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First Deputy
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REPORT № 4

under **Contract № BFDP/GEF/CQS/16/29-34/18**

dated August 24, 2018

A report including a Methodology for carbon sequestration assessing by felling wastes in carrying out final fellings (clear, non-clear), and also Recommendations and range of activities for biodiversity conservation and ensuring optimum nutrient content and minimization of emission of carbon dioxide emission in areas where clear and non-clear cuttings of final felling were implemented and handling with felling wastes on the results of monitoring, taking into account the balance of socio-ecological and consumer interests of forest management

Activity 3.1.3.3: Assessment and monitoring of nutrient and carbon content in soil and state of biodiversity on final felling sites were felling wastes in addition to timber has been harvested according to the criteria developed by the round table on ensuring sustainable production and use of biomass. Assessment, annual monitoring and recording of results will be implemented on a number of pilot sites over the whole period of project implementation

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ACTIVITY 3.1.3.3. **STAGES 5 AND 6**

STAGE 5

Development of a Methodology for an assessment of sequestration of carbon by felling wastes in carrying out final fellings (clear, non-clear) in the context of two main forest-forming species (spruce, pine). Using the developed Methodology and data for carbon sequestration by biomass of felling wastes during final fellings, obtained on pilot plots, calculate the total carbon sequestration by biomass of felling wastes on the sites of final felling in the forest fund of Belarus. For the calculation we take an average annual area of final fellings, including non-clear cuttings for the last five years.

STAGE 6

Development of recommendations and set of actions for preservation of biodiversity and ensuring optimum nutrient content and minimization of emission of carbon dioxide in areas where clear and non-clear cuttings were carried out and handling of felling wastes on the results of monitoring taking into account the balance of socio-ecological and consumer interests of forest use.

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LIST OF MAIN ABBREVIATIONS, SYMBOLS, UNITS OF MEASUREMENT, TERMS AND DEFINITIONS

BSTU: Belarusian state technological university

Bellesbumprom - production and trade concern of the forest, woodworking and pulp and paper industry;

LGC: Live ground cover;

NR: Natural regeneration;

CRS: Planting material - seedlings with closed root system;

FC: Forest cultures;

IPCC: Intergovernmental panel on climate change.

The Ministry of forestry: Ministry of forestry of the Republic of Belarus;

NCCFF: Non-clear cutting of the final felling; non-clear cutting

PP: Pilot site, pilot plot, station;

FW: Felling wastes;

FF: Final felling;

RUE "Belgosles": Forest management Republican unitary enterprise (RUE) "Belgosles" of the Ministry of forestry;

CC: Clear cutting;

TCP: Technology code of practice;

C: Carbon;

CO_2: Carbon dioxide;

$D_{1.3}$: The average diameter of all trees of tree species at a height of 1.3 meters, cm;

G: Sum of the basal areas of all the trees in a stand in m^2 per 1 hectare, m^2/ha;

FSC: Forest Stewardship council;

PEFC: Programme for the Endorsement of Forest Certification;

P: Average density of forest stands of the forest fund;

g: Gram;

ha: Hectare, 10^4 m^2;

Kg: 10^3 g, kg;

Mg: 10^{6} g, megagram, ton;

t: Ton, 10^6 g, megagram;

toe: Ton of oil equivalent;

mln.t: 10^6 t, 10^{12} g;

m^2: Square meter;

m^3: Cubic meter;

m^3/ha: Cubic meter per hectare;

%: Percent;

Bet; Betula pendula;

Que: Quercus robur;

Pic: Picea abies;

Al: Alnus glutinosa;

Pop.tr: Populus tremula;

Pin: Pinus sylvestris;

pter: Pteridiosum;

myrt: Myrtillosum;

pleur: Pleuroziosum;

oxal: Oxalidosum;

European white birch: *Bétula péndula*;

English oak: *Quércus róbur*;

Polish larch: *Larix palonica*;

European spruce:*Pícea ábies*;

Wood-sorrel spruce forest: *Piceetum oxalidosum;*

Mossy spruce forest: *Piceetum pleuroziosum;*

Bracken spruce forest: *Piceetum pteridiosum*

Myrtillus spruce forest: *Piceetum myrtillosum;*

European aspen: *Populus tremula*;

Scots pine: *Pínus sylvéstris*;

Heath pine forest: *Pinetum callunosum;*

Wood-sorrel pine forest: *Pinetum oxalidosum*

Mossy pine forest: *Pinetum pleuroziosum*

Bracken pine forest: *Pinetum pteridiosum;*

Myrtillus pine forest: *Pinetum myrtillosum;*

Wood-sorrel-type: *Oxalidosum;*

Mossy: *Pleuroziosum;*

Bracken-type: *Pteridiosum;*

Myrtillus-type: *Myrtillosum;*

$CO2_{absorption}$**:** Carbon dioxide absorption from atmospheric air, tCO_2;

Coarse woody debris (CWD): Fallen tree trunks or their parts: twigs, branches, dry and rotting. Forest fallen by wind (windbreak), snowfall, etc., and also forest felled and partly processed, but not removed and left (often as refused);

age class: A classification unit determined by the age of final felling and by the age class duration. The following classes are identified: young, mid-aged, maturing, mature and over-mature;

forest stand: Trees that are the main component of forest stand;

Green economy: economic model aimed at economic growth and social development through the use of predominantly intensive factors, but without excessive pressure on natural resources, without increasing the level of environmental pollution;

bonitet class: Indicator of the potential productivity of stands;

"carbon forests": Grown or created forests removed from economic use for a long period for carbon sequestration deposit carbon within their phytomass;

forest litter: Forest ground cover formed from the plant litter with different decomposition rate;

forest fund: Lands intended for forestry;

decidious species: Flowering trees covered with lamina petiolar foliage (*Betula pendula, Quercus robur, Alnus glutinosa* and others);

deciduous forest: Forest consisting of deciduous trees;

forest stand Growing on the site of the forest fund tree and shrub vegetation of a certain species composition and live ground cover;

young growth: Forest stands of age classes 1 and 2;

softwood species: Deciduous woody plants, mainly with small leaves, with wood of low density (*Populus tremula, Alnus incana,* and others);

softwood forest: Forest formed by trees with small leaves and softwood (*Populus tremula, Alnus glutinosa* and others);

softwood farm: Economic unit of the forest fund, combining stands with a predominance of soft-leaved species;

complete stand: A stand having such a structure, species, age and growing conditions to be considered the most perfect-quality (M. M. Orlov). A stand with the relative density of 1.0;

aspen forest: Aspen trees growing together (*Popular tremula*);

forest understorey (Subsilva): Shrubs, less often tree species, growing under the forest canopy and incapable of forming a forest stand under the existing conditions;

undergrowth (silva succrescens): Woody plants of natural origin, growing under the forest canopy and capable of forming a forest stand, the height of which does not exceed 25 per cent of the height of the main canopy trees,

overmature forest stands: Forest stands older than the age class for which felling age is set;

ripenings: Age class preceding the age of mature forest stands;

dominant species: Wood species, which accounted for the majority of the stock of stand stem wood;

middle-aged forest stands: Forest stands older than young growth and younger than maturing stands;

middle-aged forest stands: Forest stands over the age of young growth and up to the age of ripening stands (in the exploitable forests 3 age class, in the forests of other categories – 3 and 4 age classes);

estimated cutting site: The amount of annual issue of standing timber, set for final fellings;

Mature forest stands: Tree stand age class which is set as the felling age;

hardwood species: Deciduous woody plants with solid wood and mostly with broad leaves (*Qurcus robur, Fagus silvatica* and others);

hardwood forest: Forest formed by hardwoods (*Acer platanoides, Ulmus laevis, Quercus robur* and others);

hardwood forestry: Economic unit of the forest fund, combining stands with a predominance of hardwood species;

coniferous forest: Forest consisting of trees of one or more conifers (*Pinus silvestris, Picea abies* and others);

conifers: Tree species of coniferous origin, usually evergreen, covered with spiny leaves (*Picea abies, Pinus ponderosa* and others);

coniferous forestry: Economic unit of the forest fund, combining stands with a predominance of coniferous species;

SUMMARY

The essence of the problem within reporting stages 5 and 6 of the Activity 3.1.3.3 consists in the following.

Against the background of global climate change due to the increasing volume of greenhouse gas emissions from the combustion of fossil hydrocarbon fuels from the broad public the requirements for the transition to other energy sources are increasing. Some attention is paid to the use of renewable wood resources for energy purposes. For the production of biofuels firewood and felling wastes are used. They are formed during the harvesting of wood in the process of final fellings and intermediate use and others.

Based on the results of the fifth and sixth stages, including the previous ones, some recommendations were prepared for legal entities involved in timber harvesting and felling wastes processing. Appropriately applied recommendations will allow to organize the production and disposal of felling wastes for energy purposes in compliance with the environmental, socio-economic interests of consumers and sustainable forest management and increasing the role of forests in greenhouse gas absorption.

Steps 5 and 6 of the Activity 3.1.3.3 were implemented taking into account the following. The Republic of Belarus has undertaking to reduce greenhouse gas (GHG) emissions by 2030 not less than 28 % of 1990 level, excluding greenhouse gas emissions and effluents in the "Land use, change in land use and forestry" sector.

At the summit on measures in the field of climate change of the 74th session of the UN General Assembly on September 23, 2019, Belarus announced its intention to make an unconditional commitment to reduce greenhouse gas emissions by at least 35% by 2030 compared to 1990 solely by the expense of its own resources.

With the observed economic growth of the Republic, achieving the expected reduction of GHG emissions will require the implementation of serious effective measures. Among them will be the task of including the contribution of the forestry sector to GHG absorption through carbon dioxide effluents in the primary synthesis of organic substances (forest photosynthesis).

Under article 13 of the Paris agreement, all States are required to provide information on their contributions to GHG emission reductions. In order to reliably assess this information, a regulation on the establishment of an emission monitoring and assessment system is currently being developed.

With regard to forests, it should be recognized that their contribution to the Paris agreement is small and is possible primarily in ways to increase forest productivity, prevent forest degradation and over-logging, increase reforestation and afforestation. These actions will require investments to increase carbon dioxide absorption by forests for each activity.

It is possible to ensure the conservation of forest biodiversity through the integration of relevant activities at all stages of forest management, including the renewal, cultivation, protection, conservation and use of forests. It is not enough to limit the solution of this problem by the stages of felling of ripe forest and management of felling wastes.

Therefore, the implementers considered it appropriate to expand the scope of the Activity 3.1.3.3, specified by the stage 6, in order to comprehensively cover measures and actions necessary for the conservation of forest biodiversity. The final document was a plan to preserve biodiversity, ensure optimal nutrient content and increase carbon sequestration function in the forests of the Republic of Belarus. The plan provides for a system of measures, the timing of their implementation, implementers, as well as forecast indicators of their implementation, which can be specified taking into account the actual situation in forestry.

In the ***first part (5.1) of the report*** on the fifth stage of the task, the methodology for assessing the carbon sequestration by felling wastes in the areas of final fellings. The method includes the determination of carbon content in felling wastes, the calculation of the emission of

carbon during decomposition of felling wastes and the calculation of the absorption of carbon dioxide by regeneration, which occurs simultaneously with the decomposition of wastes that have not been removed from the cutting site.

The presentation of these methods is preceded by general methodological information on possible ways of carbon flows (emission flow) in the formation of felling wastes in the cutting sites. The advantage of balance calculations based on stocks (biomass) of different fractions of felling wastes is stated. As a result, the expediency of assessment of the above mentioned three carbon flows is reasoned: felling wastes carbon, emission of carbon during felling wastes decomposition, the absorption of carbon by the resgeneration of young generation after the cutover of the mature parent forest stand.

The method of determining the carbon in forest wastes based on the selection before sample trees felling and determination of the mass of the felling wastes on them by fractions. Subsequent conversion coefficients of biomass density and carbon content per unit mass of felling wastes are used.

When calculating carbon emissions from decomposition of felling wastes, it is recommended to divide the felling wastes into groups of fractions according to the period of their decomposition. Three groups are proposed with decomposition periods of 1-2 years, 3 to 10 years and over 10 years. Taking into account the integrated time period for a cutting site, volumes of emission for the entire period of decomposition of the mass of felling wastes are set. There is a lack of information on the proportion of sequestrated carbon by soil and forest litter.

The method of absorption of carbon dioxide in photosynthesis by young generation (regeneration) is determined on the basis of phytomass growth and conversion factors of carbon content per unit of wood stock.

In the second part (5.2) of the report on the fifth stage of the task, the forecast of wood harvesting and the volume of felling wastes in the sites of final felling for the future 2030 and 2050 is presented.

The role and place of final fellings in the system of forest felling and forest management are designated. The concept of the estimated cutting site and the methodology of its definition is revealed. The size of the estimated cutting site on final fellings in the Republic of Belarus for the period from 2014 to 2018 is given. Its development and actual harvesting of realizable timber in the context of species groups and individual species are analyzed. Final felling areas in the context of felling techniques (gradual and selective cutting) and farms (coniferous, hardwood and softwood) are given. The forecast of the size of final fellings for 2030 and 2050 by the species, groups of species and methods of felling was prepared. The volumes of reforestation for 2030 and 2050 are predicted by methods: creation of forest cultures, assistance for natural regeneration and natural regeneration.

The reserve base of timber for determination of the volume of felling wastes biomass from final fellings was examined. The standards for classification of woody biomass to felling wastes in the context of fractions are noted. The paper presents the recommended standards for determining the volume of stem wood. The volumes of branches, thin tree tops, woody vegetation, stumps and roots from final fellings for 2030 and 2050 in terms of species, groups of species and methods of fellings are forecasted.

On the basis of criteria (conversion factors) the calculation of carbon content in felling residues predicted for the future 2030 and 2050 is executed.. The issue of the use of increasing (up to 5.8 million m^3 annually) volumes of felling wastes in the country is analyzed. The existing regulations of felling sites clearing from felling wastes are considered depending on forest growth conditions under different methods of felling, prospects of use in connection with the demands of consumers.

In the first part (6.1) of the report on the sixth stage of the task, recommendations on biodiversity conservation, ensuring optimal nutrient content and minimizing carbon dioxide emissions in the areas of final felling are formulated.

During clear cuttings less favourable conditions for preservation of floral diversity are created than it is during gradual and selective cuttings. With the purpose of biodiversity preservation of felling wastes on cutovers is preferable especially for live ground cover. Non-removal of felling wastes has a negative impact on forest fire and forest pathology situation.

A number of measures are recommended, the use of which in the implementation of final fellings, reforestation, use/non-use of felling wastes contribute to biodiversity in the felling areas.

Methods of final felling and removal/non-removal of felling wastes in connection with their influence on soil fertility, nitrogen and mineral nutrition of the younger generation of the forest are analyzed. The content and nutrient removal from forest ecosystems is considered on the example of pilot plots, created on the instructions of the Activity 3.1.3.3 and facilities of the Department of forestry BSTU and RUE "Belgosles". Removal of felling wastes does not reduce the productivity of subsequent stand generation. Preservation of felling wastes has a positive effect on the nutrition of the lower layers of the stand (live ground cover, subsilva).

The possibilities of increasing the absorption of carbon dioxide in the ways of the right choice of felling techniques, conservation and promotion of natural regeneration are considered. The efficiency of the use of felling wastes for fuel purposes with the minimization of carbon dioxide emissions is noted. The impact of work with the population about handling of felling wastes and increase of the role of forests in the absorption of carbon dioxide is analyzed. The article presents cost-effective methods of handling with felling wastes in order to replace hydrocarbon fuel with wood raw materials.

Taking into account the discussion at the Round tables, the consistent generalization of diverse studies at all stages of the Action 3.1.3.3, the materials of the sociological survey, proposals and comments of the Contract sponsors on the basis of a synergistic approach, the estimates of the methods of felling wastes management were refined.

The impact of felling wastes on forest formation and biodiversity is considered taking into account factors: creation of forest cultures, natural renewal, the content of nutrients in the soil, biodiversity conservation, carbon dioxide absorption. Positive and negative consequences of all standard recommended methods of felling wastes management are established.

The positive and negative opinions of various segments of the population on conducting of fellings, clearing of forests of dead phytomass are formulated. The materials are of interest for forest management practice. The low awareness of people about the purposes and tasks of forest management, forest cultivation, protection and preservation of forests is established.

The analysis of the efficiency of production and sale of fuel chips from felling wastes is implemented. The conclusion is made about the lack of accounting by the forestry enterprises of the possibility of obtaining additional revenue from the sale of felling wastes. When calculating the cost of wood chips from the felling wastes some circumstances are not taken into account: free cost of felling wastes, unlike fuel wood; also the cost for felling wastes gathering, previously included in the clearing of cutting sites during felling. The reason for the reduced demand for wood chips of felling wstes is also the excess of wood in the republic today. Wood chips are more competitive in both domestic and foreign markets. In the short term, the situation will change.

To minimize the negative impact on the environment and rationalize the use of wood biomass, it is proposed to make changes and additions to the standard STB 1360-2002 " Sustainable forest management and forest use. Final fellings. Technology requirements".

In the second part (6.2) of the report on the sixth stage key activities of national plans and strategies affecting the biodiversity of forest ecosystems of Belarus are analyzed. A Plan has been under the review on the conservation of biodiversity, provision of optimal nutrient content and increase in the carbon-producing function of forests.

Attention is paid to the importance of integration of the existing program documents in the Republic in the development of forestry activities for the conservation of forest biodiversity.

Activities aimed at forest biodiversity and increasing the role of forests in the absorption of greenhouse gases, such as programme documents, are analyzed:

– National plan of action for the conservation and sustainable use of biological diversity for 2016-2029;

- National action plan for adaptation of forestry to climate change until 2030;

- National action plan to increase the absorption of greenhouse gases by absorbers (forests, swamps) for the period up to 2030 and others.

The ecological and economic consequences of clear and non-clear cuttings of final felling are analyzed. On the basis of previously obtained results on the Activity 3.1.3.3 some measures for the conservation of forest biodiversity were proposed.

The Developed plan for the conservation of biodiversity, ensuring optimal nutrient content and increasing the carbon sequestration in forests provides recommendations for groups of activities, such as:

- Forestry activities;
- Forest use aimed at biodiversity conservation;
– Organizational measures.

Specific types of measures and actions are time related, addressed to specific performers (SFPA and forest fund managers) indicating the amounts of their implementation.

This substantive response concludes analytical, research-experimental and recommendation components of the Contract. In accordance with the terms of Reference for the Activity 3.1.3.3, the Report № 5 on the materials of the Round tables is provided. Round tables were held, the results are summed up and additions are made to the decisions of the Round tables in the Final conclusion on the results of the Contract . The draft of the Final report is presented in the Appendix to the present report. The expected remarks and suggestions for the consideration of Project Activities 3.1.3.3 by the contractors will be taken into account in the outcome document of the Conclusion by results of the Contract № BFDP/GEF/CQS/16/29-34/18.

INTRODUCTION

The implementation of the previous stages of the Activity 3.1.3.3 based on established pilot sites of the Department of forestry of BSTU and RUE "Belgosles", taking into account international experience, allowed to identify an effect of the methods of final fellings, reforestation and handling with felling wastes at all stages of creation and development of forest stands on:

– carbon flows in the system, "emission flow»;

– nitrogen and mineral nutrition of forest stands;

– productivity of the subsequent generation of forest stands of various methods of regeneration;

– floral diversity of forest stands;

– ecological, socio-economic consequences of different ways of using of felling wastes.

Methodological approaches in monitoring of forest indicators, of nutrients, including carbon, and indicators of forest biodiversity on final felling sites with or without use of felling wastes.

The results obtained allow to propose a set of actions to conserve biodiversity and minimize "emissions" of carbon dioxide on the areas of different kinds of final fellings, including the balance of socio-environmental and consumer interests in forest use in the framework of the transition of forestry of the Republic of Belarus to a "green economy".

Tasks solution set by the Technical task of the Action 3.1.3.3 on the stages 5 and 6, which is the content of this Report, is carried out in the following sequence.

Methodology of estimating of carbon sequestration by felling wastes for carbon pools was formulated: carbon from felling wastes for the beginning of the final felling, carbon in the period of felling wastes decomposition, carbon of the renewable cutting site for the period of felling wastes decomposition.

The estimated cutting site for the final use in the forests of the Republic of Belarus for 2030 and 2050 is defined. The projected volume of wood harvesting is presented in the context of the predominant species, by groups of species and forestries, felling and regeneration methods.

The expected volumes of felling wastes by fractions are set: branches, twigs, thin tree tops, woody vegetation, stumps and roots. The volumes of carbon sequestrated by felling wastes for the years 2030 and 2050 were defined. Suggestions for the use of felling wastes are considered.

Recommendations on biodiversity conservation in the areas of different methods of fellings and handling of felling wastes have been developed. Under these conditions, recommendations about providing of forest plants with nutrients, minimization of carbon dioxide emissions are suggested.

The analysis of key activities affecting biodiversity at all stages of forest management in the existing programme documents, such as Strategies, National action plans and Programs, Standards of forest management systems and forest certification.

The final document of this Report is the Plan for biodiversity conservation, to ensure optimal nutrient content and increase carbon sequestration in forests of the Republic of Belarus. The plan provides for a system of activities, deadlines, executors, as well as predictive indicators of their implementation, which can be specified taking into account the actual situation in forestry.

In General, the objectives set for the stages 5 and 7 have been fully implemented.

5. METHOD OF ESTIMATION OF CARBON SEQUESTRATION BY FELLING WASTES IN CARRYING OUT CLEAR/NON-CLEAR CUTTINGS OF FINAL FELLING. FORECAST OF TOTAL CARBON SEQUESTRATION BY BIOMASS OF FELLING WASTES IN THE AREAS OF FINAL FELLINGS IN THE FOREST FUND OF BELARUS FOR 2030 AND 2050 ON THE BASES OF THE AVERAGE ANNUAL AREA OF CLEAR / NON-CLEAR CUTTINGS OVER THE PAST FIVE YEARS

In forest ecosystems, both positive carbon flows that absorb carbon dioxide from the air during the life of plants and negative flows that emit carbon dioxide during the decay of biomass function simultaneously.

As for the positive cycle, the processes of carbon accumulation in the biomass of forest ecosystems are well studied in the Republic. Methods for the assessment of total carbon accumulation by a growing forest stand and other components of forest phytocenosis are developed: organic carbon of soil, forest litter, dead fallen wood. National conversion factors for all age groups of the main forest-forming species have been developed to convert wood stocks into biomass.

However, carbon processes in nonliving phytomass of forest biocenoses is insufficiently studied in the republic: fires from burning phytomass, forest litter, deadwood, humus and peat; the violation of forest biocenosis during the final fellings and intermediate fellings, clear and selective sanitary fellings as a result of various natural disasters, storms, windblown, massive damages to forest stands by diseases and pests of the forest, in felling wastes created during final, intermediate and other fellings.

Processes occurring in forest ecosystems in dynamics are insufficiently studied: changes in carbon content and nutrients in different growing conditions, changes depending on forestry activities and natural factors.

In fact, there are no recommendations on the carbon function for forest organizations in the implementation of forest activities and they are not applied in practice.

Forest in the Republic of Belarus is the most important natural resource of the state. The forest policy carried out in the last decades has significantly changed the forest fund, increased wood stocks; the problems of rational forest management are being solved. In modern conditions, forest management is organized taking into account strict adherence to the principles of sustainable development, ecological compliance with the functions performed by forests. The Forest code of the Republic of Belarus defines the concept and at the legislative level defines the types of activities for which the withdrawal and consumption of natural resources grown in the forest are carried out.

The term "forest management" implies the use of various forest products. A broad and narrow perspective of forest management has recently emerged. The former is characterized by the terms "multi-purpose forest management" or "integrated forest management".

It should be the focus of all modern forestry activities.

Today, timber is the real resource in the country. Obtaining of timber from forest stands occurs during the final and intermediate fellings and other fellings. Final fellings are the main fellings for timber harvesting in forest stands. Their volume primarily depends on the availability of ripe stands in the forests.

Forest statistics have relatively reliable data on wood stocks of stem wood in the context of the constituent species. This is due to the urgent need to have information about growing, felled, used in the processing of volume indicators of wood mass. Less used tree parts are not considered due to the absence of established criteria for determination of their volumes. First of all, this can be attributed to the determination of stocks of felling wastes from all types of felling carried out in the republic. These data are necessary not only for the organization of their direct use and construction of long-term forecasts, but also for the assessment of total and annual carbon sequestration by forests of the Republic of Belarus.

5.1. METHOD OF ESTIMATION OF CARBON SEQUESTRATION BY FELLING WASTES IN CARRYING OUT CLEAR/NON-CLEAR CUTTINGS OF FINAL FELLING

In recent years, the forest Fund of the Republic of Belarus has harvested up to 8 million cubic meters of realizable timber for final fellings. With the average stock of operating stock 267 cubic meters per 1 ha, and taken into account that about 15% of realizable timber is harvested during non-clear cuttings of felling, the sites area of forest fund, involved in the final felling annually is not less than 35 thousand hectares.

During logging operations during final fellings significant number of not exported biomass of forest wastes (tree tops, branches, stumps, non-liquid parts of trees, damaged silva succrescens and subsilva, needles and leaves) are left. According to estimates of different authors, the mass of felling wastes, depending on the composition and completeness of the felled forest stand, forest growing conditions, technology of cutting and other factors can be from 10 to 40% of the volume of felled wood. Consequently, the volume of felling wastes on the cutting sites after the final felling in the Republic of Belarus as a whole will be up to 2 million cubic meters (the average figure is taken into account – 25%).

Felling wastes contain significant amounts of combined carbon.

In Belarus, according to [2] cutting site cleaning in carrying out of final fellings is implemented by the methods when the main mass of felling wastes is not removed from cutting sites and is left in forest for rotting. Therefore, it is important for forest industry workers with regard to carbon exchange to know what carbon processes occur with the felling wastes that are left in the cutting site for rotting.

The purpose of the development of this methodology is to provide specialists and other forestry workers with the necessary information to make optimal environmentally sound decisions in the selection of methods of final fellings and methods of clearing of cuttings sites from felling wastes in the design and implementation of fellings.

