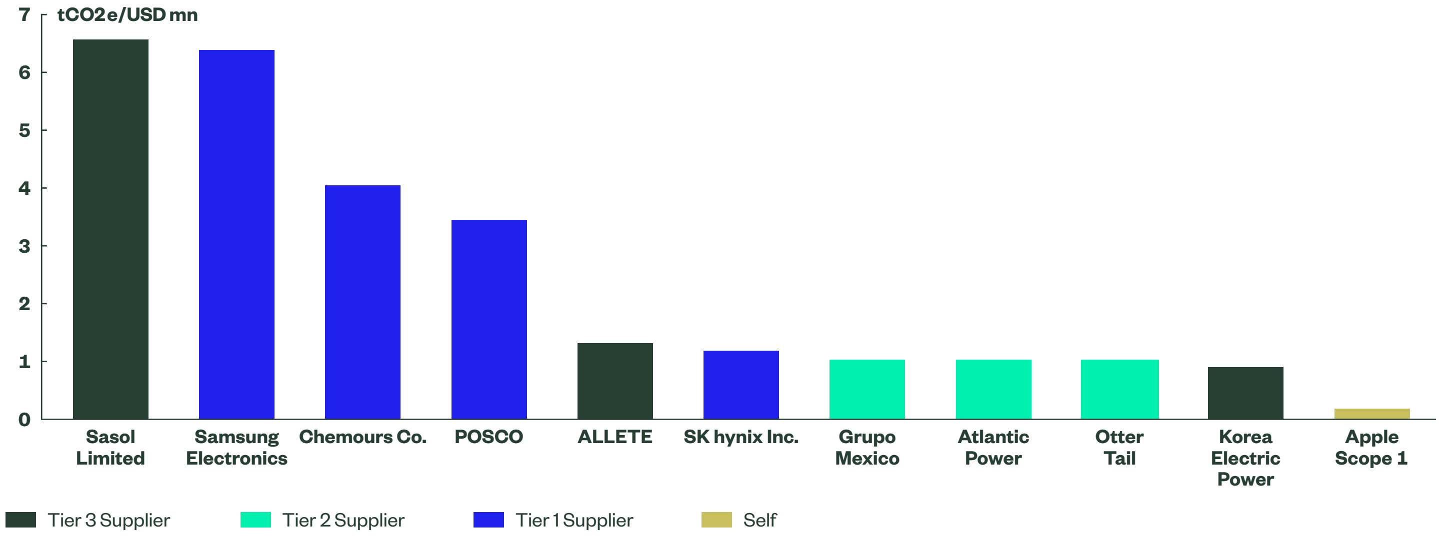
$$TUCI = (I - M)^{-1} * DCI.$$ [7]

The information contained above is for illustrative purposes only.

We note that the TUCI metric in our calculation is closely related to upstream Scope 3 carbon emissions, but it is not the same. TUCI captures direct carbon emissions as well as all indirect ones along the supply chain up to the point of final product, or the "cradle to gate" carbon emissions. Some categories defined as GHG Protocol Scope 3, such as business travel, employee commuting, or anything not reflected in the supply chain, are not included in our calculation. Arguably, supply chain carbon emissions can be reduced more easily than other indirect emissions partly because a company can influence supplier behaviour through its procurement policy. For example, our approach can help a company identify the "dirtiest" links in its supply chain and engage with them more selectively.

To further illustrate, we use Apple Inc. as an example and plot the top 10 contributors to its TUCI value as of January 31, 2021, based on our calculation (Figure 6).[9]

Figure 6
Top 10 Contributors to TUCI of Apple Inc.



Source: State Street Global Advisors, as of January 31, 2021.

Interestingly, only four out of the 10 top contributors are first-tier (direct) suppliers, according to our supply chain data; three of them are second-tier and three are third-tier suppliers. Clearly one could materially miss the forest for the trees if concentrating only on the direct suppliers of a company, which highlights the rationale of promoting measures to address indirect carbon emissions. Importantly, our approach enables us to not only paint a more complete picture of total upstream carbon emissions, but also to identify the links of the supply chain to focus on in order to improve a company's climate profile.

