

Net-Zero Greenhouse Gas Mitigation Potential Across Multi-Tier Supply Chains

Corresponding Author: Professor Timothy Smith

This file contains all editorial decision letters in order by version, followed by all author rebuttals in order by version.

Attachments originally included by the reviewers as part of their assessment can be found at the end of this file.

Version 0:

Decision Letter:

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Dear Professor Smith,

Your manuscript titled "Achieving Net-Zero GHG Emissions Goals Across Multi-Tier Global Supply Chains" has now been seen by two reviewers, whose comments are appended below. You will see that they find your work of some potential interest. However, they have raised quite substantial concerns that must be addressed. In light of these comments, we cannot accept the manuscript for publication, but would be interested in considering a revised version that fully addresses these serious concerns.

We hope you will find the reviewers' comments useful as you decide how to proceed. Specifically, for publication in Communications Earth & Environment to be appropriate, we will need you to provide compelling new insights into the question how to measure and mitigate scope 3 greenhouse gas emissions, based on country-level case studies, in a coherent and well-argued storyline.

Should additional work allow you to address this editorial threshold as well as all the concerns from our reviewers, we would be happy to look at a substantially revised manuscript. If you choose to take up this option, please either highlight all changes in the manuscript text file, or provide a list of the changes to the manuscript with your responses to the reviewers.

When resubmitting, please provide a point-by-point response to the reviewers' comments.

Please submit your responses as a separate file, distinct from your cover letter where you can add responses to the Editors' comments that you do not want to be made available to the reviewers. Word files are preferred. We recommend that any figures, tables or graphs that are included in the response to reviewers are also included in the main article or Supplementary Information.

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Please do not hesitate to contact us if you have any questions or would like to discuss the required revisions further. Thank you for the opportunity to review your work.

Best regards,

Heike Langenberg, PhD
Chief Editor
Communications Earth & Environment

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REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

1. In this paper, "Achieving Net-Zero GHG Emissions Goals Across Multi-Tier Global Supply Chains", the authors present arguments recognizing that scope 3 emissions present a barrier to the goal of net-zero and emissions goals, more generally, e.g., under the SBTi initiative. The authors broadly identify two sub-problems therein: 1. monitoring, measurement, and inclusion, and 2. mechanisms for effective mitigation. This is a useful, if standard, framing of the problem. The paper motivates and studied an important problem, it describes clearly the context of the study but can be more focused. However, the paper fails to address either aspect of the question with sufficient novelty.
2. Using national-level input-output tables, the authors present a comparative analysis across four countries on the structure of scope 3/supply chain emissions across industry sectors. I fail to see the methodological novelty in this analysis or what the message is from this analysis. One message appears to be that much of the scope 3 emissions arise from tiers 1 - 3 and much less so in deeper supply chain tiers. But this message is not surprising that in manufacturing, mining and agriculture (which are themselves upstream sectors) much of scope 3 emissions arise from the first few tiers.
3. In any case, this must be then a positive message because it would then make the problem of measuring and mitigating scope 3 emissions more manageable with coordination across a few tiers of the supply chain. However, the subsequent discussion does not dwell on this.
4. Also an important problem left unaddressed here is that while the paper motivates the problem of scope 3 emissions measurement, the solution presented is based on an input-output framework which is necessarily at the industry level. There must be a better link of the two. While these numbers can be a useful guide for the firms in the industry, they cannot replace a more careful measurement of the scope 3 emissions specific to a firm. So, there is a bit of a bait and switch in how the problem is described versus the solution and analysis proposed.
5. It is possible that some of my comments above misunderstand the general message the authors intend to convey. But a central problem in the paper is that it appears disjointed leaving it unclear what the central message(s) being articulated are.
6. This analysis also ignores trade and thus the paper is in some ways misleadingly titled to include the phrase "global supply chains" – the supply chain analysis is certainly not global since it fails to incorporate trade.
7. The plots in the paper also appear to add questionable value and are not clearly formatted and must be presented better.

I am afraid I am not more positive on this version of the paper, and I recommend rejection at this stage. I encourage authors to pursue this research agenda and sharpen the focus and messaging of the paper.

Reviewer #2 (Remarks to the Author):

This paper tackles an important, long-standing issue in corporation carbon accounting – how to determine the boundaries of scope 3 emissions in a meaningful way for effective supply chain coordination? I think this paper offers valuable methods and meaningful insights into this question. I only have a few suggestions and questions that I hope the authors can address for better clarity before the publication.

