Response to the Reviewers Comments

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Manuscript title: A comparison of the climate and carbon cycle effects of carbon removal by Afforestation and an equivalent reduction in Fossil fuel emissions

Authors: K. U. Jayakrishnan and Govindasamy Bala

List of major changes

The following major changes are made in the revised manuscript.

1) In response to the suggestion from a reviewer, some part of the first two paragraphs in the introduction which contained well established facts are now removed.
2) We have combined Figures 1,2,3,4,6 and 7 into three figures (Figure 3, 4 and 7) in the revised manuscript and moved two figures and a table (Figures S6, S14 and Table S2 is now Figure 1,2 and Table 2 respectively) from supplementary to the main text. Figure 3c and Figure S15 are newly added to the manuscript and supplementary, respectively.
3) The model description is made more comprehensive by adding more details on the dynamic vegetation model and previous literature that compare model performance to observations (Please see Sect 2.1).
4) The results are compared with the previous literature in a more comprehensive manner by citing the papers suggested by the reviewers (Please see page 15, lines 442-458).
5) Discussion on the effects of changes in evapotranspiration is added to the main text (Please see page 11-12, lines 305-323).
6) An additional section (Sect. 3.2) is included specifically for discussing the biophysical effects of afforestation.
7) Many sentences in the main text are rephrased according to the suggestions from the reviewers to improve readability of the main text.
8) A discussion on the dependence of the effects afforestation on the background scenario is added in the revised manuscript (Please see page 15, lines 437-443).

Reviewer 1

Our responses to the reviewers' comments are in red.

General remarks

In this study, the climate effects of two different methods to reduce atmospheric CO_2 concentrations, namely afforestation and reduced CO_2 emissions, are analyzed. For this purpose, long-term climate simulations with an Earth System Model of intermediate complexity are performed. In a first step, reference simulations are performed for three different climate change scenarios. Subsequently, the three simulations are repeated, but with an afforested land mass, where forests replace agricultural areas wherever forest can naturally grow. In a last experiment, the different amounts of CO_2 that would have been removed by these afforestation runs are finally implemented in the three scenario runs, but without afforestation.

Results show that CO_2 reductions caused by reduced CO_2 emissions lead to a stronger temperature reduction than CO_2 reductions caused by afforestation, because of the lower surface albedo of forests and the resulting increase in absorbed solar radiation. In addition, the results of the study indicate that the climate benefit of afforestation depends on the background climate and is less pronounced in a warmer climate.

The manuscript is timely, clearly structured and its topic fits to the scope of Biogeosciences. However, there are some issues which need to be addressed by the authors before the manuscript is ready for publication.

We thank the reviewer for the positive remarks on our work. We have addressed the comments of the reviewer in the revised manuscript as discussed below.

Comment 1

The whole manuscript is written like a research paper and some aspects are succinctly formulated. In some cases, presented results are tried to be shortly explained in only one sentence, but without success (see point 2 and minor comments). More detailed explanations would therefore be good for the manuscript and increase its comprehensibility. For instance, the additional text in the supplement should be integrated in the manuscript. Some of the supplement figures (e.g. S6, S7, S16, S17) should also be included.

Response to Comment 1

We appreciate this comment. We agree that moving some of the figures (Figure S6 and S14) and Table S2 in the supplementary to the main text will improve the comprehensiveness of the main text. Some of the important details about the dynamic vegetation component of the model were described in the Supplementary Text earlier, which is now moved to the main text. Important details about the model that are now newly included in the main text are: i) how agricultural land is specified in the model, ii) what happens to the carbon in the trees and shrubs when deforestation is performed in our historical simulations, iii) description of the variable called VEGBURN which is an important component of the atmosphere to land carbon fluxes in the UVic model, iv) discussion of the literature that compare the UVic model simulations to observations and v) the list of the plant functional types represented by the UVic model (Please see section 2.1)

Comment 2

The explanation for the dependency of the cooling effect of reduced CO2 concentrations on the climate change scenario is too short. I understand that, in a scenario with a generally high CO2 concentration, even a larger removal of CO2 has a smaller cooling effect, since already for such a reduced CO2 concentration some kind of saturation effect takes place. However, the CO2 cooling effect is comparable in SSP2 and SSP3, although the CO2 concentrations are quite high in SSP3. Is there a critical point in the CO2 concentrations which is not yet reached in SSP3? In addition, the albedo warming effect in SSP3 is almost as strong as in SSP5, although the CO2 cooling effect is in SSP3 much stronger. This might be related to biogeophysical feedback (e.g., changes in cloud cover etc.), which take place in SSP5 but not in SSP3. It would be nice if the authors would discuss this.

Response to Comment 2

We thank the reviewer for this important comment. About 100 PgC more atmospheric carbon is removed as a result of afforestation in the SSP3-7.0 case compared to the SSP2-4.5 case. Therefore, even though the cooling effect per unit carbon additionally stored is less in the SSP 3-

7.0 case, the net cooling effect is comparable to the SSP2-4.5 case. However, when we compare the SSP3-7.0 scenario with SSP5-8.5, we find that the amount of carbon additionally stored is less in SSP5-8.5 as a result of an increase in soil respiration with temperature and saturation of CO_2 fertilization effect. Therefore, in SSP5-8.5 the cooling effect per unit carbon is smaller and the amount of carbon removed also is smaller compared to SSP3-7.0. Hence the net effect of CO_2 removal is also less in SSP5-8.5. The manuscript is revised to make this point clear (Please see page13, lines 363-368).

Comment 3

In order to be able to understand all these processes, more information about the model are required and how the complex interactions between the land surface and the atmosphere are considered in the model. By the way, what is the spatial resolution of the model?

Response to comment 3

The model description is made more comprehensive in the revised manuscript as described in response to comment 1 (Please see section 2.1). The resolution of the model is 3.6^o longitude by 1.8^o latitude, which is now discussed in the revised manuscript (Please see page 6, lines 132-134).