In the course of the work, the available methods and guidelines for the assessment of carbon sequestration by felling wastes in carrying out final fellings. Some provisions have been studied and taken into account [3-5].

The objective of this work is to develop a Methodology for carbon sequestration assessing by felling wastes during clear and non-clear cuttings of final felling in the context of two forest-forming species (spruce, pine) with the use and non-use of cutting waste for fuel and other utilization purposes.

5.1.1. General methodological approaches in the content of the Methodology

The most objective information about carbon sequestration by felling wastes, as well as other components of the forest ecosystem, can be obtained by direct measurements of carbon flows and carbon exchange between the atmosphere and the ecosystem [6]. This method involves the use of special expensive equipment. As it is noted by many experts at present time, this method does not provide reliable results with a limited number of observations. It is mostly appropriate for measuring the carbon content and the level of carbon exchange between the ecosystem and the atmosphere only for individual sites and in a limited time frame. In a view of the above and the need for expensive equipment, this method cannot currently be widely used in forestry practice for the purpose of carbon sequestration assessment by felling wastes of final felling.

Other methods are based on balance calculations of carbon flows based on the principle of equality of changes in carbon content in the components of biocenosis, changes in carbon flows to or from the atmosphere.

The basis of balance calculations is the stock (weight) of stem wood. The correlation between different fractions of wood biomass is widely used. To calculate carbon balances, the mass of stem wood and other parts of the phytomass is converted into dry organic matter for further determination of carbon in it. In addition to instrumental measurements, certain conversion factors of carbon content in the dry phytomass of the forest ecosystem, density coefficients of stemfor coniferous and deciduous tree species, roots, including stump, and other factors can be used for further calculations.

According to the Marrakesh agreements, the calculations are carried out for five large carbon reservoirs (pools): above-ground phytomass, underground phytomass, deadfallen and dead wood timber, forest litter and soil organic matter. As for carbon sequestration by felling wastes, this process is not generally considered separately. Carbon sequestration by felling wastes during final felling are a set of carbon processes in their component fractions: tree trunk, branches, small twigs, needles and foliage, stump and roots, as well as individual components of forest stands – silva succrescens and subsilva, live ground cover.

Forest ecosystems are characterized by multiple and multidirectional carbon flows. However, in the world today, all these processes have not been fully studied.

In the present work in assessing carbon sequestration by felling wastes two main carbon flows are considered:

– sequestration of atmospheric carbon by tree fractions and forest ecosystem components comprising felling wastes before final felling;

– carbon emission during decomposition of felling wastes and the processes of carbon exchange occurring in the felling wastes after clear and non-clear cuttings of final felling.

Both of these flows are estimated only from phytocoenotic component of forest biocenosis point of view.

In order to evaluate the processes in the dynamics of carbon in felling wastes after final felling, it is necessary to have data on the amount of carbon sequestration by relevant parts of the forest biocenosis during the period of forest stand growth.

The fundamental principles of this methodology are as follows:

– carbon sequestration by felling wastes after the final felling is not implemented;

- the calculations is based on the amount of carbon absorbed by the respective fractions of the tree trunk and components of the forest biocenosis before the final felling;

– carbon emission by selected fractions of tree trunk and forest biocenosis components after the final felling is implemented evenly across time;

– in cutting sites after the final fellings the process of carbon sequestration of renewable trees, shrubs and herbaceous vegetation occurs.

5.1.2. Calculation of carbon sequestrated by felling wastes

The amount of carbon sequestration by felling wastes before the final felling is determined from the amount of felling wastes created during clear and non-clear cutings of the final felling, equity participation of various fractions and components of felling wastes in their total volume and conversion ratios of carbon content per unit of stock of the related tree species.

To determine the total amount of felling wastes formed during the final felling, the method of research of the forest Institute of the National Academy of Sciences of Belarus is used (V. G. Shatravko, N.V. Tolkacheva). The method was applied by the Forest Institute of the National Academy of Sciences of Belarus in the framework of forest-ecological justification of the use of biomass of cutting wastes in stands of the main forest-forming species [7].

The method of determining the total volume of felling wastes is based on bucking of model trees, that is, the cut of branches, twigs, foliage and needle gathering and other biomass fractions of a tree trunk of average trees with their subsequent weighing.

Average trees according to the average valuation parameters, size and shape of the crown of the trees for all the constituent species of the forest stand are selected as model trees. The number of model trees is calculated according to the required accuracy of the results.

Weighing of felling wastes is carried out separately for each fraction. In this case, small branches and small roots are separated into separate fractions, since carbon emission in branches and roots of different volumes occurs at different rates. The weighted component can be produced both for individual trees and component species.

All these works, including measurements of heights and diameters are performed before the final felling, or during the fellings observing safety regulations.

The fractional composition of felling wastes on different cutting sites varies greatly depending on the species composition of the stand, completeness, type of forest conditions, seasonal time of felling. Such situation makes it extremely difficult to determine the weighted average fractional composition of felling wastes, as well as their total share in the root stock of the felled stand. In carrying out final felling in winter season, foliage fraction completely falls out from the accounting, it is difficult to take into account the fraction of needles and small branches and roots. In this regard, works on accounting for the total volume and fractional composition of felling wastes must be performed during the vegetation period before the defoliating.

The volume of each model tree is determined by the diameter and height of the corresponding volume tables. The average volume of a model tree is defined as the arithmetic mean of the volumes of the selected model trees.

Root stock during final felling is set according to the material-monetary estimation of forest clearings, in other cases according to the mensurational description or from other reliable sources.

The composition of the felling wastes in addition to the fractions of the tree trunk includes silva succrescens and subsilva felled during the final felling or damaged to the extent of growth cessation. Accounting of phytomass of silva succrescens and subsilva is carried out on a circular or rectangular pilot plots, laid evenly over the area of the cutting site after the felling of the forest stand before the cutting site clearing. At the same time, only unviable specimens of silva succrescens and subsilva are taken into account at the sites. The size of the accounting area is advisable to take equal to 1% of the cutting site, and the total area of the accounting areas should be at least 5% of the cutting site.

Having the volumes of model trees, the root stock of the stand in the allotment (forest site), the weight data of the mass of felling wastes according to separate fractions through the conversion ratios of volume and mass, the total volume of felling wastes in the allotment including the components species is calculated. If necessary, the volume is determined per 1 ha, per cubic meter of wood stock, etc.

Calculation of carbon sequestration by felling wastes is carried out separately for each fraction of the tree trunk and other components of the forest phytocenosis.

The specific weight of felling wastes is calculated by the formula (1):

$$K_{f.w.} = A_{f.w.} \times n / V_{m.t.} \times n, \qquad (1)$$

where: $K_{f.w.}$ – specific weight of felling wastes, kg / m^3;

$A_{f.w.}$ – average mass of felling wastes per tree, kg;

$V_{m.t.}$ – average volume of model tree, m^3;

n – number of model trees.

The total biomass of felling wastes on the cutting site is calculated from the total root stock of wood growing in this forest area before felling, and proportion of biomass of felling wastes creating in the result of forest felling by the formula (2):

$$A_{site} = K_{f.w.} \times V_{site} / 1000, \qquad (2)$$

where: A_{site} – the mass of felling wastes in the site, t;

$K_{f.w.}$ – specific weight of felling wastes, kg / m^3;

V_{site} – wood root stock on the site, m^3;

1000 – conversion factor of the mass of felling wastes in tons.

The total organic carbon content in felling wastes is calculated by the formula (3):

$$C = A_{site} \times K_c \times KC_{f.w.}, \tag{3}$$

where: C – total organic carbon content, t;

A_{site} – the mass of felling wastes in the studied site, t;

K_c – coefficient of conversion of the mass of felling wastes into the mass in dry state;

$KC_{f.w.}$ – the share of carbon in the phytomass of felling wastes, in %.

The share of carbon in selected fractions of wood phytomass and other components of forest phytocenosis is taken from the Method [4] (table 5.1).

Table 5.1 – Share of carbon in dry phytomass of different fractions of a stand and components of forest stand [4]

Dominant tree species	The share of carbon in phytomass, non-dimensional value					
	Stemwood	Twigs and branches	Needles or foliage	Roots and stump	Silva succrescens and subsilva	Live ground cover;
Pínus sylvéstris:	0.501	0.526	0.522	0.517	0.500	0.484
Pícea ábies	0.505	0.515	0.528	0.528	0.500	0.474
Quércus róbur	0.504	0.530	0.518	0.506	0.500	0.500
Bétula péndula	0.500	0.516	0.444	0.513	0.500	0.500
Álnus glutinósa	0.500	0.517	0.454	0.512	0.500	0.485
Pópulus trémula	0.503	0.519	0.462	0.515	0.500	0.500
Others	0.503	0.500	0.485	0.494	0.500	0.471

In practice, when highly accurate results are not required, and in order to save labor and material costs, it is allowed to use a single conversion factor of carbon content in dry weight of all fractions of stands and components of forest stand that is recommended by the IPCC [3], and equal to 0.5 in.

Using the formula (3) in the presence of a sufficient amount of research material it is possible to calculate the arithmetic mean values of the specific weight of felling wastes formed in the process of different types of fellings, both of final felling and intermediate felling; clear and non-clear cuttings; on all major forest-forming species for different growing conditions and regions of the republic.

Based on the weighted average values of the specific gravity coefficient of felling wastes for different types of felling, the final equation for estimating the organic carbon content in felling wastes will be as follows (4):

$$C = V_{site} \times K_{f.w.} \times KC_{f.w.}, \quad (4)$$

where: C – total organic carbon content, t;

V_{site} – wood root stock on the site, m^3;

$K_{f.w.}$ – dry weight of individual fractions of felling wastes per 1m^3 of stem wood, t / m^3 [4, Appendix A];

$KC_{f.w.}$ – share of carbon in biomass of felling wastes.

In the absence of the ability to perform labor intensive work on the determination of the total mass of felling wastes and their constituent factions and components of the above weighting method, the carbon content in felling wastes at the moment of final felling is determined using the coefficients of fractional carbon content in the fractions of tree trunk and forest biocenosis (table 5.2)

Table 5.2 – Share of carbon in stand components per stock unit (tC/m3) in dry state [4]

The dominant tree species	Conversion coefficients, tC / m3 of stock					
	Stemwood	Twigs and branches	Leaves, needles	Roots, stump	Silva succrescens and subsilva	Live ground cover;
Pínus sylvéstris	0.268	0.050	0.012	0.046	0.0005	0.004
Pícea ábies	0.235	0.034	0.038	0.044	0.0005	0.001
Quércus róbur	0.343	0.142	0.027	0.072	0.0005	0.006
Bétula péndula	0.300	0.047	0.024	0.050	0.0005	0.005
Álnus glutinósa	0.275	0.060	0.025	0.047	0.0005	0.001
Pópulus trémula	0.224	0.027	0.018	0.045	0.0005	0.005
Others	0.138	0.037	0.016	0.020	0.0005	0.008

Proposed specifications for determining the share of fractions and components of felling wastes during final fellings (Table 5.3)

Table 5.3 - Proposed specifications for determining the share of fractions and components of felling wastes during final fellings [13]

Species	As a percentage of stem wood volume				Stumps and roots that are possible to remove
	twigs, branches, tree tops	butting, slovens	sawdust	bark	
Pínus sylvéstris	4.8	1.2	1.0	11.0	14.0
Pícea ábies	7.5	1.2	1.0	10.0	17.0
Quércus róbur and other hardwoods	8.0	1.2	1.0	17.0	18.0
Bétula péndula	5.8	1.2	1.0	10.0	14.0
Pópulus trémula	4.5	1.2	1.0	7.0	14.0
Álnus glutinósa	3.8	1.2	1.0	11.0	14.0
Other softwood	3.6	1.2	1.0	10.0	10.0

Also it should be borne in mind that the total volume of phytomass of felling wastes, as well as their fractional composition in different cutting sites varies greatly depending on many factors. In this connection, the reliability of the results can not always be guaranteed.

The carbon content in felling wastes at the time of final felling is determined for each fraction and component of felling wastes according to the formula (5):

$$C = V_{site} \times KC_{f.w.} \times K_{f.w.}, \quad (5)$$

where: C – total organic carbon content, t;

V_{site} – wood root stock on the site, m^3;

$K_{f.w.}$ – dry weight of individual fractions of felling wastes per 1m^3 of stem wood, t / m^3 [4, Appendix A];

$KC_{f.w.}$ – the share of carbon in the biomass of felling wastes is taken from table 5.2.

The total amount of sequestrated carbon is defined as the sum of carbon sequestrated by all constituent fractions and components of felling wastes.

5.1.3. Calculation of carbon emissions (emissions into the atmosphere) from decomposition of felling wastes

The fractional structure of felling wastes in different cutting sites is not homogeneous. The share of felling wastes fractions depends on many factors. First of all, it is the species composition of the felled stand, the season of felling, the type of forest and forest growing conditions, the technology of logging operations and many other factors.

Taken into account the heterogeneous fractional composition of felling wastes, the decomposition period (carbon emission) is from one to several years. And some factions of felling wastes, as stumps and illiquid butt-log portion in upland habitats, may decompose more than one decade.

In connection with the above, in order to estimate the total period of carbon emission by felling wastes, in addition to their total volume, it is necessary to know the fractional structure of felling wastes. It is proposed, depending on the period of decomposition, to divide the components of the fractions of felling wastes into at least three groups of fractions:

- the first group, fractions with a short decomposition period (1-2 years);
- the second group, fractions with an average decomposition period (up to 10 years);
- the third group, fractions with a long decomposition period (more than 10 years);

The first group includes pine needles and leaves, small branches and roots, small pieces of silva succrescens and subsilva ; the second – illiquid part of the branches, unrecorded in the first group parts of silva succrescens and subsilva, medium roots; third – illiquid part of the trunks, large roots, stumps.

The fractional and component structure of felling wastes should be determined simultaneously with the determination of the total volume of felling wastes by their weighing. In some cases, when high accuracy is not required, the share of fractions of felling wastes can be determined by eye-measuring method, or use the average literature data based on the species composition of the felled forest stand and forest vegetation conditions.

The share of individual fractions and components of felling wastes is expressed in percentage terms of the numerical value of the total biomass of the studied forest area.

It is assumed that all carbon accumulated in felling wastes during the life of the stand is completely decomposed over a certain period of time.

The specific carbon emissions over a given period of time (e.g. 10 years) and the decay period of a given amount of carbon (e.g. 50%) are determined by a graphic (figure 5.1). The diagram is built for each specific site based on the initial data of the volume of carbon sequestration for each group of fractions and the estimated period of total carbon emission for each group of fractions. The resulting carbon emission diagram for the cutting site is obtained on the basis of the constructed diagrams for each group of fractions. It is assumed that the emission of carbon for each group of fractions occurs uniformly over time.

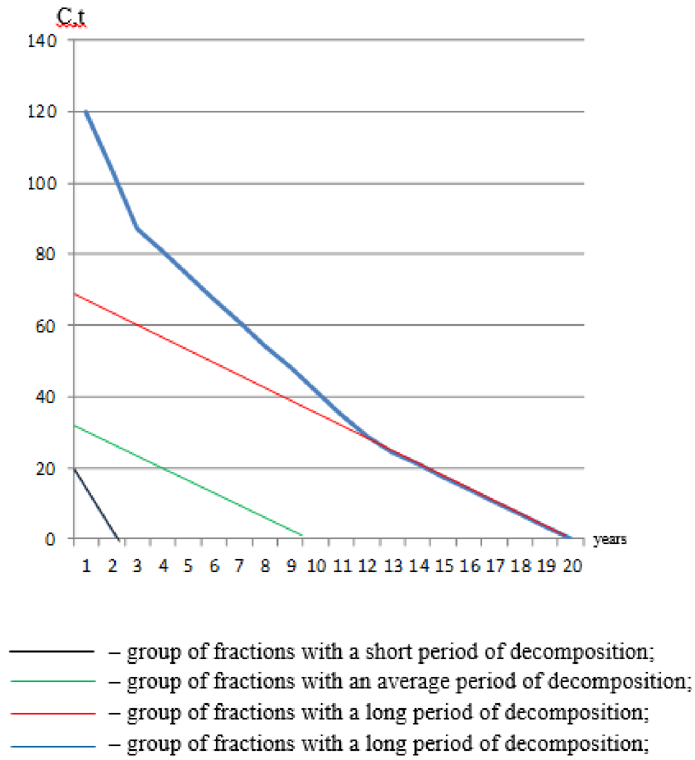

Figure 5.1 – Carbon emission by different groups of fractions and components of felling wastes

For graphing as an example it is the determination of the volume of the fractions with a short period of decomposition in the quantity of 20 tons and a two-year period of expansion, with an average period of decay in the amount of 30 tons and a decade of decay - 70 tons with a full period of the decomposition of felling wastes during 20 years.

In the present work, when estimating the volume of emissions from felling wastes, the calculation is based on the terms of all carbon sequestrated by felling wastes during the period of growth of a stand returns to the atmosphere within a certain period of time. In fact, some of the carbon is sequestrated, goes into the soil and litter. This process is currently insufficiently studied, so in this technique, the carbon remaining in the forest biocenosis was not taken into account. More researches are needed to address this shortcoming.

5.1.4. Calculation of carbon sequestration in a renewable cutting site

Carbon sequestrated by felling wastes remains bound for a long time without emission. The process of carbon emission in felling wastes occurs gradually over decades.

Along with this, from the first years after the final felling, the sequestration of carbon dioxide is activated when the cutting site is regenerated.

Disturbed areas are overgrown with young growth. In the first years, deforested area assimilates carbon more efficiently than ripe trees, i.e. there is expanded reproduction of sequestration ability of the forest: the more intensive young growth replace the felled stands, the greater the carbon storage capacity of the disturbed forest area. As a result of clear or non-clear cutting of the final felling and the appearance of open spaces the mode of lighting, temperature, humidity and other factors are radically changes. On the illuminated, relatively dry and well-heated places, a community of light-loving grasses is formed. Species with easily spreading seeds develop first: stage of open felling.

Later reforestation starts: light-loving *broadleaved species* (aspen, birch, willow) shrubs occurs. A rich and diverse community of overgrown felling is formed. This stage takes on average 2-3 years. Then the intensive development of light-demanding *deciduous species* (aspen, birch) occurs. Grown trees gradually displace shrubs, and the most light demanding species of grasses;

brushwood and grassland community gives way to deciduous young forest with the spacing between tree crowns. The carbon-absorbing properties of the forest are rapidly restored.

According to some foresters, in certain growing conditions, since the first years of felling regeneration, the volume of carbon sequestration by herbaceous and tree-shrub vegetation exceeds the volume of carbon emission by felling wastes.

Schematically, this process can be expressed by the following equation (6):

$$\pm D = C - E + S, \tag{6}$$

where: D – the difference between carbon sequestration in terms of D regeneration [tC] and carbon content in felling wastes (C) [tC];

C – the volume of carbon sequestration by felling wastes during the period of stand growth; is taken as a time constant for a particular area of forest fund, tC;

E – carbon emissions over the estimated time period. It is determined by the diagram (figure 5.1), tC;

S – carbon sequestration by the young stand/regeneration after the final felling, tC. It is calculated according to the current methods in the republic.

The issue of felling wastes placement in cutting sites is quite important in terms of the carbon stock in soil. The exact amounts of such accumulation cannot now be estimated, but there is no doubt that such accumulation can occur, and the only source for it is the decomposition of organic plant residues.

Issues of carbon sequestration by felling wastes after the final felling in the republic are insufficiently studied. At the same time, recently the issues of carbon flows in forest stands draw more attention of the republic's foresters. In this regard, with the lack of knowledge of carbon flows, it is necessary to intensify work in this direction.

The proposed estimation method of carbon sequestration by felling wastes can be used in forestry production in the determination of the method of final felling and ways of cutting sites clearing from the felling wastes and, as well as in the process of forest management in determining methods of final fellings.

The methodology can be used in the process of forest management in terms of the formation of the information base of forestry, planning the size of timber useage, growing of high productivity forests, maintaining a positive carbon balance and compensation of industrial greenhouse gas emissions.

5.2 FORECAST OF TOTAL CARBON SEQUESTRATION BY BIOMASS OF FELLING WASTES IN THE AREAS OF FINAL FELLINGS IN THE FOREST FUND OF BELARUS FOR 2030 AND 2050 ON THE BASES OF THE AVERAGE ANNUAL AREA OF CLEAR / NON-CLEAR CUTTINGS OVER THE PAST FIVE YEARS

The term "forest management" implies the use of various forest products. In a broad sense, this term defines the rational, careful human use of all forest resources and its ecological functions and benefits. When receiving timber by various fellings, not only assortments are harvested but also significant amounts of biomass are produced. Positive changes in the forest fund of the republic allow us to expect a promising increase in wood stocks and, as a result, the volume of their felling, and especially final fellings. How to rationally manage and use assortments and felling wastes from forest fellings in10-20 years we have to decide now.

The conservation of felling wastes and other dead wood in the forest will affect the intensity of soil "respiration", which will eventually lead to additional carbon dioxide emissions, i.e. a reduction in the absorption of greenhouse gases by forest stands. The collection and use of felling wastes for fuel or other purposes will reduce carbon dioxide emissions. The main direction of utilization use of waste wood biomass in the republic will be the production of wood chips for energy purposes. But this production should be more cost-effective than its production from fuelwood. The main condition for this benefit is the European value of wood and wastes. In this regard, high prices for roundwood is a significant economic incentive to maximize the use of biological resources. In this case, if there is parity of prices, the price of fuelwood will start to grow, only then the production of wood chips from the felling wastes will be economically profitable and the issue of usefulness of removal/non-removal of felling wastes will be settled. To solve the problem of efficient use of logging wastes, it is necessary to change the legislation, take measures to create conditions for the development of harvesting and processing of wood waste.

5.2.1. The main use of forest and its prospects in the Republic of Belarus

The fellings carried out in the republic can be divided into two main blocks: planned (calculated) fellings and fellings according to the need.

The first block includes final and intermediate fellings, the second includes other fellings. If the first fellings can be regulated by the introduction of certain standards or decision-making, the second-are the consequence of the phenomena and activities that have become the basis for their conduct.

The estimated cutting site according to final fellings, determined on the basis of materials of forest inventory while managing the forests with a 10 year cycle of the frequency is scientifically based norm (limit) of the possible withdrawal of resources of the ripe wood.

The principles of its definition are sustainable, permanent and non-diminishing use of wood resources. The entire system of forest resources reproduction is built on the calculated cutting site. Artificial increase of an approved and put into action calculated cutting site is making a failure in the strategy of forest management and use of forest and reduces the forest potential. This is confirmed by practice. Over a long period of time (in 30-e years and postwar period) by decision of government authorities calculated cutting site was recut, replacement of volumes of the calculated cutting site of hardwoods with conifers and the so-called prescheduled felling was widely practiced. As a result, by the end of the 80s, ripe forests were accounted for 2.4% and by softwood species - 1.3% wit a in forestry-economic rate of 20%. The estimated cutting site decreased to the lowest level in the history of forestry – less than 5 million m^3. Former Ministry of forestry of BSSR implemented the final fellings, fully developed the calculated cutting site not only by coniferous and hardwood species, but also by softwood.

After the collapse of the USSR in the forest complex there were significant structural changes, Ministry of forestry was transformed into a concern "Bellesbumprom". For economic reasons, wood consumption has fallen sharply. This concern reduced the volume of timber harvesting from 5 million m^3 to 2 million m^3. The Ministry of forestry of the Republic of Belarus (Minleskhoz) and small timber producers adopted the functions of development of the calculated cutting site.

The Ministry of forestry, with the support of the government, has radically revised the strategy of forest management with the transition to forest felling in strict accordance with the estimated cutting site, in order to restore the raw material potential of forests undermined by excessive exploitation. As a result of the measures implemented, the situation with the structure of forests has been steadily improving.

To date, the stock of mature and overripe stands amounts to 11.5% by area and 16.3% by stock against 7.7% and 9.7% respectively in 2000 [9]. The stock included in the final felling for this period increased by 140%. However, it should be borne in mind that, since the mid-90s to the present time, specially protected natural areas in the forest Fund are intensively created.

Implementation of final fellings there in accordance with environmental legislation is prohibited. Therefore, the real areas and stocks of ripe wood laid in the estimated cutting site, the so-called fund "possible for exploitation", are 20% lower than the available resources.

The methodology for calculating the size of the main use is based on multifactorial analysis of forest resources and the following basic principles:

– consistent equalization of the age structure of forests and bringing it to the criterion of " forest normality»;

– increasing productivity and improving the species structure of forests by involving in the primary felling of forest areas not promising for forest cultivation;

– calculated cutting site should be anually provided with available supplies of mature forest stands;

– the size of the harvest of ripe wood should not be reduced and, if possible, its increase is projected proportionally to changes in the age structure and productivity of stands;

– clear felling of mature forest sites should be replaced in accordance with ecological requirements with a system of selective and gradual felling of stands;

– the size of the calculated felling site should not exceed the size of annual growth of wood.

In accordance with the order of determination and approval of the calculated cutting site - cutting site is determined and is accepted by the square [2,10,11]. The calculation and approval of the size of the main use in general and liquid stock is based on the average stock per 1 hectare. The productivity of ripe forest stands directly affects the determination of the size of calculated cutting site by final fellings.

The size of the calculated cutting site for both the legal entity and in the Republic of Belarus for final fellings is approved by the total amount of liquid and industrial wood separately by groups of tree species (coniferous, hardwood, softwood), taking into account the size of particular species (pine, oak, birch, black alder, grey alder, aspen), as well as categories of forests, logging techniques (clear, gradual, selective).

Algorithm and mathematical models of calculated cutting site determining according to the age structure, the productivity of ripe forests, reservations and other factors at present can be considered quite justified and aimed not only at enhancing forest potential of forests and improvement of their species structure, but also on meeting the needs in wood for the republic [12].

As a result of legislative actions of regulated natural growth of the stands, the calculated cutting site annual is provided by the annual increase in the volume of harvested ripe wood on average 250-400 thousand.m^3. In the period of revision of the distribution of forests in new categories, in some years there is a more significant increase (2018.-789 thousand m^3). But such fluctuations will get into smooth growth after forest management activities on the redistribution of categories.