- 1) The authors mainly focused on the US, South Korea, Mexico, and China. I am wondering why EU countries are not included. Is it a limitation of their regional IO development? Some clarifications will be helpful for the readers to understand the rationale for the focus on these countries.
- 2) Results – “Barriers to Scope 3 GHG Accounting”. This section has great discussions on literature, current barriers, and the status of Scope 3 GHG accounting, but they should not be parts of the results. I think moving them to the Introduction or literature review section will be much better than the current position.
- 3) Page 4, would you explain a bit more on STBi’s 67% coverage criteria and provide a reference for this specific number?
- 4) On page 5, the first paragraph, the authors mention “embedded emissions.” I assume they meant “embodied emissions,” which usually are cradle-to-gate emission factors. The “cradle-to-gate emissions” are also mentioned in the last paragraph of page 4. I suggest the authors use consistent terminologies or let the readers know that they are equivalent; otherwise, it can be confusing.
- 5) The discussions of different tiers are easy for industrial ecologists but challenging for researchers and practitioners in the GHG accounting field. It would be helpful if the authors could provide an intuitive example showing what tier 1 and 2 supplies and their GHG emissions would be in real-world contexts.
- 6) I am quite surprised to see that water treatment and distribution would have more emissions associated with the direct purchase of electricity and heat than chemicals. The chemical sector is one of the most energy-intensive (in terms of both unit and total energy consumption) in the US and globally. What are the possible reasons for this result?
- 7) Page 8, SBTi’s 40% screening threshold was mentioned – it was mentioned as 67% in the earlier place. I suggest the authors add clarifications here to explain what these percentages mean and why different criteria were used in their analysis.
- 8) On page 12, I like the discussions on hard-to-trace GHG emissions and the effectiveness of supplier engagement. I am wondering about the authors’ opinions on focusing on scopes 1 and 2. Based on the results from this study, if all sectors make efforts to reduce their scope 1 and 2 emissions, then the scope 3 emissions of supply chains that they are involved in are “naturally” reduced. Will this be more effective than trying to track and trace back supply chain Scope 3 emission ownership?
- 9) How was trade included in this study? As the approach seems not to be an MRIO, I wonder how international supply chains that involve trade are treated in the authors’ modeling approaches. If trades are not considered, I suggest adding some discussions about this limitation and future research directions.

Minor issues:

1. Page 5, KR was used first without full name spelling, then South Korea (KR) was introduced later in the same paragraph.
2. Page 6, “Figure 1 presents the results from the perspective of production...” I think it should be Figure 2?
3. Figure 4 is hard for me to read for different tiers, I suggest only keeping the top sectors with big values and moving the rests to SI (which can make bars more readable).

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Version 1:

Decision Letter:

**** Please ensure you delete the link to your author home page in this e-mail if you wish to forward it to your coauthors ****

Dear Professor Smith,

Please allow me to apologise for the delay in sending a decision on your manuscript titled "Net-Zero Greenhouse Gas Mitigation Potential Across Multi-Tier Supply Chains" has now been seen by our reviewers, whose comments appear below. In light of their advice we are delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment.

We therefore invite you to revise your paper one last time to address the remaining concerns of our reviewers. Please ensure the writing is as accessible and focussed as possible, and pay particular attention to reviewer 1's suggestions for improving the text. At the same time we ask that you edit your manuscript to comply with our format requirements and to maximise the accessibility and therefore the impact of your work.

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We hope to hear from you within two weeks; please let us know if you need more time.

Best regards,

Heike Langenberg, PhD
Chief Editor
Communications Earth & Environment

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REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

In this revised paper, the authors based on four national environmentally-extended input-output (EEIO) models, find that scope 3 reporting implementation focusing on two tiers of suppliers can mitigate 63% to 81% of economy-wide final use emissions but corporate net zero strategies will often need to reach deep into supply chains (often to tiers 5 and 6) to include sufficient operational emissions to approach net zero criterion.

Overall, there is less over-claiming in the revised paper, and the messaging in the paper has also been sharpened to make it more consistent. However, I still have concerns regarding the paper.

First, and arguably most important concern is the novelty in the message of the paper, and/or the methodologies used to arrive at the message. There is arguably little that is novel in terms of the methods adopted by the paper itself, and therefore, we have to weigh the importance of the central question of the paper -- how much of Scope 3 emissions can be addressed by considering the first few tiers. This is indeed an interesting question but the paper meanders far too often and leaps to making inferences ill-supported by the analysis.

