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10th Nov 22

Dear Dr Wenz,

Your manuscript titled "Towards a comprehensive and inclusive European Carbon Border Adjustment Mechanism" has now been seen by 2 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. In particular, we require that the following editorial thresholds are met in the revised manuscript:

1. Provide a thorough and robust assessment of the influence of different carbon pricing mechanisms in optimizing the EU's Carbon Border Adjustment Mechanism.
2. Provide a clear justification of the applicability and utility of your findings given the differences between your CBAM design and that of the EU.
3. Place your findings clearly into the context of the associated limitations and account for this in your conclusions and interpretations.

We hope you will find the reviewers' comments useful as you decide how to proceed. Should additional work allow you to address these criticisms, 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.

Please bear in mind that we will be reluctant to approach the reviewers again in the absence of substantial revisions.

If the revision process takes significantly longer than three months, we will be happy to reconsider your paper at a later date, as long as nothing similar has been accepted for publication at Communications Earth & Environment or published elsewhere in the meantime.

We understand that due to the current global situation, the time required for revision may be longer than usual. We would appreciate it if you could keep us informed about an estimated timescale for resubmission, to facilitate our planning. Of course, if you are unable to estimate, we are happy to accommodate necessary extensions nevertheless.

We are committed to providing a fair and constructive peer-review process. Please do not 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 reviewers' comments with a list of your changes to the manuscript text (which should be in a separate document to any cover letter) and any completed checklist:

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Please do not hesitate to contact me 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,

Sagar Parajuli, PhD
Editorial Board Member
Communications Earth & Environment

EDITORIAL POLICIES AND FORMAT

If you decide to resubmit your paper, please ensure that your manuscript complies with our editorial policies and complete and upload the checklist below as a Related Manuscript file type with the revised article:

Editorial Policy Policy requirements (Download the link to your computer as a PDF.)

For your information, you can find some guidance regarding format requirements summarized on the following checklist:(<https://www.nature.com/documents/commsj-phys-style-formatting-checklist-article.pdf>) and formatting guide (<https://www.nature.com/documents/commsj-phys-style-formatting-guide-accept.pdf>).

REVIEWER COMMENTS:

Reviewer #1 (Remarks to the Author):

The manuscript “Towards a comprehensive and inclusive European Carbon Border Adjustment Mechanism” provides an analysis of the potential CBAM designs and implications of alternative CBAM revenue recycling schemes. Overall, the paper fits the scope of the journal, is clearly written and provides an interesting theoretical contribution to the field. At the same time, policy relevance of the provided results could be questioned and need to be further justified. In addition, the paper would benefit from further clarifications and revisions, as discussed below.

General comments

Three key concerns regarding the provided analysis include the following:

1. Considered CBAM design is purely theoretical and is far beyond schemes currently discussed in EU, both in terms of commodity and emission scopes' coverage. While authors mention that the CBAM design considered in the paper is "hypothetical comprehensive", the fact that it seems to be so far beyond the current EU proposal, seems to alleviate the potential policy validity of results. What is currently discussed in EU is a coverage of selected commodities (cement, steel, aluminum, etc.) and Scope 1 (with potentially Scope 2) emissions. Inclusion and even comprehensive accounting of Scope 3 emissions currently presents only a theoretical validity, though, of course, is worth exploring. In this regard, having an additional/sensitivity analysis part that incorporates a CBAM scheme that is closer to what is currently discussed in EU would make findings of the paper much more policy relevant.

2. Methodology applied to estimate potential impacts of CBAM (CBAM pressure) and implications of alternative revenue recycling schemes is based on the (static) input-output framework, i.e. does not allow for any adjustment in agents' behavior, such as reallocation of trade flows to alternative destinations (away from EU) or change in the composition of trade patterns (e.g. like the representation allowed by computable general equilibrium models). As a result, outcomes presented in the paper correspond to the worst-case scenario with "0" adjustment opportunities. However, what would likely happen in reality is that countries that e.g. export carbon-intensive steel to EU would (a) Switch to alternative export destinations that do not apply CBAM or apply less stringent policies, e.g. China, reducing exports to EU; (b) Reduce their volumes of domestic steel output (thus domestic emissions would reduce) and (c) Reallocate part of the production resources to other less polluting sectors, such as light manufacturing, increasing output and exports of such activities. Earlier studies suggest that the impact of such adaptations could be non-trivial (e.g. see the EC CBAM assessment document for the case of EU impacts or Chepeliev (2021) for the case of Ukraine) and thus actual outcomes could be substantially different from the 'static' first-round effects estimated without any adjustments. In addition, application of the CBAM would impact global prices of energy and energy-intensive goods and services, reducing overall demand for these commodities and putting a downward pressure on prices. This would further negatively impact large exporters of these commodities.

While authors briefly mention these limitations in the concluding part, the paper can do better job in putting these effects into the context of the provided analysis. A more detailed discussion of these potential impacts and their reconciliation with the applied methodological framework would improve the paper.

3. Applicability of the proposed revenue reallocation schemes might be questioned on the practicality grounds. A simple exclusion of the low-income countries from CBAM might be the simplest practical solution in this regard. Administrative and monitoring efforts required to implement one of the suggested options might be a substantial obstacle in practical terms. In the case of options (A), (B) and (D) metric is constantly updated over time and thus lagged estimates need to be used. Some of these statistics would be backward-revised by countries (e.g. trade flows) and might lead to conceptual collisions. At the same time option (D) can be rather challenging to justify, due to the nature of the climate damage estimates.

In addition, these estimates do not take into account the dynamic first round effects that are caused by CBAM and impact real incomes across countries. When both channels are combined, total distributional outcomes could be rather different from those presented here.