The sizes of the calculated cutting sites for 2014-2018 are shown in table 5.4. The increase during this period was 115.5 %, although in the context of tree species there are significant differences in the change in volumes. Softwood stands are predominant in the calculated cutting site – 51,9%. In recent years, there has been an increase in the growth of the size of the calculated cutting site for coniferous plantations. This is partly due to the involvement in the felling of those stands that have become exploitable when classified in accordance with the requirements of the new forest code.

Table 5.4 – the size of the calculated cutting site on final fellings in the Republic of Belarus for 2014-2018 (thousand m^3 of liquid wood)

Species groups, species	2014	2015	2016	2017	2018	Total for 2014-2018	Average per year	%
Coniferous	4927.4	5108.9	5382.0	5671.7	6154.9	27244.9	5449.0	46.6
including Pínus sylvéstris	4096.3	4273.8	4515.7	4731.7	5092.0	22709.5	4541.9	38.8
pícea ábies	831.1	835.1	866.3	940.0	1062.9	4535.4	907.1	7.8

Hardwood	182.2	181.1	180.7	180.8	182.3	907.1	181.4	1.5
including quércus róbur	175.2	173.8	173.4	173.5	174.0	869.9	174.0	1.5
Deciduous	5902.8	5969.4	6022.8	6082.1	6386.3	30363.4	6072.7	51.9
including bétula péndula	2527.9	2618.2	2695.0	2826.2	3014.3	13681.6	2736.3	23.4
pópulus trémula	1326.0	1309.4	1343.7	1381.7	1449.3	6810.1	1362.0	11.6
Álnus glutinósa	1777.4	1777.2	1769.5	1787.5	1820.4	8932.0	1786.4	15.3
Total	11012.4	11259.4	11585.5	11934.6	12723.5	58515.4	11703.1	100.0

The actual harvesting, unfortunately, does not use the defined size of the final fellings. Since 1989, for the development the estimated cutting site does not reach 100%. Under-development reaches 20-35% in some years(table 5.5). Over the past five years, 17.3 million m^3 of wood has been under-developed, that is 1.5 times of the size of the average calculated cutting site for the analyzed period. To the analyzed volume of harvested wood the wood from final fellings of current period and that was harvested given posponement is included i.e., all wood, felled in a calendar year from the fellings of this kind.

Table 5.5 – Actual timber harvesting for final fellings throughout the Republic of Belarus with provided postponement of previous years for 2014-2018 (thousand m^3 of realizable timber)

Species groups, species	2014	2015	2016	2017	2018	Total for 2014-2018	In average for the year	%	The development of the calculated cutting site by species, %
Coniferous	4869.0	4497.7	3873.4	4195.4	4133.9	21569.4	4313.9	52.3	79.2
including Pínus sylvéstris	3736.0	3746.2	3231.3	3399.0	3295.4	17407.9	3481.6	42.2	76.6
pícea ábies	1133.0	751.5	642.1	796.4	838.5	4161.5	832.3	10.1	88.0
Hardwood	175.5	134.8	121.5	106.7	148.9	687.4	137.5	1.7	75.8
including quércus róbur	166.0	132.7	116.1	102.6	146.1	663.5	132.7	1.6	76.3
Deciduous	4630.0	4031.7	3132.8	3288.7	3862.7	18945.9	3789.2	46.0	62.4
including bétula péndula	1665.5	1374.9	1029.5	1139.3	1425.8	6635.0	1327.0	16.1	48.5
pópulus trémula	1332.8	1183.1	913.6	982.4	1045.6	5457.5	1091.5	13.2	80.1
Álnus glutinósa	1470.7	1362.5	1109.2	1080.3	1283.5	6306.2	1261.2	15.3	70.6
Total	9674.5	8664.2	7127.7	7590.8	8145.5	41202.7	8240.5	100.0	70.4
The development of the calculated cutting site, %	87.8	76.9	74.8	63.6	64.0	70.4	70.4		

The greatest under-development occurs on soft-leaved species. This led to a significant accumulation of stocks of mature and over-mature stands, especially for Álnus glutinósa and pópulus trémula (35.4 and 65.7%, respectively). Although the area of aspen stands is only 2.3%, but there is the most significant disproportion in age distribution. Over-mature pópulus trémula forest stands have a low marketability, and their sale is difficult.

Such situation, both in the main, and in other types of wood forest management developed generally because of lack of effective demand for low-grade, small-scale and soft-leaved wood. This is mainly due to the lack of capacity for its deep processing in our country. But no less significant factor that has influenced the volume of the final felling in recent years, was the catastrophic drying of pine stands, where the volume of cut wood in terms of sanitary measures came up with the annual size of the final felling.

Among tree species, the greatest amount of harvesting accounts for pine forest stands (table 5.5) is 42.2%, with its share in the calculation of 38.8%. Birch is the second tree species by the volume of fellings, however its development is least of all – only 48.5%.

The average annual area of felling for the five-year period (table 5.6) was 35.1 thousand hectares or 0.4% of the forested land in the country. The areas subjected to the clear cuttings prevail (68.5%). The share of non clear cuttings by the area was 31.5%, and by the stock on average for 2014-2018 - 16.5% of the harvested realizable wood. The decrease in the mass fraction of non-clear cuttings from the estimated is explained by unemployment of the estimated cutting site.

Table 5.6 – Final felling sites for 2014-2018, ha

Indicator name	2014	2015	2016	2017	2018	Total for 2014-2018	Average per year	%
Final fellings, total	45435.5	37177.8	30044.0	31002.5	31889.9	175549.7	35109.9	100.0
including:								
gradual and selective felling	17661.1	11310.9	9444.5	8671.4	8139.0	55226.9	11045.4	31.5
clear cuttings	27774.4	25866.9	20599.5	22331.1	23750.9	120322.8	24063.6	68.5
including:								
no coniferous economy	22882.4	19294.8	16634.4	16839.4	16075.0	91726.0	18345.2	52.2
no hardwood economy	960.3	613.8	549.7	491.9	530.8	3146.5	629.3	1.8
no deciduous economy	21592.8	17269.2	12859.9	13671.2	15284.1	80677.2	16135.4	46.0

Based on the current state of the forest fund, the need to distribute the forests by new categories in accordance with the requirements of the Forest code until 2021, it is projected to increase the reserves of stands suitable for exploitation. Using the existing ages in the calculations, it is projected to achieve the volume of final fellings in the republic (table 5.7) by 2030, up to 16.7 million m^3 of realizable wood (an increase of 131% compared to 2018.), but by 2050 20.1 million m^3 (158%). But on the growth of the final fellings according to coniferous stands, mass drying of pine stands can adversely affect in a short time period. Ripening stands were also undergone this impact.

Table 5.7 – Forecast of the size of final fellings, thous.cubic meters/thous.ha

Species groups, species	2030			2050		
	total	including		total	including	
		clear	gradual, selective		clear	gradual, selective
Coniferous	8600 37.08	5360 18.44	3240 18.64	10600 45.76	6610 22.80	3990 22.96
including Pínus sylvéstris	7100 31.27	4370 15.49	2730 15.78	8900 39.17	5490 19.46	3410 19.71
pícea ábies	1500 5.81	990 2.95	510 2.86	1700 6.59	1120 3.34	580 3.25
Hardwood	200 0.97	110 0.45	90 0.52	210 1.01	120 0.49	90 0.52
including quércus róbur	180 0.86	105 0.43	75 0.43	190 0.91	110 0.45	80 0.46
other species	20 0.29	5 0.02	15 0.09	20 0.10	10 0.04	10 0.06

Deciduous	7900 33.06	6200 23.27	1700 9.79	9300 38.87	7340 27.54	1960 11.33
including bétula péndula	3740 16.73	2710 10.54	1030 6.19	4650 20.69	3420 13.30	1230 7.39
Álnus glutinósa	2140 7.62	2020 7.39	120 0.23	2350 8.30	2220 8.05	130 0.25
pópulus trémula	1670 7.10	1190 4.22	480 2.88	1850 7.81	1340 4.75	510 3.06
other species	350 1.61	280 1.12	70 0.49	450 2.07	360 1.44	90 0.63
Total	16700 71.11	11670 42.16	5030 28.95	20110 85.64	14070 50.83	6040 34.81

In the table 5.7, on the basis of data sample of forest inventory projects of the calculated cutting sites for 2019 and subsequent years (table 5.8), the distribution of the forecast size of the final felling on groups of species, species and methods of felling is shown. With projected non-clear cuttings of final felling in the total amount of 30%, in the context of wood species this value is significantly different and is the highest for pine - 37.7%.

Also on the basis of projected data forecast distribution of volumes of clear cuttings by types of reforestation in the context of felled species was made (table 5.9).

All this information is initial for the subsequent definition of the forecast volumes of the felling wastes while carrying out final fellings, and also consideration of prospects of their application and use.

Table 5.8 – Share of groups and species in the estimated cutting site by felling methods, %

Species groups, species	clear cuttings		gradual, selective cuttings	
	by forestries	by species	by forestries	by species
Coniferous, total	45.9	100.0	64.4	100.0
including Pínus sylvéstris	37.4	81.5	54.3	84.3
pícea ábies	8.5	18.5	10.1	15.7
Hardwood, total	0.9	100.0	1.8	100.0
including quércus róbur	0.9	95.5	1.5	83.4
other species	0.0	4.5	0.3	16.6
Deciduous, total	53.2	100.0	33.8	100.0
including bétula péndula	23.3	43.7	20.5	63.2
pópulus trémula	10.2	32.6	9.5	29.4
Álnus glutinósa	17.3	19.2	2.4	2.4
other species	2.4	4.5	1.4	4.3
Total	100.0		100.0	

Table 5.9 – Volume of clear cuttings by the types of forest regeneration (thousand m^3 of realizable timber)

Species groups, species	2030				2050			
	Creation of forest cultures	Promoting natural regeneration	Natural regeneration;	Total	Creation of forest cultures	Promoting natural regeneration	Natural regeneration;	Total
Coniferous	2600	700	2060	5360	3440	750	2420	6610
including Pínus sylvéstris	1980	535	1855	4370	2800	570	2120	5490
pícea ábies	620	165	205	990	640	180	300	1120
Hardwood	55	15	40	110	75	20	25	120
including quércus róbur	55	10	40	105	70	20	20	110
other species	0	5	0	5	5	0	5	10
Deciduous	3160	850	2190	6200	4010	930	2400	7340
including bétula péndula	1390	370	950	2710	1875	430	1115	3420
Álnus glutinósa	1050	280	690	2020	1135	300	785	2220
pópulus trémula	580	160	450	1190	820	150	370	1340
other species	140	40	100	280	180	50	130	360
Total	5815	1565	4290	11670	7525	1700	4845	14070
%	49.8	13.4	36.8	100.0	53.5	12.1	34.4	100.0

5.2.2. The volumes of felling wastes biomass in carrying out final fellings

In accordance with the definition of state forest standards, felling wastes include logging wastes consisting of twigs, branches, needles, leaves, tree tops, stumps, roots, stem wastes. – logging wastes are created in the process of wood harvesting directly in the forest. This report discusses the forecast calculation of volumes and the possible use of the above-ground part of the felling wastes obtained as a result of final fellings. The following fractions of felling wastes are considered:

– tree tops-a separate upper end of the trunk, which can not be used as a industrial assortmentby its characteristics;

– twigs – growing from the tree trunk woody side shoots of the tree;

– branches growing from the tree trunk or twigs of not fully ligneos or not ligneous side shoots of a tree;

– woody vegetation – needles, leaves, not ligneous shoots and sprouts of newly felled trees.

– stumps – the stump wood of the tree remaining above the soil surface after its felling.

The trunks of trees felled as a result of felling are cleared of twigs. The altitude of the remnants of branches above the surface of the unpeeled whip should be no more than 2 cm. Twigs are non-coniferous or non-decidious branches with a diameter of more than 2 cm. Non-realizable tops include their parts with diameter up to 3cm. Woody vegetation is a coniferous or non-decidious branch with a diameter of up to 0.8 cm. The greatest supply of vegetation is accumulated in coniferous and deciduous trees in June, beginning of July, when new needles is growing and the old ones have not disappeared, and on deciduous trees the growth of young foliage is over.

The increase in demand for renewable natural resources in recent years requires a more complete and reliable determination of the biomass of logging wastes during various loggings. A noticeable increase in the volume of wood harvesting leads to the formation of significant reserves of felling wastes, from the correct accounting of which depends their use. Accounting such a resource is quite time-consuming and costly process. A number of conducted studies on the assessment of the reserves of biomass of logging wastes showed that a lot of factors are involved and affect the correctness of the final result [7-13]. These volumes significantly depend on the age, typological, structural composition of stands of forest-forming tree species and their productivity.

Table 5.10 – Proposed specifications for determining the volume of felling wastes during final fellings

Species	As a percentage of stem wood volume		
	twigs, branches, subtle tree tops on growing trees	woody vegetation	Stumps and roots that are possible to remove
Pínus sylvéstris:	9.0	4.8	14.0
Pícea ábies	13.0	9.4	17.0
Quércus róbur and other hardwoods	18.0	3.8	18.0
Bétula péndula	12.0	3.2	14.0
Pópulus trémula	9.0	2.6	14.0
Álnus glutinósa	8.0	4.1	14.0
Other softwoods	8.0	2.3	10.0

Table 5.11 – Volume of twigs, branches, and tree tops during final fellings, thousand m^3

Species groups, species	2030			2050		
	total	including		total	including	
		clear	gradual, selective		clear	gradual, selective
Coniferous	834.0	522.0	312.0	1022.0	639.7	382.3
including Pínus sylvéstris	639.0	393.3	245.7	801.0	494.1	306.9
pícea ábies	195.0	128.7	66.3	221.0	145.6	75.4
Hardwood	36.0	19.8	16.2	37.8	21.6	16.2
including quércus róbur	32.4	18.9	13.5	34.2	19.8	14.4
other species	3.6	0.9	2.7	3.6	1.8	1.8
Deciduous	798.3	616.3	182.0	948.5	737.4	211.1
including bétula péndula	448.8	325.2	123.6	558.0	410.4	147.6
Álnus glutinósa	171.2	161.6	9.6	188.0	177.6	10.4
pópulus trémula	150.3	107.1	43.2	166.5	120.6	45.9
other species	28.0	22.4	5.6	36.0	28.8	7.2
Total	1668.3	1158.1	510.2	2008.3	1398.7	609.6

Table 5.12 – Volume of woody vegetation, stumps, and tree tops after final fellings, thousand m^3

Species groups, species	2030			2050		
	woody vegetation	Stumps and roots that are possible to remove	total	woody vegetation	Stumps and roots that are possible to remove	total
Coniferous	481.8	1249.0	1730.8	587.0	1535.0	2122.0
including Pínus sylvéstris	340.8	994.0	1334.8	427.2	1246.0	1673.2
pícea ábies	141.0	255.0	396.0	159.8	289.0	448.8

Hardwood	7.6	36.0	43.6	8.0	37.8	45.8
including quércus róbur	6.8	32.4	39.2	7.2	34.2	41.4
other species	0.8	3.6	4.4	0.8	3.6	4.4
Deciduous	258.8	1091.4	1350.2	303.7	1284.0	1587.7
including bétula péndula	119.7	523.0	642.7	148.8	651.0	799.8
Álnus glutinósa	87.7	299.6	387.3	96.4	329.0	425.4
pópulus trémula	43.4	233.8	277.2	48.1	259.0	307.1
other species	8.0	35.0	43.0	10.4	45.0	55.4
Total	748.2	2376.4	3124.6	898.7	2856.8	3755.5

For the production of forecast calculations, the published results of the conducted research and previously adopted accounting standards were considered in the republic. According to estimates of different authors, the mass of felling wastes, depending on the composition and completeness of the felled forest stand, forest growing conditions, technology of cutting and other factors can be from 10 to 40% of the volume of felled wood. For further calculations were proposed specifications [13], as the most appropriate to average value from the data obtained (tables 5.11, 5.12, figure 5.2)

Woody vegetation is separately taken into account, as for deciduous species, its presence in felling wastes will depend on the felling time (table 5.13).

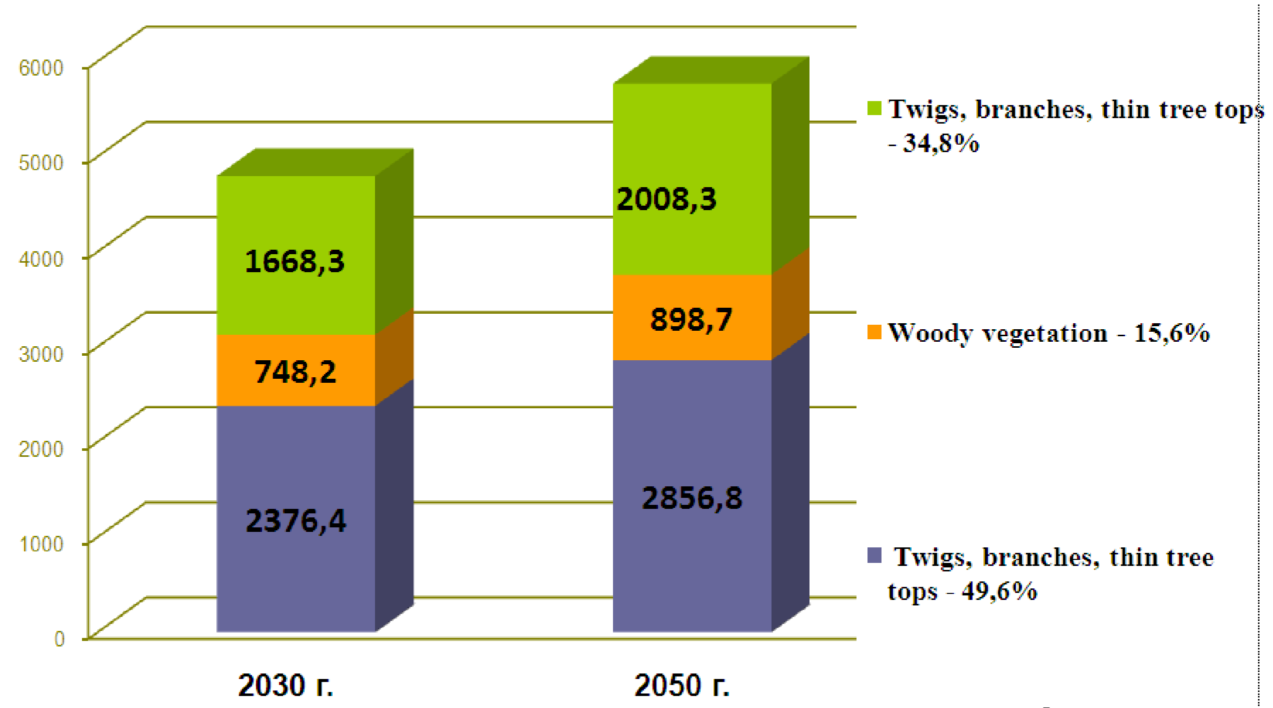

Figure 5.2 – the volumes of fractions of felling wastes, thousand m^3/%

Table 5.13 – Volume of felling wastes after final fellings, thousand m^3

Species groups, species	2030			2050		
	total	including		total	including	
		clear	gradual, selective		clear	gradual, selective
Coniferous	2564.8	1604.0	960.8	3144.0	1967.4	1176.6
including Pínus sylvéstris	1973.8	1214.9	758.9	2474.2	1526.2	948.0
pícea ábies	591.0	390.1	200.9	659.8	431.2	228.6

Hardwood	79.6	43.7	35.9	83.6	47.7	35.9
including quércus róbur	71.6	41.7	29.9	75.6	43.7	31.9
other species	8.0	2.0	6.0	8.0	4.0	4.0
Deciduous	2148.5	1679.5	469.0	2536.2	1994.6	541.6
including bétula péndula	1091.5	790.9	300.6	1357.8	998.8	359.0
Álnus glutinósa	558.5	527.2	31.3	613.4	579.5	33.9
pópulus trémula	427.5	304.6	122.9	473.6	343.1	130.5
other species	71.0	56.8	14.2	91.4	73.2	18.2
Total	4792.9	3327.2	1465.7	5763.8	4009.7	1754.1
%	100.0	69.4	30.6	100.0	69.6	30.4

The projected increase in the volume of final fellings will lead to an increase in the volume of felling wastes (figure 5.3).

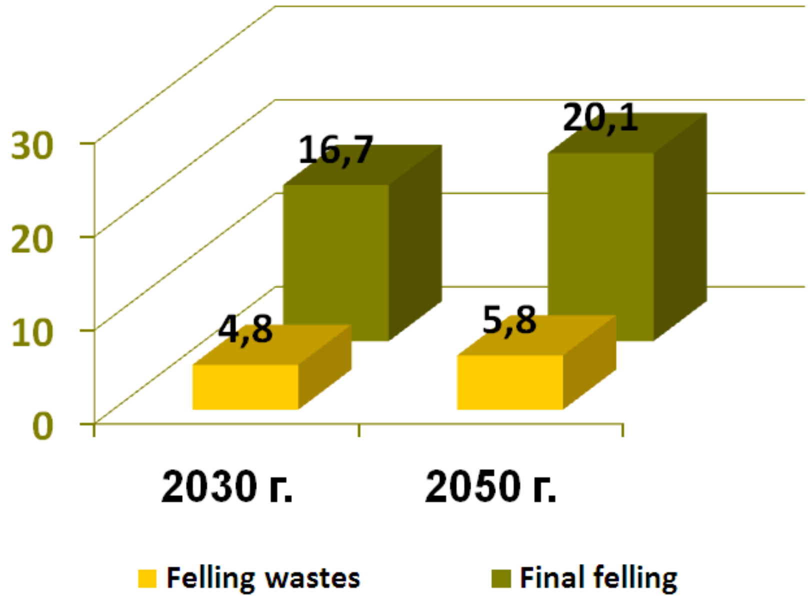

Figure 5.3 – Volume of final fellings and felling wastes, million m^3

5.2.3. Forecast of total carbon sequestration by biomass of felling wastes in areas of final felling

In the republic there is no system data for carbon sequestration by felling wastes after final fellings. Felling wastes are one of the important elements of forest ecosystem biomass. To date, their impact on the ability of stands to sequestrate carbon has not been studied enough. But for forecast calculations, it is proposed to determine the carbon content in the components of the forest stand in the order of "field" evaluation according to the criteria of table 5.14.

Table 5.14 – carbon content in forest stand, t/ha

Dominant species:	Stem wood	Twigs, branches, tree tops	Foliage, needles	Stump and roots
Pínus sylvéstris:	0,268 M*	0.034 M	0.010 M	0.043 M
Pícea ábies	0.235 M	0.033 M	0.012 M	0.040 M
Quércus róbur and hardwoods	0.343 M	0.060 M	0.011 M	0.065 M
Bétula péndula	0.300 M	0.045 M	0.009 M	0.050 M
Álnus glutinósa	0.275 M	0.047 M	0.008 M	0.044 M
Pópulus trémula	0.224 M	0.035 M	0.007 M	0.043 M
Other, including shrubs	0.138 M	0.040 M	0.005 M	0.030 M
Note -*) M-wood stock, m^3 / ha				

Using the information in tables 5.7, 5.11 and 5.12 forecasted volumes of carbon sequestartion separately from twigs, branches, thin tree tops (table 5.15) and other components of felling wastes from the ongoing fellings are made (table 5.16).

Table 5.15 – Carbon content in twigs, branches, thin tops during the final felling, thousand tC

Species groups, species	2030			2050		
	total	including		total	including	
		clear	gradual, selective		clear	gradual, selective
Coniferous	28.16	17.62	10.54	34.54	21.61	12.93
including Pínus sylvéstris	21.72	13.37	8.35	27.24	16.80	10.94
pícea ábies	6.44	4.25	2.19	7.30	4.81	2.49
Hardwood	2.15	1.18	0.97	2.27	1.30	0.97
including quércus róbur	1.94	1.13	0.81	2.05	1.19	0.86
other species	0.21	0.05	0.16	0.22	0.11	0.11
Deciduous	34.62	26.88	7.74	41.22	32.19	9.03
including bétula péndula	20.19	14.63	5.56	25.11	18.47	6.64
Álnus glutinósa	8.05	7.60	0.45	8.84	8.35	0.49
pópulus trémula	5.26	3.75	1.51	5.83	4.22	1.61
other species	1.12	0.90	0.22	1.44	1.15	0.29
Total	64.93	45.68	19.25	78.03	55.10	22.93

The total accumulation of carbon in felling wastes will be 177.94 thousand tC by 2030 and by 2050 will increase in1.2 times and can reach up to 213.92 thousand tC. Most of the carbon content of phytomass components accounted for stumps and roots – 59%, twigs, branches – 37%, and woody vegetation only 4%.

Table 5.16 – Overall volume of carbon content in phytomass of felling wastes, thousand tC

Species groups, species	2030				2050			
	twigs, branches, thin tree tops	woody vegetation	stumps and roots that are possible to remove	total	twigs, branches, thin tree tops	woody vegetation	stumps and roots that are possible to remove	total
Coniferous	28.16	5.10	52.94	86.20	34.54	6.19	65.14	105.87
including Pínus sylvéstris	21.72	3.41	42.74	67.87	27.24	4.27	53.58	85.09
pícea ábies	6.44	1.69	10.20	18.33	7.30	1.92	11.56	20.78
Hardwood	2.15	0.08	2.34	4.57	2.27	0.09	2.45	4.81
including quércus róbur	1.94	0.07	2.11	4.12	2.05	0.08	2.22	4.35
other species	0.21	0.01	0.23	0.45	0.22	0.01	0.23	0.46
Deciduous	34.62	2.12	50.43	87.17	41.22	2.50	59.52	103.24
including bétula péndula	20.19	1.08	26.15	47.42	25.11	1.34	32.55	59.00
Álnus glutinósa	8.05	0.70	30.18	21.93	8.84	0.77	14.48	24.09
pópulus trémula	5.26	0.30	10.05	15.61	5.83	0.34	11.14	17.31
other species	1.12	0.04	1.05	2.21	1.44	0.05	1.35	2.84
Total	64.93	7.30	105.71	177.94	78.03	8.78	127.11	213.92

5.2.4. The use of final fellings

Increase in the use of wood resources is an important link in the development of resource conservation policy, environmental management, environmental safety, the results of production activities. The issue of efficient and rational use of wood raw materials, especially unused wood wastes, is becoming increasingly important.