Second, the above problem is exacerbated since there is substantial sloppy writing that detracts from the main message and findings. I have tried to provide instances of this below and encourage the authors to improve the paper.

The paper addresses or poses an interesting question - but the writing and presentation is not very careful, which means the main message is lost. That is, with a tighter focus on the central message in the paper, and with a more carefully written version, this paper has a way forward. But in its present form, I am unable to reach a more positive verdict on the paper.

1. "with the goal of identifying mitigation potentials and main contributors and meeting the science-based target" -- can you rephrase this?
2. "We find that scope 3 reporting implementation focusing on two tiers of suppliers can mitigate 63% to 81% of economy-wide final use emissions". Since the reporting does not itself lead to mitigation, it is better to say can address 63% to 81%...
3. "Carbon accounting approaches for reporting and target-setting have evolved to translate the complexity of greenhouse gas behavior in the atmosphere into quantifiable discrete emissions units owned and influenced by specific actors" - the sentence is needlessly convoluted, please rephrase.
4. The second paragraph on page 2 makes some interesting points but needs to be rewritten to make the message clearer here.
5. I think this statement is problematic, and in any case, in my opinion, it does not detract from the paper that the EU is not considered: "The European Union (EU) is not covered due to a lack of high-resolution data. However, this region can be largely represented by the US for their similar economic structures."
6. "Operational emissions extending deep into supply chain tiers are often necessary to meet decision-useful requirements in both the near- and longer-term." Please rephrase this sentence.
7. "Results indicate that current supplier engagement, implemented to satisfy SBTi scope 3 short-term target criteria, are likely falling far short of meeting SBTi's coverage objectives." Please clarify this.
8. Figure 4 must be re-plotted to make it clearer to the reader what it conveys.

Reviewer #2 (Remarks to the Author):

The authors have satisfactorily addressed my comments, I recommend a publication.

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Response to Reviewer #1

Remarks to the Author:

Q1. In this paper, "Achieving Net-Zero GHG Emissions Goals Across Multi-Tier Global Supply Chains", the authors present arguments recognizing that scope 3 emissions present a barrier to the goal of net-zero and emissions goals, more generally, e.g., under the SBTi initiative. The authors broadly identify two sub-problems therein: 1. monitoring, measurement, and inclusion, and 2. mechanisms for effective mitigation. This is a useful, if standard, framing of the problem. The paper motivates and studies an important problem, it describes clearly the context of the study but can be more focused. However, the paper fails to address either aspect of the question with sufficient novelty.

[Reply: Thanks for your positive assessment of our study and the constructive feedback. Please see our detailed response below.](#)

Q2. Using national-level input-output tables, the authors present a comparative analysis across four countries on the structure of scope 3/supply chain emissions across industry sectors. I fail to see the methodological novelty in this analysis or what the message is from this analysis. One message appears to be that much of the scope 3 emissions arise from tiers 1 - 3 and much less so in deeper supply chain tiers. But this message is not surprising that in manufacturing, mining and agriculture (which are themselves upstream sectors) much of scope 3 emissions arise from the first few tiers.

[Thank you for your comments. The issues you raise are central to the paper's contribution and we have made significant changes to the structure and presentation of analyses to improve clarity.](#)

[With regard to the novelty of the analyses, we agree that the general approaches toward national EEIO models, and the power series expansion approach to produce insights into direct and indirect relationships between sectors, are well documented. However, our study represents the first known comparative study of large producing economies, using high-resolution models to examine targeted mitigation strategies across multi-tier supply chains toward net-zero. The primary contribution of the paper is therefore a result of the insights offered into sectoral and geographic heterogeneity.](#)

[With regard to message clarity, we have rewritten the abstract, introduction and discussion sections \(please take a look\) to better focus readers on the main findings of the paper: 1\) sector-level emissions intensity and country-level final use emissions differ significantly by geography and sector; 2\) depending on geography, supply chains must cascade ambition into supply tiers 2 and 3 to meet decision-useful requirements of reported emissions information in the near-term, and well into tiers 5 and 6 to address longer-term net-zero objectives; and, 3\) beyond direct tier-1 supply, operational emissions of high-impact sectors are distributed across many difficult to trace intermediate inputs across multiple tiers of supply. These deep upstream emissions account for 16%-99% of total emissions by sector, and 42%-65%, on average, by geography.](#)

