

ESTIMATION OF THE ENERGY INTENSITY OF LIVE BIOMASS COMPONENTS OF PINE STANDS IN UKRAINIAN POLISSYA

**R.D. Vasylyshyn, Doctor of Agricultural Sciences,
I.P. Lakyda, Candidate of Agricultural Sciences,
O.V. Shevchuk*, M.O. Lakyda**, O.A. Slyva**, PhD students**

Results of development of reference materials for estimation of energy content in aboveground live biomass of Scots pine trees in forest phytocoenoses of natural and artificial origin of Ukrainian Polissya are presented. The algorithm of development of reference materials for assessing energy content, based on the results of modeling qualitative parameters of live biomass components of stands is proposed. The article is grounded on the results of biometric estimation of 110 temporary sample plots (TSP) laid in Scots pine stands of artificial origin, and 20 temporary sample plots – in stands of natural origin.

Ukrainian Polissya, energy, live biomass, stand, stem, bark, diameter, height, reference materials, Scots pine.

The current functioning of energy sector in Ukraine occurs in the conditions of a limited number of imported energy, which in the current difficult Ukrainian realities, still occupies the dominant position in the energy balance of the country. Energy dependence from the aggressor country, in a struggle for independence and territorial integrity, requires three major changes in approaches of state leadership in the formation of energy strategy of the development of Ukrainian society. Along with searching the ways of diversification of the import of natural gas, special attention should be paid to the local energy resources, including renewable energy resources of biological origin. In this situation, in order to reduce the energy dependence of the national economy and improve the energy security of the country, the scientific community and businesspersons initiate the development of a number of research and innovation projects on biomass usage, including wood, as a strategic energy resource [1, 2, 4, 5].

The aim of the research is to develop the regulatory support to estimate the total

* Scientific adviser – Doctor of Agricultural Sciences, P. Lakyda.

** Scientific adviser – Doctor of Agricultural Sciences, R. Vasylyshyn

energy intensity of the aboveground live biomass components of pine stands of different origins in conditions of Ukrainian Polissya.

Materials and methods of research. Theoretical, methodological and experimental research within this work is based on the principles of system approach with a combination of general and special methods of cognition. Algorithm of realization of the research consists of the following stages: 1 – acquisition, processing and analysis of experimental data; 2 – mathematical modeling of quantitative indicators of live biomass components of the investigated stands and adequacy test of models [3]; 3 – evaluation of sequestered carbon content in tree live biomass [6]; 4 – development of regulatory-reference tables for estimation of total energy intensity of the components of the stands live biomass. In order to develop these standards quantitative parameters of energy content in one ton of carbon, sequestered in tree live biomass were used [2, 7], as well as specific energy intensity of wood and bark of trees of the investigated tree species (Table. 1).

1. Specific energy intensity of live biomass components of stem and crown branches of Scots pine trees in Ukrainian Polissya

Live biomass component	Energy content in absolutely dry matter of live biomass components, GJ·(m ³) ⁻¹		
	wood	bark	wood over bark
Stem	7,635	4,953	7,331
Crown branches	7,080	6,151	6,848

Herewith, the calculations are based on the initial data that were gathered over the past decade. The dataset is a representative experimental base for research of aboveground live biomass of pine stands in Ukrainian Polissya [3, 7]:

– *artificially created (planted) Scots pine stands*: data from 110 temporary sample plots, where 592 model trees (MT) were cut down for assessment of live biomass components were used for further processing, analysis and modeling;

- *naturally regenerated Scots pine stands*: the estimation of live biomass components was conducted using the results of research on 20 TSP where 156 MT were cut down for assessment of live biomass components.

The results of the research. Currently, based on the numerous experimental data, there the standards for estimation of the aboveground live biomass of pine stands of the researched region have been already developed. Those research activities are a part of a large-scale integrated scientific project aimed at research of bioproductivity processes in forest plant communities of Ukraine [3]. In order to expand the existing regulatory support towards estimation of structure of energy wood biomass in forest areas, on basis of the mentioned experimental data the algorithm of calculation (Table 2) and the system of regulatory tables for estimation of total energy intensity of aboveground live biomass of Scots pine stands of Ukrainian Polissya were proposed.

