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## Energy intensity of wood biomass of Zhytomyr Polissia forests

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**Abstract.** The development of renewable energy is one of the principal areas of decarbonization of the energy sector of Ukraine, including in forestry. Improving the efficiency of using wood biomass for energy purposes, along with providing an appropriate level of technological processes and technical equipment, requires reliable information tools for managerial decision-making. An essential component of this toolkit is regional assessments of the energy function of forest phytocenoses. The information base of this study included information from the database of Industrial Association “Ukrderzhlisproekt”, which contains a specific inventory characteristic of tree stands of the region under study, as well as a system of mathematical models for quantitative assessment of phytomass and mortmass of forests. As a result, quantitative values of the total energy intensity of phytomass and mortmass of the forests of Zhytomyr Polissia were established. The total amount of energy accumulated in the plant biomass of the region’s forests is 3,035.7 PJ, which is equivalent to 100.2 million tonnes of conventional fuel. At the same time, the share of the total energy intensity of mortmass is 11.1%. The structure of the energy intensity of plant biomass in the region is dominated by pine stands, which accumulate over 60% of the energy of the forests of Zhytomyr Oblast, namely 70.8% – in the phytomass of tree trunks. Over 40% of the energy is accumulated in the plant biomass of stands of the site index class I, which mainly grow in relatively poor forest conditions (subors). In the overall structure of the energy intensity of the mortmass (336.2 PJ), more than 60% belongs to the forest floor (212.8 PJ), but it is not considered as a source of renewable energy, dry matter – 12.3% (41.3 PJ), dry branches – 17.8% (almost 60 PJ). The results obtained in this study will serve as an information basis to devise a strategy for the development of forest bioenergy in the Zhytomyr region

**Keywords:** wood biomass, energy, mortmass, plantings, low-carbon development, inventory characteristics

### Introduction

The development of renewable energy is one of the principal areas of decarbonization of the energy sector of Ukraine, which is reflected in the Low-Carbon Development Strategy adopted by the Cabinet of Ministers of Ukraine in 2018 (Strategy..., 2018). The document also makes provision for increasing carbon sequestration and reducing greenhouse gas

emissions in the forestry sector, specifically through the development of forest bioenergy.

Improving the efficiency of using wood biomass for energy purposes, along with providing an appropriate level of technological processes and technical equipment, requires reliable information tools for managerial decision-making. An essential

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component of this toolkit is regional assessments of the energy function of forest phytocenoses, which also characterize the energy intensity of woody biomass and the energy productivity of modal tree stands (Vasylyshyn, 2018; Vasylyshyn, Lakyda & Sliusarchuk, 2019).

In the conditions of Zhytomyr Polissia, where forests are a key natural object that ensures the ecological balance of the environment and serves as a source of wood resources, assessing the energy intensity of wood biomass will provide a scientific basis to devise a regional forest bioenergy program.

### Analysis of recent studies and publications

Currently, the problems of researching various aspects of energy production and consumption are reflected in technical (Dubrovin, Korchemnyi & Maslo, 2004), economic (Prokip, 2010), ecological (Vasylyshyn, 2016; Sytnyk, 2017) and biological (Kukhar, Kuzminskyi & Holub, 2005) scientific studies.

Fundamental bioenergetic studies of the innovative and technological direction of the use of plant biomass are currently conducted by scientists of the “Biomass” Scientific and Technical Centre and the Institute of Technical Thermophysics of the National Academy of Sciences of Ukraine under the leadership of H.H. Geletukha (Geletukha, 2021).

Scientific studies of researchers of the M.H. Kholodnyi Institute of Botany of the National Academy of Sciences of Ukraine also characterizes eco-oriented studies of the energy of natural ecosystems, using evidence from the study of the energy balance of the phytocenoses of Kyiv and its green zone (Didukh, 2007).

This scientific area is relevant for scientists from the European Union countries, since in the vast majority of cases the development of the economy here depends on imported natural gas. The specified topic

is presented in studies by representatives of the Swiss Federal Institute for Forest, Snow, and Landscape Research (Burg et al., 2018). They estimate that the annual theoretical potential of biomass in Switzerland is about 209 PJ, including 108 PJ due to wood biomass.

