"**Regional variation in the effectiveness of methane-based and land-based climate mitigation options**"

Hayman et al. (ESD-2020-24)

Response to Reviewer 2 Comments

The reviewer comments are in normal font, with our responses in ***bold italics and indented***. All line numbers refer to the originally-submitted manuscript.

Reviewer 2

Overall, I found the paper "Regional variation in the effectiveness of methane-based and land-based climate mitigation options" interesting and relevant. I have several comments that should be addressed prior to its publication.

Lines 21-24: Why only land-based mitigation and CH4?

> ***Response:*** ***We only considered methane and land-based mitigation options as we could investigate the climate/land carbon-cycle interactions and feedbacks of these mitigation options within our modelling framework. The paper also builds on our earlier studies, as described in the Introduction (lines 83-86).***

Line 40-43: Add reference

> ***Response:*** ***We add reference(s). Refers to "Meeting the Paris Agreement goals will, therefore, require sustained reductions in sources of long-lived anthropogenic greenhouse gases (GHGs) and some short-lived climate forcers (SLCFs) such as methane, alongside increasingly extensive implementations of carbon dioxide removal (CDR) technologies. Accurate information is needed on the range and efficacy of options available to achieve this."***

Line 44-45: Add reference

> ***Response:*** ***We add reference(s). Refers to "Biomass energy with carbon capture and storage (BECCS) and afforestation/reforestation (AR) are the most widely considered CDR technologies in the climate and energy literature".***

Line 51-54: This sentence as written is confusing. Why are the requirements greater if the literature says they are similar? Are you saying that within the same model and socioeconomic background land for BECCS is larger in 1.5 than 2C, but across the full literature range 2C scenarios have higher land requirements?

> ***Response:*** ***We cite Smith et al. (2016) for the land needed for large-scale bioenergy crops to achieve the 2°C target. "BECCS delivering 3.3 Gt Ceq yr−1 of negative emissions would require a land area of approximately 380–700 Mha in 2100 (Table 2)". From the cited paper of van Vuuren et al. (2018), "In the default mitigation scenario (DEF_1.9 which is compatible with the 1.5°C target), more than 600 Mha is required for bioenergy".***
>
> ***Our earlier paper (Harper et al., 2018) clearly shows that less land is required for bioenergy crops to achieve the 2°C warming target. This is the case within a given shared socio-economic pathway (SSP2 as used here) but there are larger differences across different SSPs. The land requirements for bio-energy productions strongly differs in the literature. Key***

elements include the contribution of residues and the assumed yields and yield improvement. In IMAGE, the total land use requirement in 2100 is 360 Mha for the SSP2-2.6 and similar numbers for the SSP2-1.9. Interestingly, area used for bio-energy is higher in the SSP1-2.6 scenario given the much lower land claim for food production. We will use this to amend the text.

Line 59-60: This sentence should be made more elaborated on or removed.

***Response:** We delete the sentence.*

Lines 255-259: Do you also adjust the energy system or its emissions to account for the reduction in bioenergy?

***Response:** The reviewer is correct, as there would be an adjustment to the energy system. We do not account for this. We however do acknowledge this limitation for the converse case when bioenergy crops are grown (lines 416-418) "Further, we do not allow for the reduced emissions from fossil fuel combustion due to the bioenergy crop being grown, as this would require energy sector modelling that is beyond the scope of this study". We will add this as a caveat to lines 255-259 and amend lines 416-418 to cover both cases.*

Line 284: does "preferred mitigation pathway" mean lowest terrestrial emissions or lowest total emissions (including CCS)?

***Response:** This refers to our earlier work. "Harper et al. (2018) find that the land-use pathways do not provide a clear choice for the preferred mitigation pathway." We will amend the text.*

Lines 286-292: Can you determine how much bioenergy (in EJ or Mt per year) you produce from this calculation?

***Response:** We will add this information.*

Lines 347-354: This seems repetitive with previous text.

***Response:** It was intended as a summary but we accept that it repeat texts in previous sections. In reply to the comments from Reviewer 1, we restructure Sections 2.3-2.5 to remove any duplication.*

Lines 384-387: This paragraph needs some editing for clarity. The analysis you are doing is focused on the climate sensitivity of mitigation options, not an analysis of their economics or how that would change under different temperature targets. I don't think you can say that these are "worthwhile mitigation approaches" given your analysis. But, you can say that across the range of temperatures you analyzed there is no noticeable difference in the potential or performance of these mitigation strategies.

