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Short communication

Carbon balance for wood production from sustainably managed forests

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ABSTRACT

This Short Communication Paper approaches the CO_2 emissions from forest biomass produced in sustainable managed forests from aspects related to photosynthesis and variations in vitality and capability of CO_2 uptake, depending on i.a. different rotation periods and management regimes. These aspects are ignored or diminished in most other analyses on the subject as those analyses typically are based on simplified rigidly structured models. This Short Communication Paper suggests application of more relevant methodologies closer to actual real conditions. Two CO_2 issues are covered; the CO_2 balance between growth and harvesting of biomass in sustainably managed forests, and combustion of woody biomass in comparison with fossil fuels with regard to CO_2 emissions. The analysis of the first issue leads to the conclusion that biomass harvested from sustainably managed forests should be regarded as "carbon neutral" as the vitality and CO_2 absorption is sustained and kept on the same (or better) level. Moreover, to transform old pristine forests to young vigorous forests would be an effective (long term) means of reducing atmospheric CO_2.

Regarding the second issue, we notice that some other authors of papers on bioenergy claim that biomass would not be "climate neutral" when used for energy as, for generation of a given energy amount, more fixed carbon is released from biomass than from fossil fuels. In our opinion, authors of these papers apply obsolete, too general or sometimes illogical default values. This Short Communication Paper suggests that emissions from combustion of forest biomass should be compared with emissions from coal as it is the most common and relevant fuel to replace. Also additional emissions from mining/harvesting, transport, leakage, etc. should be included both for biomass and for reference fuels like coal, gas, and oil. The comparison should also be based on state-of-the-art technology, which for biomass would mean i.a. flue-gas condensing and efficient fuel treatment. Under these conditions, typical biomass applications for energy would be both carbon neutral and climate neutral.

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1. CO_2 neutrality of forest biomass

After having been highlighted at the "Rio Conference" 1992, the interrelations between vegetation, biomass fuels, and climate change became subject to analyses and modeling, e.g. those developed within the IEA Bioenergy Program [1–4]. While these early models were based on simplified and standardized assumptions, they have been used as bases for further elaborations up till now. In recent years a number of studies on bioenergy and related CO_2 emissions have been carried out. Comprehensive lists of references for this type of studies are found in Refs. [5,6]. Typically the starting point has been to "burn a tree" emitting CO_2 (applying default values for heat values, combustion technology, fossil fuels substituted, etc.) and to calculate the time it would take for a new identical tree to grow and take up the same amount of CO_2. i.a. [7–9]. The time lag and the surplus of emitted CO_2 have been named "carbon debt" and it is frequently used in the debate. However, the limited scope of the studies behind "carbon debt" means that effects on the biomass production and on forest vitality are ignored. Thus, those studies have been based on models in which only one function (harvested products) of forests is included but not considering the other (dynamic growth "apparatus") These limitations of the approach have resulted in misleading conclusions. An approach by Ref. [10] with analyses on the "Landscape

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Scale" is applying wider modeling, but also in that study the issues of harvesting regimes related to yield production and CO_2 uptake are not covered fully.

The analyses of this Short Communication Paper have another starting point, namely the net CO_2 uptake in the photosynthesis process of a (sustainably managed) forest. Appropriate harvesting regimes (with reforestation) will keep, even improve, the CO_2 uptake capability; while forest devastation, but also decreased harvesting will lead to reduced lower CO_2 uptake capability of the forest. As mentioned above, forest management (when focusing on wood production) deals with the integration of two functions of forests; both to be a production means ("apparatus") and at the same time to be products. It is the growth of the trees that is recorded as yield production. But the trees can also be harvested and converted to products, e.g. saw-logs, pulp wood, biomass for fuel, etc. These functions of a forest are interdependent: a change in one will have effects on the other and *vice versa*. Balanced sustained harvesting regimes will preserve the yield production. "Yield" would here be synonymous to "net CO_2 uptake". Harvesting in form of over-exploitation would lead to reduction of the yield production of the remaining forest, and low harvesting rates would in the long run also lead to low yield production as trees grow old and become less productive. It is also obvious that more intensive and sustainable management of forests would lead to increased yield and opportunities for increased harvesting.

Most long-term forest management models take this dual character of forests into consideration and they are often based on rather complex economic analyses and empirical data. The aim is to arrive at an optimum solution for both combined functions, normally fulfilling sustainable forest yield and even supply of products to markets. While traditional forest management models focus on production of saw logs, pulp wood etc., it is possible to adapt them to biomass models, e.g. by applying biomass functions related to known parameters. Thus, by these adjusted models it is possible to plan biomass harvesting rates that would keep the biomass yield (and therefore also the current CO_2 uptake) of the forest on high and sustained optimum levels.

