”Interactive comment on “Simulating sustained yield harvesting adaptive to future climate change” by Rasoul Yousefpour et al.”
Anonymous Referee #1

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The authors use a state-of-the-art Earth System Model (ESM) "JSBACH“ to show that a revised harvest schedule in order to keep the forest carbon pools constant under climatic change will lead to harvest amounts twice to four times larger than those scheduled under standard harvesting rules, with the latter being based on Integrated Assessment Models. The net mitigation effects over the 21st century would then be much higher than under standard assumptions.
This paper is well written and illustrated and the results stress the importance of forest management, but there exists concern about the assumptions made to generate these results. The assumptions appear in part too artificial, so that the conclusions made are possibly not all well justified.

Response: *We appreciate the comment of the reviewer #1 agreeing on the importance of simulating forest management effects in a global study. Below we respond to the concerns regarding assumptions behind our experiment and all general and specific comments raised by the reviewer.*

General comments:
1) Harvesting always the timber growth (increment) is a famous traditional forest management rule, which foresters have tried to apply already for more than one century, but which is hardly possible to be achieved. For example, following an empirically/iteratively based form of forest planning, the so called “Kontrollmethode” has been developed for forest management already at the end of the 19th century by de Liocourt (France) and Biolley (Switzerland). Implementation of such traditional harvesting rule into a state-of-the-art ESM has some originality, although it appears rather unrealistic that the assumption to apply this rule may ever be a realistic guide for real world forest management. This would also raise doubts about its usefulness for aggregated global projections.
In forest management the timber increment may only be measured post hoc and past increments can hardly be used to predict future timber increments. The historical and future timber increment depend both much on the actual forest structure, which is continuously
changing. But this is only one limitation for the application of the modelled harvesting rule. Even more important is the in this study disregarded accessibility of the standing timber volumes in the world’s forets. It may be totally uneconomic to harvest on steep mountain slopes or to carry out sustainable harvest (without deforestation) in hardly accessible tropical regions. Disregarding the probability with which a harvest will actually occur at a certain place will always lead to a great overestimation of the actually possible harvest. Such overestimation appears to be the case with the current paper as well. In conclusion, a better justification of the adopted harvesting rule and a more critical discussion of the results would be desirable.

Regarding the comment 1*): We agree that SY may serve as an experiment to simulate the ecological potential of global forest resources for producing wood and mitigating CO_2. We make it clear in the revised manuscript that the aim of our study is to estimate potentials, not actually possible harvest, and to show by the large changes in potentials under climate change that it is essential for models such as IAMs to capture the effects of climate change on harvestable material. We acknowledge that SY decisions are solely ecologically driven and economic factors such as wood*

prices are not considered. Global DGVMs mainly have a coarse resolution and application of spatially explicit forest harvest decision rules such as Control Method of Biolley is very limited if not impossible. We agree that it is worthwhile for future model development to regard this recommendation, as it is e.g. done in European studies (e.g. Naudts et al., 2016), if the aim is to estimate actual harvest.
We make now clearer to the general reader that this study simulates the potentials of global forest resources for wood production, rather than actually possible rates. The changes in the manuscript are stating explicitly that our estimates refer to ***potential*** *wood harvest rate throughout the manuscript, that our simulations should therefore be seen as* ***thought experiments*** *(see also comments by reviewer #2), and that, correspondingly, our assessment of mitigation potentials serves as a link of these* ***potentials*** *to CO_2 emissions and concentrations. Limiting ourselves to simulating ecological potentials of global forests in producing wood also means that we do not mask out non-accessible forests and protected areas. Therefore, and according to the suggestion by the reviewer #1, we bring this important issue not only at two occasions in the discussion but also outline it explicitly in the introduction to avoid misunderstanding.*

Concerning the comment that past increments cannot serve to predict future increments: Indeed, our simulations capture that forest structure is changing over time. Only the target biomass stocks are derived from a fixed state: The present amounts of above-ground wood biomass of global forest resources serve as the harvest baseline for our SY decision rule. We make decisions based on the present stocks (over 10 years), and consider the future changes in growth (including regrowth after harvesting) of forests in deciding about the amount of wood harvest.

