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Climate effects of forestry and substitution of carbon-intensive materials and fossil fuels – a country level study for Sweden

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A topic of active discussion in Sweden is how forests should be managed. Specifically, there is much interest in how forest resources should be used effectively to mitigate climate change. Forests can play several roles in carbon emission reduction strategies, for example as a reservoir for storing carbon and as a source of renewable energy and material. To better understand the linkages and possible trade-offs between different forest management strategies, there is a need for integrated analysis where both sequestration of carbon in growing forests and the effects of substituting carbon intensive products within society are included.

In this presentation, we analyse the climate effects of directing forest management in Sweden towards enlargement of the set-aside area in forests, or towards increased forest production, relative to the current forest management over 100 years. We consider various scenarios of forest management and biomass use, and we estimate the carbon balances of the forest systems and their climate impacts in terms of radiative forcing.

The presentation is built on three general forest management scenarios: Business as usual (BAU), Set-aside, and Production. The BAU scenario reflects current forestry practices. In the Set-aside scenario, the protected area is doubled at the starting year of the simulation and then kept constant while all other settings are equal to BAU. In the Production scenario a higher forest productivity is achieved through more intensive management. Each forest management and harvest extraction scenario combination provides a supply of biomass raw materials to be used in the building and energy sectors. Different building construction and energy system scenarios are considered.

We ensure that the same services are delivered to society in the different forest management scenarios. In the Production scenario, more biomass is harvested compared to the BAU, increasing the potential production of timber buildings and bioenergy. In the Set-aside scenario, the harvest is less compared to BAU, decreasing the potential production of timber buildings and bioenergy. With less production of timber buildings and bioenergy, the construction of concrete buildings and use of fossil fuels need to increase to deliver the same amount of service to society.

Simulations of forest development and biomass harvest were made with the Heureka Regwise simulator, which is a forecast tool for forests and forestry on a large scale regional level. The core of the tool is simulation models for the tree-layer: growth, mortality and ingrowth. Models for individual trees simulate height growth in young stands (mean height < 7 m), and basal area for established stands (mean height ≥ 7 m). It also includes models for management, harvest, effect of climate change, and storm fellings. Input data for the simulations came from Swedish National Forest Inventory permanent and temporary plots.

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Simulations were made in 20 five-year intervals for each scenario; these results were then linearly interpolated and used as annual input data for further modelling.

Soil carbon stock changes in mineral soils were estimated with the Q-model. This is a soil decomposition model based on the continuous quality theory, where organic material entering the soil is decomposed over time in cohorts with specific initial qualities for needles, fine roots, branches, coarse roots, stumps, and stems.

The building construction scenarios include modern prefabricated concrete construction, prefabricated modular timber and cross-laminated timber building systems. A prefabricated concrete frame building in Växjö, Sweden (latitude 56°87′37″N; longitude 14°48′33″E) adapted to meet the Swedish passive house criteria, is used as reference building and is redesigned in detail with prefabricated modular timber and cross-laminated timber building systems. The building is 6 storeys high and has a total of 24 apartments, comprising 1-3 rooms with a total heated floor area of 1686 m^2. The full lifecycle implications of the building versions are considered excluding the operation phase, as the building versions are designed to have the same operating energy use. We consider complete materials and energy chains, including the primary energy used to extract, process, and transport the required materials, and taking into account material losses and efficiencies of fuel cycles and conversion and distribution systems. We also consider calcination and carbonation carbon flows linked to cement-based materials. The service life of each building version is assumed to be 80 years. At the end-of-life of the building, steel is assumed to be recycled as scrap for production of new steel, concrete is crushed into aggregate and exposed to the atmosphere to increase carbonation during four months and then used for below-ground filling, while wood is recovered and used for energy. For comparison, a 4-storey high residential building with a different architectural design is also analysed.

There is a large potential for biomass to be used in the electricity, heating, and transportation sectors, replacing fossil energy. The shares of fossil fuels and renewable energy in the European Union in 2014 were about 72% and 14% (bioenergy: 9.1%; hydro: 2.0%: others: 2.6%), respectively. In comparison, of the global primary energy use in 2014, fossil fuels, biomass and nuclear constituted about 81%, 10% and 5%, respectively, giving a fuel dependence of 96%. Increased use of bioenergy may help reduce the dependence on fossil fuels and mitigate the integration of wind and solar in renewable energy systems. Here, harvest residues from forest thinning and final fellings as residues from wood processing and building construction and demolition are assumed to be used for bioenergy. Net CO_2 emissions from bioenergy systems are compared to those from fossil energy systems that provide the same services. Each bioenergy scenario has a corresponding fossil energy system that makes equivalent products based on coal or fossil gas for cogeneration of heat and electricity or diesel oil for transportation. For biomass used for bioenergy an international transport of 1000 km is included in the analysis.

In the first 20 years of the analysis, the differences between the scenarios were small when bioenergy was assumed to replace fossil coal. After this initial period, a strategy aimed at high forest production, high residue recovery rate, and high efficiency utilization of harvested biomass gave most climate benefits which also increased over time. At the end of the analysed period, the effect of setting aside more forest for carbon storage resulted in higher total emissions, also compared to the reference, due to lower forest harvests leading to higher carbon emissions from the energy and material systems.

The climate benefits are significantly reduced if bioenergy replaces fossil gas, and take longer to manifest. Replacing gas, the Set-aside scenario gave climate benefits during the first 20-50 years compared to the Production scenario, but after 50 years the Production scenario with high residue recovery rate gave clear climate benefits that increased over time, compared to the Set-aside scenario. Using biomass to replace liquid motorfuels further reduced the climate benefits of the Production scenario compared to the Set-aside scenario. The assumed type of wood building system or the type of residential building has a rather small impact on the results.

In this analysis, the climate implications of bioenergy and wood construction are considered in a holistic life-cycle system perspective. The analysis is based on detailed description of forest systems and technical systems, where a landscape perspective is used to consider the dynamics of productive forests in Sweden. All significant annual flows of CO_2 to and from the atmosphere are considered, but not other climate effects such as albedo. Hence, the cumulative radiative forcing is calculated based on annual net CO_2 emissions to the atmosphere. The timespan of 100 years appears to be long and technological development may change the results, but still only about one forest rotation period is included in the analysis. In longer timespans the climate benefit of the Production scenario is expected to further increase compared to the Set-aside scenario, as the carbon stock in the set-aside forest may reach a dynamic steady state, while the forest in the Production scenario continues to produce biomass that can be harvested and used for bioenergy and materials.

Key factors steering the results are forest management, amount of harvested biomass, use of forest biomass and replaced non-wood products and fuels, end-of-life management of building materials and timespan of the analysis.

In summary, active forest management with high harvest and efficient forest biomass utilization with replacement of carbon-intensive non-wood products and fuels appear to provide significant climate benefits, compared to setting aside forest land and storing more carbon in the forest and reducing the amount of harvest biomass.

Main sources:
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Ongoing work by Dodoo, A., Gustavsson L., Sathre, R., Tettey, U.Y.A. and Truong, N.L.