[Country-level scope 3 coverage could extend, on average, to 63-81% through the implementation of scope 3 reporting reaching only into T2s1s2, potentially increasing the quality of scope 3 reported data and improving mitigation coordination across supply](#)

chain partners. But, in order to approach net-zero scenarios, most companies will need to complement supplier engagement activities with participation in market mechanisms stimulating additional and attributable emission mitigation projects targeting large emitting inputs, occurring deep in their supply chain, and distributed across many difficult-to-trace intermediate components. We illustrated this through two example sectors in Fig 5, Passenger Automobiles in South Korea and Garment Manufacturing in Mexico. In these cases, operational emissions occurring upstream of direct purchases (T2s1s2, T3s1s2, etc.) account for 73% and 48% of total emissions, respectively. We illustrate how these emissions largely occur in primary steel-making for KR automobiles and crop/animal agriculture and petrochemical processes of natural and synthetic fibers used in MX garment manufacturing.

Q3. In any case, this must be then a positive message because it would then make the problem of measuring and mitigating scope 3 emissions more manageable with coordination across a few tiers of the supply chain. However, the subsequent discussion does not dwell on this.

As discussed in response to Q2 above. We stress dual messages in this paper:

1. Findings that suggest to governments and standards bodies a scope 3 reporting implementation focus on operational emissions occurring within tiers 1 and 2 (T1s1s2 & T2s1s2) to facilitate improved data quality of supplier surveys and facilitate supply chain actor coordination, with coverage that, on average, captures 63% to 81% of economy-wide final use emissions of geographies examined.
2. Findings that support coordinated company strategies toward net-zero objectives, where direct action (addressing S1 & S2), supplier engagement (addressing T1s1s2), and participation in tradable market mechanisms (addressing T2s1s2, T3s1s2, T4s1s2, etc.) provide practical guidance for targeted action toward supply chain decarbonization.

We present these as positive messages, whereby key implementation challenges to scope 3 reporting and mitigation are addressed. Findings provide important comparative results to scholars and are of critical relevance to practitioners and policy-makers struggling to overcome roadblocks and delays toward scope 3 reporting mandates, and controversies associated with the use of tradable market mechanisms to meet scope 3 targets.

Q4. Also an important problem left unaddressed here is that while the paper motivates the problem of scope 3 emissions measurement, the solution presented is based on an input-output framework which is necessarily at the industry level. There must be a better link of the two. While these numbers can be a useful guide for the firms in the industry, they cannot replace a more careful measurement of the scope 3 emissions specific to a firm. So, there is a bit of a bait and switch in how the problem is described versus the solution and analysis proposed.

Reply: You raised a great point. We agree that hybrid LCA based partly on a firm's process data and partly on EEIO data would be the best to evaluate a firm's scope 3 emissions in terms of both specificity and system completeness (Pomponi & Lenzen 2018; Suh et al. 2024). But as you pointed out, EEIO models can be a useful guide. High-resolution EEIO models that differentiate hundreds of sectors are especially helpful,

striking a balance between specificity and system completeness. This is why we focused on these four models in our study rather than those aggregate models that differentiate only dozens of sectors. High-resolution EEIO models are also widely used by companies for footprint analysis, see, e.g., the US-EEIO model developed by the USEPA (to which our team contributed; Yang et al. 2017).

In addition, our study aims partly to provide a broad picture across sectors regarding the contribution of suppliers at different tiers to scope 3 and total emissions. For this purpose, EEIO models are the right scoping tool.

In response to your concern, we have revised our limitations paragraph in the Discussion to touch upon this point, clarifying the scope and purpose of our study and emphasizing future research needs for continuous development of high-quality process databases using suppliers' data for accurate scope 3 assessment. Please see lines 457 to 460.

Pomponi, Francesco, and Manfred Lenzen. "Hybrid life cycle assessment (LCA) will likely yield more accurate results than process-based LCA." *Journal of cleaner production* 176 (2018): 210-215.

Suh, Sangwon, et al. "System boundary selection in life-cycle inventories using hybrid approaches." *Environmental science & technology* 38.3 (2004): 657-664.

Yang, Yi, et al. "USEEIO: A new and transparent United States environmentally-extended input-output model." *Journal of cleaner production* 158 (2017): 308-318.

Q5. It is possible that some of my comments above misunderstand the general message the authors intend to convey. But a central problem in the paper is that it appears disjointed leaving it unclear what the central message(s) being articulated are.