2) One could consider it also as a limitation that the area occupied by a specific plant functional type have been kept constant, which means that an important element of dynamic vegetation modelling has been excluded. The assumption of a constant forest area over the next 100 years alone is very strong, meaning that land-use/cover change is ignoredover such long period. Furthermore, one of the most important tasks of forest management is to plan meaningful change of the forest composition, for example to adapt to climate change. As mentioned already the structure of the harvests (size of harvested timber, tree species) would be important for the structure of the remaining timber volume. This would also have an impact on the timber growth. It is still a bit unclear how these complexities have been addressed. Alternatives to the harvesting algorithms applied in this paper should be discussed, or even better applied.

Regarding the comment 2*): We agree that land use and land cover change, species composition and other adaptive measures in the future may change forest productivity and consequently the actually available material for wood harvest. Therefore, we discuss this important issue now in the paper.*

As stated in the manuscript, the simulations were conducted without dynamic vegetation and without land-use transitions to prevent changes in the areas occupied by the different PFTs and to be thus able to isolate the effects of forest management activities.

3) In addition, the notion that socio-economic rules to decide when and how much timber to harvest would always disregard actual environmental conditions is not fully valid. Often, the achieved timber size (Europe) or an economic criterion (international perspective), such as the maximum soil expectation value, are criteria to decide when to harvest. These criteria depend on the environmental conditions and could alternatively have been used to carry out predictions on timber harvests or to provide scenarios on a more realistic basis.

Regarding the comment 3*): It is true that in reality such socio-economic factors are included in making a harvest decision. However, the IAMs used to project harvest rates in the representative concentration pathways do not allow variables such as maximum soil expectation value to change in response to altered environmental conditions. We add this discussion point to the manuscript.*

4) A central outcome of the submitted study is a much increased timber harvest particularly in the tropical forest biome (Figure 2). This result could be interpreted with more care. The tropical biome still comprises vast area of more or less natural forest, where NPP may actually be high. But NPP is not equal to commercial timber harvest and harvesting up to 25 - 30 kg C per square meter (2006-2100) in these forests would certainly destroy these ecosystems, with their particularly rich biodiversity. A harvest of 25 kg C per square meter would mean harvesting in the order of 1000 cubic meters per hectare over 94 years (or around 10 cubic meters per ha per year). This rough estimation implies 50% C content in dry woody biomass and an average timber density of 500 kg per cubic meter. Such harvest would be detrimental, as these natural ecosystems can often provide not much more than 0.5 cubic meter commercial harvest per hectare per year on a sustainable basis.

Regarding the comment 4*): It is of course true that only a fraction of the standing biomass in tropical forests is suitable for commercial timber harvest. It needs to be noted, however, that the harvest we simulate beyond that prescribed by the RCPs stems from the increase in standing biomass due to environmental changes, not from increasing harvest from the "baseline" biomass (baseline being present-day levels of harvest). This means that we do not reduce the current forest biomass, but harvest only biomass in excess of this, therefore not causing a degradation of standing biomass stocks. It is possible of course that it is mostly unusable plant species (such as lianas) that are responsible for the increase in biomass; however we have no reason to speculate that this is the case. It is possible that our model in general overestimates tropical biomass stocks, but this seems unlikely given evaluation studies revealing rather low vegetation carbon estimates for related model versions (Anav et al., J. Clim., 2013). It also needs to be noted that our harvest rates do not refer to commercial timber harvest, but also to fuel wood harvest, which can be fulfilled from a much wider range of biomass than commercial timber.*
As stated above, we have added statements to the manuscript (discussion part) that our estimates of harvest potentials does not consider biodiversity or conservation aspects and acknowledge that such considerations might lead to lower actual than potential harvest rates.