It is well recognized that the proposed concepts are purely theoretical, but a broader and more grounded discussion of their applicability and policy relevance would be very helpful.

Additional comments

1. P. 2, line 26. Authors briefly discuss the difference between “comprehensive CBAM” and the current proposal. However, for the reader the magnitude and specifics of difference are not entirely clear. Perhaps, a section in the supplementary materials that better explains the “comprehensive CBAM” approach and compares to the currently discussed one would be helpful. Listing EORA sectors that are assumed to be covered by ETS and CBAM might be also helpful.

2. P. 2, line 47. “We explore three approaches to price CO₂ emissions...”. Can you please clarify (in a footnote or appendix) what exact emissions’ coverage is applied? Presumably, CO₂ emissions from fuel combustion and industrial processes, but excluding other CO₂ emissions (e.g. land-based).

3. General comment on the carbon accounting framework. The following point might be worth clarifying from the accounting point of view. In the EU it is assumed that the carbon price is applied to ETS sectors only, which e.g. exclude ground transportation activities. When the carbon content of imported commodities is estimated (for further CBAM application), how is this part of Scope 3 emissions (e.g. ground transportation) treated in the case of exporting country (emissions from ground transportation activities used in the process of steel production). Presumably, such emissions (from non-ETS sectors) should be excluded from the carbon content of steel produced in the exporting country. It might be worth to briefly clarify this point.

4. P. 3, line 54. Authors refer to export rebates (first time in line 31 on p. 2). It might be worth adding a brief explanation note with an explanation of the “export rebates” concept and additional references for interested readers might be helpful.

5. P. 3, lines 58-59: “In our simplified framework, the volume of industrial emissions that could be covered by a comprehensive EU ETS varies from 2.2 to 3.8 Gt CO₂, depending on the implementation option.” Can you please clarify how the free allocations are considered (or not considered) in the discussed framework? If a long-run assumptions, where EU eliminates all free allocations is used, please provide corresponding clarification.

6. P. 4, lines 87-89: “Assuming a carbon price at 100€/t CO₂, the combination of a domestic carbon price, a CBAM and export rebates could yield up to €290 billion per year, more than twice the EU budget in 2015. The CBAM alone could create a fiscal revenue of €160 billion.” From the figure 1, it appears that the volume of emissions covered by CBAM (green part of the bar under DCP + CBAM + ER option) is larger than the volume of ‘imported’ emissions (red part of the bar), however from the point of view of revenue flow the opposite seem to be the case (€160 billion from CBAM and €130 billion from ETS). Can you please double check the numbers and/or clarify this point.

In regard of the estimates referenced in the above sentence, it might be also relevant to mention the impact of potential structural adjustments (trade, production patterns, as discussed in the general point (2)). It might be also worthwhile to refer to the temporal

context of the analysis and the fact that EU's CO₂ emissions would be reducing over time, presumably more dramatically than in the rest of the world, thus changing the overall revenue and the reallocation of revenue between EU ETS and CBAM.

7. P. 6, lines 130-133: "Refunding countries proportionally to the upstream pressure they experience (fig 3A) or based on their trade share with the EU (fig 3B) would implicitly favor fossil fuel exporting countries (e.g., Russia, Algeria, Saudi Arabia, South Africa) or countries with relatively low carbon content in their exports (e.g., the UK, the USA or Japan), respectively."

Under the option (a), isn't it the case that net gains/losses from CBAM recycling are exact "0" in all countries, since countries get back exactly the amount they are paying? If this is the case why it is then states that this scheme favors fossil fuel exports (or is it for the case of comparison with no revenue recycling option)?

8. Could it be relevant to include a map with CBAM per capita net gains/losses for the case of no revenue recycling case, so that readers can better understand the difference? In this case, the EU would be the only one gaining and the rest would be experiencing net losses.

Reviewer #2 (Remarks to the Author):

The EU has proposed the implementation of a Carbon Border Adjustment Mechanism (CBAM), which has recently sparked wide debate. In fact, research and discussion on CBAM have been going on for more than a decade. This literature has provided rich insights into the effectiveness, feasibility, and equity of CBAM and its different policy designs. Yet, despite its theoretical appeal, CBAM faces a fairness controversy in praxis and much of the opposition comes from developing countries.

This paper explores how different carbon pricing mechanisms can pressure different countries, how this policy can incentivize exporting countries to adopt more stringent climate policies and suggests different ways in which revenue use can mitigate the impact on vulnerable economies. As mentioned above, the question of how CBAM revenues can be better spent is a relevant and pressing issue. The main conclusions of the authors are that (1) EU CBAM severely affects developing countries; (2) EU CBAM would encourage non-EU countries to adopt carbon pricing; and (3) Adopting some revenue recycling scheme can reduce CBAM's impact on developing countries. Developing countries could even become net beneficiaries. Therefore, this would increase developing countries' support for EU CBAM. The study had a good motivation and research question. Yet, several key issues could undermine the validity and robustness of its conclusions. (1) The authors' policy design is not in line with the CBAM design of the latest release. (2) The quantitative estimations suffer from methodological limitations that are not explicitly mentioned. (1) and (2) together might lead to an unneglectable upward bias in the estimation results. (3) Conclusion 2 appears questionable. Addressing these concerns requires a significant amount of work. For this reason, the reviewer's recommendation is to reject but would like to encourage the authors to continue improving the study for resubmission in the future.

