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FACTORS OF ECONOMIC SUSTAINABILITY OF LOGGING ENTERPRISES IN THE SYSTEM OF RATIONAL FOREST RESOURCE USE

Aliaksandr Tarsevich [1]

[1] Engineer, Foreign Economic Activity and Production Department, Krasnopolye Forest Enterprise, Krasnopolye, Republic of Belarus

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Abstract

The article examines the factors of economic sustainability of logging enterprises within the system of rational forest resource use. It is established that the financial performance of a logging enterprise is determined not so much by harvesting volume as by the condition of the raw material base, the level of resource risks, the timeliness of harvesting degrading sites, and the effectiveness of managerial resource allocation. Special attention is paid to the role of forest stand monitoring and predictive assessment of timber raw materials in preserving their economic value. It is substantiated that a sustainable model of logging enterprise operation should combine resource, technological, and financial management dimensions, thereby ensuring loss reduction, increased usable timber yield, and stabilization of economic indicators.

Keywords: *forest stands, forestry, forest industry, logging enterprises, economic sustainability, forest stand monitoring, rational forest use*

Introduction

Modern logging enterprises operate under conditions of strong dependence on the state of the forest stock, the quality of timber raw materials, the spatial accessibility of resources, the seasonality of operations, and changes in market conditions. Unlike many industrial sectors, the economic performance of logging is determined not only by the volume of output, but also by the enterprise's ability to identify changes in the condition of forest stands in a timely manner, minimize timber losses, and preserve its commercial value at all stages of the production cycle.

A significant emphasis in existing conditions of the sector is placed on the efficient use of forest resources, where both compliance with the criteria for environmental sustainability in forest use and economically justified management of the quality of resource base come into play. Failure to timely harvest deteriorating resources, poor monitoring of forested areas, as well as insufficient risk evaluation may result in the reduction in assortment value of harvested wood, costs increase, waste increase, and financial performance degradation.

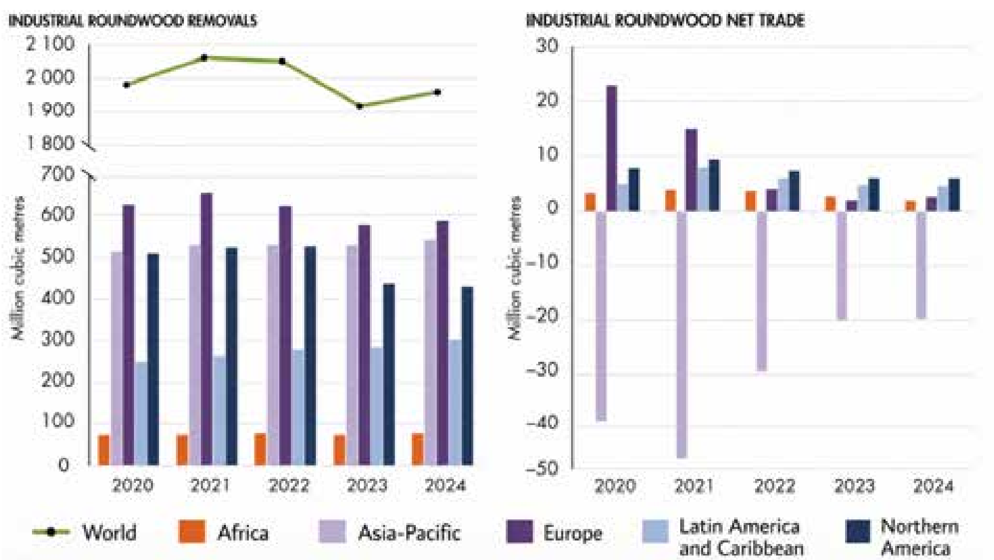
The aim of the article is to identify and systematize the factors of economic sustainability of logging enterprises within the system of rational use of forest resources. To achieve this aim, the article examines the sectoral specifics of sustainable functioning of logging enterprises, the influence of timber quality and resource risks on financial performance, as well as the role of monitoring, risk assessment, forecasting of forest stand conditions, and organizational and economic decisions aimed at reducing losses and improving the efficiency of timber use.

Sectoral specificity of economic sustainability in logging

The economic sustainability of a logging enterprise is shaped not only by internal costs, machinery productivity, and production organization, but also by forest stock conditions, timber quality, site accessibility, natural risks, and market demand. Since forest resources change under biological, climatic, market, and infrastructural factors, sustainability should be understood as the ability to maintain profitability and production stability despite changes in species composition, assortment yield, transport conditions, prices, and stand damage (García-Jácome et al., 2025).

