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Peer Review File

Global emissions from digital technologies are largely hidden in other industries' supply chains

Corresponding Author: Dr Janna Axenbeck

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:

** 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 Dr Kunkel,

Your manuscript titled "Global Embodied Emissions of Digital Technologies:The Hidden 42 %" has now been seen by 2 reviewers, and we include their comments at the end of this message. They find your work of interest, but some important points are raised around the clarity and justification of methods employed. We are interested in the possibility of publishing your study in Communications Sustainability, but would like to consider your responses to these concerns and assess a revised manuscript before we make a final decision on publication.

We therefore invite you to revise and resubmit your manuscript, along with a point-by-point response that takes into account the points raised. Please highlight all changes in the manuscript text file.

Please submit your point-by-point 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.

We are committed to providing a fair and constructive peer-review process. Please don't hesitate to contact us if you wish to discuss the revision in more detail.

Please use the following link to submit your revised manuscript, point-by-point response to the referees' comments (which should be in a separate document to any cover letter), a tracked-changes version of the manuscript (as a PDF file) and the completed checklist:
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We hope to receive your revised paper within six weeks; please let us know if you aren't able to submit it within this time so that we can discuss how best to proceed. If we don't hear from you, and the revision process takes significantly longer, we may close your file. In this event, we will still be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Sustainability or published elsewhere in the meantime.

Please do not hesitate to contact us if you have any questions or would like to discuss these revisions further. We look forward to seeing the revised manuscript and thank you for the opportunity to review your work.

Best regards,

Alice Drinkwater, PhD
Consulting Editor
Communications Sustainability

Associate Editor
Communications Earth & Environment

EDITORIAL POLICIES AND FORMATTING

We ask that you ensure your manuscript complies with our editorial policies. Please ensure that the following formatting requirements are met, and any checklist relevant to your research is completed and uploaded as a Related Manuscript file type with the revised article.

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• Ecological, evolutionary & environmental sciences
• Life sciences
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In particular, the Data availability statement should include:
- Unique identifiers (such as DOIs and hyperlinks for datasets in public repositories)
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- If applicable, a statement regarding data available with restrictions
- If a dataset has a Digital Object Identifier (DOI) as its unique identifier, we strongly encourage including this in the Reference list and citing the dataset in the Data Availability Statement.

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Please refer to our data policies at http://www.nature.com/authors/policies/availability.html.

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

1. The methodology section of an academic paper is one of the central pillars of the study, which details how the study was conducted and provides a basis for the reliability of the results. This dissertation does not have a methodology section and does not provide a systematic description of the specific steps of how the input-output analysis methodology was implemented in this study, how the data was processed, and the details of the model construction. Readers cannot clearly know how the study transforms EU FIGARO data into valid analysis results, and it is difficult to judge whether the research process is scientific and reasonable, not to mention that the study cannot be reproduced and verified, which seriously undermines the credibility and academic value of the study.

2. The conclusion section is a high level summary of the entire study and should clearly present the core findings, contributions, and implications for future research. The dissertation lacks a conclusion section.
3. The structure of the paper is seriously lacking. In order to meet the basic requirements of academic papers and achieve the standard of publication, authors need to complete the structure of the paper, systematically explain the research methodology, refine the core conclusions, and improve other necessary chapters.
4. The time span of the adopted data is 2010 - 2021, while the development of digital technology is rapidly changing, and in recent years, emerging technologies such as artificial intelligence and big data have been rapidly emerging, and their emission characteristics are quite different from those in the past. It is difficult to capture the dynamic changes of the current and future emissions of the digital industry by using relatively lagging data, which leads to the lack of timeliness of the research results and fails to provide effective references for the current and subsequent policy formulation.
4. The input-output analysis method does not elaborate on its applicability in the specific scenario of this study when studying the implied emissions of the digital industry. The digital industry is characterized by rapid technological updating and a complex industrial chain, and it is not clear whether the method can accurately portray its emission association and transfer, and the lack of sufficient justification for the rationality of the method makes the research foundation not solid enough.
5. The research content and conclusions are not innovative, and the research direction of quantifying the “hidden” emissions of digital industries in non-digital industries is interesting, but does not show a significant breakthrough in methodology and conclusions. The extended Leontief methodology used is not entirely innovative and does not show significant advantages over existing methods in practical application; the proposed emission reduction recommendations are mostly repetitions of existing policies and theories, and do not incorporate the unique findings of this study to propose novel and effective solutions.
In summary, the paper has serious problems in terms of data, methodology, argumentation, innovativeness and practical value, which makes it difficult to meet the requirements for publication in academic journals.