The authors may consider the following issues

1. The CBAM proposal referred to by the authors is a draft of the legislation released by the

European Commission in 2021. The draft has now been revised by the European Parliament and the changes have been adopted by vote in Jun 2022e. The revised draft already contains export rebates, and the use of CBAM revenues for investments in developing countries, a revenue recycling scheme. The authors' description of the EU CBAM should be updated. The amended text of the proposal is to be found here:

https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.html

2. Following the previous issue, the authors seem to view export rebate as a different policy from CBAM. That is, CBAM is an import adjustment and export rebate is specifically an export adjustment. In fact, both import and export adjustments are often referred to as alternative options of a CBAM. It can theoretically include both import duties and export rebates.

3. The two other design components of CBAM specified by the authors do not correspond to the actual EU CBAM. The authors modelled a comprehensive CBAM, which includes all sectors. This is far wider than the scope of the proposed EU CBAM, which only covers cement, electricity, fertilizer, iron and steel, aluminium, organic chemicals, hydrogen, and ammonia, and would expand to EU ETS sectors before 2030. Therefore, it would lead to an overestimation of the potential revenue that EU CBAM could generate. The authors might consider a sectoral scope more in line with the EU CBAM design.

4. ...Following the previous issue, the authors consider direct and all indirect carbon emissions, which is also inconsistent with the current policy design. The proposal adopted by the EP covers only Scope 1 and Scope 2 (only part of the indirect carbon emissions). In addition, CBAM coverage should not exceed that of the EU ETS, otherwise, this would seriously undermine its WTO compliance. The authors might want to consider a more practical policy design.

5. For the estimation of potential CBAM revenues, the authors have used a formula that multiplies the amount of carbon covered by the CBAM price. This appears to be an oversimplified calculation for revenue, which assumes that price changes do not affect market outcomes, i.e. trade volumes, at all (price elasticity of 0). Yet, this would not be supported by most of the previous CBAM-related literature, which finds CBAM does have trade impacts. The authors can adhere to this approach to provide a rough estimate, but the limitations need to be clarified.

6. The authors' conclusion 2 that "EU CBAM would encourage non-EU countries to adopt carbon pricing" seems to be based on the argument that EU CBAM generates fiscal revenues for the EU and that developing countries would prefer to adopt carbon pricing measures themselves to obtain these revenues themselves. This is seen as a way for CBAM to get other countries to adopt more stringent climate policies. Yet this is an oversimplified analysis of countries' motivation. The response of a country is not only determined by the access to CBAM revenue. There are costs associated with raising the domestic price of carbon. The following cited study shows that as a response to the proposed CBAM by the climate coalition, China and Russia would respond by adopting binding abatement targets, while other noncoalition countries prefer to retaliate. Therefore, CBAM does not necessarily lead to a cooperative outcome.

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2016). The strategic value of carbon tariffs. *American Economic Journal: Economic Policy*, 8(1), 28-51.

7. On the topic of revenue recycling for CBAM, the authors offer a solution that redistributes CBAM revenue according to certain arbitrarily chosen indicators. What are the authors' rationale and criteria for choosing these metrics? From a climate equity perspective, it is logical to choose climate-relevant indicators. Why was a trade-related indicator selected?

That appears to render the EU CBAM even less inclusive than if the revenue is not recycled.

8. It is suggested also to consider how much revenue recycling schemes affect the effectiveness of CBAM. Particular the effectiveness against carbon leakage. It is critical that adopting revenue recycling schemes don't nullify the anti-leakage effect of CBAM, which is the primary rationale for implementing CBAM. In other words, would there be potential compromises between effectiveness and the proposed schemes? What are the policy implications?

9. It is also suggested to expand the literature review; previous articles with similar contributions, particularly to conclusions 1 and 2, are insufficiently acknowledged.

Response to Reviewer #1

The manuscript “Towards a comprehensive and inclusive European Carbon Border Adjustment Mechanism” provides an analysis of the potential CBAM designs and implications of alternative CBAM revenue recycling schemes. Overall, the paper fits the scope of the journal, is clearly written and provides an interesting theoretical contribution to the field. At the same time, policy relevance of the provided results could be questioned and need to be further justified. In addition, the paper would benefit from further clarifications and revisions, as discussed below.

Thank you for reviewing our paper.

We have taken your comments seriously and have revised our manuscript in light of them. You will find the detailed answers to your comments below, in blue. We have also marked all changes in the manuscript in blue.

We hope you will find our revised manuscript suitable for publication.

General comments

Three key concerns regarding the provided analysis include the following:

1. Considered CBAM design is purely theoretical and is far beyond schemes currently discussed in EU, both in terms of commodity and emission scopes' coverage. While authors mention that the CBAM design considered in the paper is “hypothetical comprehensive”, the fact that it seems to be so far beyond the current EU proposal, seems to alleviate the potential policy validity of results. What is currently discussed in EU is a coverage of selected commodities (cement, steel, aluminum, etc.) and Scope 1 (with potentially Scope 2) emissions. Inclusion and even comprehensive accounting of Scope 3 emissions currently presents only a theoretical validity, though, of course, is worth exploring. In this regard, having an additional/sensitivity analysis part that incorporates a CBAM scheme that is closer to what is currently discussed in EU would make findings of the paper much more policy relevant.