The practical significance of this point is confirmed by the scale of the global wood products market and the continuing volatility of the forest industry sector. According to the statistical review released by the Food and Agriculture Organization of the United Nations in December 2025, global exports of wood and paper products increased by 1.4% in 2024 and reached USD486 billion after a 14% decline in 2023; at the same time, industrial roundwood removals grew by 2% to 1.96 billion m^3, while global trade in industrial roundwood decreased by 1% to 96 million m^3, its lowest level since 2009 (fig. 1).

Figure 1. *Dynamics of industrial roundwood removals and industrial roundwood net trade by world region in 2020–2024, million m^3 (FAO, 2025)*



The reduction in the volume of world trade in industrial roundwood in 2024 can be attributed to lower import demand in China, which continued to be the biggest importer of industrial roundwood, although imports in China decreased each year since 2021 and dropped 43 percent between 2021 and 2024, as reported by FAO. In general, the statistics in the FAO report show that the increase in demand in the forestry industry cannot remove companies' dependence on raw material supply and logistics.

In 2024, according to the FAO report, global production of wood-based panels increased by 5% to 393 million m^3, while international trade in panels grew by 6% to 90 million m^3 (FAO, 2025). Wood pulp production rose by 3% to 189 million tonnes, and its international trade increased by 2% to a historical maximum of 73 million tonnes, indicating the growing importance of deeper processing, stable raw material quality, sorting, and predictable supply.

A separate risk is the damage and degradation of forest resources. According to World Resources Institute and Global Forest Watch data published in 2026, tropical primary forest loss fell by 36% in 2025 compared with the record level of 2024, but still amounted to 4.3 million ha, or more than 11 football fields per minute; moreover, this level remains 46% higher than a decade ago (Goldman et al., 2026). For logging enterprises, this increases uncertainty regarding raw material quality, harvesting costs, salvage timelines, and the share of timber downgraded from high-value assortments to low-grade or damaged wood.

Under these conditions, the economic sustainability of a logging enterprise cannot be reduced to increasing harvesting volumes. Its key factor is the ability to manage timber quality over time: delayed detection of forest degradation, fire risk, pest damage, reduced accessibility, or declining assortment structure leads to higher unit costs, lower commercial yield, more waste, logistical problems, and reduced margins. Therefore, forest monitoring, risk assessment, timber quality forecasting, and prioritization of degrading stands become core elements of economic sustainability.

Thus, the sectoral specificity of economic sustainability in logging lies in the combination of three interrelated groups of factors: resource, market, and organizational-managerial factors (table 1).

Table 1. *Groups of factors affecting the economic sustainability of a logging enterprise*

Group of factors	Content of factors	Impact on the economic sustainability of the enterprise
Resource factors	Condition of the forest stock, species composition, timber quality, degree of stand damage, presence of degrading areas, spatial accessibility of raw materials.	Determine commercial yield, assortment structure, level of losses, harvesting costs, and potential revenue from timber sales.
Market factors	Demand for sawnwood, wood-based panels, pulp and paper products, packaging materials, construction products, bioenergy feedstock, and bioeconomy products.	Affect selling prices, choice of timber utilization channels, margins of individual assortments, and stability of cash flow.
Organizational and managerial factors	Forest stand monitoring, assessment of resource and production risks, harvesting schedule planning, assortment optimization, loss reduction, logistics management.	Ensure timely decision-making, preservation of timber commercial value, reduction of unit costs, and greater predictability of financial results.

In this regard, the sectoral sustainability of logging enterprises should be understood as the result of coordinated management of the resource base, market positioning, and operational decision-making. The enterprise becomes economically stable when it is able not only to harvest timber, but also to preserve its commercial value, adapt to changes in demand, reduce losses, and transform monitoring data into timely production and financial decisions.

Timber quality and resource risks as factors of financial performance

Timber quality is one of the key determinants of a logging enterprise's financial performance, as it affects not only harvested volume, but also subsequent utilization, assortment yield, waste levels, transport feasibility, and final margins (Gao et al., 2025). In logging, the same physical volume of wood may generate different economic outcomes depending on stand damage, moisture, decay, cracks, stem curvature, pest infestation, fire impact, or the time damaged timber remains in the forest. Therefore, financial stability depends not only on cost control, but also on timely quality classification, forecasting of value loss, and selection of economically rational utilization channels.

A particularly significant factor reducing timber value is **biotic damage**, primarily bark beetle and other pest infestation. Even when the physical volume of stemwood is preserved, deterioration of external and internal wood characteristics reduces its suitability for high-margin processing. For example, recent studies on the western United States show that bark beetles killed about 3.8 billion trees between 1997 and 2018, confirming the large-scale nature of this risk for timber quality and logging planning (Andrus et al., 2025).

Abiotic risks also affect timber quality and financial performance, particularly through drought, windthrow, storms, excessive moisture, and temperature stress. These factors may reduce stand stability, increase the share of damaged or deadwood, complicate harvesting operations, and shorten the period during which timber retains commercial value. As a result, abiotic disturbances transform natural vulnerability into direct economic risk by increasing salvage urgency, reducing assortment quality, and raising operational uncertainty.