For the conditions of Spain, to estimate the amount of biomass in *Pinus sylvestris* L. stands, an international group of scientists used lidar scanning, which allowed establishing the amount of biomass for seven components of the stand: aboveground biomass, belowground biomass, trunk biomass, needle biomass, and biomass of large, medium, and small branches (Hernando et al., 2019).

Ecological consequences for the forest biogeocenosis from the use of wood biomass for energy purposes have become the object of research by scientists from Sweden (De Jong et al., 2017), who note that increasing the volume of wood biomass harvesting in Swedish forests may have adverse consequences for the state of the environment. An analogous study was also conducted by Polish scientists (Nurek, Gendek & Roman, 2019), who analysed the physical and chemical properties of crushed forest residues of *Pinus sylvestris* L. At the same time, for Uruguay, eucalyptus (*Eucalypts* Sp.) stands are a relevant energy resource of wood biomass, which are being studied to establish their productivity and energy intensity (Bentancor et al., 2019).

The purpose of this study was to estimate the energy content in the components of phytomass and mortmass of the forests of Zhytomyr Polissia.

### Materials and Methods

The information basis of this study was information from the database of VO “Ukrderzhlisproekt”, which contains a specific inventory characteristic of tree stands (over 300 thousand forest plots) of the region under study (Table 1).

**Table 1.** Distribution of the number of forest plots in Zhytomyr Polissia by dominant forest-forming species

Type of woody plant	Quantitative indicator		Type of woody plant	Quantitative indicator	
	pcs.	%		pcs.	%
Silver birch	56,146	17.8	Common aspen	3,656	1.2
Common alder	31,128	9.9	Scots pine	178,794	56.8
Common hornbeam	1,445	0.5	European spruce	3,562	1.1
Common oak	35,421	11.2	Other tree species	4,890	1.6
Total				315,042	100.0

The method for estimating the energy intensity of wood biomass lies in an integrated combination

of the array of forest inventory data with a system of mathematical models for quantitative assessment

of the phytomass and mortmass of the forests of the region (Bilous, 2018; Schepaschenko et al., 2017; Shvidenko et al., 2014) and quantitative parameters of the specific energy intensity of the components of wood biomass (Shvidenko, Nilsson, Obersteiner, 2004; Vasylyshyn, 2018) of the main forest-forming plant species. For other wood species, the mentioned energy intensity indicators are set based on weighted average values of these species.

## Results and Discussion

The processes associated with the supply, transformation, and use of energy are identified as key in the environment, since the effective functioning of any

natural ecosystems depends on their intensity. During the study, it was established that the estimate of the total amount of energy accumulated in the plant biomass of the forests of Zhytomyr Polissia (170.4 million tonnes of absolutely dry matter, namely 151.6 – phytomass, 18.8 – mortmass) is 3,035.7 PJ, including in phytomass – 2,699.5 PJ (Table 2).

According to its equivalent, this roughly corresponds to 100.2 million tonnes of conventional fuel (t c.f.); specifically, for coniferous stands – 1,866.4 PJ, or 61.6 million t c.f., for hard-wood stands – 500.4 PJ, or 16.5 million t c.f., soft-wood stands – 668.6 PJ, or 22.06 million t c.f. The energy share of other tree species is under 0.1%.

**Table 2.** Total energy content in plant biomass of Zhytomyr Polissia forests

Species group	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
Coniferous	1673.0	193.4
Hard-wood	426.4	74.0
Soft-wood	599.7	68.9
Other tree species	0.3	0.1
Total	2,699.5	336.2

The share of the total energy intensity of mortmass in the total structure of energy accumulated in the plant biomass of the forests of Zhytomyr Polissia is 11.1%.

