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POTENTIAL OF PHOTOSYNTHESIS AS A RENEWABLE SOURCE OF ENERGY AND MATERIALS

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Responding to recently published considerations concerning biomass as a renewable substitute for fossil fuels to provide at least part of the necessary total amount of primary energy annually consumed in an economy system the authors estimate capacity of photosynthesis in a case study of the Republic of Latvia (Eastern coast of the Baltic Sea). The calculations are made on the basis of recent inventory data on land use, distribution of forest land between the stands of the main dominating species, and the average level of forest productivity specific to species at felling age. Sustainable annual supply of dry biomass from the present forest area available for economic purposes is estimated being equal to 3.7 million metric tons the energy equivalent of species (aspen and grey alder) traditionally harvested for firewood including logging residues from timber wood comprising ~ 13 thousand GWh, which is equal to ~ 24% of the present annual consumption of primary energy.

Key words: *photosynthesis, energy, biomass, forest stands, grey alder.*

1. INTRODUCTION

Globally, photosynthesis is obviously the most important source of renewable energy and materials, and the only source of food. Transforming of solar radiation by photosynthesis into the energy of chemical bonding naturally accumulated in the product – the biomass, has the same advantage as that making the use of fossil energy carriers particularly practical. Under the present circumstances, however, the primary benefit of using biomass instead of fossil fuels is stabilising the pace of climate change by possible preservation of the level of CO_2 concentration in the atmosphere.

The problem of using biomass as a carrier of energy instead of fossil fuels is not rather a tiny proportion of the available solar energy captured by photosynthesis – the net product in terms of energy is about 10 times the amount of energy the global economic system presently consumes; the problem is the growing needs of human population already controlling 40% of the net product of photosynthesis – the basis of the whole biosphere of the planet. As a result, the planet is rapidly losing wildlife, biodiversity, and the stability of the biosphere essentially speeding up the climate change. The options for human civilisation are restricted by the local and global assets of the planet and by processes in the environment. To make reasonable decisions it is necessary to be aware of the available assets, to know and understand the preconditions and consequences of the choices. The ultimate source of renewable energy is the finite flow of solar radiation intercepted by the global system, so the solution of the problem of supplying energy to an economic system has to be searched in rational and efficient use of the asset.

An idea of the kind of analysis required for independence from fossil energy carriers is given by the Danish Commission on Climate Change Policy [1]. A review of current standards for sustainable forest management with regard to forest fuel is given by I. Stupak *et al*. [2]. A number of reports consider different aspects of the transfer to renewable sources of energy and materials in Latvia [3–6]. The present reflection is an attempt to comprehend the limits of the potential of photosynthesis as a renewable source of timber, wood biomass (for materials including chemicals), and energy.

2. POTENTIAL OF PHOTOSYNTHESIS

The annual potential of photosynthesis determined by the average annual insolation is equal to ~ 1 $MWh{\cdot}m^{-2}$ or 10 $GWh{\cdot}ha^{-1}$ at the latitude of Latvia [7]. The average volume of the current annual increment of timber wood is estimated to be 8 $m^3{\cdot}ha^{-1}$ [8]. Taking the average content of dry biomass of the Latvian forest species equal to 450 $kg{\cdot}m^{-3}$ [3, 8] and the energy equivalent of wood biomass equal to 5 $kWh{\cdot}kg^{-1}$ (18 $MJ{\cdot}kg^{-1}$), the average annual amount of solar energy accumulated in timber wood is 18 $MWh{\cdot}ha^{-1}$. Assuming that branches and other usable logging residues contain additional 4 $MWh{\cdot}ha^{-1}$, the total practically used amount of primary energy accumulated in wood biomass over the forest area of Latvia comprises 0.22% of the annual insolation of the forest land. According to recent inventory data [9], the current annual increments at the most productive age of the different species dominating in forests of Latvia vary from 9 to 16 $m^3{\cdot}ha^{-1}$ (0.23 to 0.33% of the annual insolation).

