**Response to Reviewer #2 (Wei Li)**

*The difference in Eluc estimates between DGVMs and bookkeeping models has been reported in many previous studies but never been quantified by decomposing into more specific fluxes like LASC. The authors filled this research gap using fractional simulations by various DGVMs. The analysis is very detailed and comprehensive with precise definitions of different LULCC fluxes and components and corresponding quantifications. It is a significant step in disentangling the Eluc components on top of Pongratz et al. (2014) and Gasser & Ciais (2013) and has important implications on the definition of Eluc in the global carbon budget and implementing climate mitigation measures. The manuscript is well written with clear description and detailed supplementary materials. I see no major flaw in this manuscript and thus suggest this work for publication with few minor revisions.*

Thank you very much for the review and the positive evaluation of our manuscript.

*I have some concerns that may need some clarification and discussion.*

*Although the LASC explains the Eluc difference between DGVMs and bookkeeping models, it would be better to address whether LASC exists in the real fluxes of carbon emission and sink, i.e. whether can be observed. If I understood correctly, positive LASC represents the loss of potential carbon sink and thus didn't physically exist, i.e. this part of CO2 wasn't released into the atmosphere. For the negative LASC like in reforestation, this part should be physically stored in the biomass or soil C pools, right?*

We agree with the reviewer and will add corresponding discussions:

NEW - 'This example illustrates an interesting aspect of the LASC: It has been acknowledged that the LASC in its literal sense (a loss of carbon, positive LASC values) is an unrealized flux, a lost sink instead of actual emissions and is not reflected in any real change in atmospheric $CO_2$ concentration (Pongratz et al., 2014). However, as the LASC captures the foregone sinks a given LULCC event destroys and accumulates even in absence of further LULCCs, it manifests in the budget of atmospheric $CO_2$ as compared to a reference excluding LULCCs (Pongratz et al., 2014). In contrast to the theoretical nature of positive LASC values, negative values counted towards the LASC, for example due to reforestation, depict realized C uptake which is theoretically observable (though observations in the field are highly complex due to co-occurrence of natural carbon fluxes)

NEW - 'On the other hand, as discussed, the lost sinks in DGVM-based $f_{LULCC}$ under realistic, transient environmental conditions do not correspond to observable fluxes.'

*As the authors stated, the timing of LULCC matters. Therefore, from my understanding, estimation of the accurate LASC for a specific LULCC event (a deforestation event in 1950 for an example) needs simulations similar to the S0 and S4 but using the climate and CO2 status when the LULCC event occurs (i.e. 1950) instead of the pre-industrial climate and CO2 status. Although the authors came to this point somewhere in the text, it would be better to emphasize this point explicitly.*

This is a very good idea which we like to incorporate into the revised manuscript. However, our idea is slightly different. Instead of recycling the climate and $CO_2$ status of the actual LULCC event for LASC derivation, we argue to theoretically set all LULCC occurrences to the same time (e.g.

1950), thereby all accumulation periods would span the same period (and similar environmental changes) and LASC quantities would become independent of the actual timing of LULCCs. Moreover, to eliminate the variability resulting from the very heterogeneous effects of altered climatic conditions on NBP, we recommend to use $CO_2$-only forced simulations for LASC estimation (excluding climatic changes). Despite not fulfilling the modeler's need for a closed budget, this would make $f_{LULCC}$ attribution more independent of environmental changes and timing of LULCCs and lead to a more balanced quantification across space and time e.g. for regional or national $f_{LULCC}$ attribution. We will change several parts of the manuscript to emphasize the importance of the timing of LULCCs for $f_{LULCC}$ estimation as suggested in the following:

NEW - 'The LASC results from the impact of environmental changes on land carbon storage potential of managed land compared to potential vegetation, and accumulates over time, which is not captured in bookkeeping models. $f_{LULCC}$ from transient DGVM simulations, thus, strongly depends on the timing of land use and land cover changes mainly because LASC accumulation is cut off at the end of the simulated period.'

