We would like to thank Dr. Pekka Lauri and Mr. Walter Cervi Rossi for the time spent on reviewing our manuscript and the valuable remarks which pointed out some important issues which will help to further improve the paper.

Below is our updated point-by-point response to the reviews including a list of all relevant changes made in the manuscript. Reviewer comments are in grey, and our responses are in black. The responses below are an update version of our earlier responses to the reviewers during the open discussion phase of this manuscript from https://doi.org/10.5194/gmd-2021-76-AC1 and https://doi.org/10.5194/gmd-2021-76-AC2

General comments (Dr. Pekka Lauri):

p12L200-215: The expansion of timber plantation depends on the share of production that comes from plantations (η). This parameter is exogenous and extrapolated from Pöyry (1999). This means that the expansion of plantation is not endogenous in the model, but it is taken as given. According to figure A5, the model assumes that share plantation increases on average from 25% in 2000 to 62.5 % in 2100. This issue should be made clear already in the abstract because it has significant impact on the results. For example, if the share of plantations were endogenous in the model, then an increasing demand for roundwood would increase the share of plantations relative to natural forests in EUR region. But because the share is exogenous this does not happen, and EUR region is not able adapt higher demand by intensifying their forest management (Figure A6).

Yes, you are right, this is an important point. We will make this limitation clear in the abstract and add a sentence that highlights the assumption regarding the η parameter.

p1L14 in the revised manuscript is changed as follows: (...) elsewhere. *Using exogenous extrapolation of historical roundwood production from plantations and timber demand, we prescribe expansion of forest plantations at the regional level*. As a (...)

The outcome of the optimal rotation models depends much on interest rates and usually these models include sensitivity analysis relative to different interest rate. To avoid this complication, the rotation times could be solved by maximizing increment (f'=f(ac)/ac) instead of maximizing NPV (f'(ac)/f(ac)=r). This would also be more reasonable objective for the recursive dynamic model where all other choices are based on recursive optimization instead of intertemporal optimization.

Thank you for this important comment. We added this capability in the model to calculate rotation lengths via maximization of increment, however we now choose rotation length based on maximization of current annual increment i.e. f'(ac) only.

Justification for this assumption is reflected in p7L133:141 as well as additional discussion on this in p27L400:408 of the revised manuscript.

Add some discussion about the forest age-class dynamics and optimal rotation models in the introduction. Basically move some material from discussion to introduction. Including forest age-class dynamics in the large-scale land-use model is the main contribution of the study, but this issue is completely ignored in the introduction.

We moved the segment discussing the forest age-class dynamics and rotation lengths to the introdzuction in p3L78:81 of the revised manuscript.

Specific comments (Dr. Pekka Lauri):

p2L26: According to FAOSTAT global roundwood demand was 3969 Mm3 in 2019 and industrial roundwood 2024 Mm3. Global roundwood demand cannot be 1683 Mm3.

We replaced this instance of *roundwood* with *industrial roundwood* in p2L28 of th revised manuscript.

As there are no new estimates of the share of industrial roundwood production coming from plantations, we assume that the trends observed by Jürgensen et al. 2014 still hold. We also updated the industrial roundwood production data now based on latest FAOSTAT numbers.

p2L28 in the revised manuscript is updated to (...) *likely supply more than 33% (654 Mm3) of global industrial roundwood demand (1984 Mm3) in 2020 based on historical trends (Jürgensen et al., 2014).*

p2L26 Add reference or explanation for 33% (560 Mm3) plantation supply -> Pöyry (1999) extrapolation (Figure A5). This it is not data but model outcome.

We added Jürgensen et al. 2014 as a reference for this sentence.

In fig. A5 the caption has a new formulation as: *Modeled contribution of timber harvest from natural forests and plantations to industrial roundwood and wood fuel production in forestry scenario (1995-2100)..*

p2L38: Add more relevant references for high roundwood productivity of plantations relative to natural forests than FAO (2013), e.g. IPCC (2006). Also, add some explanation why roundwood productivity is higher in plantations than managed natural forests.