Thank you for this feedback. We have significantly rewritten the abstract, introduction and discussion sections to improve clarity. In addition, we have added a new Fig 2 to illustrate sectoral and geographic heterogeneity, and to better connect sector level intensity results (Fig 1) with the tier structure of operational emissions (Fig 3). We also streamlined results presented in Fig 5 to illustrate the central message that coordinated mitigation action, including direct action, supplier engagement and tradeable market mechanisms, is likely needed to reach sufficient emissions toward net-zero objectives.

Please see our responses to your comments Q2 and Q3 for further summaries of how we have revised the manuscript to make our main messages clear.

6. This analysis also ignores trade and thus the paper is in some ways misleadingly titled to include the phrase "global supply chains" – the supply chain analysis is certainly not global since it fails to incorporate trade.

Reply: Thanks for the comments. This is another good point. Technically, we included trade, but the national EEIO models basically assume imported products have the same carbon footprints as domestic products (see more discussion in Yang & Suh 2011). Linking the national EEIO models with one another under an multiregional input-output (MRIO) framework will probably better estimate the footprint of imports. However, MRIO models are typically highly aggregated and rely on many assumptions to make trade work (e.g., all sectors have the same import structures; see, e.g., Miller & Blair 2009). In short,

national EEIO models suffice for our study given i) our main goal to determine the mitigation potential across tiers of suppliers and ii) the cons of MRIO models.

Per your comments, we have removed the word “global” from the title and substantially revised the discussion around trade, pointing to research needs toward hybridization under the MRIO framework. Please see lines 460 to 463.

Yang, Yi, and Sangwon Suh. "Environmental impacts of products in China." *Environmental science & technology* 45.9 (2011): 4102-4109.

Miller, Ronald E., and Peter D. Blair. *Input-output analysis: foundations and extensions*. Cambridge university press, 2009.

7. The plots in the paper also appear to add questionable value and are not clearly formatted and must be presented better.

Reply: Thanks for pointing it out. We have substantially revised the figures and made them much clearer. We also added another figure (now figure 2) to better navigate the reader from individual sectors from the production perspective (figure 1) to final demand (now figure 3). Please take a look.

I am afraid I am not more positive on this version of the paper, and I recommend rejection at this stage. I encourage authors to pursue this research agenda and sharpen the focus and messaging of the paper.

Reply: Thanks for your constructive feedback. We've taken the effort to substantially revise the manuscript per your suggestions. Hopefully it now meets your expectations.

Response to Reviewer #2

Remarks to the Author:

This paper tackles an important, long-standing issue in corporation carbon accounting – how to determine the boundaries of scope 3 emissions in a meaningful way for effective supply chain coordination? I think this paper offers valuable methods and meaningful insights into this question. I only have a few suggestions and questions that I hope the authors can address for better clarity before the publication.

Reply: Thanks for your very positive assessment of our study and the suggestions. Please see our detailed responses below.

1) The authors mainly focused on the US, South Korea, Mexico, and China. I am wondering why EU countries are not included. Is it a limitation of their regional IO development? Some clarifications will be helpful for the readers to understand the rationale for the focus on these countries.

Reply: Yes, exactly. EU countries have really aggregated IO tables, e.g., ~60 sectors for Germany and ~90 sectors for Netherlands, offering limited insight into the multi-tier supply-chain structure analyzed in this paper. However, the EU's economic structure is, to a large extent, similar to that of the US, leading scholars to model the EU using US-EEIO

models (Huppes et al. 2006). Thus, the US model in our study also provides insight for the EU countries.

Per your comments, we have provided additional explanations for the focus on these models. Please see lines 103 to 105.

Huppes, Gjalt, et al. "Environmental impacts of consumption in the European Union: High-resolution input-output tables with detailed environmental extensions." *Journal of Industrial Ecology* 10.3 (2006): 129-146.

2) Results – “Barriers to Scope 3 GHG Accounting” . This section has great discussions on literature, current barriers, and the status of Scope 3 GHG accounting, but they should not be parts of the results. I think moving them to the Introduction or literature review section will be much better than the current position.

Thank you for this great suggestion. We have blended this section into the Introduction, serving as part of the literature review on barriers to scope 3 emissions.

3) Page 4, would you explain a bit more on STBi’s 67% coverage criteria and provide a reference for this specific number?

SBTi Screening and Coverage requirements are now clearly described in the introduction (lines 48 to 53) with citations for the relevant standards and guidance now included in references.