Comment 4

The dependency of a positive climate effect of afforestation on the background climate is from my point of view the second important message of this study, beside the counteracting albedo effect. This finding is new, at least for me. Therefore, this point should be stronger emphasized and its reasons should be discussed in more detail, and not only be mentioned in one sentence (line 293).

Response to comment 4

We agree with the reviewer. The manuscript is revised with a more detailed explanation of the dependency of climate effect of afforestation on the background climate as follows, "In our simulations, the cooling effect of afforestation is completely offset by its warming effect in the higher emission scenarios (SSP 3-7.0 and SSP 5-8.5). However, in lower emission scenario (SSP 2-4.5), the offsetting of the cooling effect of afforestation is only partial, because the removal of atmospheric carbon by afforestation results in a stronger cooling effect when the atmospheric CO2 is lower. Therefore, the biophysical warming effect of regrowth of trees does not completely offset the biogeochemical cooling effect from the atmospheric carbon removal by afforestation. This suggests that afforestation may have a larger climate benefit in the lower emission scenarios" (Please see page 15, lines 437- 443).

Responses to minor comments

1) Line 185: mean global land surface albedo.

   The suggested change is made in the revised manuscript.

2) Line 229: the warming, caused by the albedo effect of forests!?

   Changing the grasslands to forests reduces the albedo of the land surface resulting in a warming effect. This is now discussed in the revised manuscript (Please see 12, lines 355-357).

3) Line 244: Please replace the comma with a dot after "(Table S1)"

   The suggested change is made in the revised manuscript.

4) Line 254: Please explain this buffering effect in more detail? Isn't this reduced ocean carbon uptake a result of the increased temperatures?!

   Buffering capacity of the ocean refers to the ability of the ocean to regulate the pH at increasing atmospheric CO_2 levels. In the revised manuscript, we have cited papers that describe the reduction of buffering capacity of the ocean and how it leads to reducing carbon uptake (Middelburg et al., 2020, DeVries, 2022). The increase in temperature will reduce the solubility of atmospheric CO_2 in sea water, which also will lead to reduced carbon uptake (Duan and Sun, 2003). The manuscript is revised including the above details (Please see page 14, lines 394-398).

5) Line 289: warming effect caused by a reduced albedo?!

   Please see the response to minor comment 2.

Reviewer 2

General comments

The manuscript entitled 'A comparison of the climate and carbon cycle effects of carbon removal by afforestation and an equivalent reduction in fossil fuel emissions' investigates the method of atmospheric carbon dioxide reduction in a climate change context. More specifically, the authors use a simple Earth system model to investigate the impact on the climate system of reducing atmospheric CO2 by fossil fuel emission reduction or by afforestation (increase C uptake by vegetation). The authors pose an interesting and timely question as to whether the carbon dioxide reduction method matters, but the manuscript has in its current form several shortcomings, that need to be addressed before further publication.

Overall, the manuscript would benefit from thorough proofreading, as many paragraphs are not clear and concise. Below follows major and minor comments and suggestions to improve the manuscript.

We thank the reviewer for the positive remarks on our work. We have addressed the comments of the reviewer in the revised manuscript as discussed below.

Comment 1

Biophysical feedbacks: Throughout the manuscript, the authors state how afforestation affects biophysical feedbacks. Yet, they only consider one aspect of biophysics, namely albedo. The authors completely fail to mention the cooling effect of evapotranspiration. This is a major shortcoming of the current study and needs to be addressed. I am not familiar with the UVic ESM, but since it includes an energy-moisture model for the atmosphere, I assume that evapotranspiration can be inferred. This needs to be included in the analysis.

Response to Comment 1

We appreciate this comment. We agree that some discussion on the cooling effect of evaporation should be added in our manuscript. Another reviewer had a similar comment. In the AFFOREST case, the evapotranspiration is smaller compared to the reference case because of the increase in water use efficiency of the trees at elevated atmospheric CO_2 levels (Figure 3c). In contrast, evapotranspiration is larger in REDUCED_FF case compared to reference case because of the lower plant water use efficiency at lower atmospheric CO_2 levels (Figure 3c). Therefore, the smaller (larger) evapotranspiration in the AFFOREST (REDUCED_FF) case relative to the reference scenario causes a warming (cooling) influence in our simulations. In the revised manuscript, we have included two new figures (Figure 3c and S15) and a detailed discussion on the effects of changes in evapotranspiration (Please see pages 11-12, lines 305-323).

Comment 2

The impact on the ocean: The authors have chosen to look at how carbon content in the ocean and pH are affected by afforestation and a reduction in fossil fuel emissions. This part is not well linked to the rest of the manuscript. The two variables they a focusing on are tightly linked to the atmospheric CO2, and as this is essentially the same in both simulations (AFFOREST and REDUCED_FF) they arrive at the same results. It is by no means a surprise and it follows logically that when the atmospheric CO2 is lower than in the reference simulation, the carbon content of the ocean is lower, and the pH is higher. Maybe some more interesting variables to investigate could be sea surface temperatures or variables related to heat transport in the ocean. The analysis of the impact on the ocean needs to be a better couple to the rest of the manuscript.

Response to comment 2

We thank the reviewer for this comment. To understand the impact on ocean, the vertical profile of ocean potential temperature is plotted (Figure 6), and the results of the analysis are discussed in the main text as follows, “The REDUCED_FF case has lower surface ocean potential temperature (averaged over 2471-2500) compared to the FIXED_AGR case, while the ocean potential temperature is nearly same in the AFFOREST and FIXED_AGR cases (Figure 6). The effects of atmospheric carbon removal are only seen in the surface ocean as it equilibrates with the changes in the atmosphere on shorter timescales compared to the deep ocean” (Please see page 13, lines 373-377).