Reviewer #2 (Remarks to the Author):

General Comment: This is a very important topic with significant findings of unaccounted for embodied emissions amounting to 42% within the digital industry. The following are my comments.

1. The tense in the following sentence doesn’t sound correct. “Hardware contributes the largest share to global embodied emissions of digital industries, while the increasing demand for services drives emissions growth in the past decade."

2. This sentence is too long and difficult to understand and has wrong tenses maybe due to its length “Our findings highlight the need to reduce digital emissions along all industries’ value chains, by considering embedded digital inputs, following circular economy principles for hardware manufacturing, and limiting embodied emissions associated with IT services, such as artificial intelligence services.” Consider breaking it up into shorter sentences.

3. There are a lot of unsupported quantitative data…eg, paragraph one on the introduction “We are currently witnessing profound technological change driven by the widespread adoption of digital technologies (1). Despite extensive evidence linking technological change to environmental impacts (2), systematic assessments of the GHG emissions of the digital transformation remain limited and vary greatly (3; 4; 5; 6). Based primarily on company data, (7) and (8) report global greenhouse gas (GHG) emissions of the information and communication technology (ICT) sector of 1.4% in 2020 and 1.7% in 2022, respectively. In contrast, based on a systematic literature review, and adjusting previous life cycle assessment (LCA) estimates for a potential truncation error1 , conclude that the global climate footprint of digital technologies in 2020 is likely to be between 2.1% and 3.9% of global emissions (9). To overcome the truncation error of bottom-up methods such as LCA, and fully assess the GHG emissions in global value chains of digital technologies, the input-output (I-O) framework offers a valuable top-down perspective (10). Using input-output analysis, (11) report that digital industry embodied emissions accounted for 0.3% in 2014. (12) considering upstream and downstream emissions of digital technologies, in contrast, find digital technologies to account for 4.0% of global emissions”

4. The first-time authors introduce “the input-output (I-O) framework” it should be further explained and maybe refer to a more detailed appendix
5. Why did the authors use FIGARO and not other datasets, eg the following datasets also have the same data as FIARO (i) Eurostat's Supply, Use, and Input-Output Tables (ii) OECD Inter-Country Input-Output (ICIO) Tables. There is need to enhance the methodology.

7. Some claims need referencing, eg “as emissions in the end-of-life phase (e.g., emissions of dismantling hardware). Including these emissions using figures reported in (9) could raise our 2021 total emission estimate by approximately 20%.”

8. Not everyone knows what “NACE 3-digit is?” Please define this.

9. The results presentation and explanation can be enhanced. The authors should present the results so that a non-expert can follow through. Further explanation, especially before the results, is needed.

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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 Dr Kunkel,

Your manuscript titled "Global Embodied Emissions of Digital Technologies:The Hidden 42 %" 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 Sustainability.

We therefore invite you to revise your paper one last time to 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,

Alice Drinkwater, PhD
Consulting Editor
Communications Sustainability
Associate Editor
Communications Earth & Environment

REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

I am satisfied with the authors' response

Reviewer #2 (Remarks to the Author):

My comments have been fully addressed, and the manuscript is okay for publication.

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Communications Sustainability: COMMSSUSTAIN-25-0092-T

Dear Mrs. Drinkwater, Editorial Team, and Reviewers,

We greatly appreciate the opportunity to resubmit a revised version of our paper "Global Embodied Emissions of Digital Technologies: The Hidden 42 %".

First of all, we want to thank you very much for your supporting, useful comments, and the possibility to revise and improve our paper. We understand the points raised in the first review and are convinced that the remarks add great value to our analysis. We have taken them all very seriously and considerably reworked our paper along the following lines:

- We improved clarity about the employed methods (as well as their appropriateness) by integrating a *Methods* section into the main body of our manuscript.
- We added more details, where needed.
- We restructured our paper along the *Communications Sustainability* guidelines.

We believe that the revisions have significantly improved the paper and we look forward to your feedback.

