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Developing a Model of Forest Enterprises Activities with the Prospect of Moving into Sustainable Development

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Abstract. The sustainable development concept is highly relevant in the modern scientific and applied agenda of country's social and economic development. Russia has approved a number of programs for its active implementation. This is reflected in almost all branches of the economy. The forest industry is crucial in this context as it uses and restores wood, one of major resources for the planet's ecosystems. The aim of the research is to develop a model for optimizing the activities of forest industry enterprises, taking into account the prospects of moving into sustainable development. The aim was predetermined by a necessity to design a means for supporting the idea of moving into sustainable development. The model includes a range of effects that impact the profit through the use of various resources. Forest enterprises activities concern a set of technical, economic, ecological and social aspects. The presented model helps to calculate the remaining profit available to the enterprise. It also covers crucial aspects such

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as competitiveness and efficiency, which are determined by the effects of social, ecological and economic nature. An important finding is the demonstration of the need and interest of forest enterprises to fulfill the existing restrictions imposed by stakeholders. The presented results may be valuable for researchers of the forest sector economy and to the industry in general; for the federal authorities to implement sustainable development programs and create industrial policy; for the heads of forest businesses to develop relevant strategies and plans.

Key words: forest enterprise, sustainable development, model developing, effect, production factors, restrictions, optimization, profit.

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Introduction

The forest industry currently has a relatively small impact on the Russian economy. However, due to the huge natural forest resources, there is potential for significant growth in the industry, which could increase country's GDP. Finland provides a successful example of an economy that has fully used forest resources of the country (Halonen et al., 2022). Although there are difficulties in transferring foreign experience to Russian reality due to differences and restrictions, the forest industry is capable of producing high-quality, expensive products that are in demand on the world market. Obviously, the contribution of this industry cannot be compared to the oil and gas sector. However, improving the efficiency of the forest industry benefits both the state and businesses, profiting from the production and sale of products. It is an important and urgent task, confirmed in the Strategy for development of the forest industry[1].

The forest industry has been affected by the significant restrictions imposed on domestic economy by a number of countries. European countries, which were traditionally the major consumers of timber products and suppliers of equipment and machinery, have been replaced with Asian and other friendly countries. Enterprises have to cope with the current realities and overcome various challenges. Under these circumstances, optimizing is a crucial factor for increasing efficiency. Finding the most relevant methods and directions for this work is of great interest from both practical and fundamental perspectives.

Current geopolitical situation has led forest enterprises to search ways to improve their efficiency. Use of various modeling methods is a common option to achieve this goal. These methods provide valuable information about the consequences of certain decisions without the need for expensive experiments. There are many of them available. In practice, mathematical tools for economics can be some of the most relevant directions for business. These methods can be used for optimizing production programs, forecasting and solving problems. They can also represent, analyze, and describe complex social and economic processes in the economy, including the forest industry. Obtaining general models of forest enterprises' behavior under specific conditions is an important result.

[1] Strategy for development of the forest industry in the Russian Federation for the period up to 2030 (approved by RF Government Resolution 1989-r, dated September 20, 2018).

According to some experts and government agencies, sustainable development is a crucial strategic direction for domestic industry[2]. Many of the largest Russian companies are implementing projects to reduce their environmental impact. Sustainable Development Concept, which involves implementation of many different tasks, aims to organize production activities while considering the interests of future generations. However, Russian enterprises are lagging behind their Western counterparts in implementing solutions that contribute meeting this target. This situation arose largely due to the level of development of civil society. The need for clean environment, safe production, and respect for the interests of local communities in Russia, which have become a priority in a number of developed countries, is not yet considered as a prime concern. However, changes are taking place and there is a growing demand for responsible business. Despite the existing number of skeptical views, the evidence suggests that the Sustainable Development Concept will become increasingly relevant, and its principles will be implemented at more and more enterprises.

This research aims to develop a model for optimizing activity of forest industry enterprises, considering the moving into sustainable development. The focus should be on developing a suitable mathematical framework to determine the impact of decision-making on an enterprise's development. According to the authors, the primary challenge in implementing sustainable development principles is the business targeting on economic performance with less regard for social and environmental effects. Therefore, the proposed model should consider various social, ecological and economic parameters and their impact on forest enterprises' final outcomes.