We added the following references for high roundwood productivity of plantations relative to natural forests:

a) IPCC 2006
b) Payn et al. 2015
c) Cubbage et al. 2007
d) Evans and Turnbull 2004

From a qualitative point of view, plantations have more control on breeding material, fertilization, management intensity etc. than managed natural forests and hence more control of quality and quantity.

We added following explanation for higher productivity in plantations than managed natural forests in p2L40 of the revised manuscript: (..)imperative. P*lantation forests for timber production have potentially higher annual average increment per area than natural forests and managed natural forests (IPCC 2006, Payn et al. 2015, Cubbage et al. 2007, Evans et al. 2004) because they are managed more intensively (fertilizer, thinning) and rely on high quality seeds and seedlings for regeneration. Because of* their (...)

We updated the formulation in eq. 1. with new assumption regarding choice of rotation length.

This is a very important point. We noticed that not having enough heterogeneity in the parametrization of our growth function with underlying parameters from Braakhekke et al. 2019 resulted in relatively homogenous rotation lengths within MAgPIE regions.

We changed our rotation length calculation to maximize current annual increment – decoupling the calculation from dependence on interest rate. Assumptions regarding growth curves in MAgPIE are described in p8L146:147.

In MAgPIE we do not use or model the minimum diameter constraint for sawlogs. Biomass extraction from trees is calculated based on expected yield and area information for simplicity. We added additional discussion regarding this in p27L414:418 of the revised manuscript.

Natural forests are not bounded by rotation length constraints. The model is free to choose which age-class in natural forests to harvest based on harvesting costs and associated trade-offs i.e., during each optimization step, while harvesting natural forests, a decision is made whether it would be cheaper to harvest from alternative sources i.e., plantations. MAgPIE's objective function is to minimize global production costs. We use a lower harvesting cost (per ha) for plantations than in natural forests. This implicitly provides a signal to the model to harvest forests with higher growing stock first.

We added an additional sentence in p8L150 of the revised manuscript for clarity: (...) *Natural forests are not bounded by rotational constraints of plantations*.

We renamed section 2.3 to *Rotation lengths* instead.

We increased the share of production which can possibly come from plantations in EUR. Altering rotation length calculations by maximizing CAI and increasing the share of production than can in principle come from plantations in EUR (0.54 in 1995 to 0.86 in 2100) now results in stable growing stock development over time in EUR.

Updated numbers are shown in table A4 and updated results are shown in fig. A5, fig. A7 and fig. A8 in the revised manuscript.

General comments (Mr. Walter Cervi Rossi):

Thank you for this important comment. Using FAO 2006 (Global planted forests thematic study. Results and Analysis), the mean rotation length in Australia is 34 years (min = 28 years, max = 40 years) - mean rotation length in Latin America (using South America from FAO reported numbers) is 24 years (min = 18 years, max = 29 years). Leech 2013 suggest an optimal rotation of 45 years in Australia. Additionally, the intensity of the management, e.g. using genetic engineered plant material, irrigation and fertilization might differ between Latin America and Australia a lot, even for the same species. As these are aggregated numbers, it cannot be determined with certainty if the spatial patterns on a finer spatial scale (as in fig. 4) are going to be similar between Latin America and Australia.

We have added an additional panel in fig. 4 of the revised manuscript, using the numbers from FAO 2006 to validate the rotation lengths from MAgPIE.

MAgPIE in its current format cannot handle tree species information. Calculation of rotation lengths at the cellular level is one of the novelties of this manuscript. Calibration of cellular rotation lengths to a regional or country level data-set would result in loss of the spatial (cellular) level differentiation in rotation lengths. Instead, for the initial time step, we calibrate the growing stocks to FRA 2020 reported numbers for both natural forests and plantations. Also using a single value for rotation length per MAgPIE region would not be ideal as there are spatial differences in the way plantations grow within each region. Our way of deriving rotation lengths based on carbon stock information from LPJmL for natural vegetation (different species dominate in different cells) helps us in using spatial differences in carbon densities to act as a proxy for differences in species. We are also not aware of any spatially explicit data which is on a finer spatial scale (e.g., 0.5° resolution) with information on both

tree species and associated rotation length which can be used to calibrate MAgPIE's cellular level rotation lengths correctly.

