

## Response to the letters by Kun et al. and Booth et al.

We would like to respond to the letters by Kun et al. (2020) and Booth, Mackey and Young (2020) making general comments first, and then adding a few specific remarks to some of their concerns. It seems to us that most comments in these two letters are the result of a misunderstanding of applied spatial and timescales, and maybe also a human dimension, that has to do with emotions. Some of their comments are correct and valid at particular scales and for particular carbon management problems, but not necessarily for the specific problem associated with accounting for greenhouse gas emissions from bioenergy originating from sustainably managed forests.

1. Land Use and Land-Use Change: In the introduction of our opinion letter, we clearly state that our analysis is valid only under the condition of sustainable forest management, NOT for land-use change, and NOT for exploitation forestry involving forest degradation. Thus, we object to the summarizing sentence of Booth et al. (2020), who state that we pave the way for destruction of the remnants of untouched forest in Europe or for land-use change in the tropics. We agree that some land-use changes release large amounts of CO<sub>2</sub>, but this was not the topic of our opinion letter. We focus on the spatial scale of a landscape with sustainably managed forests, and not on landscapes that are subject to land-use change, including deforestation.
2. Pristine Forest: We fully agree with the statement of Kun et al. (2020) that what is presently seen as unmanaged forests in Europe have nearly all been harvested at some time in the past. Indeed, the degree of “unmanaged” is a question of timescales. If you let any cleared managed land regenerate, it will look like “pristine” after some time. For example, large parts of the Carpathian forests in Romania may look pristine to some (e.g., Schickhofer & Schwarz, 2019), but in fact these forests were destroyed during World War I, and again during World War II

(Figure 1). With enough time to regenerate and recover, such forests give the impression today of “pristine” forests, but only because the timescale of observation does not consider previous management. There are no pristine forests in Romania. As we stated above, it is a question of timescales: Amazonia was under management by pre-Columbian groups (Levis et al., 2017). The bogs of Siberia were most likely drained by human beaver hunters in earlier times (Schulze, Lapshina, Filipov, Kuhlmann, & Mollicone, 2015). The biotas of Australia were shaped by the earliest human inhabitants and their use of fire (Bowman, 1998). Every continent has its anthropogenic history, and most forests have been intensively used and managed in the past. In Germany, numerous reports exist about the overexploitation of forests in the early 19th century (Hess, 1898) at a time, when we had most likely a biodiversity maximum in Europe (Schulze et al., 2019).