In the overall structure of the energy intensity of plant biomass of the region under study, the dominant positions are occupied by pine stands, which accumulate over 60% (1,844.8 PJ) of the energy volumes of Zhytomyr region forests. The next positions belong to oak and birch stands with 15.1% and 14.4%, respectively. The share of alder stands is about 7%, while the share of hornbeam, aspen, and spruce stands does not exceed 1%. It was established that spruce and pine stands are characterized by the

highest density of accumulated energy per unit area (Table 3). Quantitative values of phytomass energy density index for these tree stands reach 318.53 and 302.01 MJ·(m<sup>2</sup>)<sup>-1</sup>, respectively. In general, the mentioned indicator within the tree stands of dominant forest-forming species varies from 197.95 MJ·(m<sup>2</sup>)<sup>-1</sup> for aspen stands to 318.53 MJ·(m<sup>2</sup>)<sup>-1</sup> for spruce stands. The average value of the phytomass energy density indicator within the stands of the region under study is at the level of 273.05 MJ·(m<sup>2</sup>)<sup>-1</sup>. For mortmass, the mentioned indicator is an order of magnitude lower and is about 35 MJ·(m<sup>2</sup>)<sup>-1</sup>, while the dominant positions in terms of energy density accumulated in mortmass belong to oak and spruce stands.

**Table 3.** Species differentiation of qualitative indicators of energy intensity of biomass of Zhytomyr Polissia forests

Dominant tree species in the stand	Qualitative indicator of energy intensity	
	phytomass energy density, MJ·(m <sup>2</sup> ) <sup>-1</sup>	energy density of mortmass, MJ·(m <sup>2</sup> ) <sup>-1</sup>
Silver birch	217.81	19.57
Black alder	210.18	32.25
Common oak	263.48	48.76

Table 3, Continued

Dominant tree species in the stand	Qualitative indicator of energy intensity	
	phytomass energy density, MJ·(m <sup>2</sup> ) <sup>-1</sup>	energy density of mortmass, MJ·(m <sup>2</sup> ) <sup>-1</sup>
Common aspen	197.95	43.75
Scots pine	302.01	36.17
European spruce	318.53	46.45
Average within the region	273.05	34.73

Analysing the indicators of the average increase in energy in the phytomass of tree trunks, it should be noted that its highest values are typical for spruce and birch stands – 65.12 and 59.13 GJ·ha<sup>-1</sup>·year<sup>-1</sup>, respectively. In general, in the conditions of Zhytomyr Polissia, an average of 51.81 GJ·ha<sup>-1</sup>·year<sup>-1</sup> of energy is added (Fig. 1). In the region under study, over 40%

of energy is accumulated in the plant biomass of stands of site index class I [4]. About a third more are located in stands of site index class II, which is quite natural, given the regional distribution of the area and the site index structure of stands within the forest areas of Zhytomyr Polissia covered with forest vegetation (Table 4).