The 40% screening threshold identifies the requirement for a company to include a scope 3 target (in addition to a scope 1 and scope 2 target). The 67% near-term coverage requirement specifies the scope 3 emissions targeted, after it is determined that a scope 3 target is necessary. Therefore, in Fig 4, red hashmarked bars represent sectors and scope 3 emissions not required to set scope 3 targets under SBTi guidelines. The bars to the right of zero on the x-axis illustrate the tiers of operational emissions needed to meet the 67% near-term and 90% long-term coverage requirements.

4) On page 5, the first paragraph, the authors mention “embedded emissions.” I assume they meant “embodied emissions,” which usually are cradle-to-gate emission factors. The “cradle-to-gate emissions” are also mentioned in the last paragraph of page 4. I suggest the authors use consistent terminologies or let the readers know that they are equivalent; otherwise, it can be confusing.

Reply: Thank you for pointing it out. Both words mean basically the same thing in the literature, depending on one’s preference. But for consistency, we now use ‘embodied’ throughout.

5) The discussions of different tiers are easy for industrial ecologists but challenging for researchers and practitioners in the GHG accounting field. It would be helpful if the authors could provide an intuitive example showing what tier 1 and 2 supplies and their GHG emissions would be in real-world contexts.

Reply: Great suggestion! Thank you. We have added the example of a car maker to help the readers understand the multi-tier structure. Please see lines 123 to 127.

6) I am quite surprised to see that water treatment and distribution would have more emissions associated with the direct purchase of electricity and heat than chemicals. The chemical sector is one of the most energy-intensive (in terms of both unit and total energy consumption) in the US and globally. What are the possible reasons for this result?

Good question. That number refers to South Korea, and its high scope 2 emissions may be caused by finished water pumping and different treatment technologies. More details can be found in the paper below, which examines the energy use in different stages of water works in South Korea. The emissions composition for the same sectors in different countries could be surprisingly different. And this is why we present multi-region comparisons in our paper.

Li, Li, Gyumin Lee, and Doosun Kang. "Estimation of Energy Consumption and CO2 Emissions of the Water Supply Sector: A Seoul Metropolitan City (SMC) Case Study." *Water* 16.3 (2024): 479.

7) Page 8, SBTi's 40% screening threshold was mentioned – it was mentioned as 67% in the earlier place. I suggest the authors add clarifications here to explain what these percentages mean and why different criteria were used in their analysis.

SBTi Screening and Coverage requirements are described from line 48 to 53 with citations for the relevant standards and guidance now included in references.

The 40% screening threshold identifies the requirement for a company to include a scope 3 target (in addition to a scope 1 and scope 2 target). The 67% near-term coverage requirement specifies the scope 3 emissions targeted, after it is determined that a scope 3 target is necessary. Therefore, in Fig 4, red hashmarked bars represent sectors and scope 3 emissions not required to set scope 3 targets under SBTi guidelines. The bars to the right of zero on the x-axis illustrate the tiers of operational emissions needed to meet the 67% near-term and 90% long-term coverage requirements.

We have also rewritten the section describing the tier-level results applied to these requirements. Please see lines 251 to 295.

8) On page 12, I like the discussions on hard-to-trace GHG emissions and the effectiveness of supplier engagement. I am wondering about the authors' opinions on focusing on scopes 1 and 2. Based on the results from this study, if all sectors make efforts to reduce their scope 1 and 2 emissions, then the scope 3 emissions of supply chains that they are involved in are "naturally" reduced. Will this be more effective than trying to track and trace back supply chain Scope 3 emission ownership?

This is a very important point and one that has received much attention in the carbon accounting community. In short, emissions are only created in scope 1, through the direct emissions of some activity. In an EEIO context, these are associated with the direct activities related to a sector's economic output. You are right to suggest that if every sector was to focus on its own direct (scope 1) emissions, any reductions would be reflected in the final use supply chain's scope 3 emissions. The arguments for including scope 3 emissions responsibilities in GHG accounting are primarily based on the "shared" value created by supply chain networks (e.g., each actor acquires inputs, adds value to them, and makes its outputs available to others upstream, who put them to further or final

use). In short, without the efforts (and emissions) created across the value chain, no actor stands alone in the benefits or burdens created and offered to customers and society. As such, the responsibility of an organization to achieve net-zero emissions, it is argued, must also include the emissions of its value chain.