Materials

The economics of the forest industry is a relevant subject in both Russian and foreign literature (Mourao, Martinho, 2020; Pyzhev, 2021). Many studies are devoted to improving the efficiency of forest enterprises, which stand for the objects of their analysis (Yen, 2018; Grigor'ev, Grigor'eva, 2016; Gordeev, Pyzhev, 2023). The works differ significantly in their specifics, applied methodologies and approaches, as well as goals.

Forest enterprises' efficiency in scientific research is often examined either to assess the impact of changes or to identify areas for optimization (Xue et al., 2018). Direct performance evaluation is also conducted, but only for testing or comparing specific results. Plenty of works identifies various stakeholders that influence different aspects of forest industry enterprises (Butko et al., 2013; Petrov et al., 2023). Each stakeholder, including the state, local communities, and business owners, views a forest enterprise in their own ways, based on their own interests and needs. (Soviana, 2015). Finding an optimal solution for all stakeholders is a complex task that should be solved in social, ecological and economic terms.

Many works have noted the dependency between economic performance of enterprises and ecological parameters of the environment. Some authors conduct fundamental research on climate change and its impact on businesses (Stern, 2007), while others observe various tools for analyzing or developing industrial structures (Polyanskaya et al., 2017; Laso et al., 2018). According to the scientists, one of the main concepts is the idea of environmental regulations to act as an incentive for implementing technological innovations.

[2] RF Government Resolution 1912-r, dated July 14, 2021 (amended on December 30, 2023) "On approval of targets and main directions of sustainable and environmentally friendly development of the Russian Federation".

This should increase competitiveness and economic efficiency of a business unit (Porter, Linde, 1995; Hu et al., 2017).

In modern literature, studies on sustainable development often explore the dependency between the economy, ecology, and social sphere (Bobylev, 2020; Izmaylova, 2021). This topic is widely discussed in both foreign and domestic publications. Relationship between sustainable development and performance of forest enterprises is often considered in applied aspect of its potential effects (Liang et al., 2024) or simply recognized as a dependency (Terent'yeva, Savchenko, 2022). In some authors' opinion, the relationship will become more obvious in the medium and long terms in Russian conditions. Foreign enterprises normally pay attention to the principles of sustainable development; that determines their success and, in some cases, the very possibility of doing business (Hahn, Knoke, 2010; Halonen et al., 2022). Production requirements come from outside (Budanov, 2016), and domestic forest enterprises will need to cope with increasingly changing conditions to operate in this direction.

One of the main aspects of sustainable development is the use of various resources. This is a significant research topic for the forest industry. The forest industry has a great advantage of natural resources restocking through reforestation (Petrov, 2020). Optimization of resources allocation with the use of various mathematical models at forest industry enterprises is considered in both theoretical and applied aspects (Ibrahim et al., 2018). However, most studies are focused on optimization of material resources, which may not lead to obtaining objective results in the current reality and trends.

The primary aspect of this research is to examine the improvement of enterprises, taking into account prospects for their development. It is important to consider the opinions of some authors (Hahn et al., 2014), who emphasize the significant dependency between decision-making and discounting. Bringing future cash flows to the present moment obviously allow reducing some risks and correctly assess potential results. However, the forest industry is known for a long recovery period of its main resource – wood, which can take up to 100 years. For this reason, it is difficult to develop objective models for optimizing the long-term activities of forest enterprises, including discounting elements. This opinion is shared by several foreign researchers (Gadow, 2000).

In general, obtaining an objective and quantitative assessment of many facts describing the functioning of enterprises in the industry requires the use of various economic and mathematical methods. This thesis is supported by numerous studies. This research provides examples of the mathematical framework use to assess waste management effectiveness (Amaral et al., 2022) and to meet environmental and economic standards (Niero et al., 2017).

Industry models are a particular case of more global and macroeconomic modeling. In the case of forest industry research, most works are focused on optimizing and changes forecasting of production and economic indicators (Blam et al., 2017; Rogulin, 2021). However, it is important to note that the authors' approach requires the inclusion of environmental and social components in the designed model. This is presented fragmentarily in the scientific literature. The final application models comply with the authors' hypothesis regarding the dependency between economic effects and sustainable development or green economy (Glazyrina et al., 2015). Most relevant modeling examples are balance models, presented in the scientific literature (Shelukhina, 2014).