Apart from biological capability of particular species, the intensity of photosynthesis – the rate of biomass accumulation expressed as the current annual increment – depends on the actual availability of radiation, soil, water, nutrients, and other site characteristics accounted for by a general site quality index determined by the dynamics of measurable parameters of forest stands [10, 11]. In natural forest stands the stock as function of age (time t) is well known to be described by empirical Richards's growth equation [12, 13]:

$$S(t) = const\left(1 - e^{-bt}\right)^{c} \tag{1}$$

where b and c are constants.

The analytical expression of the rate of growth derived on the basis of general assumptions about photosynthesis [14, 15]:

$$\frac{dS}{dx} = const\left(1 - e^{-ax}\right) \cdot e^{-ax} \ , \tag{2}$$

where x is the time normalised with respect to the age at which the current annual increment of biomass reaches the maximum, and

$a = \ln 2$,

provides Richards's equation (in the normalised time scale x) the parameters b and c in which are equal to ln2 and 2, respectively. The optimum felling age of a forest stand for wood biomass or energy needs is the age at which the maximum of the mean annual increment (equal to the S/x ratio) of the stand is reached. In the normalised (dimensionless) time scale x this maximum is attained at 1.8 intrinsic age units (Fig. 1) [15–17]. Criteria for optimisation of the harvesting age for timber may be different and deserve a special study outside the context of harvesting unspecified biomass and firewood.

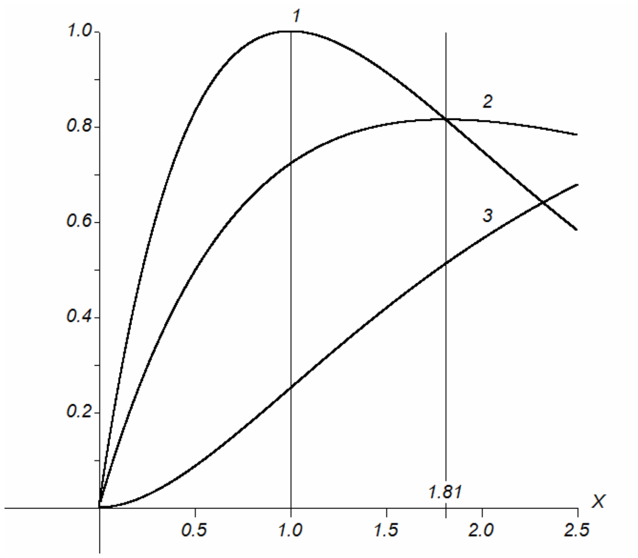

Fig. 1. Current annual increment (curve *1*), mean annual increment (curve *2*), and yield (curve *3*) of natural forest stands as functions of normalised age *X*. The scale of the current and mean annual increment is the same [15].

3. SUSTAINABLE LONG-TERM ANNUAL YIELDS

The total area occupied by forest stands of successive ages necessary for sustainable annual yields of biomass is equal to the product of the annual felling area by a factor equal to the harvesting age [16]. The productivity expressed in terms of biomass (or energy) of different species used in Latvia as firewood and some energy crops is given in Table 1.

In this table, the stock of relevant species at the harvesting age (column 2) [9] is given in column 3 while columns 4–6 show the yield per unit of the total area occupied by the stands of different age under the condition of sustainable long–term annual supply (equal to the ratio of stock to cutting age). The total area of forest stand necessary for sustainable annual supply of one GWh of primary energy and one kiloton of dry biomass are given in columns 7 and 8, respectively.

The data on stocks of wood biomass presented in Table 1 refer to the above–ground biomass of stems accounting for ~ 70% of the total product [9], stump, roots, and branches comprising the rest, of which mainly bigger limbs find reasonable use as firewood. In the cases of pine, birch, and older spruce growths the energy yields are calculated from usable logging residues and are estimated to be at least 15% of the amount of harvested timber wood. The energy per unit area of aspen, grey alder and younger spruce growths is calculated to include the logging residues in the energy balance. Productivity of alder at 20-year rotation on best sites appears to be by a factor of 1.5 higher compared with the average.