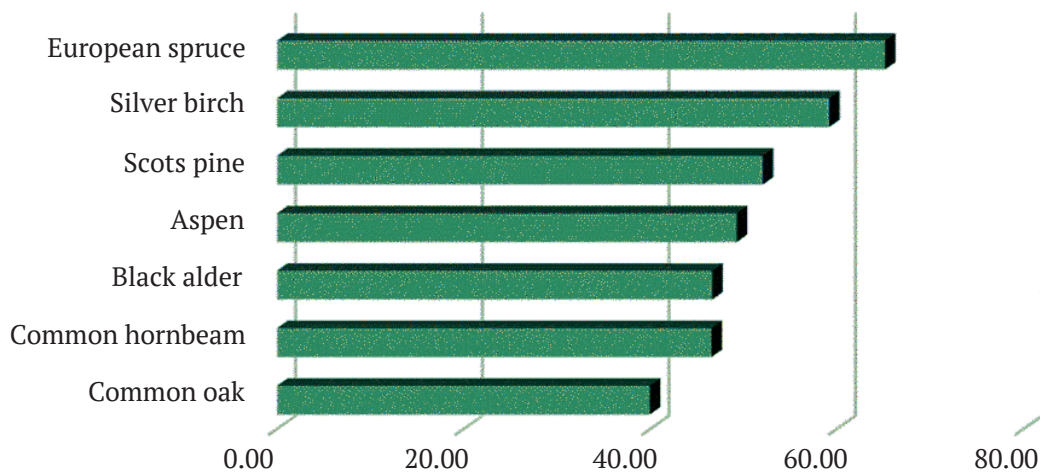


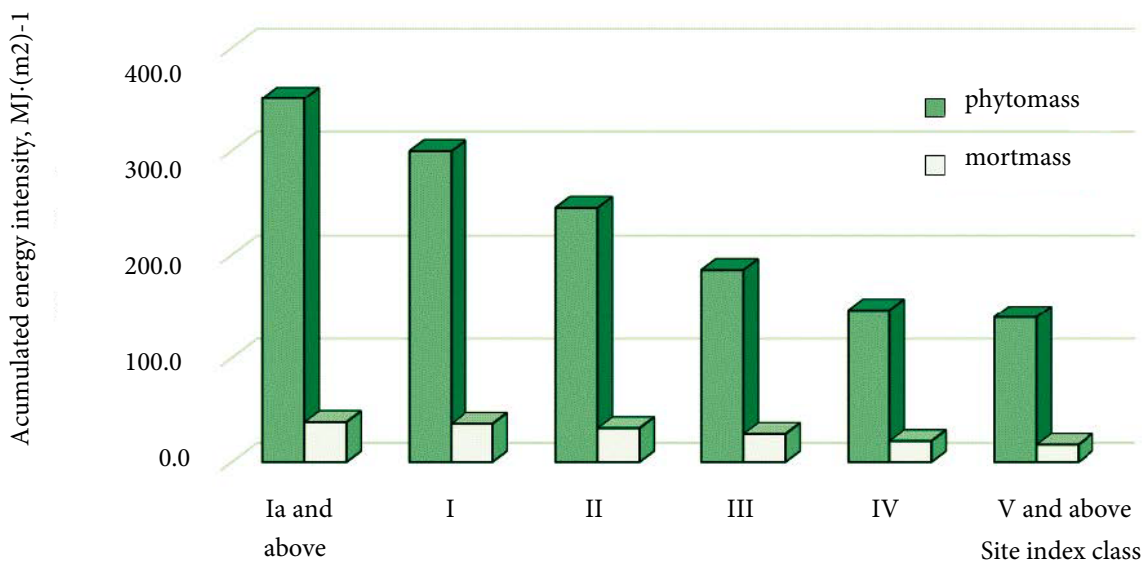
Figure 1. Energy gain in phytomass of tree trunks, GJ·ha<sup>-1</sup>·year<sup>-1</sup>

Table 4. Distribution of energy reserves in plant biomass of Zhytomyr Polissia forests within site index classes

Site index class	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
I <sup>a</sup> and above	480.96	58.71
I	1146.27	136.78
II	858.06	111.19
III	166.52	24.16
IV	29.49	3.94
V and below	18.15	1.46
Total	2699.5	336.2

At the same time, analysing the qualitative indicators of energy intensity presented in Figure 2, it is worth paying attention to the difference in the trends of their change for phytomass and mortmass of forests in the region. Phytomass is characterized by a direct dependence of energy density on the productivity of stands, which is characterized specifically by the site index class. Quantitative values of the mentioned

indicator vary from 350.69 MJ·(m<sup>2</sup>)<sup>-1</sup> for tree stands of site index classes I<sup>a</sup> and above to 139.30 MJ·(m<sup>2</sup>)<sup>-1</sup> for stands of classes V and below. Comparable trends are inherent in the change in the energy gain index in the phytomass of tree trunks, specifically in stands of site index class I<sup>d</sup>, a value of 115.9 GJ·ha<sup>-1</sup>·year<sup>-1</sup> is observed, which gradually decreases to 16.1 GJ·ha<sup>-1</sup>·year<sup>-1</sup> in tree stands of site index class V<sup>b</sup>.