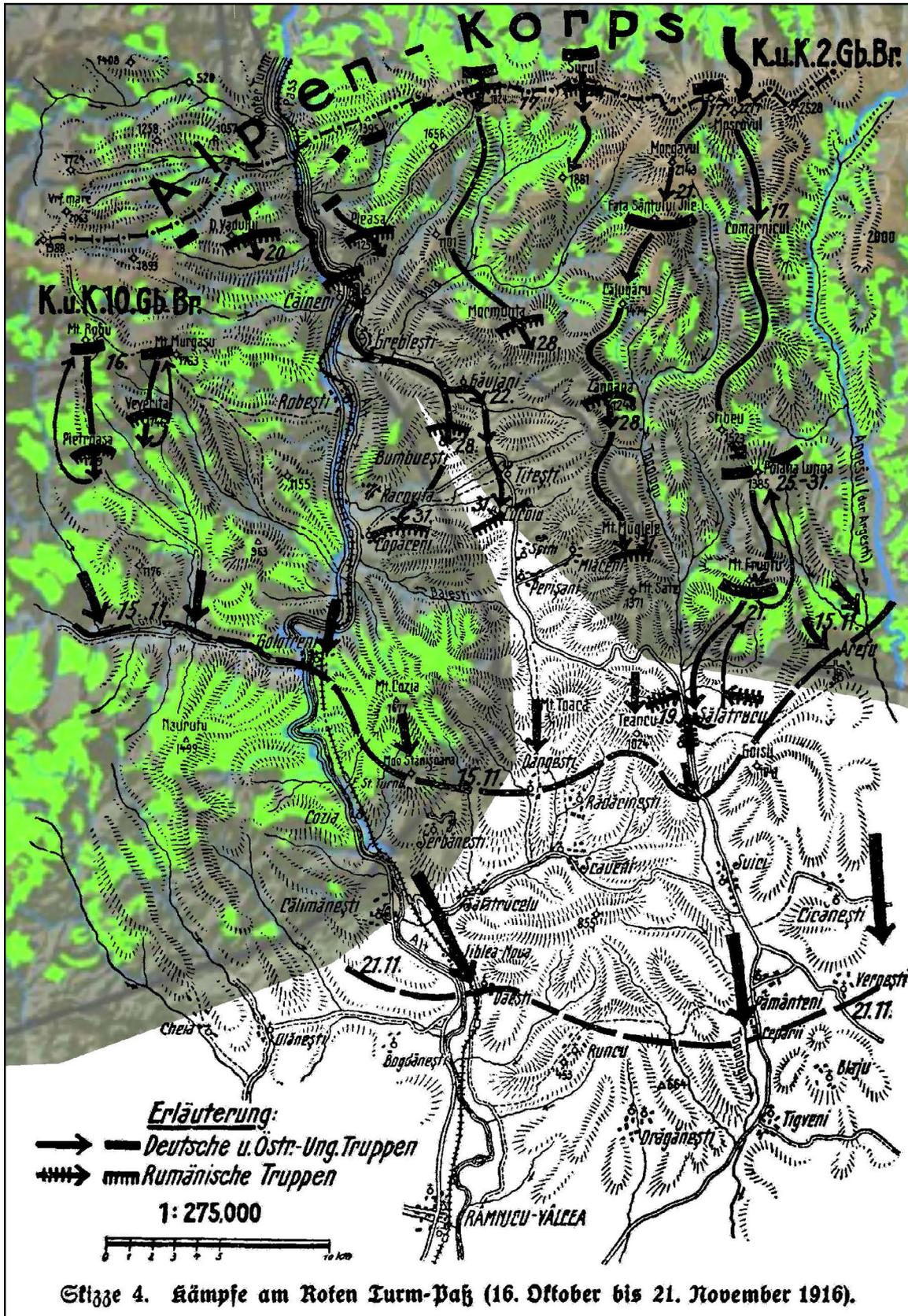
3. Fluxes versus stocks: Stocks are the integral of the net fluxes of carbon in and out of the forest, and one has to know the dynamics of the fluxes to understand the dynamics of the stocks. It is the CO<sub>2</sub> concentration in the air (the stocks of the atmosphere) that affects our climate, but we can only control this concentration by knowing the fluxes to and from the atmosphere. There is the major flux of fossil fuels (and not biogenic fluxes) that perturb the atmosphere but only slightly decreases the vast amounts of fossil fuel stocks. Another major fossil fuel use, and thus CO<sub>2</sub>-flux to the atmosphere, comes from cement production. It is not the fossil C-stocks stored in limestone that affect the atmosphere. Also, it is the EU-target of highest priority to reduce the annual CO<sub>2</sub>-equiv emissions by 40% until 2030 compared to 2005 levels ([http://ec.europa.eu/clima/policies/strategies/2030\\_de](http://ec.europa.eu/clima/policies/strategies/2030_de)). The energy that is needed for domestic and industrial purposes should increasingly be generated from renewable energy sources, as stipulated in the Renewable Energy Directive (EU 2018) and bioenergy is one of those renewable technologies. It is the flux of greenhouse gases from energy production that is important in our case, and not the installed capacity of energy plants.

Incentives to store carbon in ecosystems in order to compensate the ever increasing fossil fuel emissions give

This article is a Response to the Letters by Booth et al. 12, 1036–1037 and Kun et al. 12, 1034–1035. See also the Opinion article by Schulze et al. 12, 186–197.

