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The potential role of forest management in Swedish scenarios towards climate neutrality by mid century ☆

Olivia Cintas [a,*], Göran Berndes [b], Julia Hansson [b,c], Bishnu Chandra Poudel [d], Johan Bergh [d], Pål Börjesson [e], Gustaf Egnell [f], Tomas Lundmark [f], Annika Nordin [g]

[a] Department of Energy and Environment, Energy Technology, Chalmers University of Technology, Göteborg, Sweden
[b] Department of Energy and Environment, Physical Resource Theory, Chalmers University of Technology, Göteborg, Sweden
[c] Climate and Sustainable Cities, IVL Swedish Environmental Research Institute, Stockholm, Sweden
[d] Department of Forestry and Wood Technology, Linnaeus University, Växjö, Sweden
[e] Environmental and Energy Systems Studies, Lund University, Lund, Sweden
[f] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden
[g] Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Umeå, Sweden

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ABSTRACT

Swedish climate policy targets net zero greenhouse gases (GHG) by mid-century, with road transport independent of fossil fuels by 2030, requiring far-reaching changes in the way energy is used. Forest management is expected to support carbon sequestration and provide biomass for various uses, including energy. In this paper, we combine two energy scenarios with four forest scenarios and quantify GHG balances associated with energy-use for heat, electricity, and road transport, and with forest management and production, use, and end-of-life management of various forest products, including products for export. The aggregated GHG balances are evaluated in relation to the 2-degree target and an allocated Swedish CO_2 budget. The production of biofuels in the agriculture sector is considered but not analyzed in detail.

The results suggest that Swedish forestry can make an important contribution by supplying forest fuels and other products while maintaining or enhancing carbon storage in vegetation, soils, and forest products. The GHG neutrality goal is not met in any of the scenarios without factoring in carbon sequestration. Measures to enhance forest productivity can increase output of forest products (including biofuels for export) and also enhance carbon sequestration. The Swedish forest sector can let Sweden reach net negative emissions, and avoid "using up" its allocated CO_2 budget, thereby increasing the associated emissions space for the rest of the world.

1. Introduction

In 2015, at COP21 in Paris, world leaders agreed, among other things, to (a) aim for a peaking of global greenhouse gas (GHG) emissions as soon as possible, (b) achieve GHG neutrality ("a balance between anthropogenic emissions and removals by sinks") in the second half of this century, and (c) hold global warming well below 2 °C (UNFCCC, 2015). This will require strong mitigation efforts (IPCC, 2014). Cumulative carbon dioxide (CO_2) emissions and global temperature change are near-linearly related and independent of the timing of CO_2 emissions (Allen et al., 2009; Matthews et al., 2009; Meinshausen et al., 2009; Zickfeld et al., 2009; Knutti and Rogelj, 2015; MacDougall et al., 2015). A global cumulative "carbon budget" in line with the 2-degree limit has been proposed to be more robust and easier to implement as a policy target than emissions-rate or concentration targets (Allen et al., 2009). However, difficulties translating carbon budgets into something governments can control, such as shorter-term emission targets, have also been pointed out (Victor, 2009).

In 2013, the IPCC working group I (WGI) presented a range of carbon budgets associated with various likelihoods of staying below a 2-degree limit. For a better than likely chance of keeping the increase in global average surface temperature caused by CO_2 emissions below 2 degrees, the associated budget of cumulative emissions from 1870 and on is no greater than 3667 Pg CO_2. This budget drops by about one-fifth if non-CO_2 emissions are taken into

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* Corresponding author.
E-mail address: olivia.cintas@chalmers.se (O. Cintas).

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account (Collins et al., 2013). Rogelj et al. (2016) review the WGI budgets and others published since then, proposing that policy-making in the context of the UNFCCC associate the carbon budget range 590–1240 Pg CO_2 for CO_2 emissions from 2015 and onward with a likely chance of limiting warming to below 2 degrees.

The distribution of CO_2 emission allowances among nations is subject to debate, cf. Raupach et al. (2014). The argument that allowances should be allocated based on equal per-capita emissions has appeal, e.g., Neumayer (2000), but large variations in historical national contributions to cumulative emissions, due to, e.g., varying climate conditions, access to non-fossil resources, and the level of development (Neumayer, 2004; Raupach et al., 2007), present challenges in this regard. The contraction and convergence strategy consists of bringing national per-capita emissions to a level that is "safe" and equal for all countries over a transition period (Meyer, 2000). While taking into account where nations are currently starting from in their annual emissions, the method does not consider historical national contributions to cumulative emissions. Methods for addressing national cumulative emissions have also been proposed, e.g., Gignac and Matthews (2015), Matthews (2016).