The following is a point-by-point response to your remarks. Your comments are in *italics*, and our responses follow.

Sincerely,

Janna Axenbeck, Stefanie Kunkel, Joris Blain, and Francis Charpentier

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REVIEWER COMMENTS:

Reviewer #1:

1. Remark:

The methodology section of an academic paper is one of the central pillars of the study, which details how the study was conducted and provides a basis for the reliability of the results. This dissertation does not have a methodology section and does not provide a systematic description of the specific steps of how the input-output analysis methodology was implemented in this study, how the data was processed, and the details of the model construction. Readers cannot clearly know how the study transforms EU FIGARO data into valid analysis results, and it is difficult to judge whether the research process is scientific and reasonable, not to mention that the study cannot be reproduced and verified, which seriously undermines the credibility and academic value of the study.

Response:

Thank you very much for this valuable comment. In our initial submission, we provided a description of the employed methods and our further development of them in the appendix. In response to your crucial remark, we have now relocated this section to the main manuscript and significantly enhanced the systematic description of how the input-

output approach is implemented and how the results were generated. Our revisions can now be found in the *Methods* section (pp. 9-12), just below the discussion. After the *Methods* section, we created a new subsection *Code Availability* that now specifies where our "R" code is available on GitHub (https://github.com/jax90/i-o-tables). The code allows readers to follow how we transform EU FIGARO data into our results. Furthermore, we implemented both changes to ensure that the revised manuscript complies with the author guidelines of *Communication Sustainability* (see https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf). We sincerely hope these revisions will facilitate a thorough evaluation of the academic quality of our study.

2. Remark: *The conclusion section is a high level summary of the entire study and should clearly present the core findings, contributions, and implications for future research. The dissertation lacks a conclusion section.*

Response:

Thank you for this observation. We understand the importance of a clear and concise conclusion section. However, to align with the journal's requirements, which specify the sections *Introduction*, *Results*, *Discussion*, and *Methods*, an additional conclusion section at the end of the manuscript is not planned (see formatting guidelines of the journal: https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf).

In our initial submission, we included a concise summary at the beginning of the *Discussion* section. To adhere to the *Communications Sustainability* requirements, which call for a brief summary of the major results and conclusions in the final paragraph of the *Introduction* section, we have now relocated this part to the *Introduction* section and revised it (pp. 2-3). We sincerely hope this approach effectively communicates the key takeaways of our study, but we are open to revisiting this structure if further refinements are needed.

3. Remark: *The structure of the paper is seriously lacking. In order to meet the basic requirements of academic papers and achieve the standard of publication, authors need to complete the structure of the paper, systematically explain the research methodology, refine the core conclusions, and improve other necessary chapters.*

Response:

Thank you for your valuable feedback. We have revised the structure of our paper to align with the journal's' guidelines. Specifically, we have restructured key sections, to enhance clarity and coherence. For instance, we moved the *Methods* section to the main body of the manuscript, where we now provide a more systematic and detailed explanation of our research methodology. Moreover, we now state revised core conclusions at the end of the *Introduction* section. See also our responses to your Remarks 1 and 2 for more details on these adjustments. We sincerely hope that these improvements address your concerns.

4. Remark: *The time span of the adopted data is 2010 - 2021, while the development of digital technology is rapidly changing, and in recent years, emerging technologies such as artificial intelligence and big data have been rapidly emerging, and their emission characteristics are quite different from those in the past. It is difficult to capture the dynamic changes of the current and future emissions of the digital industry by using relatively lagging data, which leads to the lack of timeliness of the research results and fails to provide effective references for the current and subsequent policy formulation.*

Response:

We appreciate your remark regarding the timeliness of our data and fully agree that it would be desirable to have more current data or predictive models. However, we are still confident that our results remain scientifically valuable and policy-relevant for several reasons.