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**FIGURE 1** The original map of the movement of Austrian and German troops across the Southern Carpathian alps in World War I. Green areas: “Pristine” forest according to Schickhofer and Schwarz (2019), with the troop movements of World War I shown in black arrows, and battle fields shown as cross bars according to von Falkenhayn (1921). This is one of 13 “unmanaged” reference site of the Primofaro project (Schickhofer & Schwarz, 2019). Photos of the sites can be visited in the war archive of Vienna. Map prepared by Mihai Nita, University of Brasov, Romania

people a false sense of having solved the problem, but it does not give an incentive to solve the biggest problem of all, which is reducing the large fossil fuel flux from the fossil stores to the atmosphere. Thus, we clearly support the above-cited EU regulation that CO<sub>2</sub> emissions, originating mainly from fossil fuel fluxes, should be reduced and not compensated by biomass storage.

In addition, we would like to confirm that the carbon stocks of managed and unmanaged forests per area unit in Germany are not statistically different. At the time, when we wrote our opinion letter, we had access only to a limited dataset, reported in our original Table 1. However, meanwhile we had access to a reanalysis of data from the German national forest inventory (NFI), sorted by management and unmanaged forests based on original data records.

The data differ from those published in our original Table 1, because the scale has changed from plot level observations to a regional grid-based landscape scales. The *average stocks* of stem volumes are higher for *Fagus* under unmanaged conditions (worth 7 years of “average” growth) as stipulated by management to enhance growth of selected trees, but they do not differ significantly for *Picea*. More important is that the *maximum stocks* at the time of harvest are not significantly different, neither for *Fagus* nor for *Picea*. However, it takes a shorter time to reach maximum stocks for forest under management. Thus, non-intervention does not lead generally to higher stocks in the living and dead biomass at landscape scale, but biomass is accumulated faster under management. The difference in growth rate (increment) between managed and unmanaged is smaller than shown in our earlier report, probably because some of the included unmanaged plots were put aside from management at recent times. In

an earlier studies, Schulze (2017, 2018) showed that the highest and oldest *Fagus* trees were found in managed and not in protected forests. The volumes of *Fagus* reach an upper limit at an age of about 150 years, also based on observations in the old reserve of Nera (Romania) and Uholka (Ukraine). Beyond this age, trees or stands collapse, mainly because roots of *Fagus* are affected by *Armillaria mellea*, and then they become unstable and are over thrown by wind. Thus, trees do not get old in Central Europe. Coring hundreds of trees on a grid-based inventory, the oldest *Fagus*-tree we found was 286 years old.

High stocks contain a high risk of loss caused by climatic and biotic extreme events (drought, wind) and pests (bark beetles; Schulze, 2018). The collapse of the beech forest “Heilige Hallen” or “Solling” in Germany may be examples of that situation (personal observations). Thus, stocks of old-growth forest are not resistant to these extreme events and are equally vulnerable to rapid carbon losses, as it happens in managed forests by harvesting. The bark beetle outbreaks in Bayerische Wald and Harz National Parks are additional examples (e.g., Wegener, 2018). In the unmanaged forest, the dying trees are transferred to the deadwood pool that start to decay at different rates, faster for needles and small twigs and slower for the trunk. Accordingly, harvested wood is transferred to the pool of harvested wood products (HWP) where different wood products get out of use with various “decay rates” (lifetime). At the end, carbon fixed by photosynthesis and stored in the wood will eventually be released back to the atmosphere independent whether it is used as a raw material for human use or not. The time scales of decay are very similar. As shown in Table 1 of our publication, the average half-lives of natural decay and product use are not different.

