Response to review comments

We first give a general response, before responding to the reviewers' comments.

General response

We thank the reviewer for helpful comments, which have strengthened the article.

Based on the reviewer's comments, we made a number of small changes to increase clarity and changed a reference mistake. We also extended Table 7 to include uncertainty results on GWP, and discussed this in the results. Furthermore, we added references to better justify our assumptions. We are happy with the changes and feel they have improved the article.

Response to reviewer

Reviewer's comments are in *italic*, while our responses are in standard font.

Anonymous Referee #2

This article addresses a very interesting and current topic, which is the estimation of consumption- vs production-based GHG emissions as well as related uncertainties. It is very well written. My scientific background is in the field of climate metrics and carbon accounting. I thus had a hard time understanding some parts of the method dealing with uncertainties associated to economic data. I know basically what GTAP and input/output models are, but I am not comfortable with all the details. The introduction and the first paragraphs of the method section (from the beginning to page 1019 line 14) present very clearly the scope of the paper and the work that has been done.

I do not understand where uncertainties for economic data are coming from. The authors are referring to McDougall 2001, but this reference is not listed, so I could not take a look at it. I understand that uncertainties are estimated using previous studies since no uncertainties are available for the GTAP datasets (Equation 1). This equation is parameterized using only two points (min and max) and Equations 2 and 3. However, I do not understand how vmin, vmax, rmin and rmax are determined. I do not understand neither how Figure 2 was obtained. If uncertainties are determined using Equation 1, we should see only a trend line. Where are the points coming from? At page 1023 line 14 and following, the authors are talking about the calibration of the uncertainty relationship given by Equation 1. I still do not understand what they mean. "For the smallest sectors we set vmin equal to 1 USD and assume rmax = 100%, due to the lack of more precise regional uncertainty data." What is the basis of this assumption? My misunderstanding may be caused by my lack of scientific background in the subject (economic modeling), but I assume that other readers of this journal are in the same situation. The same approach is used to estimate uncertainties for emissions. Is Equation 1 also valid for this application?

We thank the reviewer for pointing out this careless reference mistake. McDougall (2006) has now been updated and listed in the reference list. The data points in Table 19.6 in McDougall (2006) is plotted as red and blue circles in Figure 2, which differ depending on how you estimate the uncertainty (see discussion on page 1019:27). In order to clarify this, we added text in the figure caption (inserted text in *italic*): "Error distribution of selected GTAP input-output data *(taken from*

Table 19.6 in McDougall (2006) and shown as colored circles), and trendlines showing the fit of the general functional relationship explained by Eq. (1). *Red and blue circles differ due to different methods of estimating the uncertainty. See the discussion in the text.*"

Using first order power regression fit, we also show trend lines in Figure 2 using Equation 1, which fits well with the observations ($R^2 > 0.9$). This indicate that Equation 1 can be used to represent the relationship between economic sectors' size and uncertainty. This is also what previous work on uncertainties in GTAP data has found (Lenzen et al., 2010; Wiedmann et al., 2008). We do not use the parameters from the regression directly since Table 19.6 is not a representative selection of the dataset, but rather show outliers. As stated in the manuscript, very little information is available in order to populate the parameters in Equation 1. Because of this, we use Equation 2 and 3 to parameterize the relationship with two extreme data points, both in terms of relative errors (rmin and rmax) and at what sector sizes (vmin and vmax) these errors should be given.

The uncertainties are difficult to estimates, but we use the trend lines of Figure 2 to explain the uncertainty on the largest sectors (rmin), which the table is representing. The largest sector in each country varies, thus this is a function of the region's economy (vmax = 4% x GDP). The lower threshold vmin has been set to 1 USD with rmax = 100% uncertainty, which has been discussed in a paragraph, starting at page 1023:28, and has also been used in a recent study (Wiedmann et al., 2008). To clarify, we added text to section 2.3 (inserted text in *italic*): "For the smallest sectors we set v_min equal to 1 USD and assume r_max=100% *(following Wiedmann et al., 2008)*, due to the lack of more precise regional uncertainty data."

Using these parameters for Equation 1, we show how this works for developed and developing countries in Figure 3. Each region has its own line, and every sector in each region will be on this line, depending on the sectors' size. To clarify this, we added text to the figure caption (inserted text in *italic*): "Functional relationship between sector sizes on horizontal axis (in kt CO2 emissions and million US dollars, respectively) and relative uncertainty on vertical axis. The red lines outline the range of developing regions, while the blue lines show the range of developed countries. *Each region has been estimated a single unique line, and all sectors, depending on their size, will fall on this line.* The form of this relationship is established independently for each pollutant."