A basic model utilized for calculations and analyses of appropriate activities for permanently managed forests is the "Normal Forest Model". The basis for the model is a demarcated area on which forestry is carried out permanently. That model is assumed to have a number of equal parcels, stands, one for each year of the rotation period. Each year, harvesting of the oldest parcel takes place, and the harvested area is replaced by an equal area of young tree plants. See Fig. 1.

As the oldest parcel is harvested each year giving space for a new replanted parcel, all other parcels grow and move to replace the parcel next to it in age. Younger parcels, after a few years, typically grow faster (and absorb more CO_2) than older parcels.

Thus, one year after harvesting of the oldest parcel, the "Normal Forest" has identical properties as it had one year before, including carbon content and uptake capacity for CO_2. The harvested biomass is balanced by the growth, the total yield production, of biomass in all parcels in the forest. The annual uptake of CO_2 and fixation of carbon is equal to the fixed carbon in the harvested biomass and the subsequent release of CO_2 from combustion or decomposition. Therefore, the harvested biomass should be regarded CO_2 neutral.

However, the "Normal Forest Model" could also be applied when predicting the development of a stand from the establishment ("plantation") through the various production stages to the time of harvesting/regeneration. In this Short Communication Paper both these aspects of the "Normal Forest Model" would be relevant.

Functions as the one above (spruce, Middle Sweden) vary considerably with e.g. species, site class, and to a limited extent management regimes (thinning, etc.) The annual growth (and consequently also CO_2 uptake) of *Salix* in "energy forests" has its peak after only a few years, pine plantations in US South around eight years, etc.

The Normal Forest Model is developed for even aged stand. (each parcel consist of trees of the same age). However, it would also be possible to apply a similar approach on mixed-aged stands, assuming a permanent repetitive harvesting regime in which trees are cut in equal quantities in a perpetual cycle. Originally, the forestry models were adapted to and applied for production of industrial forest products. Thus, the rotation period based on application of the "Normal Forest" concept was and still mostly is set to maximize average annual yield of industrial forest products (of useable wood or economic value). Obviously, these rotations are longer than a theoretical rotation period based on maximum average annual CO_2 uptake, i.a. as the rate of stem wood related to total tree biomass increases by time(Fig. 2).

In practice, conditions vary compared to the "Normal Forest Model". However, as long as the harvesting regimes fall under the restrictions of sustainably managed forests, general conclusions will lead to the same (or better) results than for the "Normal

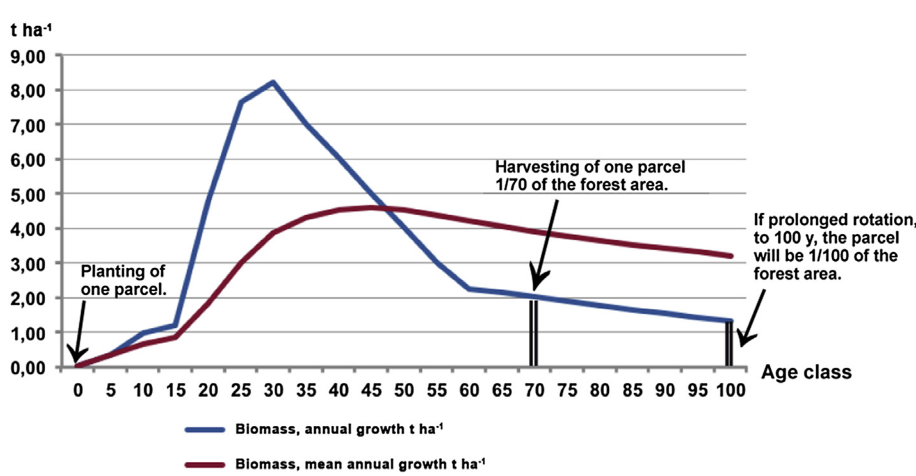

Fig. 1. Current annual growth (CAI) of tree biomass (dry substance) and mean annual growth (MAI) of tree biomass. (over ground data). Spruce Middle Sweden. Based on data from *Heureka*, SLU [11]. The curve for MAI should be read as follows: Sum of annual biomass growth divided by actual assumed years of rotation. The uptake and assimilation of carbon dioxide is closely related to the growth of biomass.

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