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LIMITS TO CO_2-NEUTRALITY OF BURNING WOOD. (REVIEW)

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Consumption of wood as a source of energy is discussed with respect to efficiency and restraints to ensure sustainability of the environment on the grounds of a simple analytical model describing dynamics of biomass accumulation in forest stands – a particular case of the well-known empirical Richards' equation. Amounts of wood harvested under conditions of maximum productivity of forest land are presented in units normalised with respect to the maximum of the mean annual increment and used to determine the limits of CO_2-neutrality. The ecological "footprint" defined by the area of growing stands necessary to absorb the excess amount of CO_2 annually released from burning biomass is shown to be equal to the land area of a plantation providing sustainable supply of fire-wood.

Keywords: *bioenergy, limits to CO_2-neutrality, sustainable supply, wood.*

1. INTRODUCTION

Sustainable consumption of renewable resources is limited by the rate of regeneration. Land area and radiation available on the area are two core factors determining regeneration of any kind of biomass while the rate depends on the productivity of the biological species – the rate of amassing wood by photosynthesis. Perennials have the advantage of accelerating the growth with time while keeping the accumulated biomass stored.

The use of biomass as a renewable source of energy has additional constraints imposed by sustainability with regard to environment the main concern being release of greenhouse gases affecting stability of the global climate. Despite the corporate belief of biofuels being neutral to CO_2 emissions [1]–[3], the subject is contentious [4]–[7] although authors of more scrupulous recent studies recognise delayed sequestration of carbon released by using biomass for energy [8]–[10] and point to radical disparity between the amounts of carbon released and recaptured [11]. The subject still requires a proper discussion and relevant argumentation providing grounds for understanding dynamics of the basic carbon cycle from biomass to atmosphere and back to biomass. The study presented to the attention of the reader considers the boundaries and factors imposed by CO_2-neutrality of wood as a source of primary energy.

2. BASIC DEFINITIONS AND THE METHOD

Since usage of wood fuel for electricity generation is extremely wasteful use of bioenergy and land assets [12], 16] and, therefore, unsustainable, hereafter attention is paid to burning wood for purposes of heating having a distinctly seasonal character at higher altitudes. Energy is consumed at the time of year when photosynthesis fixing carbon dioxide into new biomass is not active for which reason the gas released at burning wood accumulates in the atmosphere the current process being not CO_2-neutral. Therefore, it is reasonable to define the CO_2-neutrality with respect to the whole seasonal cycle: burning wood is CO_2-neutral if the annual amount of carbon dioxide released into the atmosphere is balanced by the annual amount of carbon dioxide sequestered from the atmosphere by photosynthesis and stored again in biomass. The definition implies that burning biomass is sustainable with respect to the resource and climate if the annual amount of biomass burnt is equal to the annual amount of biomass grown.

The **C**urrent **A**nnual **I**ncrement of wood biomass of a natural even-aged forest stand defined as the amount of stock accumulated during the year at the particular age is presented as the derivative of stock *S* with respect to time *t* representing the rate of growth *R* as function of time at the particular instant:

$$R(t) = \frac{dS(t)}{dt}. \tag{1}$$

The Mean Annual Increment defined by the ratio of the stock S(t) at a particular age t to the age represents the productivity P(t) of the stand at that age as function of time:

$$P(t) = \frac{S(t)}{t}. \tag{2}$$

The rate of growth expressed by (2) and stock are obviously interrelated by

$$S(t) = \int dtR(t). \tag{3}$$

It should be noted that the current annual increment being of a finite magnitude here is presented by (2) – the rate of growth as a continuous function defined for any infinitesimal instant of time. Nevertheless, the apparent inconsistency is resolved by interpreting the rate of growth as the annual increment at the respective instance of time – the annual acquisition of biomass being projected to the instant value of the rate of growth. The finite amount of stock accumulated by the stand within a particular year-long time interval $\Delta t = t_n - t_{n-1}$ under these assumptions is expressed by

$$\Delta S_n = \int_{t_{n-1}}^{t_n} dt \cdot R(t). \tag{4}$$

Dynamics of biomass accumulation in a forest stand [13] derived from the rate of growth assumed being proportional to the active light-absorbing area of the canopy is presented by Richards' equation [14]:

$$S(t) = (1 - e^{-bt})^c \qquad (5)$$

with parameter values $b = ln2$ and $c = 2$ found for dimensionless time scale $x = \frac{t}{t_m}$ normalised with respect to the time t_m at which the function derived for the rate of growth

$$R(t) = const \cdot \left(1 - e^{-bt}\right) \cdot e^{-bt} \qquad (6)$$

reaches the maximum. The rate of growth normalised to its maximum value at $x = 1$ as function of the normalised time variable x is presented by equation