**TABLE 1** Average and maximum C stocks in living and dead volumes for forest registered as managed and unmanaged in Germany, based on plot data from the national forest inventory, independently of conservation status. Data obtained from the von Thuenen Institute, Eberswalde, Germany

	Broadleaved ( <i>Fagus</i> )		Significance	Coniferous ( <i>Picea</i> )		Significance
	Un-managed	Managed		Un-managed	Managed	
Average stocks (m <sup>3</sup> /ha life and dead wood)	435 ± 34, n = 332	366 ± 6, n = 9,104	***	421 ± 37, n = 308	425 ± 6, n = 15,073	n.s.
Maximum stocks (m <sup>3</sup> /ha live and dead wood, >94.Percentile)	981 ± 148, n = 46 of 732	919 ± 195, n = 776 of 15,519	n.s.	1,118 ± 202, n = 43 of 859	1,098 ± 201, n = 1,456 of 29,113	n.s.
Area weighted age (years)	115	101		94	69	
Increment (m <sup>3</sup> ha <sup>-1</sup> year <sup>-1</sup> )	8.99 ± 0.9, n = 327	10.28 ± 0.16, n = 8,746	***	9.01 ± 1.04, n = 271	13.95 ± 0.16, n = 14,219	***

\*\*\**P* < .01

4. Plot studies versus regional surveys: We already discussed the difference between observations at stand level and grid-based inventories at landscape scale for Table 1. The same difference exists with soil surveys. The study of Mayer et al. (2020) about effects of management on soils is based on site-specific plot studies. Grid-based studies do not show such a difference (Schulze et al., in preparation).
5. Carbon sink capacity of old growth forests: The original study by Luysaert et al. (2008) was a review based on plot studies of flux measurements. It was the main objective of that study to show that fluxes were larger than zero at high stand age. Clearly, in- and outfluxes of carbon will always be larger than zero in living systems, even though Net Ecosystem Productivity (NEP) declines with age. In the study by Luysaert et al. (2008), NEP reached a maximum at stand age of 20 years after regeneration and a minimum at age 200 years. The later slight increase was due to new regeneration. Meanwhile Nord-Larsen, Vesterdal, Bentsen, and Larsen (2019) and Gundersen (2020) questioned these results of a carbon sink in old stands. In a reply, Luysaert, Schulze, and Knohl (2020) state that, given the huge variation, more data are needed to resolve this issue. Thus, after all, and in a long-term perspective, Odum (1973) may be confirmed: under steady-state conditions, ecosystems reach a balance between carbon sequestration and respiration. It is again a question of scale: the C-balance trajectory over time of regions is different from that of a single tree, or a stand.
6. IPCC guidelines and accounting: Indeed, the IPCC guidelines are complicated, and the separation between a forestry (including HWP) and an energy sector makes accounting for a closed supply chain of wood cumbersome even at national scale, especially when wood is imported and exported beyond borders. The IPCC rules were made to address a global scale problem and the accounting of carbon emissions and removals at the national level. They do not allow comparison of activities within a country. This is why we showed a table with national level fluxes in our original publication to make the main point clear that carbon sequestered by photosynthesis returns to the atmosphere by decomposition or by combustion of biomass for energy, regardless of the scales used for accounting. It is the same amount of carbon that is sequestered and released, irrespective of the fact that wood contains less energy by volume or mass than fossil fuels. The societal objective is to reduce greenhouse gas emissions from fossil fuels, because such carbon is not returned back to fossil stores. It is misleading to say that consumption of wood for energy leads to more CO<sub>2</sub> entering the atmosphere than by the natural process of decomposition. This is again a problem of spatial and temporal scale, whether we are referring to

a single tree or stand, or a region or the whole globe, or whether we refer to a decade or a century. The scale of analysis complicates the type of statements that can be made with respect to the benefits of forest management activities on climate. We reiterate here that our focus is on sustainable forest management at subnational and landscape scale, where the IPCC accounting rules, designed for global scale accounting, show limitations to make sound judgments.

7. Climate targets. It is the objective of the international agreements on climate change to limit the increase in global average temperature to 1.5–2.0 K. It is up to the nations to translate this general goal into national targets for greenhouse gas emissions reductions. Reaching the goal will require a substantial reduction in fossil fuel emissions for all nations. There are few nations, where a reduction of land-use change may also significantly contribute to improve the national greenhouse gas balance. However, in our paper, we were not dealing with land-use changes.