2. The algorithm for calculation of total energy intensity of aboveground live biomass of Scots pine stands of different origin

Natural origin	Artificial origin
$Ph_{st} = 2,288 \cdot D^{-0,162} \cdot H^{1,592} \cdot P^{1,018};$ $Ph_w = 1,844 \cdot D^{-0,145} \cdot H^{1,624} \cdot P^{1,017};$ $Ph_b = Ph_{st} - Ph_w;$	$Ph_{st} = 1,441 \cdot D^{-0,191} \cdot H^{1,748} \cdot P^{1,008};$ $Ph_w = 1,165 \cdot D^{-0,178} \cdot H^{1,778} \cdot P^{1,001};$ $Ph_b = Ph_{st} - Ph_w;$
$Ph_n = 2,625 \cdot D^{-0,0013} \cdot H^{0,138} \cdot P^{0,722};$ $Ph_{br} = 3,056 \cdot D^{0,675} \cdot H^{-0,355} \cdot P^{0,434};$ $Ph_{cr} = Ph_n + Ph_{br};$	$Ph_n = 5,096 \cdot D^{0,596} \cdot H^{-0,526} \cdot P^{0,792};$ $Ph_{br} = 1,709 \cdot D^{1,111} \cdot H^{-0,506} \cdot P^{0,332};$ $Ph_{cr} = Ph_n + Ph_{br};$
$Ph_{stand} = Ph_{st} + Ph_{cr};$ $M_C = (Ph_{st} + Ph_{br}) \cdot 0,5 + Ph_n \cdot 0,45;$	$Ph_{stand} = Ph_{st} + Ph_{cr};$ $M_C = (Ph_{st} + Ph_{br}) \cdot 0,5 + Ph_n \cdot 0,45;$
$E^w = M_C^w \cdot \kappa_e; E^b = M_C^b \cdot \kappa_e;$ $E^{st} = M_C^{st} \cdot \kappa_e; E^{br} = M_C^{br} \cdot \kappa_e;$ $E^{stand} = M_C \cdot \kappa_e$	$E^{\delta ep} = M_C^{\delta ep} \cdot \kappa_e; E^K = M_C^K \cdot \kappa_e;$ $E^{cm} = M_C^{cm} \cdot \kappa_e; E^{zin} = M_C^{zin} \cdot \kappa_e;$ $E^{\delta c} = M_C \cdot \kappa_e$

In the presented algorithm the following symbols were used: Ph_{st} – live biomass of stems over bark, $t \cdot ha^{-1}$; Ph_w – live biomass of stem wood, $t \cdot ha^{-1}$; Ph_b – live biomass of bark of stems, $t \cdot ha^{-1}$; D – stand mean diameter, cm; H – mean height, m; P – stand relative stocking; Ph_n – live biomass of needles, $t \cdot ha^{-1}$; Ph_{br} – live biomass of branches, $t \cdot ha^{-1}$; Ph_{cr} – live biomass of tree crown, $t \cdot ha^{-1}$; Ph_{stand} – aboveground live biomass of stand, $t \cdot ha^{-1}$; M_C – sequestered carbon in aboveground live biomass of stand, $t \cdot ha^{-1}$; E^w – energy intensity of stem wood, $TJ \cdot ha^{-1}$; E^b – energy intensity of stem bark, $TJ \cdot ha^{-1}$; E^{st} – energy intensity of stems, $TJ \cdot ha^{-1}$; E^{br} – energy intensity of crown