Table 1

Sustainable yields of biomass from different species depending on the age of harvesting [3, 9, 16–19]

Species	Age	Stock	Sustainable yield from total area unit			Total area for sustainable annual yield	
	years	$m^3 \cdot ha^{-1}$	$m^3 \cdot ha^{-1}$	$t \cdot ha^{-1}$	$MWh \cdot ha^{-1}$	per GWh	per kt
1	2	3	4	5	6	7	8
Pine	71	287	4.0	–	$1.2^{\dagger}$	–	–
Birch	71	292	4.1	–	$1.8^{\dagger}$	–	–
Spruce	71	312	4.4	–	$1.3^{\dagger}$	–	–
	20	91	4.5	$1.99^{\dagger\dagger}$	$11.2^{\dagger\dagger}$	100	503
Aspen	41	333	8.1	$3.45^{\dagger\dagger}$	$20.2^{\dagger\dagger}$	49	290
Grey Alder [S]	20	149	7.5	$3.71^{\dagger\dagger}$	$18.7^{\dagger\dagger}$	54	270
	30	204	6.8	$3.36^{\dagger\dagger}$	$16.9^{\dagger\dagger}$	59	297
Grey Alder* [18]	18	224	12.4	$6.15^{\dagger\dagger}$	$30.8^{\dagger\dagger}$	32.4	163
	20	226	11.30	$5.59^{\dagger\dagger}$	$28.12^{\dagger\dagger}$	35.6	179.0
	30	338	11.27	$5.57^{\dagger\dagger}$	$28.05^{\dagger\dagger}$	35.7	179.5
Rapeseed [19]	1	–	–	1.90	8.8 (oil)	113	526
Willow**	3	–	–	–	15	67	
Straw**	1	–	–	3	12	83	333

* At sites of maximum productivity
** Data presented by E. Petraitis at Seminar in LSIWC, 2010
† Energy from logging residues
†† Including logging residues

As seen from Table 1, grey alder traditionally used for firewood is the most productive species to provide wood biomass for pulp and energy. Even though birch and aspen are also used as firewood, they cannot compete in productivity with grey alder and should be grown mainly for timber of specific qualities.

The use of straw as fuel does not require allocating a particular land area for the purpose since it is a by-product of growing grain. Roughly, 50 GWh of primary energy could be obtained from the straw of each of the 1 mill. metric tons of grain harvested in Latvia in 2004 [20].

Sustainable harvesting of biomass from a finite area available for growing wood depends on the period of rotation providing maximum yield per unit area or the desired quality of timber, which is different for different species. In the case of grey alder it is between 18 to 25 years depending on the site quality [9, 16, 18]. Aspen stands [9] reach the maximum of mean annual increment at the age between 40 and 50 years. Presently, the area occupied by grey alder stands is 310 thousand ha [9]. Maintaining proportions of site qualities and the same area of grey alder would provide about 15 500 ha for sustainable annual yield of 2.3 mill. m^3 wood biomass or 5 740 GWh of primary energy at 20-year rotation. About 3 300 GWh of primary energy could be obtained annually from utilising logging residues from other species under sustainable harvesting practices.

Table 2

Potential of sustainable annual yields of biomass and energy from the area of forest land available for economic use
(calculated from available data [9, 20])

Species	Age	Sustainable harvesting area	Sustainable annual product		
	years	10^3 ha	10^6 m^3	10^3 t	GWh
1	2	3	4	5	6
Pine Spruce Birch	71	27.920	8.380	620 (log.residues)	2 700*
Aspen	41	5.970	1.980	842.5**	4 920**
Grey alder	20	15.508	2.310	1 142.3**	5 740**
	30	10.339	2.109	1 091.5**	5 240**
Total			at 20-year rotation of grey alder stands		**13 360**
			at 30-year rotation of grey alder stands		**12 860**

* energy from logging residues
** including residues

Potential of photosynthesis of the Latvian forest assessed from available inventory data [9] is summarised in Table 2. The annual felling area (column 3) for timber wood is calculated as the ratio of the total area of forest land under the relevant dominating species to the cutting age (column 2) excluding the area protected from commercial utilisation. Capacity of sustainable average annual felling area of commercial timber wood evaluated by excluding the area of aspen, grey alder and protected forest land [21] from the total forest land area is estimated to be 8 bill. m^3 of timber and 2 700 GWh of primary energy from logging residues.