Attitude towards the use of felling wastes that are formed from different types of felling, including final felling recently have been similar in many forest countries. Recognition of the efficient use of this resource for fuel purposes is increased recently. But there is no unique approache to bioenergy products production, assessment of the impact of removal/non-removal of felling wastes.

At the existing methods of processing of wood raw materials it is useful to use up to 70% of a tree biomass from various types of fellings. Major losses occur in woody vegetation, branches, bark, sawdust. Such types of potential raw materials as logging wastes, small sized wood from various types of fellings are used to produce marketable products in small quantities, and often remain completely unclaimed.

Needles and foliage have not been widely applied. These wastes are not used due to their technical and economic inaccessibility. The costs of collecting, processing and transporting of theseraw materials often exceed the cost of the finished product. However, the chemical composition of pine needles and spruce needles allows it to be used in the production of medicines, various extracts, perfumes, fertilizers and animal feeding. From the needles it is possible to get to the feed and vitamin flour, which can be used as additives in the manufacture of fodder or fodder mixtures.

The issues of possible use of felling wastes are largely depend on the established requirements for fellings. The Republic of Belarus has legislation in the field of clearing of cutting sites. In the Republic of Belarus, depending on the type of felling, wood harvesting technology, forest conditions, forest category, requirements for the conservation of biological diversity, the following methods of cutting sites clearing from felling wastes are used:

– collection of felling wastes for the production of industrial chips, fuel, and for other purposes; uniform laying of felling wastes on skidding trails with the subsequent compaction;

– collecting of felling wastes in piles up to 2.5 meters in height and diameter or bulks up to 2.5 meters in height and width and leaving them for rotting;

– stockpilling of felled trees on the ground for rotting (when cleaning and liberation felling);

–uniform stockpilling of felled trees and felling wastes in piles with a height and width of up to 2.5 meters or piles of height and diameter of 2.5 meters along the corridors during the conversion cut;

– grinding and spreading of felling wastes in the cutting site;

– collecting of felling wastes in piles with a diameter of 2.5 meters and a height of 1 meter and their combustion;

– combined (use on one cutting site of several ways of clearing).

Felling wastes left for rotting are collected and formed in:

– piles up to 2.5 m in height and 2.5 m in diameter in places free from silva succrescens;

– bulks up to 2.5 m high and 2.5 m wide not closer than 10 m to the forest wall;

– bulks up to 2.5 m high and 2.5 m wide not closer than 10 m to the forest wall in terms of using multiprocessor machines;

Felling wastes can be crushed and evenly scattered along the cutting site in accordance with the requirements specified in the flow chart.

At uniform spreading of the felling wastes along the cutting site the maximum thickness of a layer should not exceed 0.2 m.

When spreading the felling wastes after grinding in chippers, the thickness of the chips should not be higher than 0.1 m.

Shredded felling wastes should not occupy more than 60% of the felling area to ensure fire safety and create conditions for reforestation.

Due to the wide spread of forest pests at the present time, the method of burning of felling wastes is widely used during sanitary measures as one of the main methods of control. In the prevention combustion of pine felling wastes is implemented and during final fellings in the centers of distribution.

Aimed at combustion felling wastes are placed in piles up to 2.5 m in diameter and up to 1 m in height and must be located at a distance that excludes damage by fire to growing trees, undergrowth, protected or economically valuable plants.

To conserve the biodiversity of small vertebrates and invertebrates during the fellings in the forest areas, characterized by fresh and humid habitat conditions and low attendance by population, it is allowed to leave 4-5 piles of felling wastes for 1 ha.

In implementation of fellings in 100-meter strips of forest along roads and railways, with the cut of fire lines it is allowed to burn felling wastes in fire-safe period (in case of impossibility of further use or sale).

Clearing of cutting sites of clear cuttings with the subsequent artificial reforestation should be done in such a way to ensure the creation of conditions for carrying out the whole complex of reforestation (site preparation and soil processing, planting or seeding of forest crops, agrotechnical treatments), as well as care for the young growth.

Clearing of cutting sites with undergrowth of valuable species is carried out in order to ensure its safety. In the spring, summer and autumn periods, in most cases, it is advisable to put the felling wastes on the skidding trails, and the rest to bunch in places where there is no undergrowth.

All the above requirements do not prohibit the use of some of the felling wastes for processing and obtaining additional products from wood biomass. This is facilitated by new approaches to the development of cutting sites and the use of modern technology.

In the Republic of Belarus whiplash technology is replaced by harvesting technology that is more profitable because of the use of harvesters and forwarders. With the harvesting technology, the primary processing is carried out directly on the cutting site, which concentrates the volumes of felling wastes directly on the site of cutting and creates more favorable opportunities for their harvesting and use.

With promising growth in the volume of final fellings the volumes of felling wastes also significantly increase. There is a need to establish the volume of resources that are obtained in the process of felling, as well as the part that can remain in the felling site, and the part that can be used. To establish approaches to the choice of removal or non removal of felling wastes from the cutting site, consider for clear felling method the criteria for their leaving, and for non clear cuttings - the criteria of their removal (table 5.17).

The use of felling wastes is largely dependent on the availability of felling. In connection with [10], the estimated cutting site is approved separately for accessible and hard-to-reach stands, which are determined in accordance with the established conditions [14]. The main determining factor for their attribution is the types of forests, as well as the distance of the areas from dry land and roads. The share of hard-to-reach areas in the final felling is determined by the estimated cutting site for 2019 and subsequent years and corresponds to the average reference to the felling for the recent years. The most inaccessible stands of black alder-24%, birch-13%.

Table 5.17 – Criteria for determination of the amount of felling wastes left during clear cutting, %

Name	Species						
	pínus sylvéstris:	pícea ábies	quércus róbur	bétula péndula	Álnus glutinósa	pópulus trémula	Other softwoods
Hard to reach felling register	7.3	-	0.3	13.4	24.1	3.5	15.0
Raw and very raw forest growing conditions	20.4	5.0	6.0	45.5	55.9	17.3	27.1
Sandy soils with poor fertility	4.5	–	–	0.4	–	–	–
Strengthening of skidding trails	2.0	3.0	2.0	5.0	5.0	3.0	5.0
Losses during the felling	15.0	12.0	15.0	12.0	15.0	15.0	12.0
Total	49.2	20.0	23.3	76.3	100.0	38.8	59.1

From non-clear cuttings, the use (exportation) of felling wastes can be produced, in general, when carrying out band-gradual fellings. This is due to the similarity of technological processes of these fellings with clear cuttings, moreover, it is mostly economically justified in comparison with other types. The main volume of band-gradual fellings falls on the same age, stands simple in form, growing on drained soils, mainly in Pinetum vacciniosum, mossy and myrtillosum, as well as in betuletum and tremuletum myrtillosum forests with a second layer of spruce or spruce forest. The proportion of such sites from the included in the calculation for carrying out gradual fellings amounted for pine stands – 19,1%, birch – 8,4%, aspen is 5.5%.

Based on these criteria, the volume of possible use of felling wastes in clear and non-clear fellings was determined (table 5.18).

Total predictive resource on use of biomass of felling wastes is determined for 2030 in the amount of 1533.9 thousand m^3, and for the year 2050 – 1848.5 thousand m3 respectively for the years 28.4% and 32.1% of felling wastes created during loggings.

Table 5.18 – Expected volumes of possible use of felling wastes biomass from the final fellings, thousand m^3

Species groups, species	2030			2050		
	clear	gradual, selective	total	clear	gradual, selective	total
Coniferous	929.2	144.2	1073.4	1120.3	180.1	1300.4
including Pínus sylvéstris	617.1	144.2	761.3	775.3	180.1	956.4
pícea ábies	312.1	–	312.1	345.0	–	–
Hardwood	33.7	–	33.7	36.4	–	36.4
including quércus róbur	31.9	–	31.9	33.9	–	33.9
other species	1.8	–	1.8	2.5	–	2.5
Deciduous	396.7	30.1	426.8	476.5	35.2	511.7
including bétula péndula	187.1	24.0	211.1	236.7	28.7	265.4
Álnus glutinósa	–	–	–	–	–	–
pópulus trémula	186.4	6.1	192.5	209.9	6.5	216.4
other species	23.2	–	23.2	29.9	–	29.9
Total	1359.6	174.3	1533.9	1633.2	215.3	1848.5

The most promising is the use of felling wastes as fuel chips. The cost of production of wood fuel from felling wastes can vary widely, the main factors of the cost of fuel are the type of felling, harvesting technology and the distance to the consumer. The use of felling wastes is a reasonable and promising direction, provided that the fuel consumer is available at an acceptable distance. Economically justified distance is considered to be up to 100 km.

Cost structure in the cost of wood chips:

20 % - waste collection in the forest;

15 % - waste removal;

40 % - grinding;

25 % - transportation of wood chips.

6. DEVELOPMENT OF RECOMMENDATIONS AND SET OF ACTIONS FOR PRESERVATION OF BIODIVERSITY AND ENSURING OPTIMUM NUTRIENT CONTENT AND MINIMIZATION OF EMISSION OF CARBON DIOXIDE IN AREAS WHERE CLEAR AND NON-CLEAR CUTTINGS WERE CARRIED OUT AND HANDLING OF FELLING WASTES ON THE RESULTS OF MONITORING TAKING INTO ACCOUNT THE BALANCE OF SOCIO-ECOLOGICAL AND CONSUMER INTERESTS OF FOREST USE

The Republic of Belarus has committed to reduce greenhouse gas (GHG) emissions by at least 28% of 1990 levels by 2030, excluding greenhouse gas emissions and flows in the sector of "land use, change of land use and forest management". With the observed economic growth of the republic, achievement of the expected reduction of GHG emissions will require the implementation of serious effective measures. These will include the contribution of the forest sector to GHG uptake through carbon dioxide effluents in the primary synthesis of organic substances (forest photosynthesis). Under article 13 of the Paris agreement, all states should provide information on their contributions to GHG emission reductions. In order to provide a reliable assessment of this information, a regulation on the establishment of an emission monitoring and assessment system is being developed.

It should be recognized that their contribution to the Paris agreement is small and is possible primarily in ways to increase forest productivity, prevent forest degradation and over-felling, and increase reforestation and afforestation. These actions will require investments to attract carbon dioxide for each event.

The reduction of carbon dioxide emissions, biodiversity conservation is possible through the choice of environmentally sound felling methods and reforestation, removal/non-removal of felling wastes, technologies of loggings. However, scientific experiments and practices in the field of fellings and reforestation have conflicting opinions. In fact, there are no recommendations on the carbon function for forest organizations in the implementation of forest activities and they are not applied in practice.

6.1 RECOMMENDATIONS ON PRESERVATION OF BIODIVERSITY AND ENSURING OPTIMUM NUTRIENT CONTENT AND MINIMIZATION OF EMISSION OF CARBON DIOXIDE IN AREAS WHERE CLEAR AND NON-CLEAR CUTTINGS WERE CARRIED OUT AND HANDLING OF FELLING WASTES ON THE RESULTS OF MONITORING TAKING INTO ACCOUNT THE BALANCE OF SOCIO-ECOLOGICAL AND CONSUMER INTERESTS OF FOREST USE

6.1.1. Recommendations on biodiversity conservation in areas where clear / non-clear cuttings of final felling were carried out and handling with felling wastes

It is known that the final felling leads to a significant change in the microclimate of the territory, manifested in increased illumination of the earth's surface and wind, increasing the amplitude of the fluctuations in the temperature of the surface layer of air and soil, reducing the humidity of the upper soil horizons. This in its turn causes changes in the species composition of vegetation and other characteristics of subordinate layers, first of all *live ground cover*. The degree of these changes is mainly determined by the type of felling.

Clear cutting of stands (*Pinetum oxalidosum and Pinetum pteridiosum*) had a negative impact on the state of live ground cover. Felling and tree skidding, the impact of forestry equipment and subsequent artificial regeneration cause significant damage and a sharp decrease in the projective cover of the storey of *herbo-fruticosus* and *bryo-lichenis*.

The edification role of forest species weakens in relation to representatives of weeds and meadow plants. Some species of *umbraheliophyta* (*Maianthemum bifolium, Lycopódium annotínum, Óxalis acetosélla*) are preserved under the protection of stumps, but they are no longer form a solid background. There is almost complete disappearence of mosses, excluding *Polytrichum commune*, which is able to endure felling.

With the increase of stand age, forest vegetation species are becoming more widespread, and the number of meadow and edge species and their total projective cover is decreasing.

With the increase of stand closure in rows and row spacing, the flow of light under the canopy of the formed stand will decrease. As a result, some areas of live ground cover will dye out and it will become dead. Competition between the root systems of different plant species for moisture and nutrients will play an important role in the regulation of species composition and number in vegetation understory under the conditions of lack of illumination. The composition and structure of live ground cover will be in the stage of intensive restructuring, there will be screening, reduction in the abundance and occurrence of some species of *heliosphyton*. *Herbo-fruticosus* layer will be weekly reflected without any predominance and will be mainly represented by perennial herbaceous plants, rarely distributed along the area and by some particular species. The background will be mainly determined by green mosses (*Hylocomium splendens, Dicranum polysetum, Ptílium crísta-castrénsis)* with the predominance of the latter.

During clear cuttings of the final felling changes in species composition and characteristics of the subordinated layers of vegetation are shown much more strongly than during gradual. Carrying out of clear cutting leads to a sharp decrease in the projective cover of forest grassy vegetation and active replacement of forest plant species with meadow ones. Felling wastes left on the area, to some extent, can reduce the evaporation of moisture from the soil due to its shading, evaporation of its own moisture and reduce the speed of the surface layer of air, but the radical transformation of the ground cover in this direction can not be prevented. The influence of felling wastes on the ground cover is manifested before the age of young trees crown closure, gradually decreasing as a result of rotting and decomposition of their biomass.

In both cases, felling wastes handling (leaving/not leaving on cutting site) during cutovers from-under clear cutting of pine stands with participation in the composition of stands of *Pinus sylvestris*, *Pícea ábies*, *Bétula péndula* and *Pópulus trémula*, on relatively rich soils, the process of formation of forest stands *Pínus sylvéstris* before the transfer to the forested lands occurs in an unpredictable direction. Some species of *umbraheliophyta* (*Maianthemum bifolium, Lycopódium annotínum, Óxalis acetosélla*) are preserved under the protection of felling wastes, but they are no longer form a solid background. There is almost complete disappearence of mosses, excluding *Polytrichum commune*, which is able to endure felling. There is an intensive overgrowth of planting width – *Pteridium aquilinum*, *Calamagróstis epigéjos*, *Festuca ovina, Callúna vulgáris*. There can be met *Fragaria vesca*, *Verónica officinalis, Achillea millefolium*, *Lótus corniculátus, Chamaenérion angustifolium* and especially *Rúbus idáeus.*

In the fourth year after felling, the disappearance of areas with mineralized soil surface and dead-cover was noted. Unlike the first year felling, a well-developed *herbo-fruticosus* layer with an abundance of *Gramíneae* was formed. Together with *Gramíneae* species of vegetative reproduction (*Rúbus idáeus, Rúbus saxátilis*, etc.) became prevalent in the grass stand. The proportion of seed origin (*Chamaenérion angustifolium, Calamagrostis, Viola*, etc.) increased. The predominant species during the felling were *Deschampsia, Calamagrostis, Chamaenérion angustifolium*. Turf formation of *Gramínea* increased. Their share in the projective cover increased to 35%.

Thus, in the first years after felling in the place of regular companions of the forest stand (*Vaccínium, Vaccínium vítis-idaéa, Pýrola rotundifólia*, *Bryophyta* and other forest types) that are important from the point of view of preservation of stability of forest phytocenoses, the representatives of the *Calamagrostis, Poaceae, Deschampsia, Agrostis* genus and other representatives of *Gramíneae* with a mixture of foreign species occur.

To the 20th year after clear cutting, due to crown closure in rows and row spacing of forest cultures, and a substantial reduction of illumination under the canopy, the loss of *heliosphyton* species occurs. In the future, after another 20 years, gradually almost to the initial state *Bryophyta* layer was restored and slightly (15%) species of *silvaticae* didn't keep pace to restore the area of its coverage (figure 6.1).

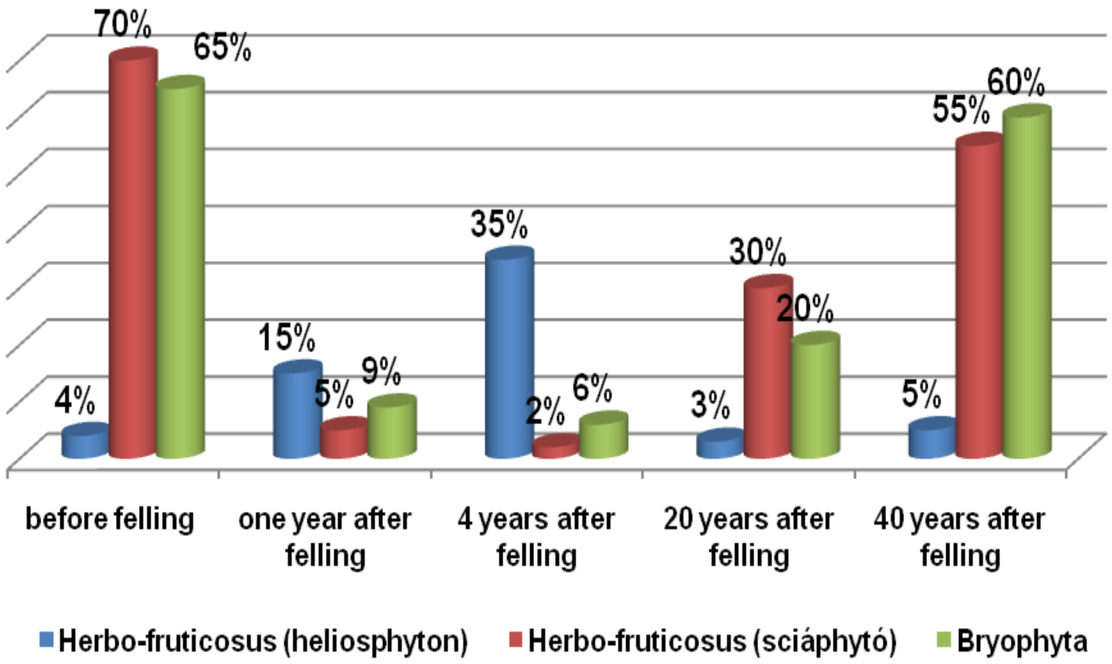

Figure 6.1 – the Dynamics of projective cover in *Piceetum* after clear felling

The impact of left felling wastes on *Subsilva*is not revealed, in both cases (leaving/not leaving*)*, it is regenerated by different types of *Sálix,* and *Sórbus aucupária, Frángula álnus* and in a fairly significant amount *Rúbus idaeus*.

Due to the preservation of the environmental-forming role of the forest, implementation of non-clear cutting has less impact on changing the species composition of plants of subordinate layers and their projective cover. Non-clear forest felling slightly changes the projective cover: to decrease by 4-7% on *herbo-fruticosus* layer, 10-15% – on the *bryo-licheneni* layer. After the first stage of EGC the number of species mainly increases due to the settlement of the area by a variety of the genus of *Gramíneae* among *cryptophytes*. The main changes occur in connection with the cutting through by technological draw plates and the work of forestry equipment on their basis.

The effect of leaving/not leaving of felling wastes during non-clear cutting is evident on cutting sites with completely cut down forest stand (skidding trails, etc.) even less than during clear cutting. Mainly on the trails and in free places *heliosphyton* plants and *compesters occur*: *Chamaenerion angustifolium*, *Leontodon autumnalis*, *Poa annua*, *Rumex acetosella*, *Solidago virgaaurea*, *Veronica officinalis*, etc. By the second stage of felling *bryo-lichenenis* layer adapts to changes in lighting conditions, that is expressed in a gradual increase in the projective cover and restoration of the original state in one to two years after the second felling stage. A small increase in coverage occurs due to *Polytrichum juniperinum* and *Hylocomium splendens*. Subsequently, according to our previous studies, the restoration of the *herbo-fruticosus* layer after felling is going faster than of *bryo-lichenenis*; but still the complitely live ground cover does not keep pace to restore before the next felling stage. Its recovery is possible only in 5-8 years after the completion of felling that is consistent with studies [15].

In spruce stands, the effect of felling on *live ground cover* is similar. In stands*Óxalis acetosélla*, *Melampýrum nemorósum*, *Pterídium aquilínum*, *Pleurosium schreberi*, *Hylocomium splendens* were dominant with a total projective cover of 60-80%. After clear cutting, regardless of the method of handling the felling wastes (leaving/not leaving), the projective cover with herbaceous plants was not more than 30%, and a dead cover was formed on most of the felling area. Ground cover in the first year after clear cutting is represented by small clumps *Cárex*, *Júncus*, *Poaceae*, *Trientális*, *Melampýrum*, *Vaccínium*, *Geranium*, *Bryophyta*, preserved near the stumps and stocks of felling wastes, in places of shading or near the walls of the forest. Growing vegetation *Gramíneae* increases its coverage area and displaces *silvaticae* species, *Bryophyta cover almost* *completely disappears.* The dynamics of vegetation change is similar to that of pine forests. The impact of felling wastes is not shown up.

Leaving of felling wastes with their even distribution over the area and further rotting on the cutting site helps to preserve the fertility of the surface layers of forest soils, that can be important for *live ground cover*. In this case, twigs and branches can be disposed after the fall of needles from them without significant damage to the plants of *live ground cover;* Felling wastes are used as mulch, it allows to preserve soil moisture, especially at the initial stage of the formation of young stand, and contribute to the formation of unique ecological niches. Organisms of *hygrophilus* (*Magnoliophyta*, *Polypodióphyta*, *Bryophyta*) find comfortable conditions for preservation and development on shade and, as a consequence, more humid areas. Later these species during the closing of the crowns restore their dominance more quickly.

Rotting timber from logging wastes according to T. Nienela [16] is a substrate for wood-destroying fungi, which in its turn form ecological niches suitable for habitat and preservation of *mycetozoa*, insects, birds and other animals [16]. The presence of rotting timber, not utilized felling wastes, according to by V. G. Sergienko and others [17] can contribute to the preservation of habitat of forest plants and animals, create special conditions for the regeneration and growth of coniferous species on the humus substrate, for the creation of which the leading role is played by Polyporaceae that can destroy organic compounds that are difficult to decompose.

Leaving of felling wastes on the cutting site until their complete decomposition has a negative impact on the forest fire and forest pathology situation. Utilization of logging waste improves the sanitary condition (prevents the reproduction of pests and the spread of diseases of trees) and reduces the burning of cutting sites.

From the forest pathologic point of view, felling wastes left on the cutting site can cause the development of reproduction centers of xylophage insect and fungal diseases, the effect from which then spreads to neighboring forest areas. Burning of felling wastes is a good measure to solve the problem with pests and forest diseases which can be used as trap trees, which must be burned in spring or early summer before insects fly away. According to the current sanitary rules in the forests of the Republic of Belarus in the centers of stem pests, vascular and necrotic cancerous diseases, felling wastes are subject to mandatory burning in compliance with the requirements of fire safety rules in the forests of the Republic of Belarus [18].

Burning of *forest litter* as a result of fires has pronounced negative consequences because of its great importance in the soil formation process, it largely determines the thermal regime and physical properties of the soil, regulates the chemical composition and aggressiveness of the solution entering the soil, supports its fertility. The stock of litter in ripe deciduous forests can reach 30 C/ha, in dry coniferous stands its mass varies from 30 to 300 C/ha and more [19]. With prolonged drought, the moisture content in the litter on the cutting site is reduced to 14% and below. The dried top layer of the litter lights up even from a spark. As a result, there is a death of forest cultures and the natural regeneration of wood species, ground cover, and also burning of *forest litter* to the mineral layer. At the same time, a significant part of the carbon accumulated by these components is emitted into the atmosphere. With strong intensity fires up to 60% of carbon is lost, at average intensity – up to 30%, at low intensity-up to 5 % [20]. Therefore, in the first 2-3 years after carrying out of final felling, cutting sites with left felling wastes are the most fire-dangerous objects. Losses from the burning of felling wastes according to our research can lead to damage from 250 to 1825 Bel. RUB depending on the type of forest [21].

On the basis of the given researches for preservation of biodiversity, from the ecological point of view, utilization and use of biomass of felling wastes during final fellings it is possible to recommend the following:

– implementation of non-clear cuttings of the final felling;

– the use of environmentally sound technologies in fellings;

– conducting of fellings in the autumn-winter period;

– in order to conserve the biodiversity of shade-loving plants felling wastes should be left in piles after final fellings;

– grinding and spreading of felling wastes evenly over the area as mulch, that retains moisture;

– leaving of forest reproductions after the clear cuttings;

– due to the fact that the regeneration process proceeds in the direction of "forest vegetation-vegetation of open areas-forest vegetation, etc." in rich growth conditions, it is desirable to increase the number of agrotechnical and silvicultural care;

– in order to prevent the occurrence of forest fires to provide for the removal or shredding and scattering of felling wastes;

– to carry out constant monitoring of compliance with fire safety rules in the forests of the Republic of Belarus.

The impact of felling wastes on floristic diversity, nutrients and carbon dioxide absorption is environmentally positive but not significant enough for the growth and development of the forest ecosystem.

6.1.2. Recommendations on ensuring an optimal nutrients content in areas where clear / non-clear cuttings of final felling were carried out and handling with felling wastes

The results of studies in the scientific literature suggest that the utilization of forest waste can reduce the growth and productivity of emerging forest stands by reducing the amount of nutrients in the soil. There is a direct relationship between the evidence of this process and the volume of felling wastes, it is more pronounced in spruce forests, forming the largest volumes of logging waste [2-4].