In the authors' opinion, developing a model of sustainable development of enterprises is insufficiently presented in scientific literature. Existing approaches are either based on general ideas of sustainable development (Il'ina, 2021), limited to describing structural elements that should be included in such models (Koryakov, 2012), or focused on a restricted number of indicators used to assess sustainable development (Yarullina, 2008). The selection of these indicators is often questionable and meets the general focus the presented research. It should be noted that in foreign literature some works are interesting and detailed from both theoretical and practical perspectives (Chang, Cheng, 2019). However, most of the studies describe parameters, indicators, and practices of enterprises that are irrelevant in Russian conditions.

Analysis of existing studies allowed us to conclude, that developing a model of forest enterprises' activities in accordance with their possible movement into sustainable development is a highly relevant topic and should be accompanied by an appropriate theoretical base. To achieve objective results, it is necessary to balance technical, economic, environmental, and social spheres. Developing a model should consider various types of resources and effects. Their integration into a single balance model will expand the existing theoretical and applied ideas about the efficiency of forest enterprises.

Methods

The research is based on general scientific methods such as analysis, synthesis, generalization, etc. Statistical analysis was carried out to process data on the current state of the forest industry and its individual subjects. The research partially includes previously obtained results for optimizing the production program of a forest enterprise (Medvedev et al., 2020) and assessing the current state of the industry (Medvedev et al., 2022). The study consists of several stages:

1. Analyzing of resource flows at a forest enterprise. This stage is necessary to design graphic models of resource flows. The significant elements of this model include stakeholders: society, state, environment, market. Resources and effects circulate between these stakeholders and an enterprise. They also impose certain restrictions on an enterprise. Research proceed from the notion that an enterprise's resources are traditional production factors.

2. Studying of the interaction features between a forest enterprise and external environment. Effects and restrictions, specified at the first stage of the research, are analyzed to determine their specific influence on various aspects of forest enterprise activity. The results serve as an applied manifestation of the balance model.

3. Forming a model to optimize the activity of forest enterprises in accordance with their possible movement into sustainable development. This stage is performed with the use of traditional approaches for obtaining economic-mathematical balance models. The important aspect is description of current restrictions and effects concerning technical, economic, ecological and social factors. The theoretical model was visualized in Statistica application software in three-dimensional space with the fulfillment and non-fulfillment of the restrictions present in the model.

Results

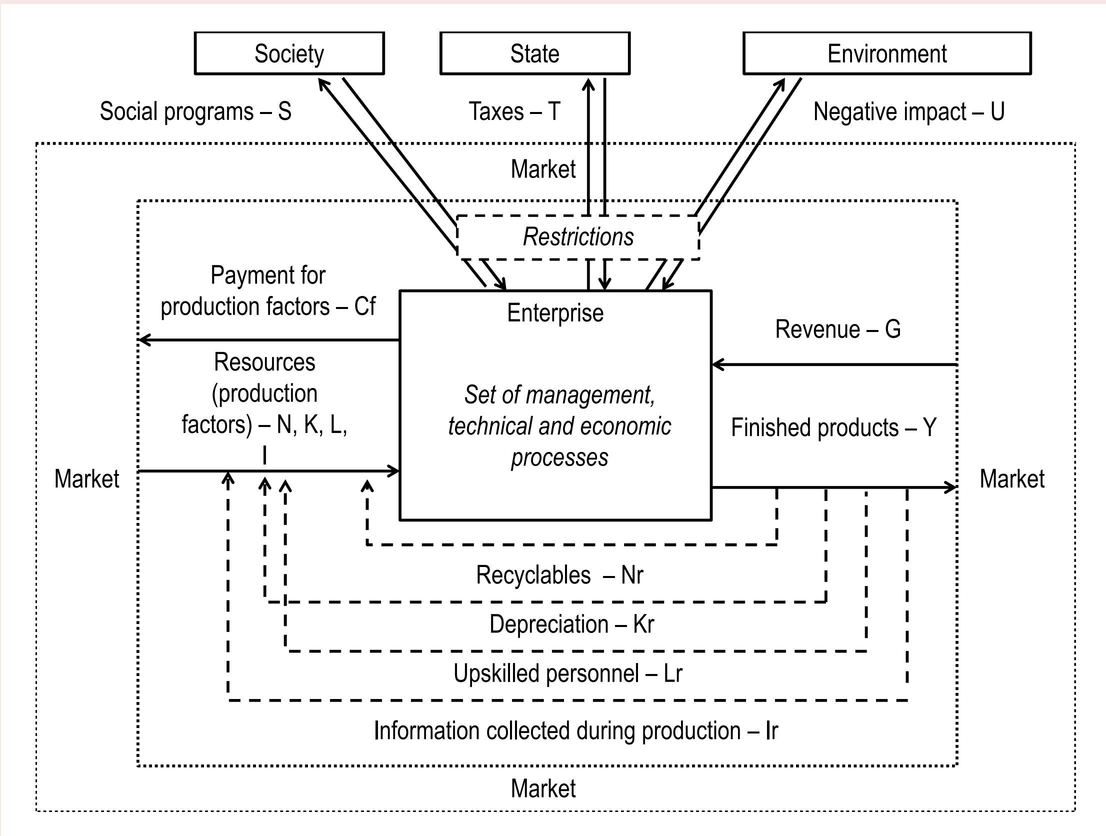
Model of resource flows at a forest enterprise are presented in *Figure 1.*

