Modeling of the bioenergetic potential of forest plots

K Rukomojnikov* and T Sergeeva

1Volga State University of Technology, 3, Lenin square, Yoshkar-Ola 424000, Mari El Republic, Russian Federation

*Corresponding email: RukomojnikovKP@volgatech.net

Abstract. The main idea of the publication is to develop a model for the integrated calculation of the bioenergy potential of forest areas, taking into account the technological operations of logging implemented on it earlier and planned in future periods. The presented model gives the researcher the possibility of a comprehensive analysis based on the growing conditions of trees and the technological features of timber harvesting. The dynamics of changes in the bioenergetic potential is taken into account. The analysis of the bioenergetic potential of production waste from various types of harvested forest products is carried out. A calculation algorithm has been developed that takes into account the factors that characterize both the forest area and the technology used to conduct work on the territory of cutting areas. The idea of the calculation was created to improve the efficiency of the implementation of logging operations for logging and fuel and energy purposes at innovative enterprises of the timber industry of the Russian Federation.

1. Introduction
The energy sector that uses renewable energy resources attracts the attention of researchers and investors from different countries [1, 2]. In countries with large reserves of forest resources, including Russia, the forest bioenergy potential is considered as a significant renewable fuel resource [3-5]. The analysis of existing methods for calculating the bioenergy potential [6-8] shows that the main part of the long-term potential is the biomass of stem wood, which is formed over decades. But the use of stem wood for energy purposes is impractical. In fact, the energy potential of the biomass must be calculated either before or after the main logging operations and the removal of the harvested wood, taking into account the remaining forest vegetation and wood waste. The calculation of the bioenergy potential used in the existing methodological recommendations, without taking into account the technological aspects of the forest industry and factors that make it necessary to carry out additional logging operations, has limited practical significance.

The purpose of the study: to form a model for calculating the bioenergetic potential of a forest plot based on a comprehensive analysis of the natural and industrial conditions of the place where tree and shrub vegetation grows.

2. Methods and Materials
To achieve this goal, the method of mathematical analysis is used. The proposed algorithm for calculating the bioenergetic potential of forest plots is shown in figure 1 (a, b). This algorithm takes into account five main components of the bioenergetic potential of forest plots [9]: the potential of the forest aboveground and underground parts of vegetation; its growth in the analyzed time period; the bioenergetic potential of forest soils, the bioenergetic potential of wood waste from logging of past periods, and the bioenergetic potential of wood during planned logging of future periods.
The final formula for the calculation using the proposed algorithm will take the form:

$$P = \sum_{j=1}^{m} \sum_{g=1}^{n} \left( \frac{Q \cdot k_j \cdot k_{jg} \cdot \rho_{jg}}{l_j} \cdot E_{jg} \right) + \sum_{i=0}^{k} \sum_{j=1}^{m} \sum_{g=1}^{n} \left( \frac{\Delta Q_i \cdot k_j \cdot k_{jg} \cdot \rho_{jg}}{l_j} \cdot E_{jg} \right) + \sum_{h=1}^{p} \sum_{j=1}^{m} \left( \frac{V_{fp} \cdot \sum_{f=1}^{d_p} N_{pjf}}{1-\sum_{f=1}^{d_p} N_{pjf}} \right) \left( Z_{org} + \sum_{g=1}^{k} \left( Z_{hi} \cdot e_1 \cdot Z_{org} \cdot e_2 \right) \right) \cdot E_{org} - \sum_{w=1}^{v} \sum_{j=1}^{m} \sum_{a=1}^{v_b} \left( \frac{Q_{raw} \cdot \left( k_{ja} - k_{ja}^{P,T} \right) \cdot \rho_{ja} \cdot E_{ja}}{l_j} \right).$$

(1)