First, the challenge of data timeliness is not unique to our study but is inherent to many widely cited analyses of greenhouse gas (GHG) emissions, particularly in the field of digitalization. For example, Malmodin et al. (2024) used a bottom-up approach to estimate GHG emissions of digital technologies for the year 2020, publishing their findings with a four-year lag (comparable to our study). Similarly, Freitag et al. (2021) relied on data up to 2015 in their meta-analysis, resulting in a six-year lag. Even larger delays are common in other sector- and country-level studies (e.g., Yang et al., 2020, eight-year lag; Xu et al., 2021, 11-year lag). One reason for the substantial time lags is the considerable effort required to consolidate datasets from multiple national sources. Importantly, despite these delays, such studies remain valuable because robust insights into historical trends can still meaningfully inform policy. In the absence of systematically gathered and harmonized data, policy decisions risk being based on incomplete or anecdotal evidence, which arguably poses a greater limitation. Moreover, our analysis provides critical information on structural patterns, emission hotspots, and supply chain linkages of digital industries. While the rapid growth of technologies such as AI and big data may introduce new dynamics, most industrial systems, including the ICT sector, exhibit significant inertia due to path dependencies, capital stock lifetimes, and long-term infrastructure investments. Hence, a substantial number of factors are unlikely to shift substantially in the short term.

To address your point, we now explicitly acknowledge and discuss this limitation in our revised *Discussion* section (p. 8):

> „Due to the time lag in publishing input-output data, our analysis does not capture recent surges in energy consumption within IT services, driven by the rapid rise of generative artificial intelligence, starting at the end of 2022 with the introduction of ChatGPT and other large-scale AI models (IEA, 2025). Nevertheless, while the rapid expansion of technologies such as AI and big data may introduce new dynamics, most industrial systems (including the ICT sector) exhibit considerable inertia due to path dependencies, capital stock lifetimes, and long-term infrastructure investments. As such, many factors are unlikely to shift substantially in the short term.“

We want to thank you for this remark and are convinced that this statement enhances transparency of our study.

5. Remark: The input-output analysis method does not elaborate on its applicability in the specific scenario of this study when studying the implied emissions of the digital industry. The digital industry is characterized by rapid technological updating and a complex industrial chain, and it is not clear whether the method can accurately portray its emission association and transfer, and the lack of sufficient justification for the rationality of the method makes the research foundation not solid enough.

Response:

Thank you for this insightful comment. We agree that the digital industry's rapid technological turnover and extended value chains pose particular challenges for any emissions accounting method. To clarify our choice of the input-output approach, we want to note that two main approaches exist for estimating an industry's embodied emissions:

(1) **Bottom-up approaches**, which draw directly on company-level data (e.g., sales figures, ESG reports) combined with life-cycle-analysis coefficients. While highly detailed, these methods can suffer from inconsistent data sources, temporal gaps, and truncation errors that omit parts of the supply chain. Indeed, Freitag et al. (2021) show that a potential truncation error may be especially severe for the digital economy, where upstream inputs and services span numerous sectors.
(2) **Top-down IO analysis**, in which global GHG emissions are apportioned to industries through input-output tables. Although sectoral aggregation (64 sectors in our case) can introduce some imprecision, the IO approach inherently traces the full length of value chains – something bottom-up models cannot achieve, as a partial exclusion of upstream pathways always exists.

Because each approach has different strengths and weaknesses, we believe that both methods are complementary and our IO approach provides an important contribution to the literature, as we are able to:

- Comprehensibly capture value chains over our chosen time span.
- Ensure methodological consistency across years.
- Leverage well-established literature on input-output tables and the Leontief inverse.

Together, these considerations provide a robust and transparent basis for modeling emissions of digital industries using IO analysis, despite digital technologies fast-evolving nature and complexity. We hope this explanation reassures you of the method's applicability and the solidity of our research foundation.

To address your remark, we state now on p. 12 in our revised manuscript the advantages of the IO approach more explicitly:

> "Also, the advantages of input-output analysis over bottom-up approaches include the availability of annually updated, open-access data, which facilitates the analysis of trends over multiple years. Another strength is that the approach attempts to model the technical processes involved in specific products and industries, allowing to comprehensively capturing value chains over the analyzed period."

In addition, we have added several new references to the *Introduction* section on sector-level environmental footprint analysis using the IO approach, to highlight the suitability of this perspective for examining sectors' total environmental impacts, along with their underlying drivers and individual components (p. 2).