We added additional discussion regarding this in p27L400:408 and p27L414:418 of the revised manuscript.

It is clear that the study was focused on creating a proof of concept that enables a forestry module in MAGPIE. However, I missed a bit the discussion on how realistic are the figures presented. For example, in section 3.1, it is mentioned a large increase in cropland at expense of primary forest areas (where exactly?). Are protected areas included in the analysis? What about agro-forestry (also included?)? Perhaps some discussions around the current and future spatial uncertainties would be relevant as well.

We added a regional level figure (fig. A9) in the appendix to clarify where does cropland expand at the cost of primary forests (and other land-use types).

In terms of protected areas, the manuscript accounts for National Policies Implemented (NPIs) in terms of forest protection and afforestation according to existing national policies until 2030, in support of the Paris Agreement. Additional land protection is based on The World Database on Protected Areas (WDPA) which earmarks category I and II areas from International Union for Conservation of Nature (IUCN) as protected in MAgPIE.

This is now made clear in the method section with additional paragraph in p7L128:131 as well as in Table 1 with an additional column.

Agroforestry is not included in MAgPIE.

In p27L419:p28L426 of the revised manuscript we added further discussion on how realistic the figures are based on uncertainties in the socio-economic model drivers across SSPs as this manuscript only considers the SSP2 scenario. We also added further discussion about the uncertainty of spatially explicit data on plantation forest, with respect to the differentiation between productive and non-productive plantations – which in turn also has a bearing on the results in this manuscript and that the management of plantations also depends on other factors such as availability of workforce, investment, R&D available to improve the management etc.

Productivity is an important component for calculating global costs of demand driven land uses. I`m not fully aware of LPJML, but doing a quick research, I found that LPJML might include the productivity of natural vegetation and planted forests. These were surely incoporated in MAGPIE (right?). But yet it is not clear to me how the productivity of secondary forest came about?

For every cell, the long-term carbon density of natural vegetation from LPJmL is converted to age-class dependent carbon densities by a Chapman-Richards volume growth function. Based on information from LPJmL, we use different parameters in the Chapman-Richards function for plantations and natural vegetation, resulting in faster regrowth of plantations as compared to natural vegetation. The resulting age-class dependent carbon densities for plantations and natural vegetation are converted to harvestable yield with the help of biomass conversion and expansion factors. For secondary forests, we use these age-class specific harvestable yields. We initialize the age-class structure of secondary forest based on observational data (Poulter et al. 2019). For primary forests, we use the highest age-class yield, which reflects natural

vegetation. This is implicitly defined in p10L166:167. We will further clarify it with an additional sentence.

We further clarified it with an additional sentence in p12L211: (...) *y is the age-class (ac) and forest type specific biomass yield in tDM/ha*, C is the (...).

To avoid confusion, we changed p2L34 of the revised manuscript to make it clear that we include secondary forest (and primary forest) in our definition of the term "natural forest", based on the rationale that secondary forest is regrown natural forest.

p13L215 in revised manuscript is updated as: (...) et al. (2020a). *Harvestable biomass yield (yr) is different between natural forests(primary and secondary forests) and plantations by virtue of differences in parametrization of underlying growth function(s).Primary forests are assumed to exist in highest age-class hence are attributed with old-growth forest yields. Both, secondaryforests and plantations yields are age-class specific but differ in growth-dynamics.*

Specific comments (Mr. Walter Cervi Rossi):

Line 175. If a fraction of forestry residues is recovered during the harvesting period, it is likely that there will be a potential decay in productivity in the forthcoming period in comparison with a plantation system that does not recover any fraction of residues. It was not cleat for me if that was included in the model, but it is something to be considered

In p11L196:p12L200 of the revised manuscript, we added an additional paragraph in methods section to include these assumptions.

Typo (Mr. Walter Cervi Rossi):

Line 119. "optimal"

The line containing this typo will be removed as we will re-write the rotation length calculation segment as requested by Dr. Pekka Lauri's review.