The question of “effectiveness” or “efficiency” between scopes 1, 2, and 3 are perhaps less cut and dry. While beyond the scope of this paper explicitly, we introduce the examples of emissions created in “hard-to-trace” and “difficult-to-abate” sectors of steel-making embodied in automobile manufacturing (and crop/animal agriculture and petrochemical production in garment manufacturing) as an opportunity for coordinated supply chain action. Through a tradeable market mechanism, a downstream automaker could make a discrete investment in, or engage in an advanced purchasing agreement to “offtake”, the future production of new low-carbon primary steel. In this example, the “green premium” necessary to create the supply chain-wide emissions reduction benefit to the automobile (e.g., <1% of the cost of the automobile) may be significantly less than the “cost differential” to the steel maker (e.g., >20% increase in the cost of production). The ability of the automaker to attribute the emissions reductions of its investment/premium to its scope 3 emissions footprint (e.g. through some type of environmental attribute certificates purchased on behalf of [or in collaboration with] key parts suppliers) could generate an “efficient/effective” reduction toward its net-zero objective, while stimulating additional supply of green steel that may not have been economically viable, otherwise.

We introduce this issue into the revised discussion (please see lines 442 to 453), but focus our main contribution on the illustration of significant emissions mitigation potential residing in these hard-to-trace emissions.

9) How was trade included in this study? As the approach seems not to be an MRIO, I wonder how international supply chains that involve trade are treated in the authors’ modeling approaches. If trades are not considered, I suggest adding some discussions about this limitation and future research directions.

Reply: Thanks for the comments. This is another good point. Technically, we included trade, but the national EEIO models assume that all inputs (imported or domestic) have the emissions profile of domestic products (see more discussion in Yang & Suh 2011). Linking the national EEIO models with one another under an multiregional input-output (MRIO) framework would likely better estimate the footprint of imports. However, MRIO models are typically highly aggregated and rely on many assumptions to map trade across different regional data environments (e.g., all sectors have the same import structures; see, e.g., Miller & Blair 2009).

Per your comments, we have added more discussion around trade, pointing to future research needs toward hybridization under the MRIO framework. Please see lines 457 to 468.

Minor issues:

1. Page 5, KR was used first without full name spelling, then South Korea (KR) was introduced later in the same paragraph.

Thank you. We introduced the abbreviation of four countries in lines 128.

2. Page 6, “Figure 1 presents the results from the perspective of production...” I think it should be Figure 2?

Thanks. This is now fixed.

3. Figure 4 is hard for me to read for different tiers, I suggest only keeping the top sectors with big values and moving the rests to SI (which can make bars more readable).

Thank you for your suggestion. We cut off the number of sectors in figure 4 (now it is figure 5). But we keep the top 20 sectors to show a better structure of different supply chains. And we provide the rest of the list in supporting information.

Response to Reviewer #1

In this revised paper, the authors based on four national environmentally-extended input-output (EEIO) models, find that scope 3 reporting implementation focusing on two tiers of suppliers can mitigate 63% to 81% of economy-wide final use emissions but corporate net zero strategies will often need to reach deep into supply chains (often to tiers 5 and 6) to include sufficient operational emissions to approach net zero criterion.

Overall, there is less over-claiming in the revised paper, and the messaging in the paper has also been sharpened to make it more consistent. However, I still have concerns regarding the paper.

First, and arguably most important concern is the novelty in the message of the paper, and/or the methodologies used to arrive at the message. There is arguably little that is novel in terms of the methods adopted by the paper itself, and therefore, we have to weigh the importance of the central question of the paper -- how much of Scope 3 emissions can be addressed by considering the first few tiers. This is indeed an interesting question but the paper meanders far too often and leaps to making inferences ill-supported by the analysis.

Second, the above problem is exacerbated since there is substantial sloppy writing that detracts from the main message and findings. I have tried to provide instances of this below and encourage the authors to improve the paper.

The paper addresses or poses an interesting question - but the writing and presentation is not very careful, which means the main message is lost. That is, with a tighter focus on the central message in the paper, and with a more carefully written version, this paper has a way forward. But in its present form, I am unable to reach a more positive verdict on the paper.

Reply: Thanks for your feedback. We agree that the novelty of this paper lies in the analysis of how much of scope 3 emissions can be addressed by the first few tiers of supply. We have made revisions where you find unclear and additional edits throughout the manuscript to further improve the clarity of our messages. We now clearly show and emphasize in the abstract, introduction, and figures that the **two-tier system boundary can address a substantial share of scope 3 emissions (56% to 71%)**, and lower tiers of suppliers would need to be covered to address a greater share of emissions (90%). Although this two-tier system might fall short of net-zero targets, **it could be utilized as a near-term strategy** that stands to substantially reduce disclosure costs and improve data quality, ultimately increasing the adoption of scope 3 implementation.