Advantages of Our Model

Manageable Input Data Requirements

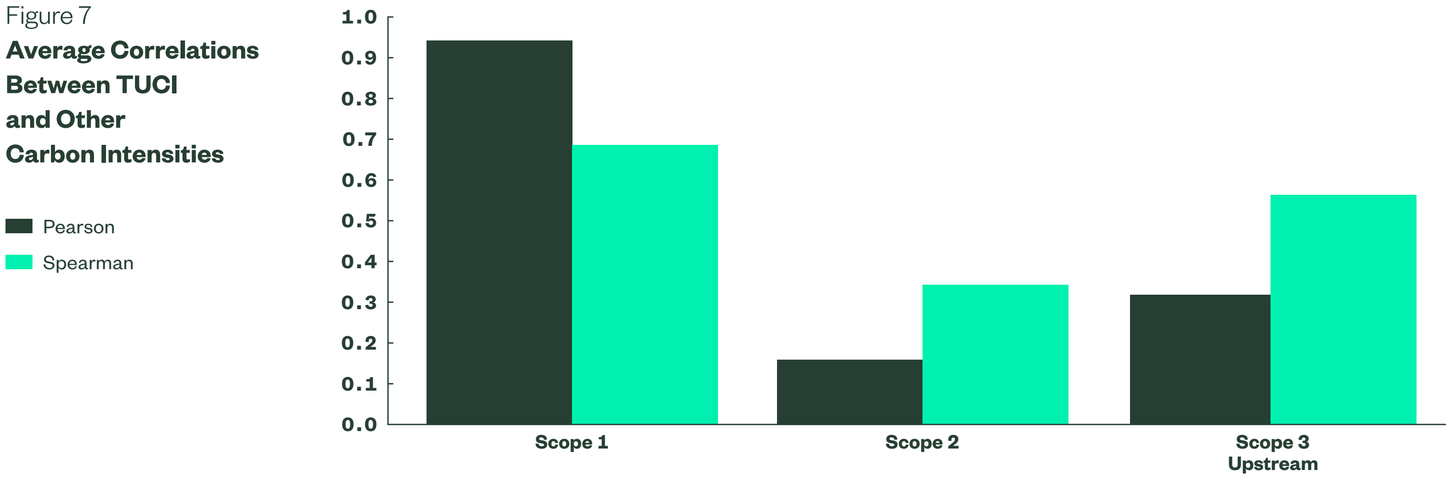
One key advantage of this model is that the input data requirements are less taxing than the data necessitated by many ESG reporting standards. Direct carbon intensity is usually the most available and highest quality of all carbon-related data.[10] Creating the input-output relationship matrix in our model requires more work, but as shown in Appendix A, the matrix is easily constructed using some reasonable simplification. The input data necessary for our calculation includes supply chain relationships, industry-wise input-output tables, and company fundamental metrics such as gross margin. Usually, this data is significantly more accessible than the measurements demanded by the commonly used GHG Protocol.

Additional Information

By taking into account supply chain information, TUCI can contain incremental information on top of other mainstream carbon metrics. In the following empirical exercise, we use Trucost[11] Scope 1 carbon intensity as the measure of direct carbon emissions. The supply chain data was obtained from FactSet, and the industry input-output table was generated from both the Organisation for Economic Co-operation and Development (OECD) and the Bureau of Economic Analysis, with some manual adjustments. Given the lower data availability in the early 2000s and in the small-cap universe, we focus on the MSCI ACWI Index from January 2015 to September 2021. To alleviate sector or country bias, which is important in assessing carbon data, we rank all metrics in a sector-neutral and country-neutral manner.

Figure 7 shows the average cross-sectional correlations between TUCI and Trucost carbon intensities.[12] Of course, the Scope 1 carbon intensity is highly correlated with TUCI because Scope 1 emissions are a key input to the TUCI calculation.[13]