NEW - 'Thus, even for the same LULCC with the same accumulation duration, the LASC will be different dependent on timing and location of the LULCC and the interaction with the pre-industrial state.
To circumvent these issues, as could be desired in the political context, one could derive $f_{LULCC}$ and the LASC based on simulations forced with the cycled climate and $CO_2$ conditions that occurred during the actual LULCC event. However, this would still result in differing accumulation periods and varying environmental conditions during and following a LULCC event. While the influence of the latter could be reduced using cycled pre-industrial or present-day environmental forcings, these neglect transient C stock changes. To consider the LASC but counteract spatial heterogeneity in $f_{LULCC}$ differences resulting from synergistic effects of environmental conditions and the timing of LULCCs, one could derive $f_{LULCC}$ and LASC from a defined reference period which is independent of the actual time that LULCCs occurred and shares the same reference conditions. For example, $f_{LULCC}$ and LASC could always be modelled for the second half of the 21st century, as here the environmental C stock changes have been amplified due to the accelerating increase of atmospheric $CO_2$ concentrations (alternative start times are of course conceivable). By using such reference period, the LASC could fully be captured also for most recent LULCCs (may they act positive or negative on C stocks) and foregone sinks would be more equally counted (same length of accumulation period with similar environmental changes)."

NEW - 'As LASC values derived by the approach so far taken in the GCB are widely independent of locally determined environmental changes (rather depend on globally determined climatic changes) and strongly dependent on accumulation periods (defined by the timing of LULCCs and the end year of the simulations), we argue for a $f_{LULCC}$ attribution that is more robust against choices of environmental drivers and accumulation period by using an adapted LASC, for example, based on a defined common reference period and homogeneously altered environmental conditions (such as only driven by $CO_2$ alterations).'

*The attribution to climate and CO2 in Sect. 2.2.2 is rather uncertain. Is there any observation data (e.g. FACE + warming experiment field data) that can be used to validate this attribution method?*

This is a good point. Experimental investigations have shown that there are interacting effects of $CO_2$ and e.g. temperature on biomass productivity (see e.g. Obermeier et al. 2017, *Nature Climate Change*). However, within the TRENDY DGVMs, no significant interactions between these influencing factors on C stocks have been observed (e.g. Fernández-Martinez et al. 2019, *Nature Climate Change*). In line, a study using a fully-coupled DGVM found very low interaction between climate and $CO_2$, indicated by the almost equal effect size for the sum of individual effects ($CO_2$ fertilization, nitrogen deposition, climate warming and LULCC) compared to their combined effect (Devaraju et al. 2016, *Climate Dynamics*). Therefore, we assume that our approach is capable to properly approximate climate and $CO_2$ induced shares of $f_{LULCC}$. To highlight the underlying reasons, we will carefully rephrase the description of the derivation of climate- vs $CO_2$-induced flux changes (also according to a comment of Reviewer #1) and add an explanation on the potential interaction (and included relevant references):

NEW - 'Here we note, interacting effects of elevated $CO_2$ concentrations and temperature or precipitation on biomass productivity (observed under experimental setups; e.g. Obermeier et al., 2017) might obscure this attribution (Lombardozzi et al., 2018). Nevertheless, the assessment of the relative contribution as done by this approach seams valid as no significant interactions between these influencing factors on C stocks were observed within the TRENDY ensemble (Fernández-Martínez et al., 2019) nor within a fully coupled single model investigation (Devaraju et al., 2016).'

*Fig. 5-7 show results from each DGVM, but not reported in the text. Could add one or two sentences to say which models always give high e.g. LASC in Fig.5 or all models are similar?*

Thank you. To focus on the main story, we will shift the region-wise plots showing individual models (Figs. 5-7) to the appendix and create new Figures 5 and 6 showing region-wise multi-model mean emissions estimates on unified y-scale (compare suggestions of Reviewer #3) for each hemisphere. In line, we discuss striking single model performances in the appendix section A1. Individual model performances of single models in the main manuscript are now only shown globally. According to your suggestion we have added the following sentence to the main manuscript:

NEW - 'A widely congruent trend was also found across the DGVMs, while their absolute values partly differ strongly across models, for example global $f_{LULCC\_trans}$ and $f_{LULCC\_pi}$ from OCN is largely higher than in the other models, with estimates more than twice as large as the one from ORCHIDEE and LPX-Bern (Fig. 3, and Sect. A1 for a discussion on individual model results).'

*L29-30: "high-latitudes" usually refers to boreal region. I think much early agricultural expansion occurred in the temperate regions. May rephrase.*

Thank you. We apologize for this confusion. We totally agree that early agricultural expansion happened rather in the temperate than the boreal zone. The wording should actually have been 'higher latitudes' as compared to the tropics that are mentioned later in the sentence. To erase all potential confusion we will change the wording into 'mid-latitudes'.