**Figure 2.** Quantitative values of qualitative indicators of energy intensity of biomass of Zhytomyr Polissia forests within site index classes

The intensity of energy production considerably depends on the types of forest conditions in which stands grow. During the study, it was established that the highest values of the energy gain index in the phytomass of tree trunks are inherent in tree stands in fresh subors (*B*<sub>2</sub>) and fresh sudubravas (*C*<sub>2</sub>), where its values are about 60 GJ·ha<sup>-1</sup>·year<sup>-1</sup>. At the same time,

the minimum values of this indicator are inherent in very dry and wet bors – 33.1 and 25.1 GJ·ha<sup>-1</sup>·year<sup>-1</sup>, respectively. In total, about 10% of plant biomass energy is accumulated in the forests of Zhytomyr Polissia (Table 5). Therewith, over 50% of the energy is concentrated in the biomass of tree stands in subors, where Scots pine stands dominate.

**Table 5.** Distribution of energy reserves in plant biomass of Zhytomyr Polissia forests within trophotopes

Trophotope	Energy intensity of plant biomass, PJ	
	phytomass	mortmass
Bors(A)	277.68	29.86
Subors (B)	1411.39	159.93
Sudubravas (C)	888.32	128.72
Dubravas(D)	122.08	17.73
Total	2699.5	336.2

As for the density of accumulated energy, here the highest values are inherent in stands in fresh subors ( $B_2$ ), sudubravas ( $C_2$ ) and dubravas ( $D_2$ ) – over  $320 \text{ MJ} \cdot (\text{m}^2)^{-1}$ .

The component structure of the total energy intensity of phytomass of Zhytomyr Polissia forests is dominated by tree trunks, the share of which exceeds 70% (Table 6).

**Table 6.** Distribution of energy reserves in the phytomass of Zhytomyr Polissia forests by components

Species group, tree type	Energy intensity of phytomass by components, PJ						
	wood and trunk bark	wood and branch bark	needles (leaves)	roots	undergrowth, understory	living superficial cover	total
Coniferous	1228.79	107.81	23.14	271.93	11.33	29.99	1672.99
<i>of which Scots pine</i>	1214.53	106.60	22.86	269.30	11.21	29.72	1654.22
Hard-wood	289.09	54.70	4.87	62.17	6.74	8.88	426.44
<i>of which common oak</i>	266.12	50.25	4.38	56.10	6.27	8.16	391.29
Soft-wood	394.27	63.49	16.13	104.98	7.21	13.64	599.72
<i>of which silver birch</i>	260.82	49.22	13.51	64.18	4.56	8.72	401.02
<i>Common aspen</i>	10.46	1.28	0.26	4.53	0.24	0.43	17.19
Other tree species	0.22	0.03	0.01	0.05	0.005	0.01	0.32
Total	1912.37	226.04	44.14	439.12	25.29	52.51	2699.47

This component of wood biomass is currently the most important in terms of energy use of forest wood resources.

8.4% of the accumulated energy is concentrated in the phytomass of branches. It is also a significant source of renewable energy, which presently has considerable reserves to increase its share in the structure of the regional renewable energy sector. At the same time, the mentioned energy resource should be used in compliance with the principles of sustainable forest management, aimed at ensuring a sufficient level of formation of the biological cycle of food elements in the “forest – soil” system.

A fairly promising component of the energy potential of wood biomass is such components of the mortmass of the region’s forests as dry matter, coarse woody debris, and dry branches.

In total, over 330 PJ of energy has been accumulated in the mortmass of forests of Zhytomyr Polissia (Table 7).

During the study, it was found that about 60% of the total energy intensity structure of mortmass belongs to forest litter, but it is not considered as a source of renewable energy. At the same time, the energy intensity of dry matter is 41.3 PJ, or 12.3%, and dry branches – almost 60 PJ, or 17.8%.