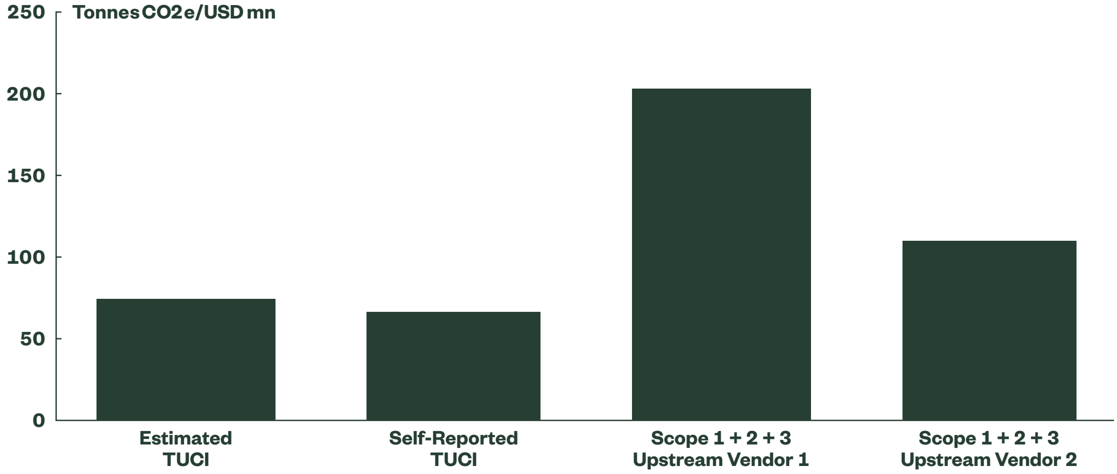
Figure 7
Average Correlations Between TUCI and Other Carbon Intensities



Source: State Street Global Advisors, S&P Global Trucost. Data averaged over the period January 2015 to September 2021.

Still, TUCI can demonstrate notable differences at the individual company level. Return to the Apple Inc. example: Figure 8 shows our calculated TUCI, the company-reported TUCI,[14] and the estimates by two data vendors, which are obtained by summing up Scope 1, 2, and upstream 3 carbon intensities. Strictly speaking, the estimate is not exactly same as TUCI, which may partly explain the differences we observe here, but they should be largely comparable, especially in the case of Apple Inc.[15]

Figure 8
Estimated TUCI of Apple Inc.



Source: State Street Global Advisors, Apple Inc., S&P Global Trucost and MSCI ESG Research, as of January 29, 2021.

As shown in Figure 8, big discrepancies in Scope 3 estimates can exist across data vendors even for one of the most analysed household names such as Apple Inc. In this specific case, our estimate provides some different insight in addition to other mainstream carbon emissions metrics despite high correlations, suggesting the complementary benefits of our model.

Broad Applications

1. **E, S, and G Issues in a Company's Supply Chain** In our view, the biggest advantage of our framework is its flexibility in being generalised to other ESG-related supply chain issues. While fossil fuel emissions are one of the world's most pressing challenges, we face other environmental risks as well, such as soil degradation, deforestation, and biodiversity loss. There are also growing concerns outside of the "E" in ESG; the United Nations' 17 sustainable development goals (SDGs) span a wide range of social and governance issues. In light of this, a company may want to monitor not only its own ESG profile, but also that of its supply chain. It would be extremely difficult — if not impossible — for companies to implement or even specify a detailed and comprehensive approach to calculate every ESG risk in its ambit with the same work-intensive methodology that the GHG Protocol used for Scope 3 carbon emissions. Our framework provides a viable and practical solution.

   By replacing DCI in Figure 5 with other ESG metrics, we can measure the aggregate level of any ESG risk in a company's supply chain. For example, an apparel company may need to know the child labour violations involved in producing its final merchandise; a paper company may need to know the total water consumed or waste generated in manufacturing its paper; or an ESG-aware investor may be interested in the gender diversity of a company's supply chain. Our framework provides a flexible tool to address these questions without a huge burden.

2. **Supply Chain ESG as an Alpha Generator** For investors seeking to generate alpha from ESG criteria, our framework can offer opportunity as well. Greener supply chains can alleviate the risks of supply chain disruption caused by potential ESG-related shocks. Also, greener supply chains can lower the risk of hefty transition costs related to future, stricter regulations on monitoring and maintaining clean supply chains. Since such information is usually well-hidden and not priced in by the market, it can potentially present an orthogonal alpha opportunity.