6. Remark: *The research content and conclusions are not innovative, and the research direction of quantifying the "hidden" emissions of digital industries in non-digital industries is interesting, but does not show a significant breakthrough in methodology and conclusions. The extended Leontief methodology used is not entirely innovative and does not show significant advantages over existing methods in practical application;*

Response:

Thank you for this comment. We are convinced that our study makes several important contributions to the literature. First, to our knowledge, no prior study explicitly quantifies the *digital embodied emissions* resulting from the increasing digitalization of traditionally non-digital value chains, nor empirically demonstrates that these emissions are a significant contributor to the overall growth of digital emissions. We address this gap by calculating consumption-based footprints but taking a production-based perspective, in which we account for digital emissions that are mediated through other industries. As highlighted in the literature, combining consumption-based footprints with a production-based perspective "leads to a better understanding of the intermediate enablers of pollution" (Hennequin et al., 2025, p. 2). Recent studies further underscore the relevance of this approach (e.g., Wilting & in't Veld, 2025). Importantly, to our knowledge, the ICT sector has not yet been examined at a global scale taking this perspective and explicitly discussing resulting insights.

Moreover, while our methodological extension of the standard Leontief inverse (that allows us to take this production-based perspective) produces numerically similar results to Cabernard et al. (2019), who analyzed material resources, it has several advantages. We discuss these in our revised manuscript, highlighting that – next to our empirical results – we also extent the literature from a methodological point of view (see p. 12):

> "Our alternative algorithm [...] is particularly well suited for a group of target sectors consisting of a relatively small number of individual industries (as it is the case for the ICT sector) since the proposed approach involves only a limited number of additional computations beyond the calculation of the standard Leontief inverse. Furthermore, the iterative nature of our algorithm allows intermediate embodied emissions from several industries to be aggregated or disaggregated, thereby providing novel insights into the interconnectedness of global value chains."

We discuss the innovativeness of our conclusions in our next answer.

7. Remark: *... the proposed emission reduction recommendations are mostly repetitions of existing policies and theories, and do not incorporate the unique findings of this study to propose novel and effective solutions.*

Response:

Thank you very much for this valuable comment. We appreciate the opportunity to clarify the scope and contributions of our study, which is (i) providing new empirical insights into the embodied emissions of digital technologies, and (ii) advancing the methodological framework through an extension of the Leontief inverse. While our

empirical results allow us to identify key drivers of emission growth and thereby support the prioritization of solutions addressing these drivers, the explicit development of novel policy solutions lies beyond the scope of our analysis.

That said, we do partly point to emission reduction strategies that have not been previously discussed in the context of digital technologies. One unique finding of our analysis is that the EU, for instance, consumes significantly more digital emissions than it produces. However, the EU Emissions Trading System (ETS) (currently the main EU climate policy instrument), addresses only production-based emissions. Based on this finding, we suggest extending the EU's Carbon Border Adjustment Mechanism (CBAM), which aims to close the gap between consumption-based and production-based emissions, to include digital products and services. To our knowledge, this proposal has not been extensively considered in prior studies. In our revised manuscript, we elaborate on this idea in more detail (see p. 8).

Moreover, to reflect the actual scope of our analysis and to strengthen the innovativeness of our recommendations, we propose an additional measure: the implementation of a universal carbon accounting framework. Such a framework would significantly enhance the understanding of the digital footprint and enable a more accurate and equitable identification of key GHG emission drivers. We also emphasize that reliable, robust, and widely applicable data will be essential for effectively managing the environmental impact of digital technologies. In addition, we have incorporated new references that offer general recommendations for comprehensively addressing corporate footprints, along with broader strategic guidance for reducing emissions along value chains (see pp. 7-8).

We sincerely hope this clarifies how our findings offer a fresh perspective on emissions reduction strategies specific to the digital sector.

8. Remark: *In summary, the paper has serious problems in terms of data, methodology, argumentation, innovativeness and practical value, which makes it difficult to meet the requirements for publication in academic journals.*

We hope that our previous responses could alleviate your concerns. We, in particular, hope that we addressed them by:

1. … highlighting that our methods, data and code are publicly available and therefore reproducible.
2. … explaining why our methodology is appropriate and demonstrating that we extending previous literature.
3. … showing that we carefully revised our manuscript to improve the clarity and coherence of arguments, highlighting the manuscripts innovativeness and practical value.

We are convinced that the revised manuscript will be of great interest to the readers of the *Communications Sustainability* community.