In 2009, the Swedish government presented a goal of climate neutrality, i.e., no net GHG emissions to the atmosphere, by 2050 (Government offices of Sweden, 2009a). The relevant government committee has since, following COP21, proposed that the schedule be tightened, with the target year changed to 2045 (Swedish Government Official Reports, 2016). Analyses by the Swedish Environmental Protection Agency (2012) have shown that dramatic changes will be needed, especially in the transport sector, for which Swedish policy specifies the further goal that road transport be independent of fossil fuels by 2030 (Government offices of Sweden, 2009b). The required rate of change in the transport sector naturally depends on the interpretation of "independent", which could be understood to require that vehicles in the transport sector run mainly, but not entirely, on non-fossil fuels by 2030. Nevertheless, the political goals have motivated various actions to achieve transformative changes in energy use in transport and stationary applications in Sweden. For instance, it is expected that the use of biofuels will need to increase drastically to supply some 54–72 PJ of total fuel use in the transport sector by 2030 (Börjesson et al., 2017).

Sweden has more than 22 million hectares of productive actively managed forest. Swedish forests are typically managed as even-aged stands that are regenerated through planting. Harvesting activities are coordinated across the forest landscape to deliver a steady flow of biomass for multiple products (Lundmark et al., 2014). The Swedish Forestry Act requires all forest owners to consider production and environmental values equally in forest management (Swedish Forest Agency, 2016). On average, the total annual harvest amounts to about 94 million m^3, while the total annual growth amounts to about 116 million m^3, or 5.3 m^3 ha^{-1} (Swedish Forest Agency, 2014). The harvested stemwood is mainly used by the pulp and paper and sawmill industries with substantial residue flows primarily used internally as process energy, but also with deliveries to the external energy market. In 2013, bioenergy contributed 23% of the total primary energy supply (470 PJ), with about 85% coming from the forest (logging and forest industrial residues). The largest share was used in industry, where bioenergy corresponded to 38% of final energy use, and in district heating, where 60% of the total energy supply was bioenergy. Biofuels accounted for about 10% (29 PJ) of transport fuel in 2013 (Swedish Energy Agency, 2015).

Considering the size of Swedish forestry, the trends in bioenergy demand, and prospects for further advancements in silvicultural practices, forest bioenergy is expected to play a major role in the transition towards fossil fuel independent road transport and climate neutrality in Sweden. The objectives of this paper are to: (i) analyze the potential role of the Swedish forest sector in scenarios for meeting Sweden's political goals for 2030 and 2050; and (ii) apply an approach where the scenarios are placed in the context of the 2-degree target and an allocated Swedish CO_2 emissions budget. Lundmark et al. (2014) used empirical data and a set of models to analyze the effects of different forest management and wood use strategies in Sweden on carbon dioxide emissions and removals 1900–2105. We combine the modeling of forest management in Lundmark et al. (2014) with scenario based modeling of the Swedish energy and transport sectors and quantify GHG balances associated with energy-use for heat, electricity, and road transport, and with forest management and the production, use and end-of-life management of various forest products, including products for export. The aggregated GHG balances are evaluated in relation to the 2-degree target and an allocated Swedish CO_2 budget.

2. Methodology and data

A modeling framework (Fig. 1) is used to quantify carbon and GHG balances associated with forest management and the production and use of forest products. Different pathways towards the 2030 and 2050 goals are established based on combining four forest scenarios and two energy scenarios, and the framework is used to determine the GHG balances associated with each pathway (Fig. 2). The fossil carbon displacement effect associated with the use of forest products in Sweden is inherent in the energy scenarios, but the displacement effect abroad associated with forest

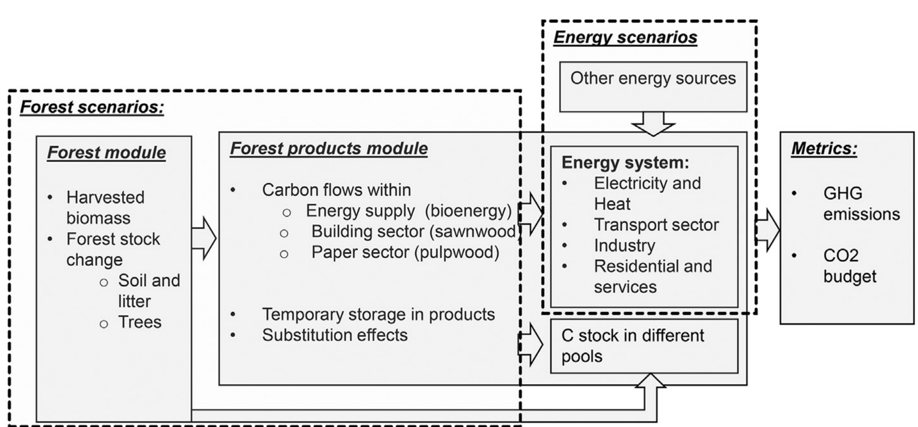

Fig. 1. Modeling framework.