   For example, many investors have included either proprietary or third-party ESG factors as part of their sustainable investing processes. One way to leverage our framework is to feed such company-level ESG scores into the formula in Figure 5 to derive a supply chain ESG signal. This signal can be viewed as a measure of the overall ESG profile of a company's supply chain, and may possess additional predictive power for future returns.

Limitations of Our Model

The simplicity of our model does come with some limitations. For example, supply chain information and data quality can be unreliable, which directly affects the accuracy of the output. Moreover, most private companies do not disclose financial data such as gross margin or extra ESG-related data such as waste management, so in practice, our analysis is focused only on public companies. An implicit assumption is the homogenous distribution between these two segments.

Nevertheless, we note that these limitations are not unique to our approach and ESG data quality and availability have been improving steadily over time (see The ESG Data Challenge: The Importance of Data Quality in ESG Investing).

Conclusions

More and more, investors and regulators are seeking a comprehensive assessment of ESG-related exposure along a company's value chain. Although the GHG Protocol approach provides a mainstream solution to quantifying supply chain emissions risks, it may prove complicated and costly to implement. Furthermore, that protocol measures only carbon emissions. In this article, we propose an intuitive framework for quantifying value chain ESG risks by aggregating information for the entire supply chain through the Leontief model. For emissions calculations, our TUCI output differs from Scope 3 emissions, but it still contains valuable orthogonal information and can be complementary to existent metrics.

There are three main advantages to our approach: First, the input data required is usually much easier to access, is more reliable, and has better coverage versus the data required by the GHG Protocol. Second, the output of our model can contain truly orthogonal information in addition to other emissions metrics. Finally, our approach is readily generalisable to many other ESG-related issues beyond carbon emissions. Overall, despite a few limitations, we believe our model can be a valuable addition to the toolbox of the broad ESG campaign.

The flexibility of the framework also opens many opportunities for future research. One research front is to better capture the data for private companies. After all, a lot of "brown-spinning" happens through the private channel. It will also be interesting to test the use cases of various ESG issues along the supply chain beyond carbon emissions. Last but not the least, the application of our model to other ESG alpha factors can be a lucrative area to explore.

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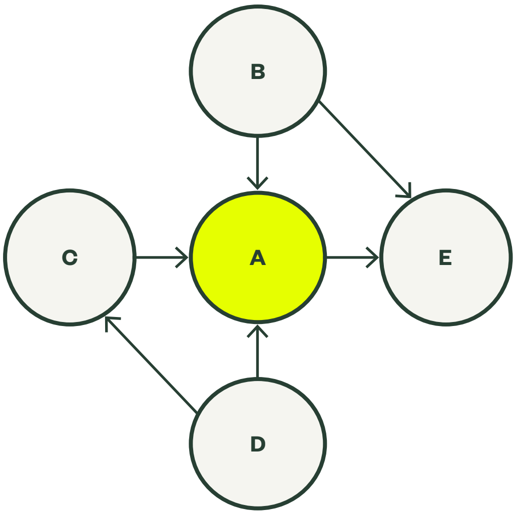
Appendix A: Calculating Leontief Matrix (Technology Matrix) M

The Leontief matrix in our model, or the technology matrix, is similar to the widely used input-output table, although we apply the model at a company level. Element a_{ij} shows that for every $1.00 of revenue of company j, a_{ij} is the cost of input coming from supplier i. We can get this value in two steps. First, we calculate the total cost of input as a proportion of revenue of the company, which can be approximated by gross margin. Second, we aggregate the total cost of input from all suppliers by using both supply chain information and industrywide input-output tables. The supply chain data is sourced from FactSet and the input-output tables are from both OECD and the US Bureau of Economic Analysis (BEA).

Consider the previous example in which there are three suppliers to Company A and for the sake of illustration, assume there is a customer, Company E in our universe, and their supplier-to-customer relationship can be depicted in the following diagram:



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The corresponding technology matrix takes the following form:

	A	B	C	D	E
A					?
B	?				?
C	?				
D	?		?		
E					

The information contained above is for illustrative purposes only.