**Table 7.** Distribution of energy reserves in mortmass of forests of Zhytomyr Polissia by components

Species group, tree type	Energy intensity of mortmass by components, PJ				
	dead wood	coarse woody debris	dry branches	forest litter	total
Coniferous	19.34	5.80	42.54	125.69	193.37
<i>of which Scots pine</i>	19.06	5.72	41.93	123.89	190.60
Hard-wood	6.35	3.06	11.07	53.49	73.97
<i>of which common oak</i>	5.78	2.76	10.15	49.00	67.70
Soft-wood	15.65	13.28	6.30	33.62	68.85
<i>of which silver birch</i>	7.93	7.05	2.58	19.29	36.85
<i>Common aspen</i>	1.97	0.55	0.31	1.22	4.04
Other tree species	0.01	0.005	0.01	0.03	0.05
Total	41.35	22.15	59.91	212.83	336.24

The energy intensity of the mortmass of coniferous tree stands accounts for 57.5%, while the share of the components of the mortmass of the tree stands under study, which can potentially be used for obtaining thermal energy (dead wood, coarse woody debris, and dry branches), is about 20%. For hard-wood stands, this ratio is 22.0% and 6.1%, respectively, and for soft-wood stands – 20.5% and 10.5%.

### Conclusions

According to the results of the conducted studies, it was established that the total energy intensity of plant biomass in the forests of Zhytomyr Polissia is 3,035.7 PJ, which in its equivalent corresponds to

100.2 million tonnes of conventional fuel. The share of the total energy intensity of the mortmass of the forests of Zhytomyr Polissia is 11.1%. The structure of the energy intensity of plant biomass in the region is dominated by pine stands, which accumulate over 60% of the energy of the forests of Zhytomyr Oblast, namely 70.8% – in the phytomass of tree trunks.

Over 60% of the total energy density structure of mortmass (336.2 PJ) belongs to forest litter. At the same time, the energy intensity of dead wood is 41.3 PJ, and dry branches – almost 60 PJ.

The results obtained in this study will serve as an information basis to devise a strategy for the development of forest bioenergy in the Zhytomyr region.

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## Енергоємність деревної біомаси лісів Житомирського Полісся

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**Анотація.** Розвиток відновлювальної енергетики є одним із базових напрямів декарбонізації енергетичного сектору України, зокрема й у лісовому господарстві. Підвищення ефективності використання деревної біомаси для енергетичних цілей, поряд із забезпеченням відповідного рівня технологічних процесів і технічного оснащення, потребує водночас надійного інформаційного інструментарію для прийняття управлінських рішень. Важливою складовою цього інструментарію є регіональні оцінки енергетичної функції лісових фітоценозів. Інформаційною базою дослідження слугувала інформація з бази даних ВО «Укрдержліспроєкт», що містить повидільну таксаційну характеристику деревостанів досліджуваного регіону, а також система математичних моделей для кількісного оцінювання фітомаси й мортмаси лісів. У результаті встановлено кількісні значення загальної енергоємності фітомаси та мортмаси лісів Житомирського Полісся. Загальний обсяг енергії, акумульованої у рослинній біомасі лісів регіону, становить 3035,7 ПДж, що за своїм еквівалентом відповідає 100,2 млн тонн умовного палива. Водночас, частка загальної енергоємності мортмаси складає 11,1 %. У структурі енергоємності рослинної біомаси регіону домінують соснові деревостани, в яких акумульовано понад 60 % обсягів енергії лісів Житомирщини, зокрема 70,8 % – у фітомасі стовбурів дерев. Понад 40 % енергії акумульовано у рослинній біомасі деревостанів I класу бонітету, які переважно ростуть у порівняно бідних лісорослинних умовах (суборах). У загальній структурі енергоємності мортмаси (336,2 ПДж) понад 60 % належить лісовій підстилці (212,8 ПДж), однак її не розглядають як джерело відновлювальної енергії, сухоостою – 12,3 % (41,3 ПДж), сухим гілкам – 17,8 % (майже 60 ПДж). Одержані у процесі дослідження результати слугуватимуть інформаційною основою для формування стратегії розвитку лісової біоенергетики в Житомирській області

**Ключові слова:** деревна біомаса, енергія, мортмаса, насадження, низьковуглецевий розвиток, таксаційні характеристики