10	0,27	0,44	0,65	0,89	1,17								
12		0,42	0,63	0,86	1,13	1,42							
14			0,61	0,84	1,09	1,38	1,70						
16				0,82	1,07	1,35	1,66	1,99					
18					1,04	1,32	1,62	1,95	2,30				
20						1,29	1,59	1,91	2,25	2,62			
22						1,27	1,56	1,87	2,21	2,58	2,96		
24							1,53	1,84	2,18	2,53	2,92	3,32	
26							1,51	1,81	2,14	2,50	2,87	3,27	
28								1,79	2,11	2,46	2,83	3,22	

It is worth noting that for the last two years the market of solid biofuels in Ukraine has increased by almost one third, and so today the producers of solid biofuels regard branch wood as an important energy resource for increasing production capacity. However, this situation still is not common and is specific for only some regions of the country, so, in majority of cases, wood and bark of branches are considered as non-commercial raw material, they are hardly used and, mainly, remain in forest for rotting. It should be mentioned that about 65–75 % of stand energy is allocated in tree stems, and 15–35 % – in crowns. In order to facilitate the establishment of quantitative indicators of energy potential of the mentioned forest energy resource, we propose a set of standards for estimation of the total energy intensity of live biomass of crown branches.

The fragments of the proposed standards for estimation of the total energy intensity of live biomass of crown branches of pine stands of different origin with relative stocking 0,7 are shown in Tables 5–6.

5. Total energy intensity of live biomass of crown branches of Scots pine stands of natural origin, TJ·ha⁻¹

Mean diameter, cm	Mean height, m												
	4	6	8	10	12	14	16	18	20	22	24	26	28
4	0,09	0,08											
6	0,12	0,10	0,10	0,09									
8		0,12	0,11	0,11	0,10								
10		0,14	0,13	0,12	0,12	0,11							

12	0,14	0,13	0,13	0,12	0,12								
14		0,15	0,14	0,13	0,13	0,13							
16			0,15	0,15	0,14	0,14	0,13						
18				0,16	0,15	0,15	0,14	0,14					
20					0,16	0,16	0,15	0,15	0,14				
22						0,17	0,16	0,16	0,16	0,15	0,15		
24							0,17	0,17	0,16	0,16	0,16	0,15	
26								0,18	0,18	0,17	0,17	0,16	0,16
28									0,18	0,18	0,17	0,17	0,17

6. Total energy intensity of live biomass of crown branches of Scots pine stands of artificial origin, TJ·ha⁻¹

Mean diameter, cm	Mean height, m														
	4	6	8	10	12	14	16	18	20	22	24	26	28		
4	0,09	0,08													
6	0,14	0,11	0,10	0,09											
8	0,19	0,15	0,13	0,12	0,11										
10		0,19	0,16	0,15	0,13	0,12									
12			0,20	0,17	0,16	0,15	0,14								
14				0,20	0,19	0,17	0,16	0,15							
16					0,21	0,20	0,18	0,17	0,16						
18						0,22	0,21	0,20	0,19	0,18					
20							0,23	0,22	0,21	0,20	0,19				
22								0,26	0,24	0,23	0,22	0,21	0,20		
24									0,26	0,25	0,24	0,23	0,22	0,21	
26										0,29	0,27	0,26	0,25	0,24	0,23
28											0,29	0,28	0,27	0,26	0,25

Application of the proposed regulatory and reference materials is effective in cases when tree trunks of the investigated stands will be used as an energy resource and components of crown live biomass will remain on the cutting areas (for further rotting) to ensure the nutrients circulation in forest soil system (during pre-commercial and commercial thinning). Moreover, the mentioned reference materials are of great value when the industrially valuable assortments are harvested and only primary forest residues in form of coarse branches are available for energy purposes [4, 5] (during final harvest).

Tables 7 and 8 contain the fragments of regulatory and reference materials for estimation of energy intensity of total aboveground live biomass of pine stands of different origin in Ukrainian Polissya with relative stocking 0,7. These materials will be valuable for practitioners in cases when the total amount of aboveground live biomass of stands is intended for bioenergy purposes.