Comment 3

Introduction: The introduction is not well linked to the rest of the manuscript. Some suggestions as to how to improve the introduction follow below:

a) L28-L42: the facts described here are all well-established. This could be shortened to free more space to describe how the different methods of reducing atmospheric CO2 would affect the climate system.
b) L66- L71 focus on deforestation, while the focus of the manuscript is on afforestation, why afforestation should also be the focus of the introduction. Thus, it would make more sense to rewrite this with a focus on afforestation, and likely also new references should be included.
c) Several of the studies highlighted in the introduction are not well described. For example, in L48-L50 Jayakrishnan et al., 2022 find that fossil fuel emissions and deforestation affect the climate system fundamentally differently, but it is not stated wherein this difference lay. Please include such information. In L51—L53 Simmons and Matthews, 2016, find that it is important to include biophysics, but it is not stated why it is important. Please explain why.
d) L71-L72 is a very bold statement. A vast number of studies are indeed looking at the biophysical effects of changes in vegetation cover (Zeng et al., 2017, Luyssaert et al., 2018, Alkama et al., 2022 and many more). Therefore, you cannot state that biophysical effects are often neglected.
e) The link to the ocean (which is analysed in section 3.3) is not introduced in the introduction, thus this analysis seems very decoupled from the rest of the manuscript.

Response to comment 3

a) The manuscript is revised according to the suggestions. Some of the well-known facts in the Introduction section is now removed in the revised manuscript.
b) The paragraph is revised with more focus on afforestation in the revised manuscript as follows, "Previous studies on the biophysical effects of land cover change are relevant in answering these questions (Anderson et al., 2011; Wang et al., 2014; Huang et al., 2018). The changes in land cover such as afforestation/deforestation have biophysical effects on the earth's climate, which primarily results from the changes in land surface albedo and

evapotranspiration. The land surface albedo depends on the vegetation type since each vegetation has different optical properties (Henderson-Sellers and Wilson, 1983; Gao et al., 2005; Houldcroft et al., 2009). Therefore, large-scale changes in the vegetation type can significantly affect the earth's climate by changing the land surface albedo. Converting the grasslands to forests will lower the land surface albedo, resulting in a warming effect (Chen et al., 2012; Wang et al., 2014; Huang et al., 2018; Shen et al., 2022). In addition to the effects on land surface albedo, afforestation can increase the evapotranspiration because of larger transpiration rates of trees compared to grasslands resulting in a cooling influence (Bonan, 2008 ; Chen et al., 2012; Wang et al., 2014; Duveiller et al., 2018; Huang et al., 2018). However, elevated atmospheric CO_2 levels could lead to an increase in the water use efficiency of the plants resulting in reduced transpiration rates (Cao et al., 2009, 2010; Gopalakrishnan et al., 2011). The effects of elevated atmospheric CO_2 on the transpiration rates are larger for trees compared to grasslands (Kirschbaum and McMillan, 2018). This could lead to a warming effect by afforestation in the future climate scenarios with higher atmospheric CO_2. The net effect of afforestation is determined by the balance of the biophysical effects and the biogeochemical cooling effect of removal of carbon from the atmosphere. While many previous studies have shown that the biophysical effects of afforestation are comparable to the biogeochemical cooling effect of afforestation (Chen et al., 2012, Huang et al., 2018 and Shen et al., 2022), it is often neglected while climate mitigations strategies are developed primarily because of the uncertainties in quantifying the biophysical effects of afforestation" (Please see pages 5-6, lines 98-116).

c) The manuscript has been revised according to the suggestions as follows, "The nature of the source or sink of atmospheric CO_2 could play a key role in determining its net effect on the earth's climate. For example, fossil fuel and deforestation emissions differ fundamentally in two ways: i) fossil fuel use transfers carbon from a relatively inert geological reservoir to the atmosphere, while deforestation results in an internal rearrangement of carbon within the active carbon reservoirs of the climate system, ii) deforestation emissions involve direct change in surface properties of land cover while fossil fuel emissions do not involve any direct change in land cover. Jayakrishnan et al., 2022 showed that the millennial scale response of the climate system to emissions from fossil fuel use and deforestation are different because of the above fundamental differences in fossil fuel and deforestation emissions. However, adequate emphasis is not given to the nature of the source or sink in many contexts. An example for the importance of including the non-radiative effects of the source of atmospheric CO_2 is discussed in Simmons and Matthews, 2016, where they show that the net response of the climate system to land cover change is non-linear when biophysical cooling effect of land cover change is included" (Please see pages 4-5, lines 54-71).

d) Though there are several studies that highlight the importance of the biophysical effects of changes in vegetation, it is mostly neglected in policy related issues. The main text is revised to make this point clearer as follows, "While many previous studies have shown that the biophysical effects of afforestation are comparable to the biogeochemical cooling effect of afforestation (Chen *et al.*, 2012, Huang *et al.*, 2018 and Shen *et al.*, 2022), it is often neglected while climate mitigations strategies are developed primarily because of the uncertainties in quantifying the biophysical effects of afforestation" (Please see page 6, lines 113-116).

e) The link to the ocean is now included in the revised manuscript. We have added the following sentences at the end of the introduction for this. "We hypothesize that the atmospheric warming in these two cases will be different because of the biophysical effects of afforestation. We compare the ocean potential temperature, ocean carbon content and surface ocean pH in the afforestation and reduced fossil fuel emissions cases to investigate the differences in the impacts on ocean in these two cases. The sea surface temperature could be different in the afforestation and reduced fossil fuel emission cases because the differences in the atmospheric state should be reflected in the surface ocean on decadal timescales. However, the impacts on ocean carbon cycle in these two cases is expected to be similar as the amount of carbon removed from the atmosphere is the same" (Please see page 6, lines 123-29).

Comment 4

Method and evaluation of the modelling setup: The method could benefit from some more details in particular concerning the vegetation dynamic. I would go more into detail as to how the dynamic vegetation works in terms of competition between the PFTs (it seems rather static for the non-afforestation cases). Also, the present-day fraction of forest is only 0.2 which is low. It would be good with a validation of the model against present-day forest extend or LAI. Moreover, I would move the description of VEGBURN from the result section to the methodology section, and I would even include some of the descriptions from the supplement as this is better described. In addition, you also need to describe how the ocean is spun-up.