We acknowledge that the comprehensive CBAM (CCBAM) envisioned here goes far beyond the current EU policy proposal and is currently still hypothetical for a number of administrative, technical, legal and political reasons, as clearly stated in the updated manuscript (fig. 1, p. 5, l. 150-151; p.9-10, l. 308-323). Nevertheless, we believe that this comprehensive CBAM (referred to as CCBAM in the manuscript now to avoid any confusion with the actual policy proposal) is an important reference scenario for two reasons (p. 5, l. 150-152; p.9-10, l. 318-322):

a. It provides a benchmark against which actual implementation options can be evaluated. Our analysis shows that implementing the current EU CBAM proposal would only cover a fraction of all emissions imported to the EU (p.4-5, l. 133-143). Therefore, it would only partially level the playing field between EU producers and their international competitors (p.5, l. 144-149). In principle, an EU CCBAM such as the one analyzed here would be needed to ensure a fully fair competition under an EU carbon price (p. 5, l. 150-151). It provides therefore a useful benchmark against which alternative implementations can be compared (fig. 1 ; p. 9-10, l. 318-320).

b. It is transparent and robust. The exact first implementation of the EU CBAM and its possible extensions are still uncertain (e.g. inclusion of indirect emissions and downstream products, further extensions of the product scope, inclusion of export rebates). Using a simpler, more ambitious setting allows us to make transparent and simple assumptions and to apply a new throughflow-based accounting method that captures the upstream and downstream effects of the EU carbon price at a high regional resolution (p.10, l. 321-323).

While we still focus on this comprehensive CBAM as a benchmark in some sections of the paper (fig. 2-4), we make sure to assess the robustness of our findings across a range of different implementation options: we find that our results are qualitatively robust against more conservative

implementation options aligned with the current EU proposal (newly added Fig. 5; p. 10, l. 323-330).

Based on your and another reviewer's suggestion, we have also added a detailed comparison of different CBAM implementation options, ranging from options in line with the current policy and the more ambitious CCBAM setting we focus on in the remainder of the paper (p. 4-5, l. 111-155; new fig. 1).

2. Methodology applied to estimate potential impacts of CBAM (CBAM pressure) and implications of alternative revenue recycling schemes is based on the (static) input-output framework, i.e. does not allow for any adjustment in agents' behavior, such as reallocation of trade flows to alternative destinations (away from EU) or change in the composition of trade patterns (e.g. like the representation allowed by computable general equilibrium models). As a result, outcomes presented in the paper correspond to the worst-case scenario with "0" adjustment opportunities. However, what would likely happen in reality is that countries that e.g. export carbon-intensive steel to EU would (a) Switch to alternative export destinations that do not apply CBAM or apply less stringent policies, e.g. China, reducing exports to EU; (b) Reduce their volumes of domestic steel output (thus domestic emissions would reduce) and (c) Reallocate part of the production resources to other less polluting sectors, such as light manufacturing, increasing output and exports of such activities. Earlier studies suggest that the impact of such adaptations could be non-trivial (e.g. see the EC CBAM assessment document for the case of EU impacts or Chepeliev (2021) for the case of Ukraine) and thus actual outcomes could be substantially different from the 'static' first-round effects estimated without any adjustments. In addition, application of the CBAM would impact global prices of energy and energy-intensive goods and services, reducing overall demand for these commodities and putting a downward pressure on prices. This would further negatively impact large exporters of these commodities.

While authors briefly mention these limitations in the concluding part, the paper can do better job in putting these effects into the context of the provided analysis. A more detailed discussion of these potential impacts and their reconciliation with the applied methodological framework would improve the paper.

Thank you for this suggestion. We have implemented it by better motivating our method in the introduction (p. 3, l. 60-66), by more explicitly acknowledging its limitations of our quantitative results in the results sections (p.4, l. 116; p. 6, l.170-171, l. 193-194 ; p. 7, l. 214-215) and by discussing them in details within the new Discussion section (p. 9, l. 270-289). It is true that our method is a static, zero-order approach and we acknowledge that it does not capture the potentially non-trivial dynamic effects that you mention. Still, we believe our methodological framework allows for a transparent assessment of the drivers of such dynamic effects at a high regional resolution, which is currently missing in the literature. Including dynamic effects would require assumptions on a large variety of parameters, such as elasticities of substitution, which would introduce a substantial degree of uncertainty and impair the tractability of our analysis.

3. Applicability of the proposed revenue reallocation schemes might be questioned on the practicality grounds. A simple exclusion of the low-income countries from CBAM might be the simplest practical solution in this regard. Administrative and monitoring efforts required to implement one of the suggested options might be a substantial obstacle in practical terms. In the case of options (A), (B) and (D) metric is constantly updated over time and thus lagged estimates need to be used. Some of these statistics would be backward-revised by countries (e.g. trade flows) and might lead to conceptual collisions. At the same time option (D) can be rather challenging to justify, due to the nature of the climate damage estimates. In addition, these estimates do not take into account the dynamic first round effects that are caused by CBAM and impact real incomes across countries. When both channels are combined, total distributional outcomes could be rather different from those presented here.

It is well recognized that the proposed concepts are purely theoretical, but a broader and more grounded discussion of their applicability and policy relevance would be very helpful.

Thank you for raising this point. It is correct that a discussion of the practicability of our revenue recycling schemes was missing. We have included a discussion of these aspects into the new discussion section (p. 10-11, l. 340-372), with a special focus on the governance questions that our proposition would raise, both within the EU and at the international level (p. 11, l. 352-368). Regarding the alternative to exclude low-income countries from the CBAM, we think this could have some pervasive effect on the medium-term, as it could motivate the most carbon-intense producers to relocate their production in these countries, thus creating lock-in effects (p. 7, l. 220-228).

Additional comments

1. P. 2, line 26. Authors briefly discuss the difference between “comprehensive CBAM” and the current proposal. However, for the reader the magnitude and specifics of difference are not entirely clear. Perhaps, a section in the supplementary materials that better explains the “comprehensive CBAM” approach and compares to the currently discussed one would be helpful. Listing EORA sectors that are assumed to be covered by ETS and CBAM might be also helpful.

