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COMMENT

Comment on 'Climate mitigation forestry—temporal trade-offs'

Leif Gustavsson[1,*], Roger Sathre[1], Pekka Leskinen[2], Gert-Jan Nabuurs[3] and Florian Kraxner[4]

[1] Linnaeus University, Växjö, Sweden
[2] European Forest Institute, Joensuu, Finland
[3] Wageningen University and Research, Wageningen, The Netherlands
[4] International Institute for Applied Systems Analysis, Laxenburg, Austria
[*] Author to whom any correspondence should be addressed.

E-mail: leif.gustavsson@lnu.se

In an article recently published in ERL, Skytt *et al* (2021) describe a modeling exercise in five Swedish counties that found short-term climate benefits from reducing forest harvest. We agree with Skytt *et al* that forests have strong potential for climate change mitigation, that effects and consequences must be considered over the short-, medium-, and long-terms, and that old forests are important and fulfil many functions including biodiversity protection. However, we argue that Skytt *et al* (a) place unfounded faith in the ability to quickly develop and deploy sustainable non-forest-based supply chains to respond to reduced forest harvest and reduced supply of wood-based materials and energy, (b) violate life cycle assessment (LCA) standards by not maintaining a consistent functional unit, (c) apply substitution factors (SF) for forest-based energy and materials that are low compared to current scientific evidence, (d) do not consider the climate mitigation potential of harvesting sustainable shares of forest residues, and (e) do not consider the effects of climate change and the risk of disturbance to carbon stored in forest ecosystems.

(a) We know that mitigation of, and adaptation to, climate change requires a strategic evolution and transformation of various technical sectors including energy, manufacturing, construction, and transport (Johnsson *et al* 2019, Tong *et al* 2019, Cowie at al 2021, UNEP 2021). For example, massive deployment of high efficiency renewable energy systems is needed. Fully avoiding climate disruption will increasingly require negative emission technologies, such as bioenergy with carbon capture and storage. Restricting forest products will limit the options available for strategic evolution and transformation of energy and material sectors and will make the implementation of sustainable technical systems more challenging. Skytt *et al* focus on short- and medium term carbon stock benefits from reduced harvest. They argue that short term gains in forest carbon stock will 'buy us the time needed to implement sustainable technical systems, such as non-fossil fuel based electricity production, carbon capture and storage etc.' Yet they assume a SF of zero for electricity in the modelling exercise, implying that such systems have already been fully deployed. They also offer an 'illustrative example' of using hydrogen for steelmaking, an immature technology still at the research stage and with uncertain prospects. Skytt *et al* appear to underestimate the challenge of rapidly transitioning from our current dependence on non-renewable energy and material resources.

(b) Skytt *et al* do not consider the decreased supply of pulp and paper products to end users when forest harvest levels and the production of pulp and paper are decreased in their study. This is a severe methodological shortcoming, which violates LCA standards by fulfilling different functional units when comparing different forest management alternatives. The LCA methodology framed by ISO14040 and 14044 standards (ISO 2006a, 2006b) is intended to compare alternatives on a functionally equivalent basis. Skytt *et al* fail to ensure functional equivalency by ignoring the services provided by pulp and paper products, which would decrease in step with decreased forest harvest. They justify this omission with reference to Sathre and O'Connor (2010) and Leskinen *et al* (2018), saying they 'included only cases where a decrease of the supply of biomass to the industry would lead to increased use of fossil fuels or materials.' This is a misuse of the recommendations of Sathre and O'Connor (2010) and Leskinen *et al* (2018), which are only applicable to calculating substitution benefits in greenhouse gas balances, and are no justification for violating LCA standards by failing to fulfill a consistent functional unit. Skytt *et al* then call out 'the need to investigate to what extent different product groups provide substitution. It is only in cases where reduced use of wood products lead (sic) to increased future use of fossil-based products or fuels, that avoided emissions can be accounted.' Yet in the case of reducing forest harvest, it is clear that 100% of the reduced service once provided by forest products, will need to be substituted to maintain identical services and fulfil the functional unit as per LCA standards.

(c) We agree with Skytt *et al* that SF can be a significant component when estimating the total mitigation potential of the forest sector. Skytt *et al* argue that technological development and renewable energy deployment will steadily improve the environmental performance of non-forest materials over time, thus reducing the climate SF of forest products. However, advancements are not limited to non-forest sectors, and current development within the forest sector offers improvements in forest management, wood-based materials, and forest bioenergy technology. Furthermore, given the urgency of climate change mitigation, the forest industry is actively seeking improved product portfolios to increase the climate benefits of wood-based products in replacing fossil materials and energy. Examples of this include wood-based textiles and modern wood construction materials such as cross-laminated timber (CLT). Novel technologies will typically develop faster than existing, more mature technologies. Furthermore, there will be substitution opportunities on the margin for a long time, as fossil fuels and carbon intensive materials remain in use in many areas. Therefore, material and energy substitution activities can be, and should be, targeted for high effect, thus specific marginal SF values should be used and not current average values. The SF values for material and energy used by Skytt *et al* are low compared to current scientific evidence. For example, Skytt *et al* used default SF values for energy that include a SF for electricity of zero. However, rough SF values for standalone electricity production including fuel cycle and end use emissions are 0.43 and 0.98 when woody biomass replaces fossil gas and coal, respectively[5]. Valid SF values are important in this sector, as woody residues from forests and forest industries can efficiently generate electricity in standalone and cogeneration power plants, in place of fossil fuels. We agree with Skytt *et al* that reduced use of wood products will reduce electricity use within the forest industry, but we note that electricity use will increase in other industries that make alternatives to wood products. Overall, the significance of accurate SF values is seen by comparing figures 7(a) and (b) of Skytt *et al* (2021): with higher SF values corresponding to modern forest product usage, the initial period during which reducing harvest may be climatically beneficial is shortened to mere decades, followed by strong climate impact thereafter.