Some specific comments to Kun et al. (2020).

- Clearly, trees and soils do not increase their carbon stocks unlimited. The famous rule of Körner (2003) of “slow in and rapid out” brings the problem to the point. NEP estimates potential changes in carbon stocks. This is not suitable as a measure of climate mitigation, because lateral fluxes (i.e., fluxes across landscapes and time) are not reported. This is why additional terms have been defined for accounting of lateral fluxes (Schulze et al., 2009), or for dealing with the degree of permanence of the sequestered carbon (Brandao et al., 2013). Fossil stores are by far the most important stocks that should be left in the ground as the fluxes from these stocks have the largest effect on climate.
- We did include the fossil fuel demand for harvesting and processing. Our data are net emissions. Other studies further show that such emissions are often relatively small for wood fuels. Only about 3%–20% of the photosynthetic carbon is contained within the wood fuels, depending if it is from local sources or from international supply chains (Taerog, Mustapha, Stupak, & Raulund-Rasmussen, 2017).
- The age class distributions of forests in Germany are public data.
- *Fagus* and *Picea* contribute about two-thirds of the forest area in Germany. We suggest that our data would also be representative also for *Pinus* because it is managed in systems similar to *Picea*. *Quercus* is different, as it can only survive in managed conditions because it is overgrown by *Fagus* under natural conditions.

Some specific comments concerning Booth et al. (2020).

- Fires: Indeed, forest fires act in a similar way as bioenergy with respect to carbon emissions to the atmosphere. In most countries, wildfires are of anthropogenic origin (Mollicone, Eva, & Achard, 2006), and should thus be accounted for as an emission. The difference between combustion and wildfires is that the energy released is being used or not. As said above, the full carbon balance needs to be considered and it will only get complete, if all processes, including ecosystem respiration from managed and protected areas and other losses, for example, by natural disturbances, are included.
- Recent photosynthesis: We used this term to separate present-day carbon sequestration by trees, from the sequestration that generated fossil fuels in very long-term geological processes. The fossil fuels we use today were also produced by photosynthesis, but millions of years ago.
- Wood balance: We believe we compiled the most comprehensive wood balance possible for Germany, even if it still contains a number of gaps, which appear to exist for the wood balances of most OECD countries. Gaps are likely due to the fact that wood is removed from forests, which is not officially recorded, such as firewood, bark, and over-size. In some countries, this may also be illegal cuttings.

The factor 10 between the climate change mitigation potential of managed and unmanaged forest as stated in our original article is based on a limited dataset that was available to us. Based on a reanalysis of the grid-based German national forest inventory (Table 1), this difference becomes smaller (see Table 1), but remains significant (about factor 2 for spruce).

The statement of Booth et al. (2020) that our paper may be cited in support of increased harvesting craving for Europe's last remnants of untouched natural forest points at an additional dimension: The human dimension. As most citizens in Germany live in cities, there is an increasing demand for recreation, outdoor sport activities, stress release, and other services provided by forests. Paragraph one of the German conservation law lists not only biodiversity but also recreation as an objective. We suggest that this human dimension, together with biodiversity, is the main reason for the desire of society to set aside forests as unmanaged or unmanaged-looking forest, that is, for conservation and recreation. If these objectives are the focus, the harvesting and transport of trees by large machines become an obstacle, while forwarding of wood by horses is welcome, because it contributes to the recreational experience. Especially for recreation, old-growth stands act as a surrogate for pristine conditions that are perceived as desirable for a number of more or less well-argued reasons. There are many good societal reasons to preserve forests as unmanaged, but climate change mitigation is not

one of them. Also, biodiversity turns out to be supported by management and not by conservation (Schall et al., 2020). There is an urgent need to disentangle arguments based on carbon and diversity management versus other dimensions of forest management.

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