Raw material quality directly affects product yield in primary processing. A 2025 study in Annals of Forest Science showed that log defects, especially taper and ovality, significantly influence sawing yield and the economic value of timber; therefore, preliminary sorting and quality assessment should be treated not only as technical procedures, but also as elements of financial management (Cataldo et al., 2025).

Fire risks intensify the problem of timber quality because they affect the available resource volume, its physical condition, salvage timing, and logistics. According to the State of Wildfires 2024–2025 report, at least 3.7 million km² burned globally between March 2024 and February 2025, while fire-related carbon emissions reached 2.2 Pg C, 9% above average and the sixth-highest level since 2003 (Kelley et al., 2025). Economically, this increases urgent salvage logging, access costs, supply uncertainty, and the risk of timber quality deterioration if removal is delayed.

Spatial accessibility is another factor that converts resource quality into financial performance. Remote location, poor road infrastructure, seasonal restrictions, and difficult terrain increase harvesting and transport costs, while delayed access to damaged stands accelerates timber value loss. Therefore, the economic feasibility of logging depends not only on the biological condition of the stand, but also on the enterprise's ability to reach, harvest, and deliver timber within the time frame in which it remains commercially valuable.

An important resource constraint is not only stand damage, but also the **condition of forest soils**, since it affects the long-term productivity of stands, forest resistance to drought, and recovery capacity after disturbances. For example, according to a 2025 USDA Forest Service review, the U. S. Forest Inventory and Analysis system includes 145,719 base forest monitoring plots, with nearly 10,000 plots already sampled for soils; the measurements include erosion, compaction, water content, bulk density, organic carbon, nitrogen, pH, and exchangeable elements (Pastore et al., 2025). For a logging enterprise, this has direct practical significance: excessive machinery impact, poorly organized skidding, and failure to observe seasonal work restrictions may deteriorate not only the ecological condition of the site, but also the future economic productivity of the forest resource base.

Market demand further determines how timber quality is converted into revenue. When demand for high-grade assortments, panels, pulpwood, or bioenergy feedstock changes, the same raw material may acquire different economic value depending on available processing channels and price conditions. Therefore, quality assessment should be linked not only to physical characteristics of timber, but also to current and expected demand for specific utilization pathways.

Thus, financial performance depends on the interaction of timber quality, damage level, processing yield, and decision-making speed. An economically sustainable model should therefore ensure early detection of resource risks and controlled allocation of timber by use, linking engineering solutions for preventing and mitigating forest disasters with the preservation of commercial value and reduction of economic losses.

Methodology for monitoring, risk assessment, and forecasting of forest stand conditions

Under current conditions, the economic sustainability of a logging enterprise depends on its ability to detect changes in forest stand conditions in advance and translate monitoring results into management decisions. Monitoring therefore serves not only as an ecological or accounting procedure, but also as an early warning tool for timber quality decline, rising costs, access constraints, salvage logging risks, and potential revenue losses. A risk-oriented model requires regular updates on stand damage, fire risk, moisture stress, sanitary condition, accessibility, and assortment structure, linking data collection, risk assessment, forecasting, and management response (table 2).

Table 2. *Stages of monitoring, risk assessment, and forecasting of forest stand conditions*

Stage	Content of the stage	Practical significance for a logging enterprise
Data collection	Collection of information on stand condition, species composition, stand age, damage, transport accessibility, and natural and climatic conditions of the site.	Forms the information base for assessing timber quality and planning harvesting operations.
Identification of deviations	Detection of dieback, pest infestation, fire damage, windthrow, waterlogging, and deterioration of forest sanitary condition.	Enables timely identification of sites with a higher risk of timber value loss.
Resource risk assessment	Assessment of the probability of raw material degradation, reduced assortment yield, increased waste, and more complex logistics.	Provides a transition from describing forest condition to evaluating potential economic consequences.
Forecasting of timber quality changes	Estimation of possible timber degradation dynamics considering damage type, season, moisture, site accessibility, and removal timing.	Helps determine critical harvesting deadlines and reduce the risk of commercial value loss.
Site prioritization	Ranking of forest sites by harvesting urgency, considering timber quality, risk level, harvesting costs, and expected revenue.	Helps allocate machinery and labor to sites with the greatest economic effect.
Management decision selection	Selection of harvesting, sorting, transport, and timber utilization scenarios.	Links monitoring data with production and financial decisions.
Result control	Comparison of forecast indicators with actual timber yield, losses, costs, and financial results.	Allows adjustment of the monitoring methodology and improves the accuracy of future planning.

