possibility of undetectable carbon debts from land-use intensification[29] or unverifiable gains from carbon restoration measures.

Our analysis suggests that land-use impacts were pronounced already in the pre-industrial period and reveals that effects of forest management and grazing on vegetation biomass are comparable in magnitude to the effects of deforestation. Therefore, a focus on biomass stocks helps to recognize options for land-based greenhouse gas mitigation beyond the mere conservation of forest area. Our findings also suggest that important trade-offs in climate-change mitigation need to be tackled. The scientific and political focus on forest protection and productivity increases needs to be complemented by analyses of the interactions between land use and the carbon state of ecosystems.

Online Content Methods, along with any additional Extended Data display items and Source Data, are available in the online version of the paper; references unique to these sections appear only in the online paper.

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Supplementary Information is available in the online version of the paper.

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