Thank you for this proposition. We have introduced a new part into the Results section to explore the differences between the comprehensive CBAM (CCBAM) we focus on and the current EU CBAM proposal (p. 4-5, l. 111-155). In particular, we have added a new figure (fig. 1) to visualize these differences. We have clarified the coverage assumptions in the Materials and Methods section (p. 12, l. 376-419; table S.2) and in the legend of figure 2 (p.5, l. 169-170).

2. P. 2, line 47. “We explore three approaches to price CO₂ emissions...”. Can you please clarify (in a footnote or appendix) what exact emissions’ coverage is applied? Presumably, CO₂ emissions from fuel combustion and industrial processes, but excluding other CO₂ emissions (e.g. land-based).

We have clarified the terminology used to refer to our different settings. We now explore different CBAM implementations along two dimensions: the *horizontal coverage* (sectors covered by the CBAM) and the *vertical coverage* (scopes of emissions considered - see fig. 1 and Materials and Methods p. 12, l. 393-419). We have added table S.2 to detail which emission categories are considered in the different *horizontal coverages*. Overall, we consider all CO₂ emission categories with the exception of emissions allocated to final users, emissions caused by international transportation and land-use, land-use change and forestry (LULUCF) emissions (legend of fig. 1, p. 4, l. 108-109).

3. General comment on the carbon accounting framework. The following point might be worth clarifying from the accounting point of view. In the EU it is assumed that the carbon price is applied to ETS sectors only, which e.g. exclude ground transportation activities. When the carbon content of imported commodities is estimated (for further CBAM application), how is this part of Scope 3 emissions (e.g. ground transportation) treated in the case of exporting country (emissions from ground transportation activities used in the process of steel production). Presumably, such emissions (from non-ETS sectors) should be excluded from the carbon content of steel produced in the exporting country. It might be worth to briefly clarify this point.

Thank you for your comment. You are right that in the current state of the ETS, transportation activities abroad should be excluded from the emission estimation, since the sectoral coverage of the EU CBAM should in principle not exceed the scope of the EU ETS. In the revised version, we explicitly differentiate between sectors that will be covered by the EU CBAM (*conservative coverage*), sectors that may eventually be included in the EU CBAM since they are covered by the current EU ETS (*ambitious coverage*) and sectors that are unlikely to be covered by the EU CBAM in the foreseeable future (*comprehensive coverage*). Inland transportation is considered within this last category (fig. 1, table S.2).

4. P. 3, line 54. Authors refer to export rebates (first time in line 31 on p. 2). It might be worth adding a brief explanation note with an explanation of the “export rebates” concept and additional references for interested readers might be helpful.

Thank you for this suggestion. We have added a short explanation and a reference to a relevant review article (p.2, l. 36-37).

5. P. 3, lines 58-59: "In our simplified framework, the volume of industrial emissions that could be covered by a comprehensive EU ETS varies from 2.2 to 3.8 Gt CO₂, depending on the implementation option." Can you please clarify how the free allocations are considered (or not considered) in the discussed framework? If a long-run assumptions, where EU eliminates all free allocations is used, please provide corresponding clarification.

As the implementation of the EU CBAM will coincide with the end of the allocation of free allocations, we here assume that all free allocations are eliminated. We provide the corresponding clarification in the legend of figure 2 (p. 6, l. 168-169).

6. P. 4, lines 87-89: "Assuming a carbon price at 100€/t CO₂, the combination of a domestic carbon price, a CBAM and export rebates could yield up to €290 billion per year, more than twice the EU budget in 2015. The CBAM alone could create a fiscal revenue of €160 billion." From the figure 1, it appears that the volume of emissions covered by CBAM (green part of the bar under DCP + CBAM + ER option) is larger than the volume of 'imported' emissions (red part of the bar), however from the point of view of revenue flow the opposite seem to be the case (€160 billion from CBAM and €130 billion from ETS). Can you please double check the numbers and/or clarify this point.

In regard of the estimates referenced in the above sentence, it might be also relevant to mention the impact of potential structural adjustments (trade, production patterns, as discussed in the general point (2)). It might be also worthwhile to refer to the temporal context of the analysis and the fact that EU's CO₂ emissions would be reducing over time, presumably more dramatically than in the rest of the world, thus changing the overall revenue and the reallocation of revenue between EU ETS and CBAM.

Thank you for your attention. We have carefully double checked the figure. The green bar under the DCP + CBAM + ER option (now renamed *DCP and CBAM (with export rebates)*, based on the suggestion of another reviewer) corresponds to intra-EU emissions, i.e. emissions caused within the EU along supply chains producing final goods within the EU market. These emissions are thus covered by the Domestic Carbon Price and not by the CBAM. We have extended the figure legend to clarify this aspect (p, 5-6, l. 163-168).

With regards to your suggestions to add more discussion on structural adjustments, we have added a sentence in the results section (p. 6, l. 193-194) and in the legend of figure 2 (p.6, l. 170-171) to disclaim that our numerical results might overestimate the revenue of the actual EU CBAM. In the discussion section, we discuss the potential impacts of these structural adjustments in detail (p. 9, l. 272-282). We also included a discussion of the temporal dimension (p. 9, l. 296-308).

7. P. 6, lines 130-133: "Refunding countries proportionally to the upstream pressure they experience (fig 3A) or based on their trade share with the EU (fig 3B) would implicitly favor fossil fuel exporting countries (e.g., Russia, Algeria, Saudi Arabia, South Africa) or countries with relatively low carbon content in their exports (e.g., the UK, the USA or Japan), respectively."

Under the option (a), isn't it the case that net gains/losses from CBAM recycling are exact "0" in all countries, since countries get back exactly the amount they are paying? If this is the case why it is then states that this scheme favors fossil fuel exports (or is it for the case of comparison with no revenue recycling option)?