$$R(x) = 4 \cdot \left(1 - e^{-xln2}\right) \cdot e^{-xln2} \qquad (7)$$

and the stock normalised to its maximum limit S_∞ at $x = \infty$ – by equation

$$\frac{S(x)}{S_\infty} = \left(1 - e^{-xln2}\right)^2 \qquad (8)$$

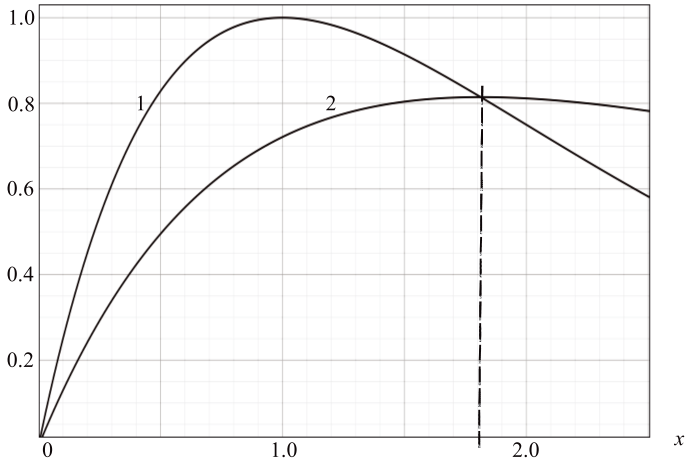

Fig. 1. Rate of growth (1) and
productivity (2) – the mean annual increment in normalised coordinates.

Graphs of the rate of growth (7) and productivity P(x) are presented in Fig. 1. The scale of the ordinate axis is normalised to the maximum of the current annual increment relative to which the maximum value of the mean annual increment is about 0.8 and is reached at the normalised age of $x \approx 1.81$ – the age of maximum productivity of the stand area and the optimum cutting age providing the highest land-use efficiency. The stock (yield) of wood biomass at this age calculated from (8) is about 0.50812, which is slightly more than twice the stock ($S = 0.25$) at the age of maximum rate of growth (at $x = 1$).

Accumulation of biomass represented by (7) and (8) is defined by a single parameter – the age t_m, at which the rate of growth of a particular stand reaches its maximum. This single parameter, apart from the bio-potential of the species, implies and presents an integrated result of the site characteristics – such as fertility, period of vegetation, availability of water and light, etc. affecting the rate of biomass accumulation.

The current annual uptake of biomass and, consequently, the atmospheric carbon is calculated from (8) as the difference of stock between the year number $n + 1$ and n the increment ΔS being evaluated in units of stock S_o at the age of land productivity optimum at $x_o \approx 1.81$

$$\Delta S_n = \frac{S_n - S_{n-1}}{S_o},\ n = 1, 2, \ldots n_c;\ \ S_o = S(x_o) \neq S_0 = 0. \tag{9}$$

For that purpose the normalised time interval corresponding to a year in the real time scale is presented by the ratio of $x = 1.8$ to n_c – the number of years at the optimum cutting age t_o in the real time scale. Since the content of carbon is proportional to the amount of acquired biomass, the obtained annual portions of biomass and carbon uptake are the same for either one – the total uptake of biomass or the carbon content by the cutting age taken as the unit.

Under such assumptions the equity

$$\sum_{n=1}^{n_c} \Delta S_n = \int_0^{x_c} dx \cdot S(x), \tag{10}$$

holds exact for any n_c.

3. RESULTS AND DISCUSSION

The annual uptake at consecutive ages of growing natural forest stands as portions of accumulated stock follows the rate of growth curve (curve 1, Fig. 1). On the other hand, it also depends on the normalised time interval Δx corresponding to real time span of a year expressed by the ratio

$$\Delta x = \frac{x_c}{n_c}\,. \tag{11}$$

In (11), the cutting age – the number of years n_c the stand has grown before felling in the real time scale and the corresponding normalised time x_c can be chosen arbitrary. For further convenience it is reasonable to choose the cutting age at the maximum of the mean annual increment (curve 2, Fig. 1) corresponding to $x_o = 1.81$ being the optimum age for harvesting at the maximum of land productivity. In that case, (11) transforms into

$$\Delta x = \frac{const}{n_c} \tag{12}$$

the constant being equal to 1.81.

From (12) it follows that logarithm of Δx is a linear function of the logarithm of n_c. Since the current annual increment ΔS_x at a fixed value of $x = const$ is proportional to Δx, it can be found for any n_c from a linear equation

$$log\Delta S_x = A + B \cdot log(n_c). \tag{13}$$

Fractions ΔS_x for $x = 0.9$ close to the maximum rate of growth (Fig. 1) calculated for selected n_c as

$$\Delta S_{0.9} = \frac{S(0.9+\Delta x/2) - S(0.9-\Delta x/2)}{S_o} \tag{14}$$

are listed in Table 1. The plot of $log(\Delta S)$ vs. $log(n_c)$ is presented in Fig. 2. The two data sets fit (13) with correlation equal to 1.0000 and values of coefficients: A = 0.08648, B = - 0.9981. The calculation shows why fast-growing species are more efficient absorbers of atmospheric CO_2 and, therefore, more preferable for the purpose.