(d) Skytt *et al* do not consider the harvest of logging residues in their forest management alternatives, despite such practice having a significant potential for renewable energy supply in Sweden. The annual current Swedish harvest of forest slash is about 10 TWh, while the annual potential slash and stump harvest may be about 65 and 40 TWh, respectively (IRENA 2019). Due to Swedish soil conditions a large extraction of logging residues could lead to a deficiency of nutrients and a reduction in forest productivity (Koponen *et al* 2015), thus sustainable management could require ash recycling and selective fertilization to ensure forest productivity. The Swedish Forest Agency (2019) has recommendations regarding the extraction of forest residues and the application of recycled ash to secure sustainable harvest levels while considering soil fertility and biodiversity. Replacing fossil fuels with harvested logging residues, which would otherwise decay naturally and release their stored carbon, will help to mitigate climate change (Sathre and Gustavsson 2011, Gustavsson *et al* 2017, 2021). Hence, the potential climate benefits are underestimated by Skytt *et al*, particularly for forest management alternatives with higher harvest levels.

(e) Skytt *et al* briefly mention the 'effects of changes in precipitation and risks of damage from extreme weather events and pests', but their analysis does not consider potential disturbances to long-term carbon storage in forests. Climate change is not considered in their modeling, yet is expected to cause various impacts to Nordic forests, which are projected to benefit in terms of higher productivity but face higher risk of disturbances. Relying on indefinite carbon storage in forest ecosystems is a risky climate

[5] Calculations are based on fuel-to-electricity conversion efficiencies of 50% for fossil gas and 40% for coal and biomass, default fuel combustion emissions from IPCC (2006), and upstream fuel cycle fossil emissions of 5% of combustion emissions for all fuels. The corresponding SF values are 0.46 and 0.91 for state-of-the-art energy technologies based on fuel-to-electricity conversion efficiencies of 56% for fossil gas, 46% for coal, and 45% for biomass (Danish Energy Agency 2020), and upstream and combustion emissions from IPCC (2006), Gustavsson *et al* (2015) and Gode *et al* (2011), and considering Swedish logging residues with an international transport of 1000 km. Using state-of-the-art technologies show rather small changes of SF compared to default values, as the technological development improves the conversion efficiencies of both the fossil and bioenergy technologies. However, more efficient technologies are important as more electricity is produced per unit of fuel.

mitigation strategy, particularly in the context of future temperature rise, precipitation variability, and altered disturbance regimes. Skytt *et al* ignore these risks, unrealistically assuming that unharvested forests will continue to store carbon indefinitely.

We agree with Skytt *et al* that science-based publications have reached different conclusions about forestry and its climate effects. The large global variation in forest ecology, forest management, and energy and material systems can partially explain these differences. However, different methodological approaches also explain the variation, especially between studies in the same ecological and technological context (Cowie *et al* 2021). Cowie *et al* conclude that focusing on short-term emissions reduction could make it more difficult to achieve medium- and long-term reductions, and that narrow perspectives obscure the most important role that bioenergy can play: to support the transformation of energy, industrial, and transport systems so that fossil fuels remain stored in geological formations.

Skytt *et al* are mainly focused on 'the coming 10–30 years' and they 'suggest that future research should focus on forest management strategies that can provide rapid climate benefits.' While appreciating the importance of the short term, we also must consider livelihood strategies in the medium- and long-term perspectives. Skytt *et al* favor the one-time climate benefit of increasing forest stock, at the expense of the continuous climate benefits of utilizing forest flows. Forest system modeling that is unencumbered by the flaws described above shows that reducing forest cuttings in south Sweden offers some climate benefits in the short term of 30–40 yr (Gustavsson *et al* 2021), in line with the results for all of Sweden (Gustavsson *et al* 2017). But after this initial period, the climate benefits are greater for active forestry with high harvest and efficient utilization of biomass. After 200 years such active forestry may generate about ten times greater carbon emission reduction, compared to the initial reduction from limiting forest cuttings (Gustavsson *et al* 2021). Many other studies also acknowledge that forest biomass as part of ongoing forest value chains can contribute to climate change mitigation, especially in the medium to long term (e.g. Marland and Schlamadinger 1997, Kraxner *et al* 2003, Lundmark *et al* 2014, Smyth *et al* 2014, Creutzig *et al* 2015, Kilpeläinen *et al* 2016, Favero *et al* 2017, 2020, Nabuurs *et al* 2017, Vance 2018, Petersson *et al* 2021). Hence, we argue that forests fulfil many functions, and in a country like Sweden the climate goals can best be met with active forestry including harvest and efficient utilization of renewable biomass for replacement of carbon-intensive non-wood products and fuels.

ORCID iDs

Roger Sathre https://orcid.org/0000-0002-1861-6423
Gert-Jan Nabuurs https://orcid.org/0000-0002-9761-074X
Florian Kraxner https://orcid.org/0000-0003-3832-6236

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