5) It appears that sustainable yield harvesting mainly reflects the NPP of the forests considered, because the size of the NPP appears to be harvested. The distribution of this NPP (see Figure 2) could be an interesting issue as well for a revised paper. Should the harvesting aspect still be the main focus of an improved manuscript, one could consider the following recommendations:

Regarding the comment 5*):*
It is correct that the harvested wood increment is strongly related to the NPP of the considered forests and harvesting it is still the focus of the revised manuscript. We considered all recommendations given by the reviewer and state our replies to these detailed issues below.

More detailed issues
1) The assumed lifetimes for wood products appear very high. They should be better justified and compared with those assumed for other studies, for example by Härtl et al. (2017) in Mitigation

and Adaptation Strategies for Global Change. One could mention that there is still very large uncertainty concerning these values.

Response: *We justify the application of different life times to the anthropogenic wood pools and refer to the suggested paper and others to justify our application.*

2) The sustainable yield scenario should be critically discussed considering the issues mentioned above. Moreover, some constraints could be considered. For example could the harvest in protected areas and in inaccessible forest areas be significantly reduced or even set to zero. For the purpose of a better prediction of the possible harvest, one could refer to the recent works by Luciana de Avila, e.g. "Recruitment, growth and recovery of commercial tree species over 30 years following logging and thinning in a tropical rain forest", which recently appeared in Forest Ecology and Management.

More detailed issue 2*): We have extended the discussion section according to the recommendations by the reviewer, i.e. discuss in more detail SY effects on biodiversity, life cycle analysis, and carbon discounting. We have also clarified throughout the manuscript that our study aims at simulating potential rather than actual wood harvest rates (see also response to comment 1).*

3) The discussion of discounting C over time is unclear. Also, more recent references could be included, such as Johnston and van Kooten (2015) "Back to the past: Burning wood to save the globe" published in Ecological Economics.

More detailed issue 3*): We now discuss the social discounting of carbon using Johnston and van Kooten (2015) as reference.*

Interactive comment on "Simulating sustained yield harvesting adaptive to future climate change" by Rasoul Yousefpour et al.

Anonymous Referee #2
Received and published: 23 February 201

Forests are one of Earth's most important resources and wood harvest is one of the main ways in which humans are managing and impacting forest ecosystems. This paper examines the question of how an alternative future wood harvest scenario, based on a "sustained yield" (SY) approach, and responsive to a changing environment, would differ from the standard demand-based wood harvest scenarios currently used by Integrated Assessment Models (IAMs).
Under the sustained yield approach, annual wood harvest rates are "optimized" and are equal to the annual rate of re-growth, thus keeping forest stocks maintained at their current levels. In addition, unlike most IAM wood harvest scenarios, the SY approach in this paper uses regrowth rates that are responsive to changing climate and CO2 concentrations, thus potentially allowing higher wood harvest rates than the IAM wood harvest scenarios that are based on static environmental conditions.
This work shows one way in which IAMs and ESMs could improve and strengthen their interactions. The paper describes the results of a set of simulations using the dynamic vegetation model JSBACH, forced with climate data from Earth System Model runs from three different Representative Concentration Pathways (and thus three different climate futures). The paper compares results from these JSBACH simulations using both the SY wood harvest scenario as well as the prescribed wood harvest scenarios from the IAMs.

This is an interesting thought experiment, and yet it is not really presented as such in this paper. In fact, one of my main criticisms with the paper is the way in which the work is framed and motivated. The SY approach is unrealistic and it is not clear why, or how, a society would want to pursue a wood harvest plan that involved harvesting more wood than demanded and doing so by harvesting every patch of forest by the exact amount it would regrow each year. It is only in the Discussion that the authors acknowledge that the SY scenario is not meant as a plausible estimate of future wood harvest, but rather as an estimate for the ecological potential for wood harvest. There is also not a lot of explanation given for why IAM demand-based wood harvest scenarios are inherently problematic (aside from not responding to changing environmental conditions). The motivation for using this particular SY approach appears to be a mix of exploring how changing environmental conditions could alter the amount of wood harvest, and also how additional wood harvest could act as a carbon mitigation method. However, the effect of changing environmental conditions on the amount of wood harvested is mixed with the effect of the additional wood harvest that is imposed by the SY approach (which attempts to harvest much more than the demand-based scenarios). In addition, the mitigation potential of the SY approach seems like a fairly inefficient way to capture and store carbon from biomass. The authors also do not address negative impacts of the SY scenario such as the impact on biodiversity (even partial removal of forest would have a negative impact on habitat), or the impact on the overall forest health that could result from continued and widespread human management.