Reviewer #2:

General Comment: *This is a very important topic with significant findings of unaccounted for embodied emissions amounting to 42% within the digital industry. The following are my comments.*

Response:

We sincerely thank you for recognizing the relevance of the topic and the importance of our findings. We greatly appreciate your engagement and constructive feedback.

1. Remark: *The tense in the following sentence doesn't sound correct. "Hardware contributes the largest share to global embodied emissions of digital industries, while the increasing demand for services drives emissions growth in the past decade.*

Response:

Thank you for carefully checking the manuscript. We changed the tense as follows (p. 1):

"Hardware contributes the largest share to global embodied emissions of digital industries, while the increasing demand for IT services has driven emissions growth in the past decade."

2. Remark: *This sentence is too long and difficult to understand and has wrong tenses maybe due to its length "Our findings highlight the need to reduce digital emissions along all industries' value chains, by considering embedded digital inputs, following circular economy principles for hardware manufacturing, and limiting embodied emissions associated with IT services, such as artificial intelligence services." Consider breaking it up into shorter sentences.*

Response:

Thank you for your remark. We broke the sentence up into two shorter sentences:

„Our findings highlight the need to reduce digital emissions across all industries' value chains. This includes accounting for embedded digital inputs, adopting circular economy principles in hardware manufacturing, and limiting embodied emissions from IT services, such as artificial intelligence."

We sincerely hope that this revision enhances the readability of our abstract.

3. Remark: *There are a lot of unsupported quantitative data…eg, paragraph one on the introduction "We are currently witnessing profound technological change driven by the widespread adoption of digital technologies (1). Despite extensive evidence linking technological change to environmental impacts (2), systematic assessments of the GHG emissions of the digital transformation remain limited and vary greatly (3; 4; 5; 6). Based primarily on company data, (7) and (8) report global greenhouse gas (GHG) emissions of the information and communication technology (ICT) sector of 1.4% in 2020 and 1.7% in 2022, respectively. In contrast, based on a systematic literature review, and adjusting previous life cycle assessment (LCA) estimates for a potential truncation error1 , conclude that the global climate footprint of digital technologies in 2020 is likely to be between 2.1% and 3.9% of global emissions (9). To overcome the truncation error of bottom-up methods such as LCA, and fully assess the GHG emissions in global value chains of digital technologies, the input-output (I-O)*

framework offers a valuable top-down perspective (10). Using input-output analysis, (11) report that digital industry embodied emissions accounted for 0.3% in 2014. (12) considering upstream and downstream emissions of digital technologies, in contrast, find digital technologies to account for 4.0% of global emissions"

Response:

Thank you very much for your helpful comment. We acknowledge that the initial version of the manuscript lacked clarity in referencing and may have given the impression that some data were insufficiently supported. In response, we undertook several revisions to improve transparency and traceability of the quantitative data cited:

(1) We revised our citation style throughout the introduction to include in-text author names and publication years (rather than numeric citations only), to better anchor each statement to a specific source.

(2) We now provide additional context and detail on the underlying data used in the referenced studies to help the reader assess their comparability and credibility.

(3) We reworked the beginning of the introductory section to improve the logical flow of argumentation (see p. 1).

We hope that these changes address your concerns regarding unsupported data. Should you have had a different issue in mind, we would be happy to further revise this section in a subsequent round of review.

4. Remark: *The first-time authors introduce "the input-output (I-O) framework" it should be further explained and maybe refer to a more detailed appendix.*

Response:

Thank you for your remark. In our revised manuscript, we now state in the *Introduction* section (p. 1):

> "Environmentally-extended input-output (EEIO) analysis is the second approach for analyzing embodied emissions. It leverages macroeconomic tables that capture the flow of goods and services and their associated emissions between sectors (see *Methods* section for details). Using these tables, total global emissions are allocated to economic sectors in a top-down manner, thereby capturing value chains more comprehensively (Kitzes, 2013)."

We sincerely hope that these explanations provide a clearer intuition of our methods in the introduction.

5. Remark: *Why did the authors use FIGARO and not other datasets, eg the following datasets also have the same data as FIGARO (i) Eurostat's Supply, Use, and Input-Output Tables (ii) OECD Inter-Country Input-Output (ICIO) Tables. There is need to enhance the methodology.*

Response:

Thank you for this comment. FIGARO refers to Eurostat's Multi-Regional Supply, Use, and Input-Output Tables (MRIOT) (see Eurostat's website: https://ec.europa.eu/eurostat/web/products-statistical-working-papers/w/ks-01-24-017).