You are right, net gains/losses from the CBAM recycling are exactly 0 for all countries in this setting. We suggest that this implicitly favors fossil fuel exporting countries because these countries get net losses in every other scenario (p. 7-8, l. 236-240). We have modified figure 4

(formerly figure 3) in the revised manuscript to clarify this. The option you are referring to is now labelled “b” and the option “a” now shows a scenario without recycling (see next comment).

8. Could it be relevant to include a map with CBAM per capita net gains/losses for the case of no revenue recycling case, so that readers can better understand the difference? In this case, the EU would be the only one gaining and the rest would be experiencing net losses.

Thank you for this suggestion. We have considered and partially applied it: we have replaced one of the recycling options (previously panel b, recycling proportional to the trade shares) by a “no recycling” alternative (now panel a), which shows the net losses of all non-EU countries. We have not included the per-capita revenue within the EU on this figure because it would have been one order of magnitude larger than the other per-capita revenues showed. However, we have added such per-capita revenue estimation to the text (p. 6, l. 190-193).

Response to Reviewer #2

The EU has proposed the implementation of a Carbon Border Adjustment Mechanism (CBAM), which has recently sparked wide debate. In fact, research and discussion on CBAM have been going on for more than a decade. This literature has provided rich insights into the effectiveness, feasibility, and equity of CBAM and its different policy designs. Yet, despite its theoretical appeal, CBAM faces a fairness controversy in praxis and much of the opposition comes from developing countries.

This paper explores how different carbon pricing mechanisms can pressure different countries, how this policy can incentivize exporting countries to adopt more stringent climate policies and suggests different ways in which revenue use can mitigate the impact on vulnerable economies. As mentioned above, the question of how CBAM revenues can be better spent is a relevant and pressing issue. The main conclusions of the authors are that (1) EU CBAM severely affects developing countries; (2) EU CBAM would encourage non-EU countries to adopt carbon pricing; and (3) Adopting some revenue recycling scheme can reduce CBAM's impact on developing countries. Developing countries could even become net beneficiaries. Therefore, this would increase developing countries' support for EU CBAM.

The study had a good motivation and research question. Yet, several key issues could undermine the validity and robustness of its conclusions.

(1) The authors' policy design is not in line with the CBAM design of the latest release.

(2) The quantitative estimations suffer from methodological limitations that are not explicitly mentioned. (1) and (2) together might lead to an unneglectable upward bias in the estimation results.

(3) Conclusion 2 appears questionable.

Addressing these concerns requires a significant amount of work. For this reason, the reviewer's recommendation is to reject but would like to encourage the authors to continue improving the study for resubmission in the future.

Thank you for your careful review of our paper, the overall positive assessment of our motivation and research questions and your insightful suggestions on how to further improve it.

We have taken your comments very seriously and revised our manuscript in light of them. First, we have extended our study to consider different CBAM implementations, ranging from the current EU CBAM proposal to the largely more ambitious option that we refer to as *comprehensive CBAM* (CCBAM) (p.4-5, l. 111-155; newly added figure 1 in the revised manuscript). Second, we have added a new discussion section, in which we elaborate on the limitations of our methods and where we discuss in details the implications of our findings with respect to current policymaking (p. 9-11, l. 270-372).

More specifically on the points raised above:

(1) We acknowledge that the comprehensive CBAM (CCBAM) envisioned here goes far beyond the current EU policy proposal and is currently still hypothetical for a number of administrative, technical, legal and political reasons, as clearly stated in the updated manuscript (fig. 1, p. 5, l. 150-151; p.9-10, l. 308-323). Nevertheless, we believe that this comprehensive CBAM (referred to as CCBAM in the manuscript now to avoid any confusion with the actual policy proposal) is an important reference scenario for two reasons (p. 5, l. 150-152 p.9-10, l. 318-322):

a. It provides a benchmark against which actual implementation options can be evaluated. Our analysis shows that implementing the current EU CBAM proposal would only cover a fraction of all emissions imported to the EU (p.4-5, l. 133-143). Therefore, it would only partially level the playing field between EU producers and their international competitors (p.5, l. 144-149). In principle, an EU CCBAM such as the one analyzed here would be needed to ensure a fully fair competition under an EU carbon price (p. 5, l. 150-151). It provides therefore a useful benchmark against which alternative implementations can be compared (fig. 1, p. 9-10, l. 318-320).

b. It is transparent and robust. The exact first implementation of the EU CBAM and its possible extensions are still uncertain (e.g. inclusion of indirect emissions and downstream products, further extensions of the product scope, inclusion of export rebates). Using a simpler, more ambitious setting allows us to make transparent and simple assumptions and to apply a new throughflow-based accounting method that captures the upstream and downstream effects of the EU carbon price at a high regional resolution (p.10, l. 321-323).

While we still focus on this comprehensive CBAM as a benchmark in some sections of the paper (fig. 2-4), we make sure to assess the robustness of our findings across a range of different implementation options: we find that our results are qualitatively robust against more conservative implementation options aligned with the current EU proposal (newly added Fig. 5; p. 10, l. 323-330).

(2) We have added a new discussion section to explicitly discuss the limitations of our methods and map promising avenues for future research to address them. We acknowledge that our quantitative results are subject to methodological limitations, both in the introduction (p. 3, l. 60-64), in the results (p. 4, l. 116 ; p. 6, l. 170-171, 193-194 ; p. 7, l. 214-215) and in the discussion section (p. 9, l. 270-289). Furthermore, we make clear that figs. 2-4 refer to a comprehensive CBAM that is more ambitious than the option currently envisaged to be implemented (p.5, l. 150-152; p.6, l. 193-194; p.9; l. 309-312 ; p. 10, l. 323-324). At the same time, we are confident that our qualitative findings remain valid for more conservative assumptions (i.e. low- and middle-income countries are relatively more strongly affected by an EU CBAM, and compensating measures could make that pressure more acceptable for these countries), though - of course - with lower numbers (p.10, l.324-330). To strengthen that point we have added complementary analyses for more conservative implementation options (newly added fig. 5).