***Response:** We accept that worthwhile has a value judgement. We amend the text*

"Despite the substantial differences in the absolute AFFEBs for the 1.5° and 2°C targets, the mitigation potential of the CH_4 and land-based strategies is similar for the two temperature scenarios considered. This similarity suggests that the ~~investment in such strategies~~ mitigation strategies are robust to the target temperature; whether the international community aims for the 1.5° or 2°C target, afforestation, reforestation, reduced deforestation and CH_4 mitigation are all ~~worthwhile~~ beneficial mitigation approaches".

Lines 464-465: Why are those regions different?

Response: ***We use information in the cited paper by Postel et al. (2016) to assume that "only 5% of the total runoff is accessible for the Brazil, Russia and Canada IMAGE regions and 40% elsewhere". Postel et al. adjusted the total runoff for geographic and temporal inaccessibility. Specifically, the Amazon River "accounts for 15% of global runoff (11). It is currently accessible, however, to -25 million people (12) - 0.4% of world population-and no massive expansion of irrigation is likely that would warrant major diversions from it. We thus consider 95% of its flow inaccessible". For rivers in the boreal zone, "The final subtraction is for the remote rivers of North America and Eurasia, 55 of which have no dams on their main channels (13). Most of this river flow is in tundra and taiga biomes that are remote from population centers. The combined average annual flow of these northern untapped rivers is 1815 km^3/year, and we subtract 95% of it". We will add a sentence about the adjustments made to the total runoff for geographic and temporal inaccessibility.***

Lines 468-471: What does "take the water requirements" mean? Do you use the water per unit of output from those studies and apply it to the IMAGE outputs? Or do you use the total water from those studies? If the latter, is it consistent? Also, does this mean you use the RCP2.6 water for the baseline and 1.9 simulations here? Is that water from the IMAGE-LPJmL model (which you note is low) or are you overwriting the IMAGE-LPJmL with the values from those papers?

Response: ***We take the water requirements for agricultural irrigation (Rost et al., 2008) and for other human activities (Bijl et al., 2016) (Table 4), as the total water withdrawal for each IMAGE region from the IMAGE-SSP2-RCP2.6 scenario. We use this for all our scenarios and add to this the additional water requirements for BECCS in the relevant scenarios. We acknowledge that this introduces new caveats and will add these to those already listed (lines 474-478).***

Lines 472-482: It would be nice to have one sentence in this paragraph reporting the quantitative results before you go through the caveats.

Response: ***Reviewer 1 has suggested adding the BECCS water demand and percent of available used to Table 4. We will use this information to add a sentence or two with quantitative results.***

Figure 3: Should the titles of panels d, f, and h say "Carbon Dioxide" instead of "Methane"? In general, I find the naming in this figure difficult since you have 1.5C and 2C on a baseline panel and 2C on 1.5C panels.

Response: ***The figure is intended to show key data inputs for or differences between the model runs to help inform reader's understanding of the paper. The titles of the panels are correct but we accept the figure and panels need careful reading. We will amend the figure to make it clearer (and potentially split the figure into two as part of the restructuring of Section 2.3-2.5).***

Figure 7: Some of the detail in the caption would be good to include in the figure. In particular, the difference between panels a & c OR b & d.

Response: ***These are a pair of plots for different BECCS efficiency scale factors (Panels a & b are for κ=1 and Panels c & d for κ= 3). The caption can be shortened by deleting "a & b are***

for the standard JULES BECCS productivity and efficiency (κ=1, Sect. 2.4.3), in c & d the BECCS productivity and efficiency uses κ=3" and adding BECCS κ=1 and κ=3 to the figure.

Figure 9: This figure is pretty busy. Do you need the map? Or if you want the map, do you need the colors on the map? It is hard to see the bars and axes.

<u>Response:</u> Figure 9 presents the regional mitigation options superimposed on a map of the IMAGE regions. The colours identify the different IMAGE regions. We accept that the colours used for specific regions make it hard to distinguish the bar charts for that region (the colours for the mitigation options are consistent with the colour scheme used throughout the paper for the methane and land-based mitigation). We will amend the figure by either using grey shading for the IMAGE regions or alternatively placing the bar charts around the edge of the plot.