Due to the SY approach involving changing forest biomass in response to changing environmental conditions, as well as additional wood harvest to meet the forest regrowth rates, it is difficult to tell how much of the increased wood harvest is coming from the additional forest growth due to changing climate and CO2 concentrations, and how much is coming from choosing to harvest more wood, and in more locations, than the IAM wood harvest scenarios. It would actually be quite interesting to look at this some more and I think the paper would benefit from an additional experiment that was devised to do this (as outlined below).

Response: *We gratefully acknowledge the valuable evaluation of the reviewer, who finds the study "an interesting thought experiment", and the useful comments to improve the readability and quality of the manuscript. We revised the manuscript accordingly to all points made by the reviewer and, below, we outline the main specific improvements requested by reviewer #2:*

I think the paper would be much improved if a couple of key changes were made:
1) A better framing and motivation for the paper in the Introduction, to make it clear that the SY approach is a thought experiment to examine how much sustainable future wood harvest is possible, and why demand-based wood harvest scenarios are not sufficient.

Key changes 1): *Reviewer #2 correctly emphasizes that the motivation for accomplishing this simulation study is to realize the potential of SY in harvesting wood and the long-term effects of wood products on the global carbon cycle for mitigation CO_2. We have now used the keyword "potential" in the Introduction and call the study a thought experiment as suggested by the reviewer to avoid misunderstandings.*
We outline in the discussion now the alternative approaches for the simulation of global forest resource management beyond SY. We discuss the shortcomings and the effects of applying harvesting rules like SY on the ecosystem services besides timber production.

2) In addition to the standard demand-based scenario, and the SY scenario, include a third wood harvest scenario that uses the prescribed demand-based wood harvest scenarios, but allows for forest regrowth rates to change due to changing environmental conditions, and thus allows for changes in the actual wood removed from forests. For example, this scenario could use the prescribed wood harvest area in each gridcell (instead of the wood harvest biomass), or it could use the ratio of prescribed wood harvest biomass to prescribed available forest biomass in each grid-cell. Either of these alternative wood harvest scenarios would retain most of the information from the prescribed demand-based scenario, but would allow the actual biomass harvested to change with changing environmental conditions. This could enable a simple quantification of the impacts of changing climate and CO2 concentrations on future wood harvest, and would separate that effect from the effect of harvesting much more wood under the SY scenario.

Key changes 2): *The suggestion of reviewer 2 for a third harvest scenario is an interesting suggestion how to interpret harvest rates prescribed by IAMs in a way such that changing environmental conditions are considered to a certain degree. However, in our study we do not target to show how IAM harvest rates might be interpreted in such a way, but to make an assessment of potentials and to state that these potentials reach far beyond the rates prescribed by IAMs.*
Regarding the separation of the impact of changing climate and CO_2 concentrations and the effect of harvesting regrowth we extended our discussion: We added another simulation to the supplementary material in which we simulate SY harvest under present-day climate. We now refer to this additional scenario in our discussion of the effects of changing climate and CO_2 on the achieved

harvest rates. We interpret the differences between this SY and SY under RCPS as the effects of changes in CO_2 and climate. Additionally, we point out that the differences in harvest potential of the three RCP-SY simulations are solely determined by their different climate and CO_2 forcings. Finally, we shortly reflect upon the differences in harvest amount between the SY simulations and RCPs in the first year of the simulation, which highlight the differences of applying supply side based harvesting (SY) versus demand side harvest (as applied in IAMs) under current climate and CO_2 conditions.