(3) We do not think the possibility of non-collaborative outcomes of a CBAM is fundamentally opposed to our findings. Rather, we think our analysis contribute to the literature about the (non-)cooperative outcomes of CBAMs by providing a new perspective on the exposure of trade partners to a CBAM and by providing avenues for mitigating the impact of such CBAMs on other countries, thus reducing the risk of retaliation. In the revised manuscript, we explicitly discuss this aspect (see our answer to issue 6, below; p. 2, l. 42-47; p. 8, l. 240-241, l. 255-257; p. 10, l. 347-349 in the revised manuscript).

You will find our detailed answer to your comments written in blue, below. Changes in the revised manuscript are also highlighted in blue.

We hope you will find our revised manuscript suitable for publication.

The authors may consider the following issues

1. The CBAM proposal referred to by the authors is a draft of the legislation released by the European Commission in 2021. The draft has now been revised by the European Parliament and the changes have been adopted by vote in Jun 2022e. The revised draft already contains export rebates, and the use of CBAM revenues for investments in developing countries, a revenue recycling scheme. The authors' description of the EU CBAM should be updated. The amended text of the proposal is to be found here: https://www.europarl.europa.eu/doceo/document/TA-9-2022-0248_EN.html

Thank you for your careful reading of the paper. You are right that the policy proposal we were referring to in the earlier version of the manuscript has been updated since we first started working on the paper. We have updated our description of the current EU CBAM proposal in line with the outcome of the trilogue negotiations from December 2022 (see ref. 1).

2. Following the previous issue, the authors seem to view export rebate as a different policy from CBAM. That is, CBAM is an import adjustment and export rebate is specifically an export

adjustment. In fact, both import and export adjustments are often referred to as alternative options of a CBAM. It can theoretically include both import duties and export rebates.

You are right that a “Border Adjustment” could entail both an “Import adjustment” (i.e. a carbon price on imports) and an “export adjustment” (i.e. a deduction of the carbon price on exports). We have adjusted our terminology accordingly: we now refer to CBAM implementations “with export rebates” and “without export rebates” (e.g. fig.1-2).

3. The two other design components of CBAM specified by the authors do not correspond to the actual EU CBAM. The authors modelled a comprehensive CBAM, which includes all sectors. This is far wider than the scope of the proposed EU CBAM, which only covers cement, electricity, fertilizer, iron and steel, aluminium, organic chemicals, hydrogen, and ammonia, and would expand to EU ETS sectors before 2030. Therefore, it would lead to an overestimation of the potential revenue that EU CBAM could generate. The authors might consider a sectoral scope more in line with the EU CBAM design.

Please refer to our answer to the next comment.

4. ...Following the previous issue, the authors consider direct and all indirect carbon emissions, which is also inconsistent with the current policy design. The proposal adopted by the EP covers only Scope 1 and Scope 2 (only part of the indirect carbon emissions). In addition, CBAM coverage should not exceed that of the EU ETS, otherwise, this would seriously undermine its WTO compliance. The authors might want to consider a more practical policy design.

This is right, the hypothetical comprehensive EU CBAM we explore in most of the study (figs 2-4) goes well beyond the current EU CBAM proposal, both in terms of number of sectors covered (*horizontal coverage*) and of scopes of emissions covered (*vertical coverage*). We have added a section within the “Results” part of the paper to compare this *comprehensive CBAM* (CCBAM) with different alternative coverages options along these two dimensions, including those aligned with the current EU CBAM policy proposal (p. 4-5, l. 111-155; fig. 1). In particular, we find that the coverage of a hypothetical EU CCBAM would be approximately between 3 and 20 times larger than the current EU policy proposal, depending on its exact design (compare the *Scope 1 emissions – Conservative coverage* and the *Scope 1 and 2 and downstream products – Ambitious coverage* values in figure 1 with the *Direct and indirect imports without export rebates – Conservative coverage* in the same figure). We further discuss and quantify the effect of these different implementation options on our findings within the discussion section (p. 9-10, l. 309-330; fig. 5).

We acknowledge that the comprehensive CBAM envisioned here is currently out of reach for a number of administrative, technical, legal and political reasons but believe that it serves as a useful and important benchmark, as argued in more detail in our answer to your overall assessment (please see above and p. 5, l. 144-155; p. 9-10, l. 319-323 in the revised manuscript).

5. For the estimation of potential CBAM revenues, the authors have used a formula that multiplies the amount of carbon covered by the CBAM price. This appears to be an oversimplified calculation for revenue, which assumes that price changes do not affect market outcomes, i.e. trade volumes, at all (price elasticity of 0). Yet, this would not be supported by most of the previous CBAM-related literature, which finds CBAM does have trade impacts. The authors can adhere to this approach to provide a rough estimate, but the limitations need to be clarified.

You are right, our estimation of the potential EU CBAM revenues assumes that trade flows are left unaffected by the implementation of the CBAM. In the new discussion section, we clearly acknowledge the limits of this assumption, namely that dynamic trade adjustments would likely reduce the revenue that an EU CBAM could realistically yield (p. 3, l. 60-62; p. 6, l. 170-171, 193-194; p. 7, l. 214-215; p. 9, l. 270-289). We motivate this methodological choice by reasons of transparency and tractability (p. 3, l. 61-64; p. 9, l. 282-287). We also argue that such dynamic effects would likely strengthen our finding that some middle- and low-income countries are

relatively more exposed to an EU CBAM as these have less diversification options (p. 6, l. 202-203, fig. S1).