In the result of the analysis of data obtained during the research on the sample sites 1-4 WB/GEF *Pinetum oxalidosum*, 5-8 WB/GEF – *Pinetum pteridiosum*, 9-12 WB/GEF *Piceetum oxalidosum* and 13-16 WB/GEF *Piceetum pteridiosum* it was found that the phytomass of twigs, branches and pine needles that form the most acceptable for the utilization of felling wastes in *Pinetum oxalidosum* before felling and is 56.6 m^3/ha (11.1% of the total phytomass of stand and needles in the noted stand), in the *Pinetum pteridiosum* - 54.3 m^3/ha (11.2% of the total phytomass of the stand and needles), in *Piceetum oxalidosum* – 82,9 m^3/ha (12.7 per cent of the total phytomass of trees and needles) in *Piceetum pteridiosum* - 80.2 m^3/ha (13.1% of the total phytomass of trees and pine needles). The content of nutrients in felling wastes (twigs, branches and needles) in these stands is given in table 6.1.

Table 6.1 – Content of nutrients in felling residues (twigs, branches and needles) in the studied plantations, kg/ha

Stand	Nutrient					
	Total	P	K	Ca	Mg	N
Pinetum oxalidosum	2451	155	355	1350	371	220
including needles	502	38	99	120	63	182
Pinetum pteridiosum	2348	149	340	1292	355	212
including needles	483	37	95	115	60	176
Piceetum oxalidosum	3478	221	512	1863	523	359
including needles	847	64	167	202	106	308
Piceetum pteridiosum	3363	215	495	1799	505	349
including needles	824	62	162	197	103	300

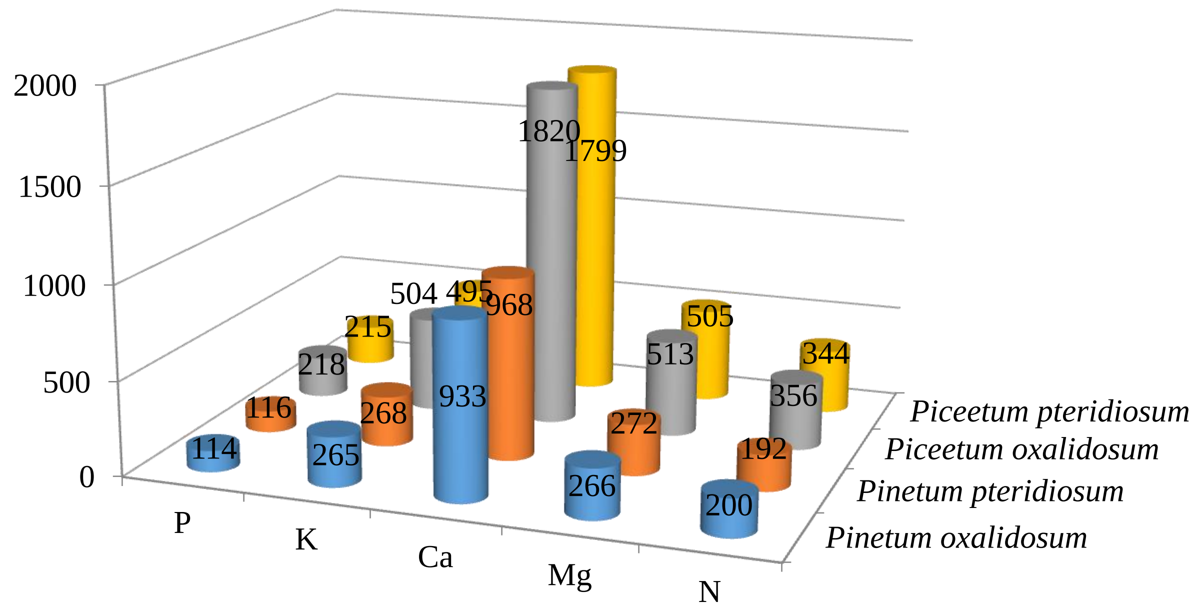

Figure 6.2 – Removal of nutrients during the removal of felling wastes in the studied stands, kg/ha .

When removing the felling wastes during clear cutting in the *phytocenosis Pinetum oxalidosum* 114 kg/ha of phosphorus, 265 kg/ha of potassium, 933 kg/ha of calcium, 266 kg/ha of magnesium, 200 kg/ha of nitrogen are removed, for a total of 1778 kg/ha of nutrients. In *phytocenosis Pinetum pteridiosum* 116 kg/ha of phosphorus, 268 kg/ha of potassium, 968 kg/ha of calcium, 272 kg/ha of magnesium, 192 kg/ha of nitrogen are removed, total – 1816 kg/ha of nutrients. In *phytocenosis Pinetum oxalidosum* 218 kg/ha of phosphorus, 504 kg/ha of potassium, 1820 kg/ha of calcium, 513 kg/ha of magnesium, 356 kg/ha of nitrogen are removed, total – 3411 kg/ha of nutrients. In *phytocenosis Pinetum pteridiosum* 215 kg/ha of phosphorus, 495 kg/ha of potassium, 1799 kg/ha of calcium, 505 kg/ha of magnesium, 344 kg/ha of nitrogen are removed, total – 3358 kg/ha of nutrients.

The results of the studies show that this value does not exceed 10% of the stock of ash elements and nitrogen in *phytocenosis* and is 30-40% of the nutrient content in *forest litter* and soil [1]. Stocks of ash elements and nitrogen in *forest litter* and soil in 10-30 years after the FF, including in areas after removal of felling wastes, are not less than in areas where middle-aged and older stands grow, and are within the range of variation of this indicator in the types of forest, i.e. the method of clearing of cutting sites practically does not affect the content of nutrients in forest litter and soil.

Thus, methods of FF, reforestation and handling of felling wastes (i.e. their removal/non-removal) do not have a significant impact on soil fertility and, presumably, the productivity of the next generation of stands. Nevertheless, taking into account permanent removal of nutrients from forest ecosystem during improvement felling, it is necessary to limit first of all on poor soils, the amount of removed felling wastes and also to remove them only after the fall of needles (foliage) from felling wastes.

Live ground cover, whose plants have root systems, located mainly not deeply (in the upper 10 cm layer of soil), is the most sensitive component of the phytocenosis to moisture and soil fertility. At the same time, *live ground cover* is a component of the phytocenosis having the greatest species saturation. It can be assumed that the removal of nutrients together with the stand biomass during the final felling in future will have a more significant impact on the formation of live ground cover in comparison with other layers of forest stands.

Live ground cover in pine forests (*Pinetum pteridiosum, Pinetum oxalidosum*) contains in its biomass 258-369 kg/ha of nutrients, which is a small proportion (0.7–0.9%) of their total stock in *phytocenosis*. In the needles of *Pinetum oxalidosum* stand, which has a similar ratio of nutrients with plants of live ground cover, contains 502 kg/ha of nutrients, *Pinetum pteridiosum* – 483 kg/ha.

The content of nutrients in live ground cover in *Piceetum oxalidosum* is 444 kg/ha, *Piceetum pteridiosum* – 422 kg/ha. The needles of the forest contain 847 kg/ha of nutrients in *Piceetum oxalidosum* and 824 kg/ha in *Piceetum pteridiosum* (figure 6.3).

To form the productivity of stands, the root system of which covers a significant soil thickness (up to 1 m or more), felling wastes and nutrients contained in them do not play a significant role;

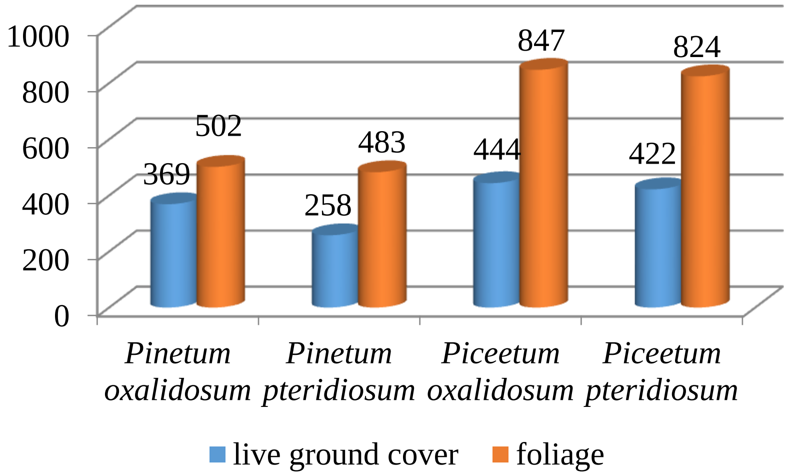

Figure 6.3 – The content of nutrients in live ground cover and needles of felling wastes, kg/ha

As it can be seen from the presented data, leaving of needles of felling wastes on the cutting site can provide with an abundance of nutrients for the formation of ripe stand of live ground cover with its usual species diversity.

From an ecological point of view utilization of felling wastes is different from burning by a removal of a certain amount of nutrients from the cutting site and by less damage to *live ground cover* and *forest litter*. It is indicated that as a result of utilization of felling wastes soil fertility is not significantly reduced. Leaving of felling wastes is beneficial for the conservation of forest biodiversity and the accumulation of part of the carbon in the phytomass and soil, but increases the risk of forest fires, pests and forest diseases.

Environmental damage from forest fires is very significant and can be seen not only in the loss of wood stock and reducing of the growth of trees, but also in the deterioration of the properties and fertility of the soil, the adverse impact on the regime of rivers, the disappearance of plant and animal species, the expansion of the boundaries of radioactive contamination.

Ecological damage from loss of nutrients (P, K, Ca, Mg, etc.) by combustion of felling wastes according to our research is from 200 to 1520 Bel. RUB, nitrogen to 2300 Bel. RUB [21, 22].

Cutting sites with felling wastes left for rotting relate to the higher (first) class of natural fire danger. This is due to the fact that the felling wastes are dead phytomass (twigs, small branches), needles and leaves, which in hot sunny days lose moisture very quickly and warm up to high temperatures, becoming excellent conductors of combustion. Combined with strong winds, this creates an extremely unfavorable environment. Extinguishing of cuttings littered with felling residues is associated with the difficulties of moving people and fire-fighting equipment along them, as well as a large amount of heat released during combustion.

Recommended utilization provides for the reduction in greenhouse gas emissions and the associated consequences of slowdown in global climate change, as the carbon entering the atmosphere from the burning of felling wastes is "neutral".

The collection and use of felling wastes as fuel resources stimulates the increase of employment in this area. This will ensure the creation of enterprises, the development of technologies and equipment for the collection, processing and utilization of biomass residues.

To maintain soil fertility it is recommended to: to implement the harvesting of felling wastes before the needle and foliage shedding; to leave in the forest up to 30% of the mass of felling wastes and scatter them evenly over the area; to leave the stumps that make up to 20% from the biomass of the trunk for rotting. To maintain soil productivity, it is necessary to avoid mixing of its upper layers. To maintain nutrients on poor soils, it is necessary to leave up to 50 trees / ha of trees with a diameter of more than 15 cm, evenly distributing them over the area of the cutting site.

6.1.3. Recommendations on minimization of carbon dioxide emission in areas where clear / non-clear cuttings of final felling were carried out and handling with felling wastes

One of the main directions to combat climate change is an increase of the level of carbon dioxide absorption by forest ecosystems. The potential should be assessed and all components of the storage and long-term storage of carbon should be considered. During FF as a result of forest stand cutover that is a main component of the forest ecosystem and accumulates more than 90% of carbon in its biomass, this chemical element is emitted into the atmosphere in the amount of tens and hundreds of tons per hectare for a short period of time.

After the forest felling due to the formation of a new forest phytocenosis, the period of restoration of the initial mass of carbon in stands begins, which is 49 years in terms of clear cutting with the removal of felling wastes, without the removal – 42 years; non-clear cutting with the removal of felling wastes – 41 years, without the removal – 35 years. Thus, the removal of felling wastes during final felling increases the duration of carbon emissions up to 6-7 years, and artificial reforestation of felling after clear cutting of final felling up to 7-8 years, that indicates the possibility of felling wastes removal without significant impact on the carbon balance [15].

The volume of felling wastes after final felling was determined on the basis of studies of pilot sites (1-16 WB/GEF), the characteristic of which is presented in the reports [15, 23].

The volume of felling wastes in *Pinetum oxalidosum* (PP 1-4 WB/GEF) is estimated at 204.7 m^3/ha, in *Pinetum pteridiosum* (PP 5-8 WB/GEF) – 195.1 m^3/ha, in *Piceetum oxalidosum* (9-12 WB/GEF) – 247.4 m^3/ha and in *Piceetum pteridiosum* (13-16 WB/GEF) – 236.1 m^3/ha. The volumes of individual components of felling wastes are shown in figure 6.4.

More effective use of felling wastes is concentrated in stumps and roots of felled trees, which, as a rule, are not utilized due to the difficulty of their harvesting. Most of the volume of bark is exported together with the stem wood, needles and leaves can be harvested for the production of various products, but can not be considered as fuel, because of quick fall from the cut twigs and branches. Thus, only branches and twigs can be considered as fuel wood, forming a *Pinetum oxalidosum* of volume at 37.6 m^3, in *Pinetum pteridiosum* – 36.0 m^3/ha, in *Piceetum oxalidosum* – 50.8 m^3/ha and in *Piceetum pteridiosum* – of 49.0 m^3/ha. 1 m^3 of harvested and exported stem wood accounts for: in *Pinetum oxalidosum* 0.095 m^3 of branches and twigs, in *Pinetum pteridiosum* – 0.095 m^3, in *Piceetum oxalidosum* – 0.100 m^3 and in *Piceetum pteridiosum* – 0.104 m^3.

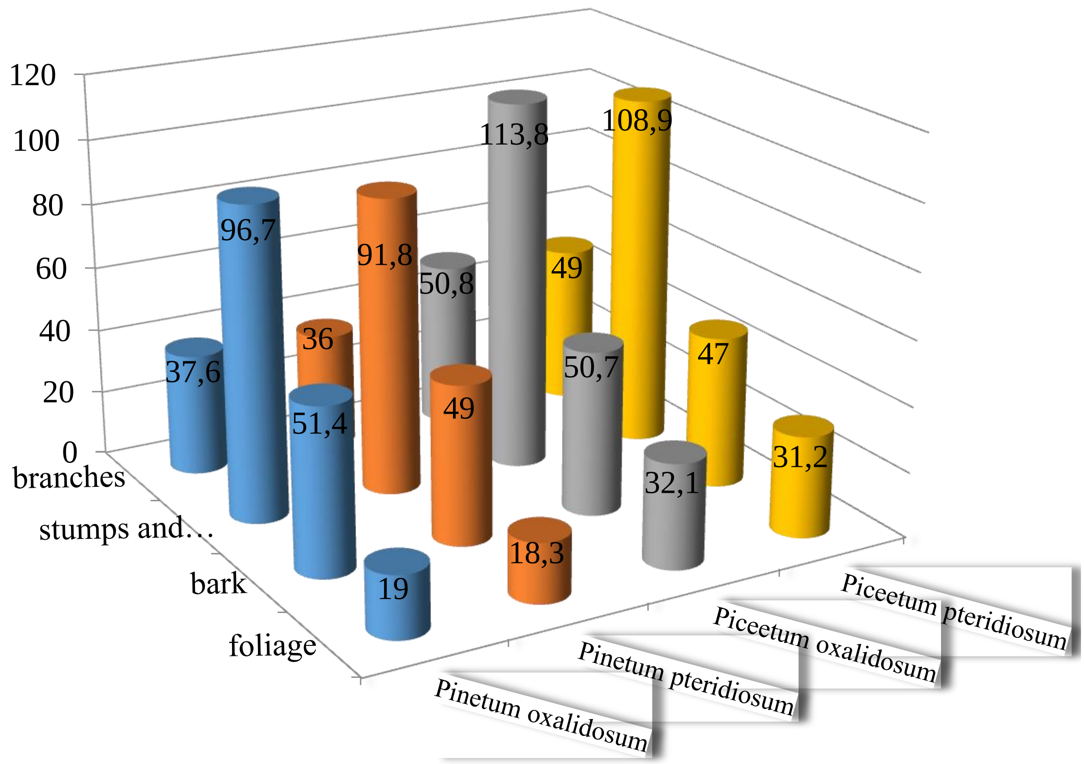

Figure 6.4 – Component composition and volumes of felling wastes on pilot sites (1-16 WB/GEF), m^3/ha

In the studied sites the complete removal of branches and twigs from the cutting site for further disposal does not contradict the requirements of current standards.

As a result of calculations it was found that the combustion of felling wastes as fuel wood harvested in *Pinetum oxalidosum*, 266.96 GJ will release (6.4 t of oil equivalent), that is equivalent to the burning of 8.4 million m^3 of natural gas. In *Pinetum pteridiosum* this value is 255.6 GJ (6.1 per t oil equivalent), which is equivalent to the burning of 8.0 thousand m^3 of natural gas, in *Piceetum oxalidosum* – 325.12 GJ (7.8 t of oil equivalent), that is equivalent to burning of 10. 2 thousand m^3 of natural gas and in *Piceetum pteridiosum* – 313.6 GJ (7.5 tonne of oil equivalent), that is equivalent to burning of 9. 9 thousand m^3 of natural gas [23], as it is confirmed by comprehensive studies carried out in the forests of Belarus, the volume of felling wastes for 1 m^3 of stem wood during the clear cuttings in oak stands is estimated at 0.019–0.130 m^3; spruce – 0.604–0.727 m^3; in pine – 0.121–0.175 m^3 [23].

In the Republic of Belarus, the replacement of natural gas with wood pulp of felling wastes and their use as fuel requires significant investment since the share of natural gas in the structure of energy consumption is extremely high. It is 57.2% in the fuel and energy balance, 80% – in the balance of boiler and furnace fuel and 97.2% – in the fuel balance of the power system.

According to the calculations of economists, the production of heat and electricity by wood fuel combustion in Belarus can be recommended for implementation at current tariffs only from the social and ecological points of view or from the position of ensuring the energy security of the country [24].

The use of wood wastes for fuel is possible only in case of an increase in natural gas prices, the adoption of measures at the legislative level, economically stimulating the use of wood fuel from forest wastes, as well as payment for environmental services in forestry (introduction of the carbon rent, improve trading mechanism, the price increase to the target to 30 Euro/t CO_2e). Sale of wood chip fuel for export is recommended as the existing foreign prices for fuel chips can offset the costs of domestic production and provide a profit when selling it for export. The commitments of the Republic of Belarus to reduce greenhouse gas emissions will require greater involvement of contribution of the forest sector both in terms of increasing the level of carbon dioxide absorption by forests and effective use of forest biomass for energy purposes.

As a result of timber combustion in comparison with natural gas in the atmosphere comes in 14.1 times more of CO, NO in 5.9 times, NO_2 in 6.1 times, CH_4 in 3 times, CO_2 in 1.4 times; in comparison with liquid petroleum products: CO – more in 2.3 times and NO more in 1.3 times, NO_2 – more in 1.5 times, CH_4 in 19.7 times, CO_2 in 2.8 times.

However, it should be noted that these substances still enter the environment after the natural death of woody plants as a result of rotting, decomposition of their biomass and oxidation of its decay products. At the same time, young woody organisms are able to remove the same substances, accumulating them in their biomass, thus carrying out a stable closed cycle of substances in the biosphere. Felling wastes timber is an environmentally friendly fuel, combustion of which does not lead to an increase in the share of greenhouse gases and pollutants in the atmosphere. The fossil fuel reserves burned and extracted from the subsoil disrupt this balance and lead to the accumulation of pollutants and greenhouse gases.

The main advantages of using timber as a biofuel are the zero effect of the carbon dioxide cycle (the amount of carbon dioxide that was absorbed by the plant during its life is released), the renewable biofuel resources, their availability and relatively low prices.

The comparison of specific greenhouse gas emissions indicators in the combustion of a unit of mass of different fuels confirms the advantage of felling wastes over natural gas and liquid petroleum products (figure 6.5).

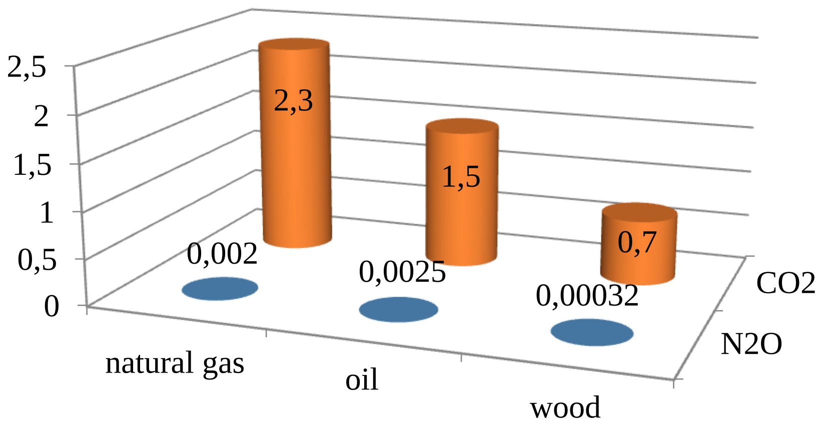

Figure 6.5 – Specific indicators of greenhouse gas emissions from the combustion of different fuels, t/t

There are less supporters of leaving of felling wastes on the cutting site for rotting. The least acceptable is the burning of felling wastes on the cutting site. Residents of small, medium and large populated areas mostly positively assesses the collection and disposal of felling wastes.

The methods of cutting sites clearing without fire are more satisfactory for the population as there is no smoke in the area, biodiversity and aesthetic perception of the area are suffered least.

Recommendations on ecological and social aspects:

– make greater use of the priority areas of investment activity in forestry for technical re-equipment of forestry, logging and woodworking industries, construction of forest roads, creation and development of infrastructure for the harvesting and delivery of wood fuel, housing construction;

– contribute to the expansion of the assortment and improvement of the quality of products, creation of additional jobs in small towns and rural areas, involvement in processing of unclaimed timber in the republic, improvement of the efficiency of the use of forest resources.

– to create export-oriented production of wood briquettes, pellets and other solid fuels, to increase revenues from the sale of these products, to reduce the share of imported energy resources, to improve the energy efficiency of the economy and the level of energy security of the country;

– to carry out explanatory work with the population on the problem of clearing of the cutting sites, that contributes to the complex forest pathology situation that still exists in the forests of the republic, in connection with the death of forest stands, causing a noticeable public reaction.

– to authorize the use of felling wastes left on cutting sites of the main use are used by local residents as a source of wood for heating of dwellings.

– among the population the views on forest management, providing for the complete utilization of biomass felled forest stand, which is considered an ideal of management are quite popular. The presence of felling wastes on the cutting site in this case is considered as a sign of a low level of forest management.

– to carry out non-clear cuttings of final felling in close proximity to populated areas, first of all underpopulated and in the forests frequently visited by local population for recreation, gathering of berries and mushrooms.

– to enhance public understanding of the basic operating normative documents in the field of forestry (the Forest code, rules of fellings in Republic of Belarus, etc.) that they have the idea of the allowed and applied types of final fellings and their standards;

– development of appropriate industries for processing of felling wastes into sawdust, the use of felling wastes as secondary raw materials in the production of cellulose and various building boards. etc. increases employment.

– the clearing of cutting sites is recommended to implement by the method without using a fire in terms of the widespread proximity of forests to populated areas and gardeners' partnerships, the smoke from the burned felling wastes is of serious concern for the population.

– utilization of felling wastes and use of wood for fuel purposes.

It is recommended to remove felling wastes in the following cases:

– the boundaries of the cutting site are in close proximity to the boundaries of small settlements (up to 300 m). In this case, the cause are reasonable fears of increasing risk of fires;

– roads or trails actively used by local residents pass through or near the cutting site;

– collection of felling wastes in piles and their leaving for rotting is applied;

– cutting sites are located in small forest lands;

– in the area of distributed phenomena of drying plants, there are centers of harmful insects and fungal diseases (left logging wastes are considered as a center of harmful insects);

For this reason, utilization collection of felling wasres, especially on cutting sites with a significant number of large branches and peaks is of interest to residents of nearby small settlements.

Fire clearing of cutting sites in areas where there were no forest fires, as well as centers of reproduction of harmful insect pests, is estimated by the population extremely negatively.

In order to maintain the global balance of greenhouse gas release/uptake it is recommended to restore forest areas. At the regional level, combating with the spread of large forest fires. Equal distribution of enterprises in the energy sector, the raw material for which is wood.

From the economic point of view, due to its properties and the possibility of utilization, biomass of felling wastes is recommended to use as:

1. Branches and twigs. The most appropriate way to use twigs and branches is obtaining of chipped wood and its further use as fuel. The yield of cellulose from the twigs is 8-10% lower than from the stem wood. The share of this component of felling wastes depends on the predominant wood species in the cutting site and is approximately: for spruce – 11% of the total biomass of forest stand, pine – 9%, small-leaved species (birch, aspen) – 12%. The wood of branches is

characterized by high density and high resin content (in coniferous species) and, consequently, increased calorific value.

2. tree top. The length of the tops reaches 2-4 m, depending on the wood species, and the share in the weight of logging wastes reaches 7-10%. Wood of tree tops is suitable for technological wood chips.

3. Tree remnants. It is considered to be a technological raw material. The share of broken trunks is 2-3%. From broken trunks it is possible to produce industrial chips.

4. Stumps and roots. The share of these felling wastes is 10-15%. The main direction of stump wood processing – production of resinous stumpwood, but its processing into wood chips and use as a raw material for board production is much more relevant.

5. Bark. if to leave it in the cutting site, the slow decomposition of the bark in soil occurs, organic nitrogen becomes available for plant nutrition. The bark contains fiber and other valuable nutrients and biologically active substances. This allows us to refer it to the source of raw materials for the production of fodder – feed flour, rough feed, additives for feed mixtures. Bark can be used as fuel.

6. Woody vegetation (needles and foliage). Woody vegetation is rich in vitamins and carbohydrates, proteins, amino acids and is used as a raw material for vitamin flour, which is added to animal fodder. Chlorophyll is extracted from needles, carotene and essential oils that are used in the pharmaceutical industry and medicine.