This model presents a number of classical ideas about the economics of production, enterprise and economic theory in general. Production is the major source of income and activity for an industrial enterprise. According to traditional ideas, it relies on production factors (resources) – labor (L), financial (K), natural (N) and informational (I).

Traditional factors "labor, land and funds" are most actively involved in the production processes of the forest enterprise. They are directly transformed into finished products. The modern forest industry is increasingly using informational resources. This includes many aspects of its activity, from market research to the use of different software solutions in various production processes (geographic information systems, systems applications and products etc.). However, the domestic information resource market lags behind advanced foreign experience.

The main component of this model is the set of management, technical and economic processes. This refers to a large number of processes that take place within an enterprise and result in the use of all material and informational resources. Essentially, incoming resources are managed and transformed into various output and/or material flows that circulate within the enterprise.

Figure 1. Model of resource flows at forest enterprise



Source: own compilation.

An enterprise's external environment consist of such components as market, society, state and environment. The market is a separate institution that forms the economic conditions for all business units. It provides necessary resources and transforms finished products into revenue. The model also includes society, the state, and the environment as separate components. Each of them plays a crucial role in the activity of forest enterprises. At the same time, these components naturally intersect each other and market in their interactions with the enterprise. For instance, the market provides labor resources which are a part of society.

Figure 1 does not present business owners and net income of enterprises they use for non-production purposes. The authors suggest considering these processes and components within the internal structure of enterprises. Therefore, this aspect of material flows and management can be described as part of the set of management, technical and economic processes presented in the model.

It is important to note that the components of the external environment impose a set of restrictions on the activities of enterprises. *Table* presents the resources and restrictions for forest enterprises. The enterprises under consideration also impose a number of restrictions on society, the state, and the environment. However, the scale of their impact is significantly smaller.

Enterprises negatively impact environment (U) by causing emissions, discharges, waste, deforestation, and soil disturbance. Some enterprises of the industry positively effect environment by reforestation and fighting harmful diseases and fires. However, Figure 1 emphasizes the dominant component of interaction between business and the environment. In fact, human activities provide minimal benefits to nature, as shown in Table.

Certain features of interaction between forest enterprises and external environment

External environment components	Provided resources / material and informational flows	Benefits	Restrictions
Market	All kinds of resources: material, financial, labor, informational etc. Revenue from products sale, infrastructure	Timber products, payment for the supplied resources. Commercial products' range and volumes expansion	Products price, possible sales volume, quality standards, available volume and quality of resources
Society	Labor resources; informational resources and informational support; the company's image	Employment; pay; social benefits; a piece of the finished product	Requirements to ensure social benefits, taking part in social programs and compliance with environmental standards
State	Access to logging base information; informational and legal support; infrastructure; access to government institutions and structures	Taxes; reduction of social tension and unemployment; GRP and GDP growth; business development	Ecological, technical, legal and regulatory and other restrictions to protect society, market, environment and state
Environment	Natural resources (wood resources), water resources; waterways for transporting raw materials and products	Set of environmental protection measures, if enterprise takes part in their implementation	Quality and amount of resources on a certain area; total water resources; possibility to create and maintain transport networks
Source: own compilation.			