7. Total energy intensity of aboveground live biomass of Scots pine stands of natural origin, TJ·ha⁻¹

Mean diameter, cm	Mean height, m														
	4	6	8	10	12	14	16	18	20	22	24	26	28		
4	0,34	0,52													
6	0,35	0,52	0,73	0,97											
8		0,52	0,72	0,95	1,21										
10		0,53	0,71	0,94	1,19	1,47									
12			0,71	0,93	1,17	1,44	1,74								
14				0,92	1,16	1,43	1,71	2,03							
16					1,15	1,41	1,69	2,00	2,33						
18						1,40	1,67	1,97	2,29	2,63					
20							1,66	1,95	2,27	2,60	2,96				
22								1,65	1,94	2,25	2,57	2,92	3,29		
24									1,92	2,23	2,55	2,89	3,25	3,63	
26										1,91	2,21	2,53	2,87	3,22	3,59
28											2,19	2,51	2,84	3,19	3,56

8. Total energy intensity of aboveground live biomass of Scots pine stands of artificial origin, TJ·ha⁻¹

Mean diameter, cm	Mean height, m													
	4	6	8	10	12	14	16	18	20	22	24	26	28	
4	0,32	0,45												
6	0,38	0,48	0,65	0,86										
8	0,44	0,52	0,67	0,86	1,10									
10		0,56	0,69	0,87	1,10	1,36								
12			0,72	0,89	1,10	1,35	1,63							
14				0,91	1,11	1,35	1,62	1,92						
16					1,13	1,35	1,62	1,91	2,23					
18						1,36	1,62	1,90	2,21	2,55				
20							1,62	1,89	2,20	2,53	2,89			

22	1,63	1,89	2,19	2,52	2,87	3,24
24		1,90	2,19	2,50	2,85	3,22 3,61
26		1,90	2,19	2,50	2,83	3,19 3,58
28			2,19	2,49	2,82	3,18 3,55

The developed regulatory and reference tables are designated for purposes of static assessment and forecast estimation of structure of energy resources and its energy potential in terms of primary energy content. The information support is recommended for application during allocation of forest areas of Scots pine stands in Ukrainian Polissya for logging in course of different types of thinning as well as of final harvest on areas of final cutting fund.

Conclusions

The results of this research will contribute to the practical implementation of forest bioenergy development in the study region as one of the most promising areas for solution of the existing energy problems. The proposed information support toolbox serves as a basis for implementation of scientific, environmental, silvicultural and feasibility substantiation of expanded use of wood energy resources of Ukrainian Polissya, where forest resources are the determining factor not only for environmental, but also for social and economic components of public development, providing financial input to the regional economy and employment for the local population.

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Наведено результати розробки нормативно-інформаційного забезпечення для оцінки вмісту енергії в надземній фітомасі деревостанів сосни звичайної у лісових фітоценозах природного та штучного походження Українського Полісся. Запропоновано алгоритм розроблення нормативно-довідкових таблиць для оцінки вмісту енергії, який базується на результатах моделювання кількісних параметрів компонентів фітомаси деревостанів. В основу роботи покладено результати біометричної оцінки 110 тимчасових пробних площ (ТПП), закладених у сосняках штучного походження та 20 ТПП – у сосняках природного походження.

Українське Полісся, енергія, фітомаса, деревостан, стовбур, кора, діаметр, висота, нормативно-довідкові матеріали, сосна звичайна.

Приведены результаты разработки нормативно-информационного обеспечения для оценки содержания энергии в надземной фитомассе древостоев сосны обыкновенной в лесных фитоценозах природного и искусственного происхождения Украинского Полесья. Предложен алгоритм разработки нормативно-справочных таблиц для оценки содержания энергии, основанный на результатах моделирования количественных параметров компонентов фитомассы древостоев. В основу работы положены результаты

биометрической оценки 110 временных пробных площадей (ВПП), заложенных в сосняках искусственного происхождения и 20 ВПП - в сосняках природного происхождения.

Украинское Полесье, энергия, фитомасса, древостой, ствол, кора, диаметр, высота, нормативно-справочные материалы, сосна обыкновенная.