7. Cuttings of stems of different lengths. Formed after tree skidding that are got after the manual felling. After this, their butting and trimming for defects removing or damage of the trunk occurs. The share of logging waste formed as a result of felling and bucking is 0.5–1%, the share of rotten edgings depends on the conditions of forest stand location, its species composition and sometimes reaches 20-25%. It is possible to obtain technological chipped wood from these wastes. Production of chip fuel is more common.

The high cost of drugs, vitamin and protein concentrates produced from biomass of felling wastes, can provide a positive economic effect from their processing. In this aspect, the most important things are bark and woody vegetation used as raw material (pine needles, pine branch, small softwoods).

Living cells of woody plants contain a lot of biologically active substances: vitamins, enzymes, hormones, protective antimicrobial and macronutrient: proteins, fats, carbohydrates and other substances suitable for medicinal, food and fodder purposes. The amount of carotene in spruce needles is 84 mg/kg, pine – 128 mg/kg, in birch leaves -187 mg/kg of absolutely dry matter. The content of ascorbic acid in pine needles in average is 250-300 mg per 100 g of dry matter with fluctuations from 160 to 540 mg per 100 g of dry matter. Fresh woody foliage have significant nutritional value: spruce – 0.21; pine – 0,28 feed unit per kilogram, i.e. is equivalent to wheat or rye straw. Pine buds and needles contain essential oils, resinous substances, tannins and microelements [25].

The economic effect from the use of felling wastes as fuel and its value are dependent on the prices of traditional fuel (oil, natural gas), the cost of removal (collection and removal) of felling wastes from the cutting site, the amount of investment in the organization of enterprises for the processing of collected biomass, power plants, the acquisition of specialized forest equipment, etc.

In the scientific literature, from the economic point of view the use of felling wastes as fuel is estimated as positive. It is indicated that due to the removal of felling wastes for energy purposes in the Republic of Belarus about 87,4 thousand tons of reference fuel can be obtained , that is 0.2% of the total amount of energy consumed annually. As a result of comparing the cost of different types of fuel and energy resources, it is indicated that the efficiency of felling wastes using in terms of their replacement by natural gas will be about 6.6 million US dollars. a year, and fuel oil – 11.8 million US dollars per year [26].

To increase the economic efficiency of disposal of felling wastes it is recommended to:

– felling wastes should be harvested, and possibly processed at the cutting site in the process of harvesting of stem wood;

– several cutting sites should be located close to each other, in order to ensure the continuous operation of the chipper. Productivity of the existing low-powered chipping machines aggregated with tractors and designed for production of chipped wood from the felling wastes accounts for 5-20 m^3 of bulked wastes .

– development and production of chipping machines with a capacity of 40-160 m^3 of bulked wastes are produced, as well as road trains for the transportation of chipped wood with a truckload of 80 bulk m^3 and chip hauler stet with removable containers with a truckload of 35-40 m^3 of bulked wastes;

– felling wastes should be stocked in large piles located within certain boundaries along the skidding trail in the cutting strip where their collapse by moving machines throught the cutting site is impossible;

– cutting site should have a good bearing capacity, in order to minimize the consumption of felling wastes to strengthen the skidding trails;

– on the cutting site there should be no undergrowth of the target species complicating harvesting;

– the distance of transportation of logging wastes should be short.

– energy production from felling wastes is integrated into all forest planning and management systems, that has an impact on the development of the production of relevant machinery and equipment, organizations engaged in transportation and specializing in the production of wood fuel;

– to improve logistics of harvesting of logging wastes in order to remove the production of chipped wood to specialized terminals and final-use facilities.

– to develop and implement detailed manuals on practical recommendations, the use of logging wastes, to include them in the quality management system of logging in the forest industry, as well as in the system of forest certification;

- the use of wood wastes in new perspective directions of board and pulp productions, their applying in the production of arbolite products for rural construction on mobile units, working in conjunction with mobile chipping machine.

– apply cost-effective systems of mobile enterprises, shuttle technology.

6.1.4. Analysis of ecological, social and economic results of felling wastes management

The influence of methods of management of felling wastes on the forest formation process in a generalized form can be presented as follows.

Removal of FW from the cutting site for utilization use has a positive effect on:

– technological conditions for the creation and care for forest cultures;

– conditions for the formation of sprouts of natural regeneration;

– expansion of floral diversity;

– reduction of" emission " of carbon dioxide when using FW to generate energy instead of hydrocarbon fuels;

– improvement of sanitary condition and pyrogenic situation in felling sites.

The negative consequences are as follows:

– the deterioration of conditions of natural regeneration in a moist and wet edaphotope;

– uncritical, but rather a negative consequence for soil fertility;

– slow down of the regeneration of shadow species;

– reduction of diversity among insects, fungi, small animals, etc.;

– reduction of the volumes of carbon sequestration by the soil.

Shredding and spreading of FW over the cutting site has a positive effect by:

– mitigation of the microclimatic factor in the cutting site;

– preservation of water-physical properties of the soil characteristic of the forest environment;

– improvement of conditions for renewal of shade-tolerant species;

– obstacles for turf formation;

– uniform receipt of nutrients in soil from decomposition of FW, some preservation of soil fertility;

– formation of impression of "well-groomed" forest in places of mass visiting of vacationers;

– additional air supply (carbon) for young stands;

– maintenance of life support conditions for useful species of flora and fauna;

– sequestration of organic carbon by soil.

The negative consequences of FW saving on the cutting site by scattering include:

– technological conditions for the creation and care for forest cultures;

– risks of deterioration of sanitary and pyrogenic situation;

– reduction of the area of contact of seeds with soil;

– "emission" of carbon dioxide in the process of biological decomposition of FW.

Collection of FW in piles and leaving them for ripening is useful for:

– mitigation of the microclimatic environment on the cutting site;

– preservation of favorable for reforestation water-physical properties of the soil;

– creation of micro-elevations in the areas of rotting of FW for natural renewal;

– maintenance of optimum soil nutrition of forest cultures for some time or natural regeneration and useful species of small animals-detritophages and other organisms;

– sequestration of organic carbon by soil during decomposition of FW,

The negative consequences of leaving the FW in piles and shafts on the cutting sites affect in this way:

– occurrence of technological difficulties for creation and care for cultures;

– formation of non-renewed "free places";

– risks of foci of pests and diseases, forest fires;

– mosaic of soil fertility, unequal conditions of soil nutrition for undergrowth or seedlings at different distances from the FW;

– "emission" of carbon dioxide in the process of biological decomposition of FW.

Burning of FW on the cutting site can be recognized as positive as:

– improvement of technological conditions for creation and care for forest cultures;

– pest control and fungal pathogenic infection;

– a favorable factor for the regeneration of pine and other pyrophylous species;

– increase in nutrients and lowering of soil acidity.

The negative consequences of pyrogenic effects on FW are as follows:

– destruction of undergrowth of main species and valuable species of shrub layer, useful species of small animals and other organisms;

– reduction of soil fertility and deterioration of water-physical conditions of the soil;

– deterioration of the renewal of shade-tolerant tree species;

– intensive" emission " of carbon sequestrated in soil, forest litter and humus horizon.

These consequences of FW management are summarized in table 6.2.

Taking into account earlier established wishes of the population to the organization to final fellings and to the application of methods of cutting sites clearing from FW [23] the following assessment of FW is offered for consideration of the Ministry of forestry (table 6.3).

Table 6.2 – Comparative ecological impact assessment of the methods of management of FW formed in final felling sites, on forest-formation process

Factors of forest formation and biodiversity	Result impacts	Methods of FW management				
		Removal of FW from the cutting site for utilization use:	Methods of clearing of the cutting site without FW removal			
			grinding and spreading of felling wastes in the cutting site	collecting of felling wastes in piles for rotting	collecting of felling wastes in shafts for rotting	combustion of FW on the cutting site
Creation of forest cultures	positive	Optimization of technological conditions for the creation and tending of cultures; improvement of sanitary conditions and fire safety	Slight mitigation of the microclimatic factor of the environment; preservation of favorable water-physical properties of the soil characteristic of forest plantations.			The improvement in the technological conditions for the establishment and maintenance of cultures; control of pests and fungal pathogenic infection.
	negative	No significant negative impact on forest production is expected	Certain technological difficulties for the creation and tending of cultures; risks of deterioration of forest pathology and forest fire situation.			Deterioration of water-physical properties of the soil.
Natural regeneration;	positive	Improvement of conditions for the formation of seedlings of regeneration; removal of a significant factor for the occurrence of forest fires	Improvement of conditions for the regeneration of shade-tolerant species; obstacles for turf formation.	Improvement of the microclimatic environment; creation of micro-elevations at the sites of FW rotting, that favors the emergence of self-seeding.		Favorable conditions for the regeneration of the pine trees; pest and fungal infection.
	negative	Deterioration for renewal in wet and wet edaphotopes due to elimination of possible micro levels from FW	Reduction of the area of contact of seeds with soil;	Formation of non-renewed "space" during cutovers; risks of foci, pests and diseases and occurrence of forest fires.		Deterioration of water-physical properties of soil; destruction of undergrowth of the main species.
The content of nutrients in the soil	positive	Uncritical, but rather a negative consequence for soil fertility;	Uniform receipt of nutrients from decomposition of FW, some preservation of soil fertility;	Focal increase of soil fertility as a factor of short-term period of optimal soil nutrition of forest or forest cultures.		Increase of nutrients in terms of decrease in acidity of a soil solution; in general decrease in soil fertility and deterioration of water-physical properties of the soil.
	negative		Negative consequences are not manifested.	Mosaic of soil fertility; unequal conditions for the supply of nutrients for undergrowth, seedlings or seedlings of forest cultures.		
Biodiversity	positive	Intensification of floral diversity	Formation of impression of "well-groomed" forest in recreational and health-improving forests. Preservation of nutrition conditions of useful species of small animals-detritophages, unicellular organisms, soil microflora.			Intensification of renewal of pyrophilic species; improvement of natural renewal of pine; reduction of forest cultures tending.

	negative	Slowing the renewal of shadow species; reducing the diversity of insects, fungi, small animals, etc.	Preservation of foci of pests and diseases, pyrogenic danger in forests of operational and other categories of economic purpose.	Reduction of species diversity of flora, small animals, fungi, soil microflora; deterioration of renewal of shadow species.
The absorption of CO_2	positive	The substitution of "emissions" of carbon dioxide from hydrocarbon to renewable sources of energy	Sequestration of organic carbon by soil during biological decomposition of FW; additional air supply by carbon dioxide from decomposition of FW during photosynthesis of forest stands.	A positive effect on carbon dioxide absorption is not possible.
	negative	Reduction of the volumes of carbon sequestration by the soil.	"Emission" of carbon dioxide in the process of biological decomposition of FW.	Intensive" emission " of carbon sequestrated by FW phytomass, forest litter and humus horizon.

Table 6.3 – Assessment of methods of clearing of felling sites from FW in the view of general public

Method of cutting site clearing from felling wastes	Assessment of methods for cutting site clearing from felling wastes	
	Positive	Negative
1. Collection of felling wastes for the production of technological chips, fuel and other purposes;	- reducing the risk of forest fires; - the improvement of the sanitary state of stands; - creation of favorable conditions for reforestation; - increase in employment; - increasing the assessment of the level of forest management by the population.	Slightly: - removal of mineral nutrients in FW; - release of carbon into the atmosphere; - change in species diversity;
2. Uniform stockpiling of felling wastes on skidding trails with subsequent compaction;	- exclusion of removal of elements of mineral nutrition; - deceleration of carbon emissions; - preservation with the increase in species diversity; - increase in employment;	- increasing the risk of forest fires and their intensity; - deterioration of the sanitary state of stands; - decrease of the assessment of the level of forest management by the population.
3. Collecting of felling wastes in piles up to 2.5 meters in height and diameter or bulks up to 2.5 meters in height and width and leaving them for rotting;	- preservation of mineral nutrition elements; - deceleration of carbon emissions; - increase of species diversity of microflora.	- increasing the risk of forest fires and their intensity; - deterioration of the sanitary state of stands; - decrease of the assessment of the level of forest management by the population.
4. Grinding and spreading of felling wastes in the cutting site;	- exclusion of removal of elements of mineral nutrition; – slowing down of the removal of carbon; - increase in employment;	- increase in the risk of forest fires; - deterioration of the sanitary state of stands; - decrease of the assessment of the level of forest management by the population.
5. Collecting of felling wastes in piles with a diameter of 2.5 meters and a height of 1.5 meters and their combustion;	- preservation of nutrition elements; - creation of favorable conditions for reforestation; - increasing the assessment of the level of forest management by the population.	- there is a locally high concentration of mineral nutrition elements; - increase in carbon emissions.

Regarding the economic assessment of the production of fuel chips from the FW, we note the following. In the production of chips from the FW (collection, delivery to an intermediate storage and for chipping) estimated cost according to specialists are higher by 22% – in domestic market and by 15% in external market (table 6.4).

Table 6.4 – Comparative analysis of the efficiency of production and sale of wood chips and felling wastes on the terms of seller's warehouse (the most used terms of delivery) according to the actual data of forestry enterprises of Belarus

Economic indicators of fuel chips production *)	Manufacture from firewood	Manufacture from felling wastes	Cost variance
The cost of production of chips when sold in the domestic market, rub/cubic meter.	27.86	33.43	5.57
Sale price of wood chips in the domestic market, rub/cubic meters	28.61	28.61	
Profit (loss), rub / cubic meters	0.75	-4.82	-5.57
Cost-effectiveness, %	2.7	-14.4	-17.12
The cost of production of wood chips in the sale of wood chips in the foreign market, euro / cubic meters	19.7	22.7	2.96
Sale price of wood chips in the foreign market, euro / cubic meters	22.5	22.5	
Profit (loss), euro / cubic meters	2.8	-0.2	-2.96
Cost-effectiveness, %	14.0	-0.9	-14.86
Note: *) – indicators of cost, price, cost-effectiveness are adopted according to the actual data of the Ministry of forestry for the period January-June 2019.			

Currently, there is no possibility of increasing the price, which leads to loss-making production of chips from FW both in the domestic and foreign markets.

In addition, trial batches of implementation of such chips have shown that consumers prefer to use wood chips, sawmill waste, as from chips made of FW ash content increases, calorific value decreases and there are various impurities (soil, etc.).

Thus, in the conditions of significant annual amount of FW in the Republic of Belarus (about 2 million cubic meters), the production of chips from felling wastes is currently useless.

Such a practice of forming the cost of production and the price of fuel chips from the FW needs a critical reassessment for the following reasons.

First, collection of FW is not an additional work and is not subject to additional payment. Clearing of cutting sites from FW is obligatory at wood harvesting. At the end of the felling FW will be ordered: collected in piles or shafts, in some cases shred and scattered or subjected to combustion. The method of clearing of the cutting site from FW is established by the forest Fund holder and indicated in the felling permit.

Secondly, the output of chips from one m^3 of dense FW is the same as from wood-burning wood.

Third, in the cost of wood chips the cost of fuelwood is included . FW (twigs and branches) are not subject to tax value, are essentially free for the forest Fund holder.

These costs should not be included in the cost of production of chips from FW.

The cost for more expensive delivery of FW to the intermediate warehouse to the place of processing for chips should be taken into account. The quality of wood chips from FW will be slightly lower than that of wood chips. This will affect the price of chips.

To minimize the negative impact on the environment and rationalize the use of wood biomass, it is proposed to make *changes and additions to the standard STB 1360-2002 " Sustainable forest management and forest use. Final fellings. Technology requirement»*:

– It should be noted that the use of felling wastes in the form of technological raw materials or fuel can be made during the final felling in the operational category of forests. From other categories of forests, it is possible to use felling wastes in the form of tree tops, twigs, branches and tree vegetation in the forests of water protection zones of the protective category of forests;

– Removal of felling wastes for subsequent implementation and use can be carried out during clear cuttings, except for remote cutting sites, as well as in wet and very wet types of growing conditions. It is not allowed to remove FW from cutting sites on sandy soils with poor fertility (lichen and heather forest types);

– In case of non-clear cuttings, the use (removal) of felling wastes can be carried out at the sites of strip-gradual felling;

– Paragraph 3.29, the third line from below"... wood and wood waste grinding ... "replace with" ... wood and felling wastes grinding ... " because we have a forest resource in the cutting site, not waste. In accordance with paragraph 21, article 1 of the Forest code of the Republic of Belarus, forest resources are wood-shrub and other vegetation growing within the boundaries of the forest Fund, and (or) its part, environmental, water protection, protective, sanitary, recreational and other useful properties of forests that are used or can be used in the implementation of economic and other activities and have consumer value. Based on this definition, only the forest resource can be on the cutting site, not felling wastes. In addition, at present this resource has a demand and consumer value, as a raw material for the production of fuel chips, etc.;

– Paragraph 4.2. the second paragraph, the 10th line from above of the word "...griding of wood and wood waste..." to replace with " ... griding of wood and felling wastes...".

In addition, according to the classifier of wastes generated in the Republic of Belarus, approved by the resolution of the Ministry of natural resources and environmental protection of the Republic of Belarus dated November 8, 2007 No. 85, there are the following types of waste: cuts of whips, canopies, otkomlevki, trimming at bucking, etc. (code of departure 1730100); boughs, branches, tops (code of departure 1730200); waste of uprooting of stumps (code of departure 1730300), etc.

On the basis of the above, in order to exclude a double interpretation of the legislation and inadmissibility of unjustified prosecution for violation of the legislation on waste management during forestry activities of legal entities engaged in forestry, it is proposed to amend the resolution of the Ministry of natural resources and environmental protection of the Republic of Belarus of November 8, 2007 No. 85, excluding from the classifier of waste codes 1730100, 1730200, 1730300, 1730400, 1739900;

– Paragraph 5.2.3. the first paragraph to state in the new edition:

Felling wastes for the production of technological chips, fuel and for other purposes are collected and piled on free from undergrowth places.

Add a paragraph (after the first):

Harvesting of felling wastes and their removal for disposal should be implemented not until they drop needles and leaves; At the same time, leave up to 30% of the mass of felling wastes on the cutting site, grinding and spreading them evenly over the area.

Further in the text.

"Felling wastes left for rotting are collected and formed in....:"

In this expression, the words "and (or) grinding" should be added after the words "for rotting" in accordance with the rules of logging in the Republic of Belarus. Then the wording of the third paragraph will be as follows:

Felling wastes left for rotting are collected and formed in:

– piles up to 2.5 m in height and 2.5 m in diameter in places free from silva succrescens;

– piles up to 2.5 m high and 2.5 m wide not closer than 10 m to the forest wall;

Further in the text.

The eighth paragraph. Replace the words "... and up to 1 m height... " with "...and up to 1.5 m heigt... " in accordance with the rules of logging;

– In conclusion, it should be noted that the proposed methods of clearing of cutting sites (except for the first) require serious scientific justification, since they are established mainly on the basis of expert evaluation, for which scientific research should be carried out on the basis of the latest achievements of science and technology and accumulated practical experience.

6.2. ACTION PLAN FOR BIODIVERSITY CONSERVATION, ENSURING OPTIMAL NUTRIENT CONTENT AND INCREASING CARBON SEQUESTRATION IN THE FORESTS OF THE REPUBLIC OF BELARUS FOR 2020, 2030 AND 2050

It is possible to ensure the conservation of forest biodiversity through the integration of relevant activities at all stages of forest management, including the regeneration, cultivation, protection, conservation and use of forests. To limit the solution to this problem by the stages of felling of mature forest and the handling of felling wastes is not enough so the executors considered to be appropriate to expand the indicated stage 6 of the Activities 3.1.3.3. Range of issues to comprehensively cover measures and actions needed to conserve forest biodiversity.

Preparation of the plan was preceded by the study of existing policy documents, research, standards of sustainable management, practice of their application, which address the issues of biodiversity conservation.

The following program documents were studied and used:

National plan of action for the conservation and sustainable use of biological diversity for 2016-2020 [28]

Strategic plan for the development of the forestry sector for the period from 2015 to 2030 [29];

Previously developed under the **Contract № BFDP/GEF/CQS/16/25-26/17** dated 23 October 2017 documents [30]:

Strategy for adaptation of forestry of Belarus to climate change until 2050.

– National action plan to increase the absorption of greenhouse gases by absorbers (forests, swamps) for the period up to 2030 and others.

– National action plan for the implementation of the principles of "green" economy in forestry of the Republic of Belarus for the period up to 2030;

– National action plan for adaptation of forestry to climate change until 2030;

In the study, the research works in the field of forestry of the leading researchers L. N. Rozhkov, A. V. Neverov, V. V. Nosnikov, A. V. Lednotskij, Pugachevskij A. V., and others were studied.

Moreover, the requirements for biodiversity conservation of existing certification systems were considered: international-FSC and European-PEFC, based on the application of national standards of sustainable forest management.

6.2.1. Key activities of national plans and strategies affecting biodiversity of forest ecosystems of Belarus

National plan of action for the conservation and sustainable use of biological diversity for 2016-2020 [28] For biodiversity conservation in forestry - the activities are designed to implement the Objective 4 – to ensure sustainable functioning of forest ecosystems, preserve biological and genetic diversity of forests and forest landscapes taking into account increasing anthropogenic impact, climate change, sustainable use of forest resources, to strengthen the role of forests in the preservation of the biosphere.

They include:

– reforestation and afforestation in order to increase the proportion of broad-leaved trees in the total amount of sowing and planting of forests;

– development of a national action plan for adaptation of forestry to climate change until 2030;

– implementation of forest management and forest use taking into account international criteria for sustainable forest management

– development of forest nursery economy and introduction of new technologies of cultivation of planting material of the main forest-forming species with the closed root system

In addition, it is necessary to take into account the activities under the Task 12 - to increase the level of scientific knowledge about the current state of biological diversity, to identify trends and causes of changes in the state of species and biotopes, to develop effective methods for the sustainable use and monitoring of biological diversity and to create a platform for the exchange of information and knowledge.

The national action plan for adaptation of forestry to climate change until 2030 [30] aims to address the following objectives**:**

1. Increasing the role of natural regeneration in the process of reforestation and as close as possible its cooperation with artificial reforestation.

2. The use of partial forest cultures, that is one of the most effective methods of reforestation, combining the advantages of natural regeneration and artificial restoration.

3. The formation of mixed stands, that is, not only the undergrowth of economically valuable, but also of secondary species should be taken into account.

4. Increasing the percentage of the use of non-clear cuttings, which will provide an opportunity to form stands of different age and have a positive impact on the forest cover of the territory.

5. Creation of mixed forest cultures, that is the basis of sustainable stands of artificial origin.

6. Increasing the role of population seed production. The use of seeds harvested from seed plantations can improve productivity, but the use of individual plus or elite trees leads to some reduction in genetic diversity and may adversely affect the sustainability of future stands.

7. Identification of local populations resistant to the negative effects of climate change. And first of all this work needs to be carried out in areas with mass drying of stands. The selected populations should be actively used in seed production.

8. Assistance in natural migration of new species as a result of changes in distribution ranges, if they may have economic, ecological and other significance. In Belarus such species are European beech, white fir and rock oak.

9. Continuation of works on creation of archives of clones of plus and elite trees which should be location-enabled where there are mother plants.

10. Reducing the consequences of forest fires, the possibility of early detection and the ease and speed of delivery to the source of fire of people and equipment. Climate change is also reflected in the increased likelihood of forest fires.

Thus, the National plan of action for adaptation of forestry to climate change until 2030 affects to a greater extent forestry activities and contains activities aimed at improving approaches, technologies and methods of reforestation and afforestation as well as improving technologies and methods of fellings, its preservation and protection.

In the National action plan on increasing the absorption of greenhouse gases by absorbers (forests, swamps) for the period up to 2030 [30[the following activities are proposed:

System of measures to increase the absorption of atmospheric carbon dioxide by the forest fund:

1) Improvement of the reforestation system based on the use of modern achievements of genetics, selection and biotechnology:

– cultivation of planting material for reforestation on the basis of innovative technologies, taking into account modern achievements in the field of forestry seed, new fertilizers, growth stimulants, plant protection products, as well as complex mechanization of works;

– the cultivation of planting material of a microclonal origin;

– carrying out activities to promote natural regeneration in ripening and ripe stands, the formation of pre-undergrowth target species for young stands in the year of final felling;

– improvement of artificial reforestation, creation of forest cultures by seedlings with a closed root system;

– priority in the formation of mixed stands with a wide range of approbated forest culture practice of native species and shrubs;

– creation of pure forest cultures in areas where the natural regeneration of related species appears in sufficient quantity;

– regulation of the use of introduced tree species in afforestation and reforestation on forest lands;

– compliance with the balance of natural and artificial reforestation and afforestation.

2) Adoption of measures aimed at reducing forest fragmentation; formation of forests of increased productivity, sustainability and conservation value, increasing the average completeness of forested lands:

– afforestation on non-forested lands of the forest fund, increase of forest cover in the country through afforestation on unused and low fertile soils of agricultural use and also lands of other categories;

– optimization of the use of land, drained and disturbed as a result of the development of nonmetallic mineral resources;

– preservation of biological and genetic diversity of forests and forest landscapes, reconstruction of forest stands of low-value.

3) Development of a system of scientifically based forestry measures and environmental technologies aimed at preserving the ecological functions of forests, optimization of species and age composition of stands, conservation of biological diversity:

– the creation of highly productive plantations through improved forest regeneration technology, carrying out of sanitary fellings, regeneration of young stands of low-value and middle-aged softwood stands;

– implementation of priority measures aimed at increasing the productivity of stands, increase in wood reserves.

The system of measures to "*Ensure sustainable long-term carbon sequestration in forest pools and sequestration by forest lands*" provides for the following tasks:

– optimization of the system of specially protected natural areas (SPNA) in accordance with the scheme of rational placement of SPNA of national importance and regional schemes of rational placement of SPNA of local importance, the development of favour methods of forest management in these areas in order to ensure sustainable forest management;

– formation of the environmental regime of forest management in swamp forests to ensure long-term sequestration of soil carbon, increasing biodiversity of swamp forests, provision of environmental services in the form of tourism, preservation of water protection and water regulation role;

– exclusion from forest use for a certain period (20-30 years) of forest lands with a low estimated cutting area with significant reserves of middle-aged and ripwning stands, possible for operation in order to perform the carbon sequestration function;

– gradual increase in the age of felling in commercial forests to 90-100 years in coniferous stands in the presence of a sufficient number of areas and stocks of ripe stands.