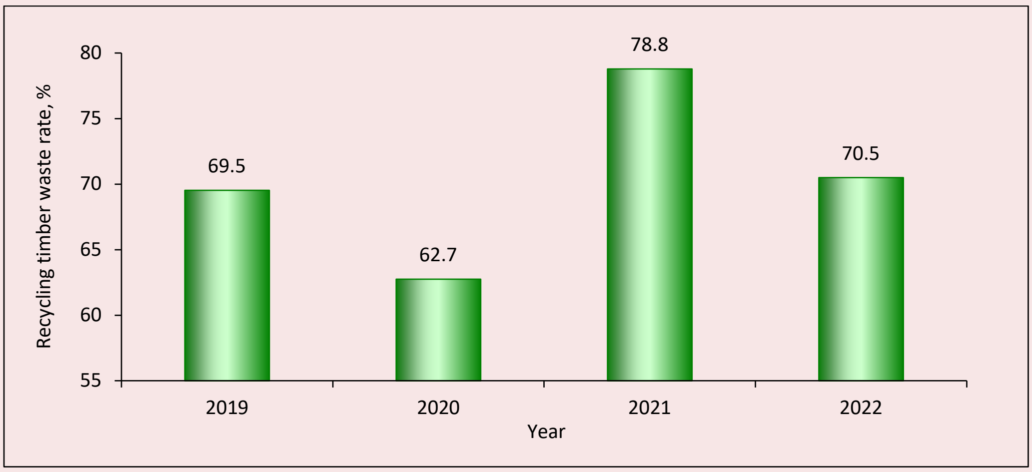
Modern Russian forest increasingly uses timber recyclables. In recent years, their recycling rate reaches approximately 70% (*Fig. 2*). This is the main resource in the model, which is being reused. On one hand, timber recyclables (Nr) expand the enterprise's resource base and, on the other hand, reduce the environmental damage.

External factors have significantly influenced the recyclable amount of waste in recent years. Fluctuations in production volumes, exports, and timber resources demand have been caused by restrictions imposed by markets and foreign governments. The industry has been refocusing on Asian markets since 2022. Products made from recycled timber resources are not in the same demand in Asian markets as they were in Europe. The most obvious example is pellet fuels (pellets).

The forest industry is primarily restricted by environmental requirements for both products and processes at enterprises. For Russian forest businesses environmental agenda has long been associated with meeting the environmental demands of export markets. Many enterprises limited to obtaining certifications (FSC, PEFC). However, in recent years, the relevance of this factor has increased due to the efforts of the state and society. Terms decarbonization, carbon footprint, and sustainable development are becoming more and more common in the goals and objectives of the industry. The activities of companies are gradually transforming as they have to meet modern requirements. Workers, environmental and public policies, as well as technologies are changing. Despite restrictions imposed by some countries, trend toward strengthening the role of environmental and social agenda continues.

Under these conditions, effective planning of activity, consideration of all restrictions and balance in decision-making at forest enterprises require proper justification. Economic and mathematical modeling is a common sufficient means to plan, analyze and forecast various aspects of enterprise activities at macro and meso levels. Currently, there are many mathematical models available for optimizing enterprise activities. Some of them also consider the balance between socio-ecological and

Figure 2. Recycling timber waste rate in Russia 2019–2022, %



Source: Federal Service for Supervision of Natural Resources.

economic interests (Shelukhina, 2014). However, such developments are rare for the forest industry and often require specification.

This study aims to design a mathematical model to find balance between economic, social and ecological development priorities and current restrictions.

Let us define a forest enterprise production to as $F\ (x_1, x_2, \dots, x_n)$ – an objective function of production. n stands here for a resource used. As it was mentioned before, production and management activity of forest enterprises features various effects. Considering the general trends in science, they can be divided into the following categories:

– ecological: degree of environmental pollution (waste, emissions, discharges, occupational noise etc.); reforestation amount; forest resources extraction etc.;

– technical and economic: production volume, amount of revenue and net income, productivity gains (workers and machinery), new products, consumers etc.;

– social: working population; average pay; implementation of social programs for workers and local communities etc.