Response to Comment 4

The model description is revised to be more comprehensive as suggested. Important details about the model that are now newly included in the main text are**:** i) how agricultural land is specified in the model, ii) what happens to the carbon in the trees and shrubs when deforestation is performed in our historical simulations, iii) description of the variable called VEGBURN which is an important component of the atmosphere to land carbon fluxes in the UVic model, iv) discussion of the literature that compare the UVic model simulations to observations and v) the list of the plant functional types represented by the UVic model (Please see Sect. 2.1).

The representation of the vegetation in the model is highly simplistic. Therefore, a comparison with the present-day forest cover might not be a relevant comparison. However, we have compared the simulated tree and grass fractions to observed fractions in the revised manuscript as follows, "The areal coverage of tree and grass type vegetations at the end of the historical simulation (averaged of the last 30 years) are 22% and 32%, respectively, compared to the observed values of 32% and 36 % (Poulter et al. 2011)" (Please see page 9, lines 225-227). UVic model is a coupled model, and all the components of the model are spun up simultaneously as described in SI TEXT S1.

Comment 5

I would suggest moving fig. S6 to the methodology section in the manuscript. I would recommend moving table S2 to the results section in the manuscript, as it very nicely summarises the results. Moreover, I would combine figures 1, 2, 3 and 4 into one figure, and I would combine figures 6 and 7 into one figure. In addition, I find it confusing all the references to the figures in the supplement, thus you might want to consider combining or moving them to the main manuscript and whether all these figures are needed. In addition, the figure captions contain a lot of text describing the results which are also included in the main text. I suggest you delete this, as it is already contained in the main text.

Response to Comment 5

As suggested by the reviewer, we have combined Figures 1,2,3,4,6 and 7 into three figures (Figure 3, 4 and 7) in the manuscript and moved two figures and a table (Figures S6, S14 and Table S2 is now Figure 1,2 and Table 2 respectively) from supplementary to the main text. Some of the results described in the main text are included in the figure captions to highlight the important message from the figures. Therefore, we would like to retain the figure captions as such.

Responses to minor comments

1) L13-L14 state that 'fossil fuel emissions directly alter the biogeochemical cycle of the climate system' but it also affects the physics of the troposphere via its impact on radiation and the energy budget. Thus, please rephrase this sentence.

   We agree with the reviewer and rephrase the sentence to "However, their effects on the earth's climate are different because reduction of fossil fuel emissions directly alters the biogeochemical cycle of the climate system and modifies the physics of the atmosphere via its impact on radiation and the energy budget, while afforestation causes biophysical changes in addition to changes in the biogeochemical cycle" (Please see page 2, lines 13-15).

2) L34 change 'fossil fuel use' to 'fossil fuel emissions'

   This line is now removed in the revised manuscript.

3) L35-36 please delete 'in the recent decade' and rephrase to 'During the period 2010-19, CO2 emissions from fossil fuel use and land use and land cover changes were 9.6±0.5 PgC yr-1 and 1.6 ± 0.7 PgC yr–1, respectively'

   This line is now removed in the revised manuscript.

4) L42 please rephrase to 'two major strategies considered for mitigating climate change are'

   The suggested changes are made in the revised manuscript (Please see page 4, lines 49-50).

5) L130 move to L111. e.g.: i) prescribed fossil fuel emission simulation with fixed agricultural land (FIXED_AGR) corresponding to the year 2005, which corresponds to the reference simulation

The suggested changes are made in the revised manuscript (Please see page 8, lines 190-191).

6) L137 please change ‘land carbon’ to ‘land carbon stock’, also throughout the manuscript.

The suggested changes are made in the revised manuscript.

7) L139 please add globally to ‘approximately 0.2 to 0.4 globally

The suggested changes are made in the revised manuscript (Please see page 9, line 228).

8) L160-L163 please rephrase these sentences as it is very hard to understand.

The lines are rephrased for a clear understanding as follows: “After the emissions peak, the rate of increase of NPP and soil respiration starts to decrease because of weaker CO_2 fertilization effect and reduced warming rates, respectively (Figure S8 and S9). During this period, the land carbon stock decreases after the emissions peak in five out of nine simulations (the FIXED_AGR and REDUCED_FF simulations of the SSP3-7.0 scenario and in all three simulations of SSP5-8.5 scenario) (Figure S6), because the sum of soil respiration and VEGBURN becomes larger than the NPP in these simulations” (Please see page 10, lines 263-269).

9) L172 please change ‘over land’ to ‘in land’

The suggested change is made in the revised manuscript.

10) L175-L176 additional already implies the amount is larger, rephrase the sentence.

The sentence is rephrased according to the suggestion as follows: “In the SSP 5-8.5 and SSP3-7.0 scenarios, the carbon stored in land during the period 2006-2500 is larger than that of the SSP 2-4.5 scenario (Figure 3a), because of the larger CO_2 fertilization effect due to larger atmospheric CO_2 concentrations” (Please page 10-11, lines 278-283).

11) L176-L179 Please rephrase for clarity

The sentences are rephrased as follows: "However, carbon stored in land after the year 2005 is more in the SSP3-7.0 scenario than the SSP5-8.5 scenario, though SSP5-8.5 has a larger atmospheric CO_2 concentration. This is due to larger warming in the SSP5-8.5 scenario which causes a larger increase in soil respiration than the increase in net primary productivity (NPP) due to CO_2 fertilization" (Please see page 11, lines 283-286).

12) L184-L185 please add global 'the global land surface albedo'

This line is now removed in the revised manuscript.

13) L186-187 please explain why the global albedo decreases initially.