Burning wood harvested from an overgrown stand at the age of $x > 1.8$ instead of choosing the cutting age at the maximum of the mean annual increment releases more CO_2 and reduces proportions of the annual uptake with respect to the amount released. Thus, the annual uptake of CO_2 at the age of $x = 0.9$ (14) comprises 0.061 of the amount released by burning wood harvested at $x = 1.8$ from 20 years old stand, while being equal to merely 0.043 of the amount accumulated by a 30 years old stand. It means that instead of 16 ha of 10 years old stands to absorb within a year the amount of CO_2 released by burning wood harvested from 1 ha of 20 years old stand it will take 23 ha to absorb the amount of CO_2 released by burning the harvest from 1 ha of a 30 years old stand. Or, to do the same – a 30 ha plantation of stands of consecutive ages up to 30 years instead of 20 ha plantation of sequentially aged stands up to 20 years. Land productivity in the latter case is by 6.5 % higher.

Table 1.
Annual biomass uptake ΔS at $x = 0.9$ as proportion of the stock accumulated by optimum cutting age $n_c = t_o$

cutting age n_c	Δx	ΔS	$log(n_c)$	$log(\Delta S)$
18	0.1000	0.067822	1.2553	-1.1686
20	0.0900	0.061046	1.3010	-1.2143
30	0.0600	0.040706	1.4771	-1.3903
40	0.0450	0.030532	1.6021	-1.5152
50	0.0360	0.024426	1.6990	-1.6121
60	0.0300	0.020356	1.7782	-1.6913
72	0.0250	0.016963	1.8573	-1.7705
80	0,0225	0.015267	1.9031	-1.8162
90	0.0200	0.013571	1.9542	-1.8674
100	0.0180	0.012214	2.0000	-1.9131
120	0.0150	0.010178	2.0792	-1.9923
150	0.0120	0.008143	2.1761	-2.0892
180	0.0100	0.006786	2.2553	-2.1684
200	0.0090	0.006107	2.3010	-2.2142

The absolute numbers are found from the amount of wood harvested at a certain age in each particular case. Not all the data are always available. However, the average data of annual biomass accumulation can be used for a rough estimate of the limits of CO_2 neutrality. Thus, for instance, according to 2008 forest inventory data [15] the average annual increment of wood biomass in Latvia comprises 834 400 m^3, which is the ultimate amount of firewood that can be used within the limits of CO_2 neutrality no matter where in the world the firewood produced in Latvia is burnt.

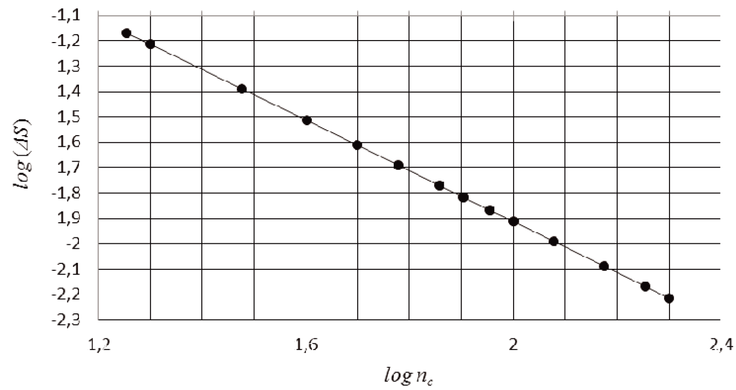

Fig. 2. Annual uptake of biomass ΔS at normalised age $x = 0.9$ as function of the number of years n_c by optimum cutting age at $x = 1.81$.

Considering a bigger picture, the global growing forest and everything made of wood are a deposit of carbon as much as coal or oil, and replacing the two latter by wood just cannot be CO_2 neutral under circumstances of shrinking area of the global forest. The evidence of it is found in the increasing atmospheric concentration of CO_2 despite the enormous quantity of wood from Canadian forest being used to produce electricity since 2008 [4].

Since the biomass (and CO_2) stored in a stand by the cutting age is accumulated in a sequence of years at successive ages, the annual uptake by a plantation comprised of sequentially aged stands (up to the cutting age) of the same size is equal to the stock felled at the cutting age. Consequently, the annual uptake of CO_2 by the plantation is equal to the amount of CO_2 stored in the stand by the cutting age and released at burning of the harvested wood biomass. Therefore, such plantation simultaneously provides sustainable supply of wood to be burned and CO_2 neutrality.

