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Forest carbon sink uncertainties in Land-Use, Land-Use Change and Forestry (LULUCF) regulation in Europe: Projections of carbon stocked in above- and belowground forest biomass using a Markov chain model under changing climate in Finland

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Forests play an important role in one of the most important ecosystem services, climate regulation. In order to mitigate climate change, various international agreements aim at decreasing emissions through Land-Use, Land-Use Change and Forestry (LULUCF) activities. In a legislative proposal by the European Union, emissions from forests are accounted for in relation to an estimate of average emissions for a range of years in the past. However, different forest structures, management activities, growth variations and impacts of changing climate may result in considerably different future emissions.

We simulated the development of carbon stocked in above- and belowground forest biomass under varying climate and harvesting scenarios using an area-based matrix model for Finland. The initial forest-area distribution and business-as-usual transition probabilities were derived from National Forest Inventory (NFI) data. The simulations were implemented as simple Markov chain models, but the model was also developed to incorporate climate-induced tree growth as a time-inhomogeneous Markov chain. We particularly used the augmented simulation model to assess the magnitude of potential uncertainties due to changing climate and forest management in the projections prolonged until 2050.

The potential amounts of both the carbon stored and extracted varied considerably depending on the level and allocation of future harvests. If realized, the highest climate-induced growth improvements could increase the carbon stocks by up to one third in the end of the simulated period, compared to observed transitions and harvests. Even if climate-induced growth was not assumed, considerable increments to the growing stock could be obtained by applying future harvests precisely according to the silvicultural recommendations instead of how their proportions and timings have been realized in the past.

Relying on past transition probabilities or harvest levels could result in considerably wrong decisions regarding future carbon stocks and harvesting possibilities. Particularly, a forest production strategy selected by projecting future removals assuming a continuation of current forest management practice and intensity could result in a lower level of carbon stocked in forest biomass, and consequently, lesser carbon sinks than possible if uncertainties were properly accounted for. When defining the reference level for future harvests, it should not be done with respect to a fixed reference period, but based on projections that account for uncertainty.