If all sustainable yield of aspen is used for firewood, it is possible to obtain 4 900 GWh of primary energy (including 640 GWh from logging residues) of aspen stands annually. The amount of energy available annually from grey alder stands depends on the cutting age. Retaining the present forest area of the country can provide a total sustainable annual yield of primary energy from photosynthesis between 12 and 13 thousand GWh comprising about 40% of the total annual consumption of the primary energy from natural gas, coal, and wood [22]. Straw from the area used to grow grain can provide 5 200 GWh of primary energy, raising the total contribution of photosynthesis to 18 500 GWh or 84% of that presently obtained from gas and coal. To satisfy the present annual demand of primary energy by sustainable supply of wood and straw biomass would require extending the grey alder plantations by 630 thousand ha.

4. CONCLUSIONS

Potential of photosynthesis of the present area of forest land of the country available for economic activities does not cover the present domestic consumption of primary energy from natural gas and coal. With account for the amount of wood presently comprising 26% of the primary energy balance of the country sustainable supply of biomass to provide substitute for 17 000 GWh of primary energy from fossil carriers (excluding oil) would require to extend the grey alder plantation by 900 thousand ha. Utilisation of straw as a source of renewable energy can reduce the required alder plantation area to 640 000 ha. Satisfying the present demand by the energy from straw, without raising the area of alder stands would require extending the area of grain fields up to 1.8 million ha.

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FOTOSINTĒZE
KĀ POTENCIĀLS ATJAUNOJAMO RESURSU AVOTS

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K o p s a v i l k u m s

Atsaucoties uz pēdējā laikā publicētajiem apsvērumiem par iespējām vismaz daļēji aizvietot fosilo enerģijas nesēju izmantošanu enerģijas bilancē ar biomasu, autori aplūko fotosintēzes kapacitāti Latvijas dabiskajās mežaudzēs un lauk-saimnieciski izmantojamās platībās. Aprēķiniem izmantoti statistiskie dati [20] par graudkopības platībām un Latvijas mežu inventarizācijas dati [9] par dominējošo koku sugu krāju ciršanas vecumā to aizņemtajās meža platībās. Koksnes biomasas enerģētiskā potenciāla novērtējumā ietvertas tikai saimnieciski izmantojamās meža platības, izslēdzot tajās iegūstamo kokmateriālu apjomus no galvenajām lietaskoku sugām (priede, egle, bērzs). Ievērojot ilgtspējīgas meža saimnieciskās izmanto-šanas nosacījumus, ikgadējā koksnes sausās biomasas ieguve no patreizējām apses un baltalkšņa platībām kopā ar praktiski izmantojamām visu cirsmu atliekām (pieņemot to apjomu 15% no krājas lieluma) sastādītu 3,7 miljonus tonnu, no kā, pārrēķinot uz gaisa sausu apjomu (pie 15% mitruma ar 15 MWh/kg siltumspēju),

var iegūt ap 13 000 GWh primārās enerģijas – 26% no patreizējā primārās enerģijas gada patēriņa. Latvijas izplatītāko koku sugu biomasas un enerģētisko kultūru aprēķinātie ilgtspējīgas ražības rādītāji apkopoti 1. tabulā, bet koksnes biomasas un tās enerģētiskā ekvivalenta ikgadējie apjomi no esošajām meža platībām – 2. tabulā. Lai primārās enerģijas gada patēriņa bilancē ilgtermiņā pilnībā aizstātu dabas gāzi un ogles ar koksni, esošās baltalkšņa audžu platības būtu jāpaplašina par 900 tūkstošiem hektāru. Izmantojot kā enerģijas avotu arī salmus, pietiktu ar 640 tūkstošiem ha. Lai to pašu enerģiju iegūtu tikai no salmiem, graudaugu būtu jāaudzē 1,8 miljonu hektāru platībā.

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