Fast-growing species are preferable for higher biomass productivity and more efficient uptake of CO_2.

The forest area necessary to neutralise the amount of CO_2 released by burning biofuels can be considered the "footprint" of using biomass as the source of primary energy. If CO_2 neutrality is defined by equality of annual amounts released and recaptured, then the area under plantation generating the relevant amount of new biomass is the "footprint" of using fuelwood provided the area is occupied by photosynthesisers to perform the work.

4. CONCLUSIONS

In general, the growing forest functions as a deposit of carbon (along with organic fossil fuels) and as a sink of atmospheric CO_2 pollution, the annual uptake of CO_2 by unit area of a forest stand, amid a number of factors, being dependent on its age.

CO_2-neutrality of fuel-wood is not granted and emissions of CO_2 from burning wood have to be accounted for in the total balance of pollution. On the global scale, under a shrinking area of the global forest using wood to substitute fossil fuels does not reduce emissions of greenhouse gases.

On the local scale, CO_2-neutrality of biomass fuels is achieved by sustainable harvesting and rotation practices of the fast-growing species being more preferable for sequestration of the atmospheric CO_2 to maintain neutrality.

Sustainable harvesting of wood (and biomass in general) for energy under conditions of limited land assets is incompatible with unrestricted profit-driven economic growth.

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KOKSNES KURINĀMĀ CO_2-NEITRALITĀTES IEROBEŽOJUMI

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Kopsavilkums

Pretēji loģiskam un labi zināmam secinājumam, ka, sadedzinot koksni, atbrīvojas tajā uzkrātais ogleklis, vēl arvien pastāv uzskats, ka biomasa (koksne) neatkarīgi ne no kā ir CO_2-neitrāls reģeneratīvs enerģijas resurss [1-3]. Tikai pavisam nesen [8-10] publikācijās atkal tiek atzīts, ka būtu jāņem vērā oglekļa parāds, kas veidojas starp kurināmā sadedzināšanas brīdi un brīdi, kad atbrīvotais ogleklis no jauna absorbējas biomasā [4-7, 11].

Piedāvātajā pētījumā autori par CO_2-neitralitātes kritēriju izvirza līdzsvaru starp gada laikā atbrīvotā un piesaistītā oglekļa daudzumu. Izmantojot labi pazīstamo empīrisko biomasas akumulācijas Ričardsa vienādojumu (5) [14] izdodas samērā uzskatāmi parādīt biomasas akumulācijas dinamiku atkarībā no audzes vecuma (1. att.) [13]. Tekošo biomasas vai oglekļa gada uzkrājumu dabiskajās audzēs atkarībā no audzes vecuma raksturo līkne **1** 1. att., attiecībā pret kuras maksimālo vērtību normalizētas augšanas ātruma (krājas tekošā gada pieauguma) vērtības laika skalā, kurā par laika vienību pieņemts audzes vecums, kad tā sasniedz maksimālo augšanas ātrumu. Šajā bezdimensiju (normalizētā) laika skalā x audze sasniedz optimālo (produktivitātes – vidējā gada pieauguma, maksimālajai vērtībai atbilstošo) ciršanas vecumu (un optimālo krāju S_o) pie $x = 1,81$. Attiecībā pret šo vērtību tekošais krājas gada pieaugums ΔS vecumā $x = 0,9$ ((9)) aprēķināts atkarībā no gadu skaita n_c, kad audze sasniedz optimālo ciršanas vecumu 1.tabula, 2. att.).

Kurināmās koksnes CO_2-neitralitāti automātiski nodrošina plantācija, kas sastāv no vienāda lieluma zemes gabaliem ar audzēm secīgā vecumā no viena gada līdz n_c gadiem, katru gadu izcērtot un atjaunojot pa vienam, tādējādi nodrošinot pastāvīgu ikgadēju koksnes produkciju neierobežotā laikā. Piemērotākas enerģijas iegūšanai (un atmosfēras CO_2 piesaistei) ir ātraudzīgās sugas.

Mežs kā oglekļa depozīts pielīdzināms fosilajiem enerģijas nesējiem un koksnes sadedzināšanas rezultātā radītais CO_2 piesārņojums ir iekļaujams kopējā piesārņojuma bilancē, bet fosilo enerģijas nesēju aizstāšana ar koksni nekādā gadījuma nesamazina CO_2 izmešu apjomu. Globālā mērogā, samazinoties kopējai augoša meža platībai, koksnes izmantošana enerģijas iegūšanai nav CO_2-neitrāla.

Ilgtspējīga koksnes izmantošana enerģijas vajadzībām nav savienojama ar neierobežotu ekonomisku izaugsmi peļņas gūšanai.

02.06.2016.