The manuscript is revised with following explanation for decreasing albedo: "In the FIXED_AGR and REDUCED_FF simulations, the land surface albedo is nearly constant, while in the AFFOREST case land surface albedo decreases initially due to the regrowth of forests and becomes nearly constant after 2250 in the three SSP scenarios" (Please see page 11, lines 295-298).

14) L188 please change 'less' to 'lower'

The suggested change is made in the revised manuscript (Please see page 11, line 299).

15) L189 is the 0.011 globally?

Yes, it is globally. The text is revised to make this clear (Please see page 11, line 299).

16) L194-196 this could be deleted, as this is more fit for the conclusion

This paragraph is intended for the readers to have a quick summary of the present section before moving on to the next section. Therefore, we keep this in the revised manuscript

17) L205-206 please rephrase to: Initially, atmospheric CO_2 increases until around the cessation of fossil fuel emissions in the year 2250 whereafter the cessation of emissions around 2250, atmospheric CO2 decreases slightly until …

The original sentence is easier to understand and hence we keep these lines in the revised manuscript.

18) L207-L208 I do not understand the last part of the sentence ‘because of further carbon uptake by the ocean (Sect. 3.3) in all nine simulations. Please elaborate.

The sentence is rephrased in the revised manuscript for better understanding as follows: “After the cessation of emissions around 2250, atmospheric CO2 decreases slightly until the end of the simulations (Figure S16) because the ocean continues to be a weak sink till the end (Sect. 3.4) in all nine simulations though the land becomes neutral.” (Please see page 12, lines 337-339.)

19) L214 I think you need to add reduced_ff to the sentence thus ‘relative to AFFOREST and REDUCED_FF simulations’

This is not needed as the amount of carbon reduced is determined by the additional carbon stored in land in AFFOREST compared to FIXED_AGR.

20) L222 Please explain why the cooling impact decreases with the warmer SSP scenarios.

The description for decrease in cooling impact in the warmer SSP scenarios is included in the revised manuscript in response to another reviewers as follows, “In our simulations, the cooling effect of afforestation is completely offset by its warming effect in the higher emission scenarios (SSP 3-7.0 and SSP 5-8.5). However, in lower emission scenario (SSP 2-4.5), the offsetting of the cooling effect of afforestation is only partial, because the removal of atmospheric carbon by afforestation results in a stronger cooling effect when the atmospheric CO2 is lower. Therefore, the biophysical warming effect of regrowth of trees does not completely offset the biogeochemical cooling effect from the atmospheric carbon removal by afforestation. This suggests that afforestation may have a larger climate benefit in the lower emission scenarios.” (Please see page 15, lines 437-443)

21) L225 please rephrase ‘this offsetting is almost full’

The phrase “offsetting is almost full” is rephrased to “the offset is nearly perfect”.

22) L229 please add ‘the warming effect from decreases in surface albedo due to’

This line is now removed from the manuscript.

23) L236-L239 this could be deleted, as this is more fit for the conclusion

This paragraph is a summary of the results from the current section. It would be helpful for the readers before moving onto next section.

24) L262 There is no Figure 22. Is this figure S2?

It was Figure S22. The correction is made in the revised manuscript.

25) L271-L273 this could be deleted, as this is more fit for the conclusion

This paragraph is a summary of the results from the current section. It would be helpful for the readers before moving onto the next section.

26) L298 'grow trees artificially', what do you be by that? By using irrigation?

The sentence is rephrased to "it might be possible to grow trees in areas where the climate conditions do not support the growth of trees using dams, irrigation, etc." (Please see page 16, lines 467-469).

Response to comments from Reviewer 3

General comments

The manuscript compares the climate effects of a world with high land-based mitigation (afforestation) and one the same carbon removed for 3 different SSP scenarios. They use the University of Victoria Earth System Climate Model and make the comparison for a variety of variables related to the carbon cycle, surface energy cycle and ocean. In general, the research is novel and is executed in a thorough way and answers interesting questions. However, at this point the manuscript somewhat lacks a critical discussion and doesn't relate nor compares the outcomes of this study to previous literature as much as it should. I think the manuscript can improve greatly by including for example a discussion section which can elevate the results and compare them to previous literature.

We thank the reviewer for the positive remarks on our work. We have addressed all comments of the reviewer in the revised manuscript as discussed below.

Comment 1

The comparison between the afforestation simulation (AFFOREST) and the reduced emission simulation (REDUCED_FF) is interesting, the way I see it in the REDUCED_FF simulation you account for the carbon effects of afforestation but neglect the biogeophysiscal effects, thus the difference between both simulations allows to quantify the biogeophysical effects of afforestation. It would be interesting to compare these effects in temperature to previous studies both observational (Duveiller et al., 2018; Alkama and Cescatti, 2016) but also modelling studies with more complex Earth System Models that quantify the biogeophysical effects (a.o. Boysen et al., 2020; Winckler et al., 2019; Portmann et al.,2022). This way you could assess how well the UVIC model represents biogeophysical effects or whether there are potential biases (a comparison can only be qualitative of course as the amounts of afforestation differ across studies).

Response to comment 1

We agree with the reviewer that a qualitative comparison of the results with previous literature is important to assess how well the UVic model represents biogeophysical effects. We have compared the results of our study with the suggested references as follows. "Several previous studies, both observational and modelling, have investigated the biophysical effects of deforestation/afforestation (Bala et al., 2007; Chen et al., 2012; Wang et al., 2014; Cescatti, 2016; Duveiller et al., 2018; Huang et al., 2018; Winckler et al., 2019; Alkama and Boysen et al., 2020; Shen et al., 2022). Observational studies on biophysical effects of deforestation by Alkama and Cescatti, 2016 and Duveiller et al., 2018 show that deforestation results in a biophysical warming effect which qualitatively contradicts our results, while climate modelling studies by Bala et al., 2007, Boysen et al., 2020 and Portmann et al., 2022 show that large scale deforestation results in a biophysical cooling effect which is qualitatively consistent with our results. Winckler et al., 2019 showed that this contradiction between the observational and modelling studies arises from the nonlocal cooling in models, which is excluded from observations. On regional scales, the net effect of afforestation could be warming or cooling depending on the location at which the afforestation occurs (Chen et al., 2012; Huang et al., 2018; Shen et al., 2022). Wang et al., 2014 showed that, the net biophysical effect from global afforestation is a warming of 0.68–1.38 °C which is qualitatively consistent with the biophysical warming effect of afforestation in our results.