An enterprise's activities result in the m amount of such activities. Matrix of effects produced can be seen below:

$$E_p = \begin{pmatrix} e_{11} & e_{12} & \dots & e_{1n} \\ e_{21} & e_{22} & \dots & e_{21} \\ \dots & \dots & \dots & \dots \\ e_{m1} & e_{m2} & \dots & e_{mn} \end{pmatrix}, \quad (1)$$

where $e_{ij} > 0$ – amount of j-effect, obtained from using of i-resource. Effects vector $\bar{o}$ is calculated as follows:

$$\bar{o}^T = E_p \cdot \bar{x}^T$$

$$\text{or } o_k = \sum_{i=1}^{n} e_{kj} x_j \,, k = 1, 2, \dots, m \,, \quad (2)$$

where $\bar{x}$ – row vector of resources used.

Since enterprises are subject to various restrictions in addition to the effects obtained, the mathematical model should include several additional conditions. The following conditions should be added:

1. H Matrix of coefficients, limiting the resources. Market, society and state significantly influence this aspect of business activity. This is an external restriction for a forest enterprise.

2. $\bar{a}$ restrictions vector, determined by internal capabilities of a forest enterprise. It includes equipment performance, highway and storage capacity, financial ability of a business, requirements established in the charter or in corporate code.

3. Regulatory restrictions vector $\bar{o}^*$ for obtained effects This aspect is the most difficult to calculate and express. Considering the three areas under consideration, the following restrictions on the obtained effects can be examined:

– environmental sphere: meeting waste generation standards, maximum allowable concentration of emissions and discharges, noise restrictions etc. In Russia, such restrictions apply to all types of emissions and impacts from the forest enterprises' activities. Forest enterprises must also comply with restrictions on the amount of logging (both overcutting and undercutting are unacceptable in the cutting areas), scale of reforestation and other environmental protection measures;

– technical and economic sphere: meeting product quality standards (domestic and foreign in the case of their export); mandatory deductions to fund and budgets (taxes, social insurance funds); obligations for sale of foreign currency earnings; patent-licensing restrictions on the use, manufacture and sale of the products, machinery and equipment (both in the case of in-house developments and those purchased from third-party organizations), etc.;

– social sphere: pay amount (minimum wage and its relation to the average one for the region); meeting the working conditions and safety standards, compliance with certificates (for example, FSC и PEFC); an enterprise's involvement in social events and programs. Territorial governments traditionally attract forest enterprises, especially large ones, to finance and implement individual programs and projects (large businesses that participate in regional projects).

Efficient operation of an enterprise requires meeting the regulatory restrictions (including the reduction of a number of costs to eliminate non-compliance with regulations) or exceeding the values of impacts above their regulatory values:

$$\bar{o} \geq \bar{o}^*. \qquad (3)$$

However, some restrictions establish the upper bound values of the effect, while others establish the minimum values. Therefore, ratio (3) is incorrect. To compare effects and their normative values, we introduced a vector $\bar{\tau}$, that defines the nature of the current restriction:

$$\tau_j = \begin{cases} -1, \text{if } o_j^* \text{ sets the upper threshold limit,} \\ 1, \text{if } o_j^* \text{ sets the minimum admissible limit.} \end{cases} \qquad (4)$$

$$j = 1, 2, \dots, m.$$

Considering the $\bar{\tau}$ introduction, ratio (3) will be expressed as follows:

$$\bar{\tau} \cdot (\bar{o} - \bar{o}^*) \geq 0. \qquad (5)$$

Let us give an example. Suppose the emission standard for a certain enterprise is 10 tons. Then, if the actual volume is 9 tons and τ = -1, the ratio is correct: -1 · (9 – 10) = 1 ≥ 0. If τ = 1, for example when there are restrictions on the volume of reforestation work, the effect must exceed the value set for the enterprise in order to fulfill the condition. If the enterprise restored 50 hectares of forest with a standard of 40 hectares, ratio (5) will be correctly expressed as 1 · (50 – 40) = 10 ≥ 0.