where: $P$ - bioenergetic potential of forest areas, kcal/t (Mj/t); $E_{jg}$ - the highest caloric value for dry biomass for $g$-fraction of the analyzed wood species, kcal/t (Mj/t); $m$ - the number of different types of wood in the forest area; $j$ - the sequence number of the analyzed wood species; $n$ - the number of analyzed fractions of forest biomass of each of the analyzed tree species; $g$ - the sequence number of the analyzed fraction of forest biomass; $\rho_{jg}$ - the density of wood $g$-fractions of $j$-rocks in a completely dry state; $i$ - the sequential number of the analyzed year following the current one (i=0...k); $k$ - the number of years following the results of which the bioenergetic potential of the forest area is calculated; $Q$ - the wood stock of $j$-breed in the forest area, m$^3$; $\Delta Q_i$ - the planned increase in the wood stock in the forest area in the analyzed year, m$^3$; $k_j$ - the share of the analyzed breed in the stand, expressed in fractions of one; $l_j$ - the volume of stem wood of the analyzed breed as a percentage of the total biomass of the tree; $k_{jg}$ - the content of the $g$-fraction as a percentage of the total biomass of the $j$-tree (table 2); $f$ - the ordinal number of the fraction of wood waste formed during the operations of logging operations; $d_p$ - the number of fractions of wood waste obtained during the operations of logging operations; $Z_{org}$ - the stock of organic matter of the soil, t.; $E_{org}$ - the energy content of organic matter, kcal/t (Mj/t); $p$ - the ordinal number of the analyzed finished products, pcs.; $h$ - the number of names of the exported finished products (trees, whips, sortiments, chips, etc.), pcs.; where $N_{pjf}$ - the share of waste generation $f$-fraction $j$-wood species in the production of finished products $p$ - name; $V_{fp}$ - the volume of finished products $p$-names $j$ - wood species, removed from the forest area during the performance of logging operations on it over the past few years (limited to the period of rotting waste), during the production of which waste was obtained in the form of $f$ - fraction $i$ - wood species, m$^3$; $Z_{hi}$ - yield of perennial forest grasses, leaf litter and needles of trees in the $i$ - year, t.; $e_1$ - yield coefficient of residues (0.15+0.2); $Z_{org}^i$ - the stock of organic matter of the soil at the beginning of the first year, t.; $e_2$ - the coefficient of mineralization of humus in the soil; $E_{jf}$ - the highest caloric value for dry biomass for $f$ - fraction, analyzed $j$ wood species, kcal/t (Mj/t); $Z_{fp}^j$ - the mass of the finished product $b$ - name, $j$ - the wood species that is planned to be harvested in the forest area in the analyzed period, t; $E_{ja}$ - the highest caloric value for dry biomass for $b$ - the name of the planned wood product, kcal/t (Mj/t); $b$ - the ordinal number of the planned name of the finished product in the volume of future logging, pcs.; $a$ - the ordinal number of the fraction that is part of the planned finished product $b$ - name; $v_b$ - the number of fractions that will be obtained during the procurement of finished products $b$-names in the planned period; $w$ - the number of items of finished products (trees, whips, sortiments, wood chips, etc.) that are planned to be harvested on the analyzed forest territory, pcs.; $V_{fp}^{raw}$ - the volume of raw materials $j$-rock required for the removal of the total volume of finished products $p$-names, during the previous logging, m$^3$; $E_{ja}$ - the highest caloric value for dry biomass for $a$-fraction of the fractions of the planned waste of forest vegetation, analyzed $j$ wood species, kcal/t (Mj/t); $k_{ja}$ - the content of the $a$-fraction included in the product of the $b$ - name, as a percentage of the total biomass of the tree of the $j$-type, %; $k_{ja}^{P,T}$ - technological losses during harvesting of the $a$-fraction included in the product of the $b$ - name of the $j$ - type, %; $\rho_{ja}$ - the density of the wood of the $a$ - fraction of the $j$-type in a completely dry state.
Figure 1 (a) Algorithm for calculating the bioenergetic potential of forest plots.
Figure 1 (b). Algorithm for calculating the bioenergetic potential of forest plots.
Table 1. Specific calorific value of combustible biomass of various fractions and rocks, kcal/kg.

| Wood species | Trunk timber | Tree bark | Needles, foliage | Branches with bark | Roots with bark |
|-------------|-------------|----------|-----------------|-------------------|----------------|
| Pine        | 4870        | 4887     | 5148            | 4990              | 4799.1         |
| Spruce      | 4830        | 4829     | 5108            | 4927              | 4829           |
| Birch       | 4762        | 4672.2   | 4503            | 4995.2            | 4672.2         |

Table 2. The volume of fractions of forest vegetation as a percentage of the total biomass of the tree, %.

| Woods species (j) | Trunk timber, % (l_j) | Stumps, % | Roots with bark, % | Branches with bark, % | Needles and foliage, % | Tree trunk bark, % | Thin trees, % | Dead standing trees and dead wood of the ground cover, % |
|------------------|-----------------------|-----------|--------------------|-----------------------|------------------------|-------------------|------------|---------------------------------|
| Pine             | 72.5                  | 2         | 11.5               | 5.6                   | 1.9                    | 6.5               | 10         | 10.8                             |
| Spruce           | 62.8                  | 2         | 16.5               | 7.1                   | 3.9                    | 7.7               | 10         | 4.0                              |
| Birch            | 64.5                  | 2         | 10.8               | 9.6                   | 2.2                    | 10.9              | 10         | -                                |

3. Results and Discussion

Thus, the assessment of the bioenergetic potential of forest areas from the perspective of a comprehensive analysis made it possible to assess the reserves of accumulated energy in the main components of the bioenergetic system of forest territories and the amount of transformed energy that can be mobilized and used for the growth and reproduction of forest and shrub plants, soil flora and fauna. The main ecological and bioenergetic functions of the organic matter of the soil on the territory of forest areas and the forest vegetation growing on it as an energy accumulator and source are taken into account quantitatively. An attempt is made to analyze the dynamics of changes in the bioenergetic potential of the territories of forest plots, to take into account the possible placement of logging waste on them from previous logging operations, the bioenergetic potential of the soil cover formed over many years, and to provide an opportunity for the researcher to trace subsequent changes associated with the planned logging operations on the territory.

4. Conclusion

The results obtained can be used by logging companies in the design of logging operations and in the detailed assessment of the bioenergy potential of the developed forest areas.

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