Previous studies (Bonan, 2008;Li et al., 2016; De Hertog et al., 2022) find that afforestation in the tropics leads to a cooling effect, while we simulate a warming for afforestation in the This contradiction is the result of higher atmospheric CO_2 concentrations in the SSP scenarios used in our study, resulting in increased water use efficiency of plants and consequently a warming effect due to a decrease in evapotranspiration (Kirschbaum and McMillan, 2018)" (Please see page 15-16, lines 448-463).

Comment 2

In the analysis of the temperature response you mainly focus on albedo as an explaining variable, this is warranted as the effects are mostly cooling however previous research as mentioned in my comment above found that afforestation might also cause a local cooling effect due to changes in turbulent heat fluxes. It might be interesting to check some of the other energy balance components in order to understand whether these effects are absent in the model or whether the temperature response is simply dominated by the global warming as a consequence of the albedo effects.

Response to comment 2

Thank you for this important comment. Another reviewer had a similar comment. In the AFFOREST case, the evapotranspiration is smaller compared to the reference case because of the increase in water use efficiency of the trees at elevated atmospheric CO_2 levels (Figure 3c). In contrast, evapotranspiration is larger in REDUCED_FF case compared to reference case because of the lower plant water use efficiency at lower atmospheric CO_2 levels (Figure 3c). Therefore, the smaller (larger) evapotranspiration in the AFFOREST (REDUCED_FF) case relative to the reference scenario causes a warming (cooling) influence in our simulations. In the revised manuscript, we have included two new figures (Figure 3c and S15) and a detailed discussion on the effects of changes in evapotranspiration (Please see pages 11-12, lines 305-323).

Comment 3

The description of the model is too limited and should be elaborated as at this point it is not clear what important processes for afforestation are resolved and which not. You should elaborate this description (or add a more detailed section in the supplements) with a larger focus on the land surface scheme (e.g. list of PFT's).

Response to comment 3

We agree with the reviewer and the model description has been made more comprehensive in the revised manuscript by including the following additional details. Some of the important details about the dynamic vegetation component of the model were described in the Supplementary Text earlier, which is now moved to main text. Important details about the model that are now newly included in the main text are: i) how agricultural land is specified in the model, ii) what happens to the carbon in the trees and shrubs when deforestation is performed in our historical simulations iii) description of the variable called VEGBURN which is an important component of the atmosphere to land carbon fluxes in the UVic model, iv) discussion of the literature that compare the UVic model simulations to observations and v) the list of the plant functional types represented by the UVic model (Please see Sect 2.1).

Comment 4

Line 186-188: you explain that the albedo increases initially in all simulations, but you never explain why this happens or what process is behind it. I assume it is the remaining natural vegetation reaching their climax as the model employs a dynamic vegetation model but it would be good to clarify that here.

Response to comment 4

The manuscript is revised with following explanation for decreasing albedo: "In the FIXED_AGR and REDUCED_FF simulations, the land surface albedo is nearly constant, while in the AFFOREST case land surface albedo decreases initially due to the regrowth of forests and becomes nearly constant after 2250 in the three SSP scenarios (Figure S13)" (Please see page 11, lines 295-298).

Comment 5

Line 238: this is still the section regarding temperature effects it is a bit strange that in the summary of this section you mention ocean acidification, I would remove this.

Response to comment 5

The line mentioning ocean acidification is removed in the revised manuscript.

Comment 6

The results have clear narrative and important conclusions which are clear and well founded, however the article would benefit from including more similar literature in a discussion chapter in order to facilitate the understanding and critical review of results which can also help draw out future research suggestions. At this point in time I lack this greatly as there is a lot of work out there on the effects of afforestation on climate and carbon (see eg Pongratz et al. 2022), it would also be good to check if some studies have assessed the ocean effects of afforestation (I am not aware of any literature regarding this so I cannot suggest any). This comparison to literature can help highlight strengths and limitations from the approach used in this study.

Response to comment 6

Thank you for this important comment. The current study is compared with the existing literature in the revise manuscript as shown in response to comment 1. The suggested paper is cited now (De Hertog et al., 2022). The effects of afforestation on ocean carbon cycle are also briefly discussed in the revision as follows, "Both afforestation and reduced fossil fuel emissions result in smaller ocean carbon stock (Figure S19 and 20), because the surface ocean equilibrates rapidly in response to changes in the atmosphere (Figure S20). However, the changes in the deep ocean are nearly zero (Figure S20) because the transport of ocean carbon between the surface and deep ocean could take multiple centuries to millennia." (Please see page 15, lines 443-447).

Comment 7

This is in part my opinion, but I don't think you need lat-lon labels in a global spatial plot, just the ticks suffice for the readability of the plot and in general it just gets cluttered more by adding all those labels, however this is just an opinion so if you want to stick with the plots you have now thats fine too.

Response to comment 7

As we show these labels only in the bottom panels, we have decided to keep these labels in the revised manuscript.

Response to minor comments of Reviewer 3

1) Line 213 : Sect. 3.1 ii)) one bracket should be removed after ii

The extra bracket is removed in the revised manuscript.

2) Line 262: Figure22 should be Figure S22

The change has been made in the revised manuscript.

Reviewer 4

General comments

This study addresses the question of the climate impact of different carbon mitigation strategies. The authors raise the question of whether a similar decrease in atmospheric carbon resulting either from afforestation or from a cut in anthropogenic emissions have the same effect on land surface temperature and ocean carbon content.