Summarizing the conditions presented above, the task of optimizing the production activity of a forest enterprise is to find the maximum of the function:

$$F(x_1, x_2, \dots, x_n) = F(\bar{x}) \rightarrow max \qquad (6)$$

set of feasible solutions

$$\begin{cases} \bar{x} \geq \bar{0}, \bar{o} \geq 0, \\ Hx^T \leq \bar{a}^T, \\ \bar{\tau} \cdot (\bar{o} - \bar{o}^*) \geq 0. \end{cases} \qquad (7)$$

The fulfilment of the final condition in system (7) (its expanded formula represents restrictions of the sum of achieved effects for each type of resource):

$$\bar{\tau} \cdot (\sum_{j=1}^{n} e_{kj} x_j - o_k^*) \geq 0, k = 1, 2, \dots, m, \qquad (8)$$

represents enterprise activity during the movement into sustainable development. The sum of all effects (technical and economic, environmental, social) should lead to a positive outcome for an organization's functioning. Therefore, a forest enterprise must meet regulatory restrictions on each effect. This results in the creation of socially and environmentally responsible businesses that receive economic benefits. However, any failure to comply with any restriction (8) should have clear consequences.

The major purpose of any enterprise is profit maximization. Profit decline or loss, a logical consequence of stepping beyond regulatory restrictions, should become a driver in stimulating businesses to implement condition described above. On the other hand, it is important to encouraged businesses to move to sustainable development, considering achievement of social, technical and economic and ecological effects. The value expression of the achieved results under such conditions is one of the most important elements of the problem being solved in this study. Let us refer to the classical definition of profit (*P*). This is revenue (*G*) minus costs (in our case for the use of production factors – *Cf*):

$$P = G - Cf. \qquad (9)$$

Let us derive the expanded form of this equation by introducing a number of new components: p – aggregated price of the forest enterprise production; c – aggregated price of the production factors use (resources); $Z(x_1, x_2, \dots, x_n)$ – objective function of recourses use task (production factors). Production volume is denoted as $G = p \cdot F(x_1, x_2, \dots, x_n)$ or $G = p \cdot F(\bar{x})$; $Cf = c \cdot Z(x_1, x_2, \dots, x_n)$ or $Cf = c \cdot Z(\bar{x})$.

Taking into account compliance with the regulatory values of the obtained effects being the crucial element for production optimization, it is logical to include in formula (9) an element reflecting sanctions for non-compliance with the established requirements. Let us introduce a vector $\bar{d}$, the components of which determine the amount of payment for the forest enterprise for non-compliance with the regulatory values of effects (if the third condition in (7) is not fulfilled):

$$\bar{d} = (d_1, d_2, \dots, d_m). \qquad (10)$$

It is also necessary to introduce a vector $\bar{\varepsilon}$, which will determine the fulfillment of the third condition in system (7):

$$\varepsilon_j = \begin{cases} 0, \text{if } \bar{\tau} \cdot (o_j - o_j^*) \geq 0, \\ 1, \text{if } \bar{\tau} \cdot (o_j - o_j^*) < 0. \end{cases} \quad j = 1, 2, \dots, m, \qquad (11)$$

where o_j and o_j^* – vectors components for obtained effects and their regulatory restrictions.

The Forest industry features the generation of timber waste which can be reused for products it was created from or to produce new ones. In the forest industry, such resources are most commonly used for energy and deep timber processing production (board materials, pellet fuels, pulp and paper products). Therefore, timber recyclables (*W*) contribute to other resources (production factors) in a form of material resources (*N*). A similar situation occurs with other resources (Fig. 1). *r* stands for recyclables' types. To each resource type x_n will be added r resources: $x_{n+1}, x_{n+2}, \dots, x_{n+r}$. The row vector of resources used will take the form of $\bar{y}$: $\bar{y} = (\overline{x_{n+r}})$. An enterprise will bear costs to reuse the recyclables, so both functions $F(\bar{x})$ and $Z(\bar{x})$. will be changed.