This methodology should integrate engineering and economic management dimensions. The engineering dimension records stand condition, degradation signs, site accessibility, and harvesting feasibility, while the economic dimension converts these data into expected revenue, costs, margins, and loss risks. Thus, monitoring helps determine the timing and method of resource use that preserve the highest timber value.

An applied monitoring model should account for the fact that risks rarely occur in isolation. Forest stands often develop cascading processes: drought weakens trees, weakened stands become more vulnerable to pests, pest damage increases deadwood volume, and this raises fire risk while accelerating the loss of assortment value. Therefore, risk assessment should be based on an integrated matrix that combines natural, technological, and economic factors (table 3).

Table 3. *Risk levels of forest sites and management responses*

Site risk level	Forest stand condition	Possible impact on financial performance	Recommended management response
Low	No damage or only minor damage is observed; transport accessibility is stable.	Planned assortment structure and predictable harvesting costs are maintained.	Harvesting according to the standard production schedule.
Moderate	Local damage, signs of stand weakening, or seasonal access restrictions are present.	Possible reduction in commercial yield and higher costs for specific operations.	Additional inspection, adjustment of harvesting timing, and enhanced sorting.
High	Significant damage, deterioration of sanitary condition, and risk of rapid timber quality loss are observed.	Lower selling prices, increased waste, and need for accelerated removal.	Priority harvesting, separate logistics scenario, and shortened processing time.
Critical	Mass damage, fire impact, severe pest infestation, or sharp deterioration of accessibility is present.	Substantial loss of timber commercial value and risk of unprofitable operations.	Crisis response scenario, selective harvesting of economically usable timber, and reassessment of harvesting feasibility.

Thus, the methodology for monitoring, risk assessment, and forecasting of forest stand conditions should be regarded as an economic management tool for logging enterprises. It helps identify sites where delays may reduce timber quality and cause financial losses, as well as sites where harvesting can be postponed without significant loss of commercial value. In this sense, enterprise sustainability depends not only on technical capacity and available cutting areas, but also on the quality, speed, and practical use of management information.

Rational and economic management of timber resources in the model of a sustainable enterprise

At the final stage of forming a sustainable model of a logging enterprise, the results of monitoring, risk assessment, and forecasting of forest stand conditions should be transformed into specific production and financial decisions. Modern management logic assumes that each forest site is assessed not only by the physical volume of timber, but also by its quality, the possible timing of commercial value loss, harvesting costs, transport accessibility, and potential utilization channels. In this case, timber is treated as an economic asset whose value changes over time and depends on the timeliness of management decisions. The main elements of this model are presented in (table 4).

The proposed model shows that sustainability is achieved not only through cost reduction, but also through precise allocation of timber by utilization channel. High-quality wood should be directed to higher value-added uses, while damaged or low-grade timber requires separate harvesting, removal, and processing scenarios. This enables a shift from reactive responses to a preventive model linking raw material quality, degradation risk, technological decisions, and financial performance.

Table 4. *Elements of rational and economic management of timber resources in the model of a sustainable enterprise (Medvedev & Nazarova, 2025; Medvedev et al., 2024)*

Management element	Content of the management action	Economic significance for the enterprise
Assessment of timber quality	Determination of assortment structure, degree of damage, and suitability of timber for different processing options.	Increases commercial yield and directs raw materials to the most profitable utilization channels.
Prioritization of forest sites	Selection of harvesting sequence considering timber degradation risk, transport accessibility, and expected margin.	Reduces the risk of timber value loss and improves the justification of production planning.
Sorting and allocation of raw materials	Separation of timber by quality, purpose, and economic feasibility of use.	Prevents mixing of high-quality and low-grade timber, reduces waste, and increases overall margins.
Management of damaged and degrading timber	Development of separate scenarios for harvesting, accelerated removal, and processing of damaged raw materials.	Preserves part of the timber resource in commercial circulation and reduces forced losses.
Logistics optimization	Selection of routes, removal timing, seasonal work regimes, and machinery deployment schemes.	Reduces transport costs and increases the profitability of remote or problematic sites.
Financial assessment of decisions	Calculation of expected cost, revenue, margin, and loss risk for each scenario.	Links production decisions with financial performance and long-term enterprise sustainability.

Conclusion

The economic sustainability of a logging enterprise is formed not only through cost control and the maintenance of harvesting volumes, but also through the ability to manage timber quality at all stages of its economic use. Rational allocation of raw materials by processing channel, timely harvesting of degrading sites, reduction of production losses, and the use of monitoring data help preserve the commercial value of timber and improve the predictability of financial performance. Therefore, sustainable enterprise operation under current industry conditions requires a shift from a volume-oriented production logic to an integrated management model in which forest stand conditions, resource risks, technological decisions, and economic efficiency are considered as interrelated elements of a unified system of rational forest use.

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Contact: greenshieldfrs@gmail.com