To tackle this question, they set up two extreme modeling experiments under 3 future climate scenarios (SSP2, SSP3, SSP5): 1/ all agricultural land is abandoned and left for forest to grow (AFFOREST) or 2/ the same amount of carbon that would be captured by such a large-scale afforestation is cut from the anthropogenic emissions (REDUCED_FF). Both extremes are compared to a baseline simulation where there is no land use change (FIXED_AGR).

The authors conclude that the reduction of atmospheric carbon from a net reduction in anthropogenic emissions has a larger impact on atmospheric cooling compared to the afforestation strategy. This results is explained by the biophysical feedbacks of albedo. The study concludes that reducing fossil fuel emissions is more effective than afforestation in mitigating climate change.

Despite a timely topic, some aspects of the paper leave me doubtful about the relevance of the experimental setup and the conclusions.

We thank the reviewer for the positive remarks on our work. We have addressed the comments of the reviewer in the revised manuscript as discussed below.

Comment 1

The scenarios are presented as " idealized" (L75). Indeed, abandoning all agricultural land has no other reality than the brutal mass extinction of humanity, which then would be followed by the total cut of FF emissions. The unrealism of the scenarios is a strong limit to the study's conclusions that should therefore be toned down as they should not be translated into policy recommendations (L23, L306).

Response to comment 1

We agree with the reviewer. Hence, the climate policy suggestions are toned down in the revised manuscript as follows, "Our results show that a reduction in fossil fuel emissions could be more effective than afforestation in mitigating climate change. Though afforestation might be relatively less effective in mitigating climate change, it has other benefits such as a reduction in ocean acidification: the removal of carbon from the atmosphere results in a slightly reduced amount of carbon in the ocean, which leads to higher surface ocean pH and less ocean acidification. While our study show that the biophysical effects have significant role in determining the net effects of afforestation in the future climate, there are many uncertainties in the representation of the processes that govern the biophysical changes in our climate model simulations. Therefore, the understanding of the biophysical effects of afforestation should be improved further before considering the implications of our research for climate policy." (Please see page 16-17, lines 484-493).

Comment 2

No order or magnitude is given for the carbon emissions that are cut (L284). Making it difficult to get an idea of the strength of the scenario. Give some reference values, for example global carbon stored on land.

Response to comment 2

Thank you for this important comment. The amount of carbon that are cut is now given in the methodology section of the revised manuscript as follows, "In the AFFOREST simulations, the amount of carbon additionally stored in land (between 2006-2500) are 319.84 PgC, 418.93

PgC, and 379.21PgC in the SSP2-4.5, SSP3-7.0, and SSP 5-8.5 scenarios, respectively" (Please see page 8, lines 204-208).

Comment 3

It is not clear to me what level of feedbacks is included in the model between emissions and climate? Are SSP climate trajectories and AFFOREST and REDUCED_FF mitigation scenarios consistent, and if not, does it matter? In the scenario REDUCED_FF, fossil emissions are cut significantly with respect to FIXED_AGR and AFFOREST scenarios. Then climate in which the trees grow, say for the SSP8.5 climate trajectory should not be the same. Is this accounted for?

Response to comment 3

We appreciate this comment. As indicated in the manuscript, we perform "idealized" simulations in order to gain valuable insight into the relative effectiveness of fossil fuel emission reduction and afforestation in cooling the global climate. These idealized simulations AFFOREST and REDUCED_FF are not consistent with the SSP trajectories but are designed in this study to gain fundamental scientific insights which are relevant to climate policy in the real world. This is now discussed in the revised manuscript as follows, "Note that our simulations (AFFOREST and REDUCED_FF) are highly idealized and are designed with the sole purpose to assess the relative effectiveness of afforestation and reduced fossil fuel emissions. Hence, these simulations are not consistent with the SSP scenarios." (Please see page 8-9, lines 209-212).

Comment 4

The description of an Earth System Model cannot be done in 10 lines. The readers need to know which processes are included and how they are modeled to be able to understand critically the simulation outputs. Some of the questions that need to be addressed are:

What types of vegetation types are included? How is the model parameterized? In the afforestation scenario, what vegetation type takes over the abandoned agricultural land? How do simulated biomass, carbon fluxes and stocks, water fluxes compare to observations (for example the value given on L145 needs to be compared to literature)?

Response to comment 4

The model description is made more comprehensive by including the suggested details in the revised manuscript as follows. Some of the important details about the dynamic vegetation component of the model were described in the Supplementary Text earlier, which is now moved to main text. Important details about the model that are now newly included in the main text are: i) how agricultural land is specified in the model, ii) what happens to the carbon in the trees and shrubs when deforestation is performed in our historical simulations iii) description of the variable called VEGBURN which is an important component of the atmosphere to land carbon fluxes in the UVic model , iv) discussion of the literature that compare the UVic model simulations to observations and v) list of the plant functional types represented by the UVic model (Please see Sect 2.1).

The comparison of land carbon stocks and fluxes to the observations are added in the main text as follows, “The land carbon stock is underestimated in the UVic model compared to the observations likely because of the simple land surface scheme used in the UVic model which does not include representation for peatlands (Meissner et al., 2003). In our historical simulation, the land act as a net source of ~10PgC, which is in the range of 30±45PgC estimated in Ciais et al., 2014.” (Please see page 10, lines 249-253). The comparison of global total precipitation in our historical simulation with the observations is added in the supplementary text as follows, “The global total precipitation during the last 30 years of our historical simulation is 1.05 m yr^{-1}, which is close to the estimate of 0.98 m yr^{-1} from satellite observations (Adler et al., 2017)”.

In addition, we have added a paragraph citing the papers that evaluate the performance of the model in simulating the present-day climate and terrestrial and ocean carbon cycle as follows. “The large-scale present-day climate is represented quite well in the UVic model (Weaver *et al.*,2001, Skvortsov *et al.*, 2009, Eby *et al.*, 2009 and Cao and Jiang, 2017). The spatial distribution of the precipitation and evaporation is simulated quite well in the UVic model compared to the NCEP reanalysis data (Weaver *et al.*,2001; Meissner et al., 2003). The vegetation biomass, areal coverage of the different plant functional types and the atmosphere to land carbon fluxes simulated by the UVic model are also comparable to the observations (Meissner et al., 2003). Further, Keller et al., 2012 show that the annual global net primary production in the ocean simulated by the UVic model is in good agreement with observations” (Please see page 7, lines 142-148).