6. The authors' conclusion 2 that "EU CBAM would encourage non-EU countries to adopt carbon pricing" seems to be based on the argument that EU CBAM generates fiscal revenues for the EU and that developing countries would prefer to adopt carbon pricing measures themselves to obtain these revenues themselves. This is seen as a way for CBAM to get other countries to adopt more stringent climate policies. Yet this is an oversimplified analysis of countries' motivation. The response of a country is not only determined by the access to CBAM revenue. There are costs associated with raising the domestic price of carbon. The following cited study shows that as a response to the proposed CBAM by the climate coalition, China and Russia would respond by adopting binding abatement targets, while other noncoalition countries prefer to retaliate. Therefore, CBAM does not necessarily lead to a cooperative outcome.

Böhringer, C., Carbone, J. C., & Rutherford, T. F. (2016). The strategic value of carbon tariffs. *American Economic Journal: Economic Policy*, 8(1), 28-51.

Thank you for highlighting this aspect. We are aware of the literature about the potential non-cooperative outcomes of a CBAM and of the paper you are citing. We acknowledge that the response of the EU trade partners to an EU CBAM cannot be fully assessed based on a single metric and we absolutely agree that a CBAM does not necessarily lead to a cooperative outcome. However, we do not think the sentence you refer to is fundamentally wrong: even if countries have an incentive to adopt more stringent climate policies, they can choose (rationally or not) to ignore this incentive and to retaliate instead. In that sense we do not believe this statement to be in opposition with the current literature on the topic.

Beyond that particular sentence, we do not think the perspective of non-collaborative outcomes weakens the relevance of our approach. Instead, our paper focuses on the analysis of the "pressures" that apply on countries because of an EU CBAM. Even though we interpret this pressure as an "incentive to adopt carbon pricing", this metric can as well be understood as an "incentive to retaliate". In that perspective, our proposition to implement an inclusive recycling of the EU CBAM revenue can be interpreted as a political option to limit the risk of retaliation too.

The revised manuscript clarifies this aspect in the introduction (p. 2, l. 42-47), in the results (p. 8, l. 240-241, l. 255-257) and in the discussion sections (p. 10, l. 347-349) and cites the study you kindly suggested.

7. On the topic of revenue recycling for CBAM, the authors offer a solution that redistributes CBAM revenue according to certain arbitrarily chosen indicators. What are the authors' rationale and criteria for choosing these metrics? From a climate equity perspective, it is logical to choose climate-relevant indicators. Why was a trade-related indicator selected? That appears to render the EU CBAM even less inclusive than if the revenue is not recycled.

The revenue recycling indicators we use were chosen based on several plausible normative perspectives on who should be entitled to receive these revenues (p. 10, l. 343-345). Our intention here is to provide a preliminary assessment of the dimensions along which an inclusive use of revenues could be designed and to highlight potential trade-offs and synergies between illustrative recycling options (p. 10, l. 340-343). Even though climate-related indicators would be in line with climate equity concerns, they would likely not been perceived as "inclusive" by some of the major EU trade partners. Instead, these countries could consider as "inclusive" a scheme that acknowledges their role as key commercial partners.

We have modified this section of the manuscript to better motivate our approach and to explicitly show associated trade-offs (p. 7-8, l. 235-258) and we discuss this issue in the discussion section (p. 10, l. 343-351). We have also exchanged one of the previous recycling options of figure 4 (fig. 3.b in the initial manuscript) by an option "without revenue recycling" to better illustrate the distributional effects of the different recycling schemes (fig. 3.a in the new manuscript – panel a of the initial manuscript corresponds to panel b in the new manuscript).

8. It is suggested also to consider how much revenue recycling schemes affect the effectiveness of CBAM. Particular the effectiveness against carbon leakage. It is critical that adopting revenue recycling schemes don't nullify the anti-leakage effect of CBAM, which is the primary rationale for implementing CBAM. In other words, would there be potential compromises between effectiveness and the proposed schemes? What are the policy implications?

Thank you for this valuable remark: some recycling schemes – in particular the one based on the absolute upstream pressure – could in principle nullify the effect of an EU CBAM if they exactly compensate the carbon price. In the revised manuscript, we mention the option of targeting the recycled revenue toward climate mitigation or adaptation projects (p. 8, l. 242-243). The governance questions that would arise from such option are then discussed in the final section (p. 11, l. 352-372).

9. It is also suggested to expand the literature review; previous articles with similar contributions, particularly to conclusions 1 and 2, are insufficiently acknowledged.

We have extended the literature review in the revised manuscript (p. 2, l. 43-51) and clarified our contribution (p. 2-3, l. 53-66).

8th Mar 23

Dear Dr Wenz,

Your manuscript titled "Towards a comprehensive and inclusive European Carbon Border Adjustment Mechanism" has now been seen by our reviewers, whose comments appear below. In light of their advice I am delighted to say that we are happy, in principle, to publish a suitably revised version in Communications Earth & Environment under the open access CC BY license (Creative Commons Attribution v4.0 International License).

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REVIEWERS' COMMENTS:

Reviewer #1 (Remarks to the Author):

Dear Authors,

Thank you for the careful consideration of the provided comments.

Since all major concerns have been properly addressed, I would like to recommend this commentary be accepted for publication.

Reviewer #2 (Remarks to the Author):

Thank you for your feedback and responses, all concerns are addressed.