The system of measures for *the formation of an effective system to reduce carbon dioxide emissions into the atmosphere in forestry* provides for the following tasks:

– the use of non-clear cuttings (gradual, voluntary-selective), ecologically sound technologies of fellings, preservation of pre undergrowth in felling, promoting natural regeneration, stimulation of natural regeneration, care for natural renewal;

– improvement of technological processes of felling, contributing to the formation of natural regeneration of the forest, the use of methods and technologies of final felling, ensuring the preservation of ecological functions of forest stands;

– rational use of growth of forest stands and regulation of fallout;

– ensuring an effective system of forest fund protection; creating a multi-level highly effective system of modern environmentally safe methods and means of prevention, early detection and rapid elimination of forest fires, crisis phenomena, illegal fellings and other forest violations, providing a significant reduction in their scale and the size of the caused economic and environmental damage;

– development of a system of cost-effective and environmentally friendly measures to protect forests from harmful organisms on the basis of advanced scientific achievements;

– strengthening control over the spread of invasive pests and pathogens;

– the use of wood in fuel purposes when clearing a cutting site. "Natural" filthiness increases further due to the increased frequency of extreme weather and climatic phenomena, causing wind and windbreak as individual trees and stands. Harvested wood after the clearing is suitable as fuel replacing hydrocarbon fuel.

– the use of felling wastes in fuel purposes formed during timber harvesting at final fellings and other fellings. The use of felling wastes does not cause ecological damage to biodiversity and soil fertility of the forest ecosystem. As a secondary wood raw material used for fuel purposes, felling wastes replace hydrocarbon fuel (coal, oil, gas), thereby reducing the "emission" of greenhouse gases.

In accordance with a research team under the leadership of Professor L. N. Rozhkov for the Activity 3.1.3.3 (**the Reports № 1-3 under the Contract № BFDP/GEF/CQS/16/29-34/18 dated August 24, 2018**) *species diversity, its preservation and subsequent recovery in the production of final felling, the handling of felling wastes and regeneration of fellings depend on a number of factors, namely:*

– organizational and technical elements of felling;

– forest valuation indicators of stands;

– conditions of habitat of the logged stand;

– sanitary condition of the pilot site before and after felling;

– presence or absence of pests and forest diseases on the surrounding areas;

– risk degree of fire on the logged area;

– the presence of registered species under different categories of protection.

Clear cutting has the most radical impact on forest stands. Preservation of live plant phytomass after felling is only about 6.9–9.0 % in terms of the abandonment of seed trees and 0.7–1.6 % without seed trees. "Removal" of biomass from the stands during the felling, that is considered as the fact of CO_2 "emission", was about 73% in *Pineta* stands with removal of felling wastes and 68% without the removal of felling wastes, in *Piceeta* 82 and 72%. Live ground cover is preserved on about one-third of the area. Areas of clear cutting are non-forested lands. Reproduction of a new generation of forest began with the creation of forest cultures. Implementation by clear cutting site of environment protection and other ecological functions will begin in 7-8 years, after the transfer of open canopy forest plantations in the forested lands.

Non-clear cutting carries out the same aim as clear cutting: Ripe parent forest stand cutover and the reproduction of a new forest generation. The achievement of this goal happens by an environmentally friendly way of influence on forest stand. Preservation of live plant phytomass during the felling in the process of consistent stages is projected to be in 10-15% higher than during the clear cutting. The new generation of natural forest will be more adapted to the observed weather and climate changes. Restoration of carbon stocks in forest stand to its level for a year of felling is expected to go faster than during clear cutting. Non-clear cutting site will be always in forested state and fully perform environment protection function.

Felling wastes are an additional source of organic and mineral substances for forest nutrition; means of support (protection) and assistance in maintaining of the diversity of vegetation cover of forest ecosystems; provide protection for the associated and subsequent forest regeneration to air and soil temperature changes, tree roots with lateral root system on the border of apiaries and at the compartment boundary.

Felling wastes that haven't been removed are the technical obstacle that reduces the volume of the performed works, during mineralization of the soil, its preparation for creation of forest cultures; the factor of fire danger growth, development of the centers of diseases and/or reproduction of pests in forest stands.

Removal (collection and removal) of felling wastes from the cutting site is an expensive activity that requires the acquisition of specialized forest equipment.

By the age of final felling forest stand reaches the wood volume (stock), that changes a little during subsequent increase in age. It can be assumed that at this stage the maximum balance of nutrients (soil+forest litter+phytomass) is formed in the forest ecosystem. Subsequent final felling results in significant losses of organic matter, nitrogen and ash elements in the forest ecosystem.

From the analysis of the balance of nitrogen and ash elements, it follows that to meet its needs, the forest stand absorbs significant amounts of nutrients from the deep layers of the soil. For this reason, the reduction of nitrogen and ash elements in the upper soil layers does not become critical in the soil nutrition of stands.

Characteristic features of clear cuttings are damage and destruction of the lower layer of vegetation, sharp change of a microclimate. This leads to a decrease in the stocks of nutrients in the surviving layers of forest live cover.

Comparative characteristics of the clear and non-clear fellings of the final fellings is given in the table 6.5.

Table 6.5 – Ecological-economic assessment of ways of FF

Indicators	Clear FF	Non-clear FF
Impact of the type of final felling on biodiversity	Radical change of the forest ecosystem Preservation of live plant phytomass is 6.9–9.0 % in terms of the leaving of seed trees and 0.7–1.6 % without seed trees.	Preservation of live plant phytomass is higher by 10-15 % than in case of clear cutting
Influence of the type of the final felling on CO_2 emissions		Over the entire period, the value of CO_2 emissions is less by 15-20%
Removal/non-removal of felling wastes:		
CO_2 emissions	Emissions of CO_2 in non-removal of felling wastes for 4-5 % lower than in removal	The same
	Removal of felling wastes increases the duration of CO_2 emissions by 6-7 years	The same
the amount of nutrients	Removal of felling wastes increases the removal of nutrients for 6-10 %	Removal of felling wastes increases the removal of nutrients for 25 %
Costs of activities		The costs for timber harvesting is an average for 20 % higher

On the basis of previous **studies on Activity 3.1.3.3** the following measures are proposed for biodiversity conservation:

– to preserve flora biodiversity on these cutting sites, with an area of more than 1 hectare, it is necessary to leave for the formation of complex composition and structure of the new generation of forests ripe, healthy trees *Pin, Que, Fr, Ac, Til, Al.g.* up to 10 trees inclusively per 1 hectare of tree species represented on the cutting site.

2. For the conservation of biodiversity of the fauna, trees with nests of predatory birds, hollow and deadwood trees as well as weakened, severely weakened trees up to 10 trees per 1 hectare (in the presence of such trees) should be left on the forestry sites where clear and band-gradual fellings of final felling are implemented;

3. During clear cutting for its natural regeneration, if it does not provide for the creation of forest cultures, seed trees in an amount of 10-20 trees should be left, inclusively per 1 hectare, evenly spaced throughout the area of cutting and (or) seed trees in amount of 4-5 trees per 1 hectare, while in the group there should be from three to five trees.

4. Conservation of a part of undegrowth Restrictions on undergrowth damage during the final felling are set. Thus, during clear cuttings in winter period, 70% of *silva succrescens* should be preserved and in summer period – 60%. The parameters are the same when implementing non-clear cuttings of final felling.

5. The use of different methods of cutting sites clearing from the felling wastes considering the relief, forest type, presence of valuable elements of forest biocenosis. The choice of the method of clearing of cutting sites from felling wastes depends on many factors and, above all, on the probability of the most dangerous consequences – the occurrence of fire, contamination of neighboring forest areas with pests and fungal diseases. However, taking into account the share of carbon content in felling wastes during final fellings from 5% to 9.3%, for nutrients from 5.8 to 8.8%, taking into account the requirements of fire safety, the felling wastes should be used as follows:

– on dry soils – grinding and uniform spreading of felling wastes;

– on cutting sites with wet and waterlogged soils of any mechanical composition, as well as with fresh loamy soils, it is necessary to use felling wastes to strengthen skidding trails and create micro-rises, collecting them in piles of 70 cm high to promote natural regeneration.

An important activity is the monitoring of biodiversity conservation, which includes:

– monitoring of forest inventory indicators of forest stands;

– assessment of the content of carbon and nutrients in soil before final felling;

– monitoring and recording of nutrients and carbon in 30 cm soil layer after felling with/without removal of felling wastes;

– monitoring and registration of nutrients and carbon in felling wastes on the pilot sites of final felling;

– monitoring and assessment of biodiversity on the pilot sites of non-clear cutting of final felling in terms of various methods of cutting sites clearing from felling wastes;

– monitoring and registration of nutrients and carbon in forest biocenosis biomass (forest live cover, silva succrescens, subsilva, forest stand).

Having regard to the above, a plan for conservation of biodiversity, ensuring optimal nutrient content and increasing the carbon sequestration function in the forests of the Republic of Belarus (hereinafter-the Plan) has been developed, which provides for a system of measures, deadlines, executors, as well as forecast indicators of their implementation, which can be specified taking into account the actual situation in forestry.

The proposed system of measures is based on an integrated approach, due to the need to preserve biodiversity, ensure optimal nutrient content, minimize carbon dioxide emissions in the areas after the implementation of final fellings and the need to increase the use of logging wastes for energy purposes in connection with the development of the energy production sector from wood fuel.

For the preservation and increase of biodiversity, optimal nutrient content and increase of carbon sequestration function of forest ecosystems, some forestry activities are held, the restrictions on forestry activities are imposed and forest management, some technological methods are recommended.

6.2.2. Action plan for biodiversity conservation, ensuring optimal nutrient content and increasing carbon sequestration in the forests of the republic of belarus for 2020, 2030 and 2050

The plan provides for activities in the following areas (table 6.3).

1. Forestry activities.

1.1 In the section " *Reforestation and afforestation. Seed*" provides for the following activities:

– relevant reforestation of felled forest areas transferred agricultural lands and lands for other purposes;

– increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation;

– increase of the share of creation of hard-leaved forest cultures from the area of artificial reforestation and afforestation;

– increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation;

– increase of the area of linden planting;

– optimization of forest regeneration methods;

– creation of forest cultures with closed root system;

– creation of forest cultures by selective sowing and planting material;

– preservation of the genetic potential of forests.

Measures to improve biodiversity when carrying out works on reforestation and afforestation solve the following tasks: – regeneration of forest cover by returning forests to a natural way of development, increasing the diversity of tree species, making the forest stand structure and appearance of the natural forest, the achievement of a diversity of habitat conditions within the forest community, the creation of the forest complex of species and spatial structure, the formation of plantations of rare and valuable forest ecosystems, increase of fodder for forest fauna, increase of productivity of forest resources

In section 1.2 *the following forest conservation and protection measures are proposed:*

– development of forest fire early detection system based on remote sensing methods;

– forest pathology survey;

– carrying out biological measures to protect the forest. Balanced application of various tools and technologies in combination with the action of natural regulators of population of harmful organisms, application of evidence-based integrated systems of forest protection, taking into account the regularities, activities that are in force in the forest biocenosis against harmful organisms are carried out using the least environmentally hazardous means and technologies to avoid or significantly limit negative impact on useful components of forest biocenosis – entomophages, warm-blooded animals, humans, the environment in general.

2. Forest management aimed at biodiversity conservation involves:

– carrying out final fellings within the strict limits of the calculated cutting site;

– reduction of volume of final fellings when increasing the volumes of timber harvesting in the development of damaged by fires, windbreaks or insects forest areas

– leaving the optimal amount of felling wastes on the cutting site (taking into account the economic usefulness of their use and the forest pathology situation in the forests);

– optimization of felling methods;

– leaving of cutting sites during the clear and band-gradual fellings of final felling, of an area of 1 ha to form forest of new generation that are complex by composition and structure, healthy mature trees *Pin, Que, Fr, Ac, Til, Al.g.*.

– leaving at carrying out clear fellings for its natural regeneration, if it does not provide for the creation of forest cultures, seed trees.

3 Organizational measures:

– compliance with the requirements of FSC (international) and PEFC (European) forest management certification systems. Timely completion of the audit;

– adoption of normative legal and local acts taking into account the requirements of biodiversity conservation;

– monitoring of biodiversity;

– raising awareness, ecological awareness and public responsibility: carrying out explanatory and educational work among the population (social network, etc.), attracting certain types of economic activity through the action "Forest week", "Clean forest" (planting of forests, collection of waste, assistance in improvement of the territory), the intensification of work in social networks (creation of groups Vkontakte, Instagram, Facebook), the organization of a permanent presence in the country's media (newspapers, online publications, radio, television) through the active publication of information materials on the state of forests.

– creation and design of ecological trails in order to familiarize the population with a variety of ecosystems (forests, meadows, swamps, lakes, rivers, etc.), individual elements of the natural complex (plant species, landforms, boulders, trees of outstanding size, etc.), cultural and historical objects (religious buildings, estates, etc.).

Table 6.6 – Plan for biodiversity conservation, to ensure optimal nutrient content and increase carbon sequestration in forests of the Republic of Belarus

The name of the activities	Execution period	Executors	Result indicator of the activity
1. Forestry activities			
1.1 Reforestation and afforestation. Seed production			
1.1.1 Relevant reforestation of felled forest areas transferred agricultural lands and lands for other purposes;	constantly	The Ministry of forestry, SFPA, forest fund managers	Within 3 years from the moment of cutting or transfer
1.1.2 Increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation	annually	-«-	The proportion of mixed forest cultures by 2050 – 95%
1.1.2 An increase of the share of creation of hard-leaved forest cultures from the area of artificial reforestation and afforestation	by 2050	The Ministry of forestry, SFPA	Share of the creation of hardwood cultures, totally the Ministry of forestry – 5.9% Brest SFPA – 6% Vitebsk SFPA – 1% Gomel SFPA – 9% Grodno SFPA – 3% Minsk SFPA – 6% Mogilev SFPA – 8%
1.1.4 An increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation	annually	The Ministry of forestry, SFPA, forest fund managers	Share of the create of ash cultures not less than 1.5%
1.1.5 An increase of the area of linden;	annually	The Ministry of forestry, SFPA	The Ministry of forestry – 80 hectares every SFPA of 15 hectares

1.1.6 Optimization of forest regeneration methods;	by 2050	The Ministry of forestry, SPFA	
including natural with assistance measures	-«-	-«-	The share of natural regeneration with assistance measures, total Ministry of forestry-33% Brest SPFA – 33% Vitebsk SPFA – 30% Gomel SPFA -39% Grodno SPFA – 33% Minsk SPFA – 35% Mogilev SPFA – 30%
natural without assistance measures	-«-	-«-	The share of natural regeneration without assistance measures, total Ministry of forestry-15% Brest SPFA – 15% Vitebsk SPFA – 20% Gomel SPFA – 12% Grodno SPFA – 13% Minsk SPFA – 14% Mogilev SPFA – 18%
creation of forest cultures	-«-	-«-	Share of creation of forest cultures: total Ministry of forestry-52% Brest SPFA – 52% Vitebsk SPFA – 50% Gomel SPFA – 49% Grodno SPFA – 54% Minsk SPFA – 51% Mogilev SPFA – 52%

1.1.7 Creation of forest cultures with closed root system;	anually since 2021	The Ministry of forestry, SPFA	The creation of forest cultures with closed root system, totaly in the Ministry of forestry 12.3 million species Brest SPFA - 1.9 million species, Vitebsk SPFA – 2.2 million specoes Gomel SPFA – 3 million species Grodno SPFA -1.4 million species Gomel SPFA – 3.8 million species Gomel SPFA – 3.5 million species
1.1.8 Creation of forest cultures by selective sowing and planting material;	by 2050	The Ministry of forestry, SFPA, forest fund managers	The share of creation of forest cultures by selective sowing and planting material from the area of artificial reforestation and afforestation-50%
1.1.9 Preservation of the genetic potential of forests	by 2050	Institute of forest of NAS of Belarus, Ministry of forestry, SPFA	The area of genetic reserves of the area of forest fund-1,5% Share of clone banks of plus trees of the selected trees – 100% Share of clone banks of elite trees of the selected trees – 100%
1.2. The forest protection and preservation			
1.2.1 Development of forest fire early detection system based on remote sensing methods	2030	The Ministry of forestry, SFPA, forest fund managers	Coverage of the system of early detection of forest fires based on remote methods from the area of the forest fund – 95%.

1.2.2 Surveys of forest pathologies	annually	The Ministry of forestry, SFPA, forest fund managers	The annual area of forest pathology surveys is 3 million hectares.
1.2.3. - carrying out biological measures to protect the forest.	annually	The Ministry of forestry, SFPA, forest fund managers	The annual area of biological measures for forest protection is 120 thousand hectares.
2. Forest use aimed at biodiversity conservation			
2.1. Carrying out of final fellings within the strict limits of the calculated cutting site;	annually	The Ministry of forestry, SFPA, forest fund managers	The annual establishment of the sizes of the estimated cutting site
2.2. Reduction of volumes of final fellings when increasing the volumes of timber harvesting in the development of damaged by fires, windbreaks or insects forest areas	as necessary	The Ministry of forestry, SFPA, forest fund managers	Adoption of the relevant decision of the state body
Leaving the optimal amount of felling wastes on the cutting site (taking into account the economic usefulness of their use and the forest pathology situation in the forests)	until 2050	The Ministry of forestry, SFPA, forest fund managers	The percentage of leaving of felling wastes after clear cuttings, % Pine – 49.2 Spruce - 20 Oak – 23.3 Birch – 76.3 Black alder – 100 Aspen – 38.8 Other – 59.1
2.4. Optimization of felling methods;	until 2050	The Ministry of forestry, SFPA	
conducting of clear cuttings with preservation of silva succrescens	-«-	-«-	The proportion of conducting of clear cuttings with preservation of silva succrescens, the Ministry of forestry - 17%

			Brest SPFA – 16.7% Vitebsk SPFA – 17.7% Gomel SPFA – 15.2% Grodno SPFA – 16.7% Minsk SPFA – 16.2% Mogilev SPFA – 17.5%
conducting of clear cuttings with preservation of silva succrescens	-«-	-«-	The proportion of conducting of clear cuttings with preservation of silva succrescens, the Ministry of forestry - 50% Brest SPFA – 50.2% Vitebsk SPFA – 53% Gomel SPFA – 45.8% Grodno SPFA – 50% Minsk SPFA – 49% Mogilev SPFA – 52.8%
non-clear cuttings	-«-	-«-	Share of non-clear cuttings, the Ministry of forestry -33% Brest SPFA – 33.1% Vitebsk SPFA – 29.3% Gomel SPFA -39% Grodno SPFA – 33.3% Minsk SPFA – 34.8% Mogilev SPFA – 29.7%
2.5. Leaving of cutting sites during the clear and band-gradual fellings of final felling, of an area of 1 ha to form forest of new generation that are complex by composition and structure, healthy mature trees *Pin, Que, Fr, Ac, Til, Al.g.*.	constantly	The Ministry of forestry, SFPA, forest fund managers	Up to 10 trees including 1 hectare of tree species represented in the cutting site

2.6. Leaving at carrying out clear fellings for its natural regeneration, if it does not provide for the creation of forest cultures, seed trees.	constantly	The Ministry of forestry, SFPA, forest fund managers	In an amount of from 10 to 20 trees, inclusively per 1 hectare, evenly spaced throughout the area of cutting and (or) seed trees in amount of 4-5 pieces per 1 hectare, while in the group should be three to five trees.
3. Organizational measures			
3.1 Compliance with the requirements of FSC (international) and PEFC (European) forest management certification systems. Timely completion of the audit;	constantly	The Ministry of forestry, SFPA, forest fund managers	The availability of the FSC certificate or (and) PEFC
3.2 Adoption of normative legal and local acts taking into account the requirements of biodiversity conservation;	constantly	The Ministry of forestry, SFPA, forest fund managers	
3.3. Monitoring of biodiversity on pilot sites: - monitoring of forest inventory indicators of forest stands; - assessment of the content of carbon and nutrients in soil before final felling; - monitoring and recording of nutrients and carbon in 30 cm soil layer after felling with/without removal of felling wastes; - monitoring and registration of nutrients and carbon in felling wastes on the pilot sites of final felling; - monitoring and assessment of biodiversity on the pilot sites of non-clear cutting of final felling in terms of various methods of cutting sites clearing from felling wastes; - monitoring and registration of nutrients and carbon in	as required	BSTU, the Ministry of forestry	Monitoring report

forest biocenosis biomass (forest live cover, silva succrescens, subsilva, forest stand).			
3.4. Raising awareness, ecological awareness and public responsibility: – carrying out explanatory and educational work among the population - attraction to certain types of economic activity through the actions "Forest week", "Clean forest", (planting, garbage collection, assistance in landscaping) - intensification of work in social networks (creation of groups Vkontakte, Instagram, Facebook), - organization of a permanent presence in the country's media (newspapers, Internet publications, radio, television) through the active publication of information materials on the state of forests	constantly	The Ministry of forestry, SPFA	Annual report on the work undertaken
3.5 Creation and design of ecological trails in order to familiarize the population with a variety of ecosystems (forests, meadows, swamps, lakes, rivers, etc.), individual elements of the natural complex (plant species, landforms, boulders, trees of outstanding size, etc.), cultural and historical objects (religious buildings, estates, etc.).	annually	The Ministry of forestry, SPFA	At least 1 per year in each SPFA

CONCLUSION

The key findings and recommendations of the Report on the implementation of phases 5 and 6 of the Activity 3.1.3.3 are as follows.

1. The most objective information on carbon sequestration by felling wastes can be obtained by direct measurements of carbon residues between the soil (location of felling wastes) and the atmosphere. The method involves the use of special expensive equipment, which limits, if not excludes, its practical application.

For widespread use it is recommended that a methodological approach based on balance calculations of carbon flows with determination of felling wastes and calculations of the carbon content in the fractions by using the conversion factors of carbon content and wood density.

The developed method recommends to calculate carbon fluxes in the context of pools: felling wastes, emission of carbon from decomposition of slash residues, carbon sequestration from the resumption of deforestation in the period of decomposition of felling wastes.

2. The carbon content in felling wastes C [t] is determined by the equation [4]:

$$C = V_{site} \times K_{f.w.} \times KC_{f.w.} \tag{4}$$

The constituents of equation (4) are defined as follows.

The root stock of wood on the site V_{site} [m^3] by fractions is determined with the bucking of model trees according to the method of the Institute of forest [7].

Weight in the dry state of individual fractions of felling wastes per 1m^3 of stem wood $K_{f.w.}$ [t / m^3], taken from the Methodology [4] of Appendix A.

The share of carbon in biomass of felling wastes $KC_{f.w.}$ is taken from the Methodology [4] according to Appendix B

2.1. An alternative determination of the carbon content in felling wastes is established by equation (5):

$$C = V_{site} \times KC_{f.w.} \times K_{f.w.} \tag{5}$$

The stock of wood on the site V_{site} [m^3] is determined by taxation method.

The share of carbon in biomass of felling wastes $KC_{f.w.}$ is taken from the Methodology [4] according to the Table 3

Proportion of felling wastes from the volume of stem wood $KC_{f.w.}$ is taken from the Methodology [4] according to Appendix A

3. The emission (emissions into the atmosphere) of carbon dioxide from the decomposition of felling wastes stretches over time (from 2 to 10 years or more). It is proposed to distinguish three groups of the fraction of felling wastes with periods of decomposition: 1-2 years, from 3 to 10 years and more than 10 years. The volumes of average annual emission of carbon dioxide by groups are established. The volume of emissions in a specific period of time can be set graphically as the sum of the annual emissions of each group of felling wastes in the estimated year after their formation.

4. After the stand is cut down, the reforestation stage begins (forest cultures or natural regeneration). The young generation of forest absorbs carbon dioxide against the background of its continued emission from the decomposition of felling wastes. In certain conditions, the volumes of carbon sequestration from the renewal of the fellings exceed the emissions of felling wastes.

Schematically, the process of" absorption – emission " of carbon in the cutting site P [tC] can be expressed by the equation (6):

$$\pm P = C - Э + Д \tag{6}$$

C indicator is taken from equations 4 or 5.

The volume of carbon sequestration S tC by the young generation of forest for the period of FW decomposition is determined by the Methodology [4]

5. Forecast for timber harvesting in final fellings for 2030 and 2050 is set on the basis of the order of determination and approval of annual allowable cut in the Republic of Belarus [2,10,11]. The estimated cutting sites are adjusted to the actual growth in the volume of timber harvesting and development of the estimated cutting site over the past five years.

6. The volume of timber harvesting by final fellings in the Republic on average per year for the period 2014-2018 amounted to 8240.5 thousand m^3 of realizable timber in the development of estimated cutting site at 70.4%.

Forecast for 2030 – 16700 thousand m^3 (+103%) and for 2050 – 20110 thousand m^3 (+144% compared to the 2014-2018).

Approximately equal growth of timber harvesting is predicted both among conifers (+99% and +146%) and softwood (+108% and +145%).

A significant increase in the share of gradual and selective fellings (+162% in 2030 and +215% in 2050) is projected against the background of lower growth of clear cuttings (+75% and +111%).

7. Felling wastes are expected from fellings by fractions:

– branches, twigs, thin tops – 1668.3 thousand m^3 in 2030 and 2008.3 thousand m^3 in 2050;

– woody vegetation 748.2 and 898.7 thousand m^3;

– stumps and roots – 2376.4 and 2856.8 thousand m^3.

8. The volume of sequestrated carbon by felling wastes, as a possible source of carbon dioxide emission during the decomposition of felling wastes, is:

– branches, twigs, thin tops – 64.93 thousand tC in 2030 and 78.03 thousand tC in 2050;

– woody vegetation 7.30 and 8.78 thousand tC;

– stumps, roots suitable for extraction – 105.71 and 127.11 thousand tC.