Comment 5

Another information needed in the model description is the sensitivity of the model to drought-induced mortality or other disturbances? Climate change scenarios as applied here for 500 years come with intense and frequent droughts, fires or storms that might impede the growth, and hence the sink simulated from fertilization effect, especially in the afforestation scenario. Are these processes included? If not, the time horizon could be reduced and the effect of these assumptions should be discussed.

Response to comment 5

This limitation is now discussed in the main text as follows, “The climate change scenarios used in our simulations would occur with frequent intense droughts and that prevent the vegetation regrowth, which is not fully accounted for in our simulations because of a simple 1-layer energy balance atmospheric model (Weaver et al., 2001) which does not simulate convection and clouds. Therefore, the magnitude of the estimated sink from the regrowth of vegetation might be lower in the real world than in our simulations” (Please see page 16, lines 475-479).

Comment 6

About the explanation of the different global climate effect between AFFOREST and REDUCED_FF, the authors argue that it is the result of albedo changes only. This is overly simplistic. As an example, many studies (for example Li et al., 2015 Nature comm. or Bonan 2008) show that growth of tropical forests have a cooling effect due to water fluxes as opposed to boreal forests that would have a warming effect due to the albedo decrease. The current study’s results in the tropics are the opposite of these (L235 afforestation in the tropics leads to warming) and no explanation is given to this apparent contradiction. More generally, the water-based energy exchanges are not discussed at all even though they are a key part of the climate system. This is a key lack of the study.

Response to comment 6

Other reviewers also commented on this issue. In the AFFOREST case, the evapotranspiration is smaller compared to the reference case because of the increase in water use efficiency of the trees at elevated atmospheric CO_2 levels (Figure 3c). In contrast, evapotranspiration is larger in REDUCED_FF case compared to reference case because of the lower plant water use efficiency at lower atmospheric CO_2 levels (Figure 3c). Therefore, the smaller (larger) evapotranspiration in the AFFOREST (REDUCED_FF) case relative to the reference scenario causes a warming (cooling) influence in our simulations. In the revised manuscript, we have included two new figures (Figure 3c and S15) and a detailed discussion on the effects of changes in evapotranspiration (Please see pages 11-12, lines 305-323).

We also discuss the contradiction in our results with previous studies by Bonan, 2008 and Li et al., 2016 as follows, "Previous studies (Bonan, 2008;Li et al., 2016; De Hertog et al., 2022) find that afforestation in the tropics leads to a cooling effect, while we simulate a warming for afforestation in the tropics. This contradiction is the result of higher atmospheric CO_2 concentrations in the SSP scenarios used in our study, resulting in increased water use efficiency of plants and consequently a warming effect due to a decrease in evapotranspiration (Kirschbaum and McMillan, 2018)" (Please see page 16, lines 460-463).

Comment 7

Also in Figure 5 the difference in AFFOREST result between the 3 climate trajectories are not explained when it is an important and surprising result (L235 and L293).

Response to comment 7

The manuscript is revised with a more detailed explanation of the dependency of climate effect of afforestation on the background climate as follows, "In our simulations, the cooling effect of afforestation is completely offset by its warming effect in the higher emission scenarios (SSP 3-7.0 and SSP 5-8.5). However, in lower emission scenario (SSP 2-4.5), the offsetting of the cooling effect of afforestation is only partial, because the removal of atmospheric carbon by afforestation results in a stronger cooling effect when the atmospheric CO2 is lower. Therefore, the biophysical warming effect of regrowth of trees does not completely offset the biogeochemical cooling effect from the atmospheric carbon removal by afforestation. This suggests that afforestation may have a larger climate benefit in the lower emission scenarios." (Please see page 15, lines 437-443).

Comment 8

The choice of figures needs to be rethought.

Too many figures from SM are cited showing their relevance to the authors' demonstration, then they should be included. Also it is hard to follow because there are so many figures. Some should be merged.

The only displayed figures in the article show differences to the reference scenario and hide the inherent dynamics of the scenarios. These dynamics are however essential to understand the processes so the figures currently shown in SM showing the 3 scenarios are the ones that should be in the paper.

Response to comment 8

Another reviewer also had a similar comment. We have included only the figures relative to the reference scenario because we compare the relative effects of afforestation and reduction in fossil fuel emissions. In the revised manuscript we have moved Figures S6 and S14 and Table S2 in the supplementary to the main text to increase the comprehensibility of the manuscript.

Associate Editor Comments

General Remarks

Thank you for your response to the reviewer comments. I now invite you to upload the revised manuscript and point-by-point answers to the reviewers. The manuscript will then be send out for review for further evaluation.

We are thankful for the invitation to upload the revised manuscript and the response to reviewers.

Comment 1

In your revisions, please also clarify well why you opt to set the fraction of agricultural land to zero in the AFFOREST simulation. This is obviously a (very) unrealistic scenario, so it merits a clear rationale (or requires further modification).

Response to Comment 1

We thank the associate editor for this important comment. We have discussed the unrealistic nature of setting the agricultural land to zero abruptly in the conclusion section (Please see page 16, lines 464-467). The goal of our study is to understand the importance of considering the biophysical effects of afforestation in climate policy negotiations. Even though our simulations are highly idealistic, study will be unchanged in more complex modeling frameworks. Several previous studies (Bala et al., 2007, Wang et al., 2014, Devaraju et al., 2018) have used similar highly idealized deforestation/afforestation experiments for providing useful scientific insights. This point is now made clear in the revised manuscript (Please see page 16, lines 481-483).

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