*L248: bookkeping -> bookkeeping*

Thank you, we will change it.

*L253, L256: What are the numbers in the brackets?*

The numbers show the actual values with two decimal places. While there was only 0.01 PgC $yr^{-1}$ difference in LASC estimates ex- or including the erroneous model output from SDGVM (included e.g. in the GCB2019), the rounding to one decimal place caused differences of 0.1 PgC $yr^{-1}$. This gives us an absolute LASC difference greater than 10%, which we found noteworthy to be mentioned. We suggest to clarify this as follows:

NEW - 'Note, the LASC of 0.8 PgC $yr^{-1}$ (0.84 PgC $yr^{-1}$ with two decimal places) for 2009-2018 presented here is based on TRENDY v8 model output combined with the newer (TRENDY v9) SDGVM output. When consistently using TRENDY v8 output, the resulting LASC (usually rounded to one decimal place) becomes pronounced higher (>10%) with 0.9 PgC $yr^{-1}$ due to rounding of 0.85 PgC $yr^{-1}$.'

*L274: What are the pulses of the purple line in Fig. 2c?*

The pulses in the purple line result from (1) the internal climate variability, and (2) the combination of differently cycled forcings for the different simulations. Thanks to your question and a comment of Reviewer #3, we will shift parts of the discussion of Sect. A1 to the main manuscript and improve the wording as well as referencing to figures:

NEW - 'Note, a high internal climate variability translated into a high interannual variability in NBP and consequently a high variability of $f_{LULCC}$ estimates (Figs. 3, 5 and A13) and of their respective differences (Figs. 4 and 6). For the differences in $f_{LULCC}$ estimates, some artefact might additionally arise due to comparison of simulations with different forcing cycles (e.g. on global scale, with periodic fluctuations in annual relative shares of EED to $f_{LULCC\_pd}$ in Fig. 2c and, on regional scale, in Figs. 6 and A4 to A6 with pronounced oscillations in some regions).'

*L312-313: Why reforestation increased fLULCC_pd?*

Thank you, we apologize for the misleading wording of the sentence. '[…] relatively increased $f_{LULCC\_pd}$' should refer to the higher emissions (may they be positive or negative) upon LULCCs under present-day as compared to pre-industrial environmental conditions. For clarification we suggest to change the wording as follows:

NEW - '[…] reflect increased C storage, and thus, a relatively stronger negative $f_{LULCC\_pd}$ due to early and widespread reforestation (Fig. 9e).'

################################################################################

In addition to changes resulting from the reviewer comments, we suggest the following changes:

- change to capitalized journal abbreviations in references and added doi that where missing

- add new Table 3 with overview of different estimates

################################################################################

New references:

Devaraju, N., Bala, G., Caldeira, K., and Nemani, R.: A model based investigation of the relative importance of $CO_2$-fertilization, climate warming, nitrogen deposition and land use change on the global terrestrial carbon uptake in the historical period, CLIM DYNAM, 47, 173–190, https://doi.org/10.1007/s00382-015-2830-8, 2016.

Fernández-Martínez, M., Sardans, J., Chevallier, F., Ciais, P., Obersteiner, M., Vicca, S., Canadell, J., Bastos, A., Friedlingstein, P., Sitch, S., et al.: Global trends in carbon sinks and their relationships with $CO_2$ and temperature, NAT CLIM CHANGE, 9, 73–79, https://doi.org/10.1038/s41558-018-0367-7, 2019.

Lombardozzi, D. L., Bonan, G. B., Levis, S., and Lawrence, D. M.: Changes in Wood Biomass and Crop Yields in Response to Projected $CO_2$, $O_3$ , Nitrogen Deposition, and Climate, J GEOPHYS RES-BIOGEO, 123, 3262–3282, https://doi.org/10.1029/2018JG004680, 2018.

Obermeier, W. A., Lehnert, L. W., Kammann, C., Müller, C., Grünhage, L., Luterbacher, J., Erbs, M., Moser, G., Seibert, R., Yuan, N., et al.: Reduced $CO_2$ fertilization effect in temperate C3 grasslands under more extreme weather conditions, NAT CLIM CHANGE, 7, 137–141, https://doi.org/10.1038/nclimate3191, 2017.