Equation 1 is also used to explain the relationship between emissions and uncertainties, due to lack of regional data, which has also been used in previous similar studies (Jackson et al., 2009; Lenzen et al., 2010). To clarify this, we added text in Section 2.2 (inserted text in *italic*): "Furthermore, we assume a similar relationship with the emissions data, based on a previous study of the UK Greenhouse Gas Inventory, where uncertainties were found using an error propagation model (Jackson et al., 2009). *This assumption is also shared by a recent study (Lenzen et al., 2010).*"

Section 2.5: Everything looks as the state-of-the-art regarding climate metrics.

Page 1033 lines 5-20: I cannot understand this paragraph because I did not understand how uncertainties for economic data have been estimated. The authors seem to say that uncertainties are *provided in the GTAP documentation. Why did they not use them? I do not understand this explanation.*

See explanation above for how we estimated uncertainties. We thank the reviewer for pointing out the possible confusion in this paragraph. To clarify, we changed the text so that we are not referring to the Table 19.6 in McDougall (2006) as “uncertainties”, but rather as “unfitted” input data and “fitted” datasets (inserted text in *italic*): “The *“unfitted” and “fitted” data* from Table 19.6 in the GTAP documentation (Fig. 2), however, act as a simple sensitivity analysis to our applied uncertainties.” Furthermore: “*Thus, the results are sensitive to the input uncertainties, as this exercise has shown.*”

The presentation of results is very clear.

Discussion:

Would there be a way to look at the sensitivity of the results to the different limitations identified regarding uncertainties for economic data which seem to be much less reliable than the two other types of uncertainty (crude assumptions, only parametric uncertainties, etc.)?

Given the challenges with the Monte Carlo analysis with regards to the economic data, model comparisons (structural uncertainties) may be a better way of estimating economic uncertainties. This has just been done by Moran and Wood (2014), and we have now mentioned this in the manuscript (inserted text in *italic*): “It is often assumed that consumption-based emissions are more uncertain (Peters, 2008), but parametric uncertainty analysis shows that the uncertainties are small; structural uncertainties may be larger (Peters et al., 2012; *Moran and Wood, 2014*). *In a recent study by Moran and Wood (2014), they find that most major economies’ carbon footprint results disagree by less than 10%*.”

What would be the impact on the results if GWP was used instead of GTP? Since the parameters used to calculate GWP are also used for GTP, this sensitivity analysis would not require more data. I understand the arguments in favor of GTP compared to GWP. However, GWP is still used everywhere and to see the difference using both indicators would be interesting.

We thank the reviewer for pointing out this, and agree that it would add valuable information to the paper if results using GWP were also available. To make the comparison possible, we have extended Table 7 to also include results using GWP20, GWP50 and GWP100. We also added a paragraph discussion these results: “Table 7 illustrates the difference between uncertainties in AGTP, and GTP and GWP values.” “GWP calculations use the same parameters as with GTP, and although we do not use GWP in our results, we include the uncertainties in the table for comparison. Overall, we find less uncertainty using GWP than the other metrics, except for NOX. The GWP calculations are not dependent on the highly uncertain climate sensitivity, since it does not relate to global temperature change. Thus it is expected to have lower uncertainties. NOX has overlapping indirect effects, with highly uncertain RF values, which suggests that the GWP20 values can be both negative and positive, with a median close to zero. Thus it has a very high uncertainty.”

Figures are not readable when printed in black and white. They are correct on the website with colors. However, if the authors wish that people could read the article when printed in black and white, it is currently not possible to understand most of the figures.

We acknowledge the problem when printing in black and white, but feel that the colors add substantial information which would otherwise be difficult to show. E.g. Figure 6, 10 and 11 uses at least 14 different colors, which would be difficult to interpret if we could only use dotted and dashed lines and fills.

Page 1019 line22: I cannot find the McDougall 2001 reference in the reference list.

We thank the reviewer for pointing out this careless mistake, and have added and updated the reference to the list in the manuscript.

Page 1020 line 23 and page 1026 line 13: What is the basis for this assumption (relative uncertainties for developing countries are twice the relative uncertainties for developed countries)? Why would it not be three, four or five times?

We agree that multiplying uncertainties in developing regions with 2 may seem arbitrary. Many argue that uncertainties in developing regions would be higher, but no datasets exists that allow us to derive this relationship on a regional level as far as we know. However, other studies points in this direction: Andres et al. 2012 shows that global independent CO2 emission statistics generally agree within about 5% in developed regions and 10% for developing regions, thus twice the uncertainty for developing regions. To clarify this, we added references to the manuscript where we mention this (inserted text in *italic*): "The terms r_min and r_max define the smallest and largest relative errors, respectively, and are functions of developed and developing regions where the latter is given twice the uncertainties of the first group using the Kyoto Protocol groupings of Annex B and non-Annex B countries *(e.g. CO2 emissions are found to have twice the uncertainty in developing regions than developed regions (Andres et al., 2012), see discussion in the next section)*.".

References

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