Suppose Company A is a car manufacturer that has three suppliers, B, C, and D. The values in column A can be calculated as in the following table:

Supplier	Sales	Industry	Input Coefficient to Auto Industry (from IO Table)	Distribute by Supplier Industry	Scale by Gross Margin (e.g. 20%)
B	200	Auto Parts	0.35	0.2 (= 0.35 x 200/(150 + 200))	0.4 (= 0.2/ (0.2 + 0.15 + 0.05) x (1-20%))
C	150	Auto Parts	0.35	0.15 (= 0.35 x 150/(150 + 200))	0.3 (= 0.15/(0.2 + 0.15 + 0.05) x (1-20%))
D	100	Tires & Rubber	0.35	0.05	0.1 (= 0.05/ (0.2 + 0.15 + 0.05) x (1-20%))

The information contained above is for illustrative purposes only.

Take Supplier B for example. From the input-output table we know that in aggregate for every $1 of auto industry output, $0.35 is needed as inputs from the auto parts industry. Since there are two suppliers, B and C, from the auto parts industry, we need to split the $0.35 between them. In absence of further information, the most natural way is to allocate by their total revenues. In this case, $0.20 of input is from Supplier B and $0.15 from Supplier C. $0.05 is from Supplier D. Lastly, we know that the supply chain information is not complete, so if we just add up the numbers we can substantially underestimate the supply chain impact. So as the final step, we scale them by the gross margin of Company A so that the input coefficients from all suppliers add up to 1 — gross margin. The rest of the matrix can be populated in the same way.

Endnotes

1 This is one form of the so-called “Brown Spinning” risk. See for example, Cyrus Taraporevala, “The Other Climate Risk Investors Need to Talk About,” Financial Times, May 14, 2021.

2 See “Food and Climate Change: Creating Sustainable Food Systems for a Net Zero Future,” Citi, July 2022.

3 See “Buying Into a More Sustainable Value Chain,” McKinsey & Company, September 2021.

4 World Wild Life Fund.org, as of June 2021.

5 Scope 3 carbon emissions include both upstream (mainly from suppliers) and downstream (mainly from customers) emissions. Our focus is solely on the former, i.e., upstream Scope 3 carbon emissions. There are some other studies closely related to the downstream Scope 3 carbon emissions, such as Hall et al., 2022.

6 The suppliers account for $0.80 of COGS, and the remaining $0.20 is value added by the company.

7 Another way to interpret this formula is through its Taylor expansion, which becomes $TUCI=(I- M)^{-}*DCI = (I+M+M^2+M^3+...)*DCI$. Remember that M gives the first-layer impact, M^2 the second-layer impact, M^3 the third-layer impact, and so on. So, intuitively speaking, this metric sums up all of the compounded impacts from a company’s suppliers plus itself.

8 For example, Kitzes (2013) illustrates an environmentally extended input-output method. Wiebe and Yamano (2016) take a similar approach to estimate GHG emissions embodied in final consumption in different countries.

9 The primary reason for choosing Apple Inc. as example is that it has been a pioneer of monitoring and disclosing company-level environmental-related data. Our calculated TUCI for Apple as of that date is around 74 (tCO2e/USD mn). Admittedly the outcome depends on the quality of input data, such as the coverage of supply chain, so it may not reflect the exact fact. The purpose of this example is primarily to demonstrate the capability of our model.

10 See “Reported Emission Footprints: The Challenge is Real,” MSCI ESG Research, March 2022.

11 This report was prepared by Hao Yin using Trucost data and the Trucost E Board portfolio analyzer tool. GHG emissions data for companies analyzed are the latest available in Trucost’s database, the Trucost Environmental Register, a comprehensive database of corporate natural capital impact data covering 93% of global markets by market capitalization. This data is owned by Trucost and Trucost reserves all intellectual and other proprietary rights therein.

12 Scope 3 metric here includes upstream indirect greenhouse gas emissions defined by Trucost.

13 Pearson correlation measures the linear correlation while Spearman correlation measures the monotonic relationship between two variables.

14 Calculated by the authors based on the 2021 Environmental Progress Report published by Apple Inc.

15 Ballpark of Apple Inc.’s upstream carbon emissions is covered by TUCI while other emissions are very minor. For example, Apple reported that during the fiscal year of 2020, 71% of its total carbon emissions came from product manufacturing, 8% from product transport, and only 1% from travel and commuting.

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* Pensions & Investments Research Center, as of December 31, 2022.
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