Please take see our detailed responses below.

1. *"with the goal of identifying mitigation potentials and main contributors and meeting the science-based target" -- can you rephrase this?*

Reply: Thank you for your suggestion. We revised this sentence as below. Also, we have substantially edited the abstract to make our messages clear. Please take a look.

Here, we investigate the multi-tier greenhouse gas emissions structures of supply chains to assess mitigation potential using environmentally extended input-output models.

2. *"We find that scope 3 reporting implementation focusing on two tiers of suppliers can mitigate 63% to 81% of economy-wide final use emissions". Since the reporting does not itself lead to mitigation, it is better to say can address 63% to 81%...*

Reply: Great suggestion! We rephrased the sentence and now emphasize the ratios of operations emissions of the first two tiers of supply to the total scope 3 emissions of the studied industry. Note that the previous numbers (63% to 81%) refer to ratios of the operation emissions of the studied industry and its two first tiers of supply to the total emissions.

We find that 56–70% of scope 3 emissions included in current science-based coverage guidance occur within the operational emissions of the first two tiers of supply.

3. *"Carbon accounting approaches for reporting and target-setting have evolved to translate the complexity of greenhouse gas behavior in the atmosphere into quantifiable discrete emissions units owned and influenced by specific actors" - the sentence is needlessly convoluted, please rephrase.*

Reply: Thanks for pointing it out: We simplified the sentence as below:

Carbon accounting approaches for reporting and target-setting have evolved to quantify greenhouse gas emissions owned and influenced by specific actors³.

4. *The second paragraph on page 2 makes some interesting points but needs to be rewritten to make the message clearer here.*

Reply: Thank you for your comments. We substantially edited this paragraph to make the messages clear, as below:

The SBTi framework offers flexibility in implementation. Scope 3 targets can be set through a contraction approach, which establishes a supply chain-wide Scope 3 emissions baseline and reduction goal against it. Alternatively, however, the framework also permits a more flexible approach of engaging a percent of suppliers toward the adoption of science-based targets (generally, before 2030). **This flexibility has accelerated adoption of SBTi among companies, but has also created challenges.** **First**, the measurement of emissions reduction is challenged by supplier networks that are constantly changing. Reporting companies struggle to track reduction progress when suppliers with attributed Scope 3 targets leave their supply chain, or when new suppliers enter with unclear historical performance or future goals. **Second**, supplier data quality and reliability are impaired by the indirect multi-tier nature of scope 3. Contractual attribution of scope 3 emissions reductions and removals, beyond direct tier 1 suppliers, have proven to be exceedingly difficult to execute. **Third**, corporate reporting of scope 3 mitigation is being delayed by the lack of clarity regarding which mitigation strategies or mechanisms can legitimately be attributed to a reporting company's scope 3 target.

5. *I think this statement is problematic, and in any case, in my opinion, it does not detract from the paper that the EU is not considered: "The European Union (EU) is not covered due to a lack of high-resolution data. However, this region can be largely represented by the US for their similar economic structures."*

Reply: Great suggestion, thanks! We deleted the statement.

6. *"Operational emissions extending deep into supply chain tiers are often necessary to meet decision-useful requirements in both the near- and longer-term." Please rephrase this sentence.*

Reply: Thanks for the suggestion. We rewrote the whole paragraph to clearly summarize our key findings, please take a look. Regarding this sentence you referred to, it has been revised as:

To meet longer-term science-based reductions toward net-zero, we illustrate that supply chain managers will likely need to accelerate mitigation efforts addressing the indirect supply of highly emissions intensive inputs, where traceability and attribution across time is challenged.

7. *"Results indicate that current supplier engagement, implemented to satisfy SBTi scope 3 short-term target criteria, are likely falling far short of meeting SBTi's coverage objectives." Please clarify this.*

Reply: Thanks for the suggestion. We revised this sentence as below, and the rest of the paragraph serves to illustrate why it is important to engage with suppliers.

Results indicate that current supplier engagement is likely falling far short of meeting SBTi's coverage objectives. However, engaging with suppliers plays a strategically important role in emissions reduction.

8. *Figure 4 must be re-plotted to make it clearer to the reader what it conveys.*

Reply: Thanks for the suggestion. We have modified the figure to make it clearer. Both panels now consistently differentiate between short-term targets and long-term targets. As also indicated above, we have edited the Abstract, Introduction, and Results sections to clearly convey our messages regarding how corporates can strategically engage lower tiers of suppliers to address short-term and long-term climate targets.