We chose FIGARO primarily because of its recency, higher industry granularity, and reliability. For example, the latest OECD Inter-Country Input-Output (ICIO) data extends only to 2020 and aggregates industries into fewer categories,[1] whereas FIGARO offers a more detailed sectoral resolution. The same issue also applies to EXIOBASE, whose last observed year is 2020. More recent years were nowcasted, and the authors recommend considering 2020 as the last available year for most analyses. FIGARO is also widely used by national statistical offices (e.g., in France and the UK) to calculate country-wide consumption-based footprints and is considered in the literature as one of the more robust and reliable MRIOTs. Additionally, FIGARO is part of and benefits from the interagency compilers network GIANT (Global Input-Output Accounts), which brings together organizations such as the European Commission, the OECD, the IMF, and the WTO. Furthermore, environmental data is readily available from Eurostat, facilitating integration into the analysis. We have clarified this choice in the revised methodology section (p. 12).

6. Remark: Some claims need referencing, eg "as emissions in the end-of-life phase (e.g., emissions of dismantling hardware). Including these emissions using figures reported in (9) could raise our 2021 total emission estimate by approximately 20%."

Response:

Thank you for this remark. We added a brief explanation on how we arrived at this statement (p. 8):

> "Including use-phase emissions alone using estimated figures for 2020 reported in Table B.5 Supplementary Material of Freitag et al. (2021), could approximately raise our 2020 total emission estimate by a bit more than 20% (additional 440 mt added to 2023 mt)."

We sincerely hope that this clarification addresses your concern and strengthens the transparency of our estimates.

8. Remark: *Not everyone knows what "NACE 3-digit is?" Please define this.*

Response:

Thank you very much for your comment. We now define NACE 2-digit and NACE 3-digit classifications in the revised manuscript. On p. 2, we state:

> "We apply the extended IO analysis to FIGARO […] covering […] 64 industries according to the industry classification scheme "NACE" (Nomenclature statistique des activités économiques dans la Communauté Européenne, 2-digit-level) or aggregates thereof (Eurostat, 2024). The NACE 2-digit level provides a broad industry classification, including, for instance, the chemical or automotive industry."

On p. 8, we add:

> "The NACE 3-digit level offers a more detailed categorization, subdividing the 2-digit divisions into 272 groups specifying distinct types of activities."

[1] https://www.oecd.org/en/data/datasets/input-output-tables.html (online; accessed on 11. Jul 25).

We hope these additions sufficiently clarify the meaning of these industry classification codes for all readers.

9. Remark: *The results presentation and explanation can be enhanced. The authors should present the results so that a non-expert can follow through. Further explanation, especially before the results, is needed.*

Response:

Thank you for this valuable remark, which we fully appreciate. In response, we have revised the manuscript to enhance the presentation and explanation of the results, making them more accessible to non-expert readers. Specifically, we now introduce each figure with a clearer description of what it shows before presenting the results. For example, we now introduce the Figures 1 and 2 as follows (p. 3):

- "Figure 1 illustrates embodied emissions of total digital demand over time, as well as the relative contributions of digital industries to global emissions and economic output."
- "Figure 2 illustrates emissions flows from industries of origin to final demand, expressed in percent for the year 2021. The left-hand side shows the industries producing the direct emissions in the digital value chain, while the middle section represents embodied emissions within final products or services, distinguishing between emissions embodied in the final demand of the three digital industries (hardware, communication, and IT services) and those embodied in intermediate demand for digital technologies stemming from other industries, such as automotive. The right-hand side attributes emissions to areas of final demand ..."

We sincerely hope that these additional explanations have enhanced the clarity of our presentation of results.

Additional changes made by the authors

In the following, we list additional changes we conducted during the revision.

To comply with *Communications Sustainability*'s style guidelines, we made the following adjustments:

- Revised the layout to align with the Nature brand standards.
- Changed the figure fonts to a sans-serif typeface.
- Integrated all footnotes into the main text.
- Prepared a Supplementary Information document.

In addition, we conducted the following changes:

- Corrected values with respect to economic output in Figure 1.
- Replaced in Figure 5 the word country by region.

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