9. The use of felling wastes depends on a large extent on the availability of sites and methods of final felling.

On the basis of the recommended criteria for the use of felling wastes expected volumes of use of felling wastes biomass of final fellings constitute:

– on clear cuttings 1359.6 thousand m^3 in 2030 and 1633.2 thousand m^3 in 2050;

– in a gradual and selective fellings 174.3 thousand m^3 in 2030 and 215.3 thousand m^3 in 2050.

The most promising is the use of felling wastes as fuel. Economically justified is the condition of having a fuel consumer at a distance of 100 km.

10. Biodiversity conservation on the sites of final fellings is provided in terms of the following recommendations

– implementation of non-clear cuttings of the final felling;

– the use of environmentally sound technologies in fellings;

– conducting of fellings in the autumn-winter period;

– in order to conserve the biodiversity of shade-loving plants felling wastes should be left in piles after final fellings;

– grinding and spreading of felling wastes evenly over the area as mulch, that retains moisture;

– leaving of forest reproductions after the clear cuttings;

– due to the fact that the regeneration process proceeds in the direction of "forest vegetation-vegetation of open areas-forest vegetation, etc." in rich growth conditions, it is desirable to increase the number of agrotechnical and silvicultural care;

– in order to prevent the occurrence of forest fires to provide for the removal or shredding and scattering of felling wastes;

– to carry out constant monitoring of compliance with fire safety rules in the forests of the Republic of Belarus.

The impact of felling wastes on floristic diversity, nutrients and carbon dioxide absorption is environmentally positive but not significant enough for the growth and development of the forest ecosystem.

11. Final fellings, removal/non-removal by various methods of felling wastes at the same time do not have a significant impact on soil fertility and, presumably, the productivity of the subsequent generation of forest stand. However, leaving of needles on the cutting site from felling wastes provides optimal nutrition of plants of live ground cover, contributes to its species diversity.

The following actions are useful for maintaining soil fertility in the sites of final fellings:

– harvesting of felling wastes and their removal for disposal should be implemented noy until they drop needles and leaves;

– to leave on the cutting site up to 30% of the mass of felling wastes, scattering them evenly over the area;

– leave stumps for rotting, the mass of which is up to 20% of the weight of the stem wood;

– to avoid mixing of the upper layers of the soil;

– leave up to 50 trees / ha of small trees on poor soils in order to maintain nutrients in the ecosystem.

12. It is possible to increase absorption and minimize carbon dioxide emissions at the stages of final felling and regeneration of felling under the following conditions:

– use of non-clear cuttings;

– preservation of pre silva succrescens and live ground cover during felling;

– use of felling wastes for fuel purposes.

13. It is possible to ensure the conservation of forest biodiversity through the integration of relevant activities at all stages of forest management, including the regeneration, cultivation, protection, conservation and use of forests.

It is also important to take into account and implement the key activities of the national action plans, strategies and programs affecting the biodiversity of forest ecosystems of Belarus.

These policy documents are of a great importance:

– National plan of action for the conservation and sustainable use of biological diversity for 2016-2020 [28]

– Strategic plan for the development of the forestry sector for the period from 2015 to 2030 [29];

– Documents previously developed under the **Contract № BFDP/GEF/CQS/16/25-26/17** dated 23 October 2017 [30]:

Strategy for adaptation of forestry of Belarus to climate change until 2050.

– National action plan to increase the absorption of greenhouse gases by absorbers (forests, swamps) for the period up to 2030 and others.

– National action plan for the implementation of the principles of "green" economy in forestry of the Republic of Belarus for the period up to 2030;

– National action plan for adaptation of forestry to climate change until 2030;

Moreover, the requirements for biodiversity conservation of existing certification systems were considered: international-FSC and European-PEFC, based on the application of national standards of sustainable forest management.

14. The method of final felling leads to different ecological and economic consequences, namely.

Clear cutting has the most radical impact on forest stands. Preservation of live plant phytomass after felling is only about 6.9–9.0 % in terms of the abandonment of seed trees and 0.7–1.6 % without seed trees. "Removal" of biomass from the stands during the felling, that is considered as the fact of CO_2 "emission", was about 73% in *Pineta* stands with removal of felling wastes and 68% without the removal of felling wastes, in *Piceeta* 82 and 72%. Live ground cover is preserved on about one-third of the area. Areas of clear cutting are non-forested lands. Reproduction of a new generation of forest began with the creation of forest cultures. Implementation by clear cutting site of environment protection and other ecological functions will begin in 7-8 years, after the transfer of open canopy forest plantations in the forested lands.

Non-clear cutting carries out the same aim as clear cutting: Ripe parent forest stand cutover and the reproduction of a new forest generation. The achievement of this goal happens by an environmentally friendly way of influence on forest stand. Preservation of live plant phytomass during the felling in the process of consistent stages is projected to be in 10-15% higher than during the clear cutting. The new generation of natural forest will be more adapted to the observed weather and climate changes. Restoration of carbon stocks in forest stand to its level for a year of felling is expected to go faster than during clear cutting. Non-clear cutting site will be always in forested state and fully perform environment protection function.

15. Felling wastes are: felling wastes are an additional source of organic and mineral substances for forest nutrition; means of support (protection) and assistance in maintaining of the diversity of vegetation cover of forest ecosystems; provide protection for the associated and subsequent forest regeneration to air and soil temperature changes, tree roots with lateral root system on the border of apiaries and at the compartment boundary.

Not removed felling wastes are: the technical obstacle that reduces the volume of the performed works, during mineralization of the soil, its preparation for creation of forest cultures; the factor of fire danger growth, development of the centers of diseases and/or reproduction of pests in forest stands.

Removal (collection and removal) of felling wastes from the cutting site is an expensive activity that requires the acquisition of specialized forest equipment.

16. By the age of final felling forest stand reaches the wood volume (stock), that changes a little during subsequent increase in age. It can be assumed that at this stage the maximum balance of nutrients (soil+forest litter+phytomass) is formed in the forest ecosystem. Subsequent final felling results in significant losses of organic matter, nitrogen and ash elements in the forest ecosystem.

From the analysis of the balance of nitrogen and ash elements, it follows that to meet its needs, the forest stand absorbs significant amounts of nutrients from the deep layers of the soil. For this reason, the reduction of nitrogen and ash elements in the upper soil layers does not become critical in the soil nutrition of stands.

17. An important activity is the monitoring of biodiversity conservation, which includes:

– monitoring of forest inventory indicators of forest stands;

– assessment of the content of carbon and nutrients in soil before final felling;

– monitoring and recording of nutrients and carbon in 30 cm soil layer after felling with/without removal of felling wastes;

– monitoring and registration of nutrients and carbon in felling wastes on the pilot sites of final felling;

– monitoring and assessment of biodiversity on the pilot sites of non-clear cutting of final felling in terms of various methods of cutting sites clearing from felling wastes;

– monitoring and registration of nutrients and carbon in forest biocenosis biomass (forest live cover, silva succrescens, subsilva, forest stand).

The plan for conservation of biodiversity, ensuring optimal nutrient content and increasing the carbon sequestration function in the forests of the Republic of Belarus (hereinafter-the Plan) has been developed, which provides for a system of measures, deadlines, executors, as well as forecast indicators of their implementation, which can be specified taking into account the actual situation in forestry.

The proposed system of measures is based on an integrated approach, due to the need to preserve biodiversity, ensure optimal nutrient content, minimize carbon dioxide emissions in the areas after the implementation of final fellings and the need to increase the use of logging wastes for energy purposes in connection with the development of the energy production sector from wood fuel.

For the preservation and increase of biodiversity, optimal nutrient content and increase of carbon sequestration function of forest ecosystems, some forestry activities are held, the restrictions on forestry activities are imposed and forest management, some technological methods are recommended.

19. In the developed plan for the conservation of biodiversity, ensuring optimal nutrient content and increasing the carbon sequestration in forests provides recommendations for groups of activities, such as:

– Forestry activities;

– Forest use aimed at biodiversity conservation;

– Organizational measures.

Specific types of measures and actions are time related, addressed to specific performers (SFPA and forest fund managers) indicating the amounts of their implementation.

The list of activities included in the Plan is as follows:

19.1. Forestry activities include: "Reforestation and afforestation". "Seed production " and " Forest protection:

19.1.1. In the section **"** *Reforestation and afforestation. Seed production***"**, provides*:*

– relevant reforestation of felled forest areas transferred agricultural lands and lands for other purposes;

– increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation;

– increase of the share of creation of hard-leaved forest cultures from the area of artificial reforestation and afforestation;

– increase of the share of mixed forest cultures creation from the area of artificial reforestation and afforestation;

– increase of the area of linden planting;

– optimization of forest regeneration methods;

– creation of forest cultures with closed root system;

– creation of forest cultures by selective sowing and planting material;

– preservation of the genetic potential of forests.

Measures to improve biodiversity when carrying out works on reforestation and afforestation solve the following tasks: – regeneration of forest cover by returning forests to a natural way of development, increasing the diversity of tree species, making the forest stand structure and appearance of the natural forest, the achievement of a diversity of habitat conditions within the forest community, the creation of the forest complex of species and spatial structure, the formation of plantations of rare and valuable forest ecosystems, increase of fodder for forest fauna, increase of productivity of forest resources.

19.1.2. The section *"Forest protection and preservation"* provides:

– development of forest fire early detection system based on remote sensing methods;

– forest pathology survey;

– carrying out biological measures to protect the forest. Balanced application of various means and technologies in combination with the action of natural regulators of the number of harmful organisms, the use of scientifically based integrated systems of forest protection, taking into account the laws acting in forest biocenoses. Measures to combat harmful organisms are carried out using the least environmentally hazardous means and technologies that exclude or significantly limit the negative impact on the useful components of forest biocenosis – entomophages, warm-blooded animals, humans, the environment as a whole.

19.2. Forest use aimed at biodiversity conservation involves:

– carrying out final fellings within the strict limits of the calculated cutting site;

– reduction of volume of final fellings when increasing the volumes of timber harvesting in the development of damaged by fires, windbreaks or insects forest areas

– leaving the optimal amount of felling wastes on the cutting site (taking into account the economic usefulness of their use and the forest pathology situation in the forests);

– optimization of felling methods;

– leaving of cutting sites during the clear and band-gradual fellings of final felling, of an area of 1 ha to form forest of new generation that are complex by composition and structure, healthy mature trees *Pin, Que, Fr, Ac, Til, Al.g.*.

– leaving at carrying out clear fellings for its natural regeneration, if it does not provide for the creation of forest cultures, seed trees.

19.3. Organizational measures include:

– compliance with the requirements of FSC (international) and PEFC (European) forest management certification systems. Timely completion of the audit;

– adoption of normative legal and local acts taking into account the requirements of biodiversity conservation;

– monitoring of biodiversity;

– raising awareness, ecological awareness and public responsibility: carrying out explanatory and educational work among the population (social network, etc.), attracting certain types of economic activity through the action "Forest week", "Clean forest" (planting of forests, collection of waste, assistance in improvement of the territory), the intensification of work in social networks (creation of groups Vkontakte, Instagram, Facebook), the organization of a permanent presence in the country's media (newspapers, online publications, radio, television) through the active publication of information materials on the state of forests.

- creation and design of ecological trails in order to familiarize the population with a variety of ecosystems (forests, meadows, swamps, lakes, rivers, etc.), individual elements of the natural complex (plant species, landforms, boulders, trees of outstanding size, etc.), cultural and historical objects (religious buildings, estates, etc.).

19.3.1. It is advisable to make changes and additions to the standard STB 1360-2002 " Sustainable forest management and forest management. Final fellings. Technology requirements", namely:

– utilization use of felling wastes is allowed in areas of clear cuttings of final felling in the operational category and strip-gradual felling in the forests of water protection zones of protective forests categories, with the exception of remote sites, waterlogged conditions of vegetation and sandy soils and heath-lichen forest types;

– add / edit paragraphs 3.29, 4.2, 5.2.3 in accordance with the proposals set out in section 6.1.4 of this Report.

20. The current practice of production of fuel chips from felling wastes in the Republic of Belarus testifies to the negative profitability of its implementation both in the domestic (-14.4%) and external (-4.9%) markets (table 6.4). At the same time, there is no possibility of increasing the price of felling wastes in the Republic,makes it uncompetitive in the conditions of excess supply of wood chips.

We consider it necessary to discuss the issue of cost and sales price of chips from felling wastes, taking into account the following:

– felling wastes, unlike wood, are not taxed;

– the costs for collecting of felling wastes are not included in the cost of chips from FW, because they are included earlier in the clearing of cutting sites during felling;

– usefulness of realization of the felling wastes ordered after clearing of places of felling of the wood, directly from a cutting site.

21. Results of work under the Contract no. BFDP/GEF/CQS/16/29-34/18 from August 24, 2019 discussed at the meeting of the section Forest ecology and forestry, Round table No. 1 of 20 June 2019 and Round table No. 2 of 04 October 2019. The reports were considered at the coordination councils for the implementation of the forest sector development Project of the Republic of Belarus. 3.1.3.3 activity reports approved. Comments and suggestions are taken into account. A report on the results of the Round tables will be presented.

22. Report No. 4 on the results of stages 5 and 6 Of the work plan of the Activity 3.1.3.3 is compiled in the volume of 86 pages of A4 format, single spacing, font equivalent to Times New Roman, size12. Includes: List of main abbreviations, symbols, units of measurement, terms with their definition; List of 24 tables; List of 8 figures; Introduction; 4 sections; Conclusion; Literature in the amount of 29 Sources; Application on 5 pages.

APPLICATION

FINAL CONCLUSION
based on the results of contract no. BFDP / GEF/CQS/16/29-34/18

Activity 3.1.3.3: Assessment and monitoring of nutrient and carbon content in the soil, as well as the state of biodiversity in the final felling sites where timber is harvested, as well as FW, in accordance with the criteria developed at the initiative of the Round table on sustainable production and use of biomass. Evaluation and annual monitoring and recording of results will be carried out at a number of pilot sites throughout the project period.

The purpose of the task:
The purpose of the task is to analyze, obtain reliable data and prepare proposals for the conservation of biodiversity and minimize carbon dioxide emissions during different types of final fellings, taking into account the balance of socio-environmental and economic aspects of forest management. The analysis includes determination of usefulness and volume of removal of felling wastes after carrying out final fellings (clear and non-clear) for stands of two main forest-forming species: pine, spruce, and at least two types of forest for each of the main forest-forming species. The task is carried out taking into account the different ways of clearing of cutting sites after final fellings (collection in piles of felling wastes and grinding and uniform scattering of FW over the area). The methodology work on the assessment and monitoring of nutrients and carbon in soil and FW, the status of biodiversity in areas of final felling should be developed and tested on the pilot sites in the process of the task implementation: clear and non-clear cuttings, on which wood harvesting and removal/ non-removal of felling wastes is carried out, including stands of two main forest-forming species: pine, spruce and the main types of forest (at least two types of forest for each of the main species).

Customer:
Ministry of forestry of the Republic of Belarus represented by the First Deputy Minister of forestry of the Republic of Belarus V. G. Shatravko

Consultant:
Educational institution "Belarusian state technological University" represented by rector I. V. Voitov

Customer representative:
Expert production Republican unitary enterprise "Bellesexport" represented by Deputy Director-head of the affiliate A.V. Minchuk

Minsk-2019

"Final fellings: use of felling wastes, forest reproduction, minimization of carbon dioxide emissions, monitoring of soil nutrient content and biodiversity status»

1. The real resources of ripe wood, forming a source of timber harvesting and FW in the order of final fellings in the Republic of Belarus as of 01.01.2019, amount to 349.4 million m^3.

The actual harvesting of wood at the FF in the Republic of Belarus amounted to an average of 8240.5 thousand m^3 of realizable wood per year in the period 2014-2018. It is projected to increase it by 2030 to 16.7 million m^3 and 2050 to 20.1 million m^3 per year. The growth is resulted from the improvement of the age structure of forests and increase their productivity. In particular, the average stock of ripe and over-ripe plantations (271 m^3/ha) increased by 1.31 times compared to 1983 (198 m^3/ha).

2. Forest stands at the age of final felling reach indicators of raw material, sanitary and environmental values, which change little with the subsequent increase in age. On the studied pilot sites of *Pineta-Piceeta pteridiosum-oxalidosum* stands some of them are as follows.

The stock of stem wood - from 377 to 507 and FW-from 36.0 to 50.8 m^3 / ha. The content of nutrients (N, P, K, Ca and Mg) in the components of stands-from 15389 to 16579 and forest litter - from 727 to 2443 kg / ha. Carbon sequestration in stands phytomass, forest litterr and soil (0-30cm) - from 178.08 to 331.94 tC-equivalent per hectare.

Floristic diversity corresponds to the forest typological category of "indigenous forests". Plant communities are represented by 33-43 species. The distribution of species by life forms is as follows: *Phanerophytes* - from 6 to 8, *Chamaephytes*-from 1 to 3, *Hemicryptophytes*-from 4 to 6, *Cryptophytes*-from 11 to 19, *Therophytes*-2, *Epiphytes*-6-7 species. *Silva succrescens* and *Subsilva* are represented by a small number (up to 2 thousand trees / ha). All plants are forest species and undergo all phenophases of development.

3. The formation of biomass of forest stands from the ecotope consumes energy and nutrients. As a result, for example, the nutrition of ripening plantations *Pineta-Piceeta oxalidosa-pleuroziosa-pteridiosa-myrtillosa* led to a decrease in nutrients in the soil (0-30 cm) by 2.2 times over 17 years (2001-2018). At the same time, the decrease occurred in a smaller volume than the required consumption. In the studied conditions, nitrogen and ash reserves exceeded the annual demand of plantations for them for 15 years in 2001 and for seventeen years decreased only by six – up to 9 years in 2018.

A significant part of the nutrients tree absorbs from the deeper layers of the soil. Consumption is also partially replenished by the annual intake of fall that forms the forest litter. For these reasons, the reduction of nitrogen and ash elements in the upper layers of the soil does not become critical in the soil nutrition of plantations.

The dynamics of carbon nutrition of plantations is different. An important sustainable trend of the forest ecosystem towards sequestration of organic carbon in soil and, to a lesser extent, forest litter has been identified. Sequestration occurs in both normally functioning stands and shrinking ones. The intensity of carbon sequestration by stands ranged from 0.17 (shrinking) to 0.68 tC-equivalent per hectare per year (normally functioning).

4. Final fellings leads to significant losses of organic matter, nitrogen and ash elements in the forest ecosystem. The ecological and economic consequences of clear and non-clear cuttings (gradual and selective) of FF differ, namely.

The cost of wood harvesting on non-clear FF is higher by an average of 20%. The use of non-clear FF ensures the maintenance of logging sites in a forested state, which allows to increase the country's forest cover by approximately 0.9 percentage. Rejection from artificial renewal methods on non-cclear FF will ensure the preservation of the natural gene pool of forest growers by 23.9% of the forest fund area and reduce the cost of reforestation by up to 40%. Preservation of live phytomass of plants at clear FF makes up to 6.9-9.0% in a variant with leaving of seed trees and

0.7-1.6% without seed trees. In the areas of non-clear FF, the preservation of live phytomass is 10-15 pp higher. There are some differences in the regeneration of live ground cover, subsilva and silva succrescens in areas of clear and non-clear cuttings. However, by the age of the stand formed after felling 35-40 years, the specific structure of all tiers of forest stands characteristic for each type of forest is regenerated.

During clear / non-clear cutting" emission " of carbon dioxide occurs in different ways. "Emission" is caused by export of the wood prepared during felling. During clear cutting together with cutover of a stand other components of plantings that increases "emission" of CO_2 are destroyed also. For the studied pilotsites *Pineta-Piceeta pteridiosum-oxalidosum* "emission" in the year of felling in the variants of non-clear cutting was lower by about 61.5% (from 96 to 170 tC-equivalent / ha) than in the areas of clear cuttings. "Emission" in case of incomplete cutting is "stretched" for the next (up to 20 years or more) period. The value of "emissions" for the period of logging turnover will be less by 15-20%; this is equivalent to an increase in carbon sequestration in areas of non-clear cuttings.

5. Removal / non-removal of FW affects nutrients, carbon flows, floristic diversity and economic results of fellings, namely.

Removal of nutrients when removing FW does not exceed 10% of its content in the harvested stem wood. This has no significant impact on both soil fertility and meeting the needs of the forest's renewable young generation. However, taking into account the regular removal of food elements during improvement and sanitary felling, it is advisable to limit the removal of FW in stands growing on poor soils. This is beneficial for the conservation of forest biodiversity and the accumulation of carbon in the phytomass and soil. This increases the risk of forest fires and outbreaks of pests and diseases of the forest.

The recovery period of the initial mass of carbon in the plant after felling is in variants: clear-cutting with the removal of FW and creation of forest cultures – 49 years, without the removal - 42 years; selective cutting with the removal of FW, and preservation of undergrowth and measures to promote natural regeneration – 41, without removing - 35. Thus, the removal of FW increases the duration of" emission "of carbon for 6-7 years, the regeneration of the ways of" creation of forest cultures – for 7-8 years.

The issues of recycling / non-recycling of FW are of a little interest to the general population of Belarus. Living in small and medium-sized settlements positively assess the collection and disposal of FW. Burning of FW is considered the least acceptable.

The condition of economically justified use of FW for fuel purposes is the presence of a consumer at a distance of 100 km. At high prices for medicines and vitamin-protein concentrates produced from biomass of FW, woody vegetation (needles, coniferous branch, small non-woody shoots) and bark can also be of some interest.

6. In the future, the formation of FW depends on the volume of wood harvesting at the FF. The volumes of non-clear FF are expected to be 30.0%.

The projected volumes of FW be 4792.9 thousand m^3 in 2030 and 5763.8 thousand m^3 in 2050. In the composition of the branches, twigs, thin tops occupy 34.8% of their volume, woody vegetation-15.6%, stumps and roots-49.6%. The carbon content in FW will be 177.94 thousand tC of the equivalent in 2030 and 213.92 in 2050. The share of carbon is distributed in this way: stumps and roots-59%, twigs and branches – 37%, woody vegetation -4%.

The total utilization resource of biomass of FW, taking into account the inaccessibility of FF sites, is projected for 2030 in the amount of 1533.9 thousand m^3 and for 2050-1848.5 thousand m^3. The volume of FW for clear cuttings of FF will be 88.4%.

7. For the purposes of evaluation, analysis, objective selection method of FW management depending on the way of FF and forest regeneration in terms of biodiversity conservation, optimal nutrient content in soil and minimizing emissions of carbon dioxide, a number of guidelines is proposed, namely.

The element-by-element "field" point estimation is carried out on the basis of the taxation characteristic of the FF site taking into account the recommendations received on the Activity 3.1.3.3. Carbon flows, the level of natural biodiversity and economic indicators are to be assessed.

Biomass of FW is calculated on the basis of the root stock of wood based on the material and monetary assessment of cutting sites. Model wood butchering method is used to determine the specific gravity of FW by fractions.

The total organic carbon content in FW is calculated on the basis of their mass, density and carbon content in FW biomass fractions.

The contents of mineral elements in is based on the mass fractions of FW and the chemical analysis of plant samples, conducted in a laboratory accredited in the Republic of Belarus.

The content of organic carbon and mineral elements in the soil is determined according to the methodology of RUE "Belgosles", which is adapted with the Manual on methods and criteria for coordinated sampling, assessment, monitoring and analysis of the impact of air pollution on the forest (ICP Forest program) and was used in the primary survey of forest soils.

Assessment of floral diversity includes description of parameters of live ground cover, natural regeneration, silva succrescens and subsilva. The difference or commonality in the trends of biodiversity conservation/restoration at the FF sites is established by the similarity indicator-the Jacquard coefficient.

The annual monitoring and recording of results envisaged in the Activity 3.1.3.3 will be carried out in pilot plots 1-16 WB/GEF in *Pineta-Piceeta pteridiosum-oxalidosum* stands. Repeatability, the total duration of monitoring, the list of forest-taxational indicators of stands, biodiversity parameters, elements of air, nitrogen and mineral nutrition in phytomass, forest litter and soil are recommended.

8. The estimates of the methods of treatment with felling wastes are specified, namely.

The positive and negative consequences of the methods of FW management on the forest formation process for the factors are established: creation of forest cultures, natural regenerationl, the content of nutrients in the soil, biodiversity conservation and carbon dioxide absorption.

The positive and negative opinions of various segments of the population on the conduction of fellings, clearing of forests from dead phytomass are formulated. The low awareness of people about the purposes and tasks of forest management, forest cultivation, protection and preservation of forests is established.

The analysis of the efficiency of production and sale of fuel chips from felling wastes is made. The conclusion about the lack of accounting by the forestry enterprises of the possibility of obtaining additional revenue from the sale of felling wastes is made. When calculating the cost of wood chips from the FW some circumstances are not taken into account: free cost of FW, unlike wood-burning wood; also the cost for FW collection, previously included in the clearing of cutting sites during felling .

9. Recommendations for biodiversity conservation, ensuring optimal nutrient content and minimizing carbon dioxide emissions at the FF sites have been developed. Forestry activities are integrated with the previously adopted in the Republic of program documents, such as the national action plan for the conservation and sustainable use of biological diversity for 2016-2020 and others

A Plan has been developed to conserve biodiversity, ensure optimal nutrient content and enhance the carbon-absorbing function of forests. There are activities in groups: forestry, forest management and organizational. Types of activities and actions are planned according to the terms of their implementation. Addressed to specific performers (SPFA and forest Fund holders) indicating the volume of their implementation.

10. It is advisable to make changes and additions to the standard STB 1360-2002 " Sustainable forest management and forest management. Final fellings. Technology requirements", namely:

– utilization use of felling wastes is allowed in areas of clear cuttings of final felling in the operational category and strip-gradual felling in the forests of water protection zones of protective forests categories, with the exception of remote sites, waterlogged conditions of vegetation and sandy soils and heath-lichen forest types;

- add / edit paragraphs 3.29, 4.2, 5.2.3.

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