According to all additional conditions, the model for optimizing a forest enterprise activity is determined as finding the maximum of function (12) in the set of feasible solutions (13)::

$$P = p \cdot F(\bar{y}) - c \cdot Z(\bar{y}) - \bar{d} \cdot \bar{\varepsilon}, \qquad (12)$$

$$\begin{cases} \bar{y} \geq \bar{0}, \\ H\bar{y}^T \leq \bar{a}^T. \end{cases} \qquad (13)$$

According to the authors' concept, the variable *P* in the functional dependency (12) represent net income of an enterprise after deducting taxes, fines, and other mandatory payments is largely influenced by the set of management, technical, and economic processes, such as the amount of profit, the level of negative impact on the environment, compliance with regulations, and the value of assets etc. In fact, it is also part of the effects received from the use of resources, which fits into the model presented. Social programs implemented by enterprises follow the same logic. The resources allocated to them lead to a variety of effects: employee motivation, increased loyalty of the population, absence of conflicts with local communities, etc. All this, as well as the interaction with the state and the environment result in significant effects on the production and economic processes within the enterprise.

The competitiveness and efficiency of forest enterprises are determined by the effects they produce. Taking into account the global trends of moving into sustainable development, joint efforts of business, society and state are required to change the existing approaches to their functioning. Structural changes and motivation of each stakeholder by all possible means are required. At the same time, in the literature (Bobylev, 2020; Hahn, Knoke, 2010) there are often references to the need for separate state programs to stimulate business to actively implement the principles of sustainable development. In the authors' opinion, such programs are an important component that will allow enterprises to improve many internal processes. The forms of state support can be different – subsidies, reduction of the tax base, allocation of additional resources (logging base), etc. In any case, the received benefits will be one of the produced effects reflected in (1). Therefore, all the changes that occur and directly or indirectly affect forest enterprises will be presented in the proposed model. The task for optimizing forest enterprises activities will be solved in practice with taking into account the input factors and the obtained effects. Each business will operate within the existing restrictions, considering the possible effects.

State stimulation to the sustainable development for forest enterprises is associated with the establishment of tighter restrictions $\bar{o}^*$. At the same time, the imposed restrictions should be accompanied by methods of positive stimulation – motivation. In this case, the positive effects will be able to exceed the negative ones, including trough the synergetic effect and the use of recyclables.

The proposed model has significant impacts in three areas: technical and economic, environmental, social. These effects are represented by a 3D model of the response surface (convex function; *Fig. 3*).

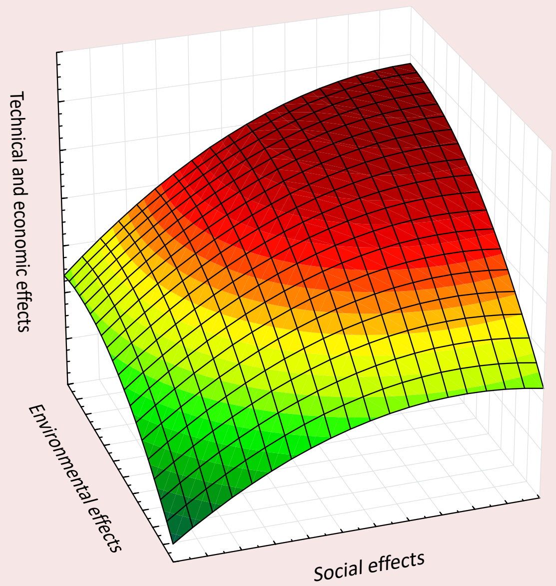
According to equation (12), non-compliance with regulatory values for effects leads to a decrease in all effects. Focusing on any one aspect of an enterprise's activity (for example, focusing on economic results only) will lead to reduction of other results, and this will affect the potential for achieving economic effects. Therefore, the maximum effect of one activity aspect will be restricted by the effects in other areas. As a result, the feasible region significantly reduces (*Fig. 4*).

The model clearly demonstrates the reduction of the feasible region to achieve desired effects. Therefore, forest enterprises are motivated to comply with the restrictions of the developed model.

To use the presented model in forest industry state management, changes in the regulatory base are necessary. They should encourage businesses to actively implement sustainable development principles. This can be achieved through the development and implementation of state programs that provide effective tools to promote responsible business (subsidies, huge resource allocation and other support measures). Changes of legal base should focus on tightening restrictive measures to ensure compliance with environmental, social, and economic requirements of state policy in the context of sustainable development.

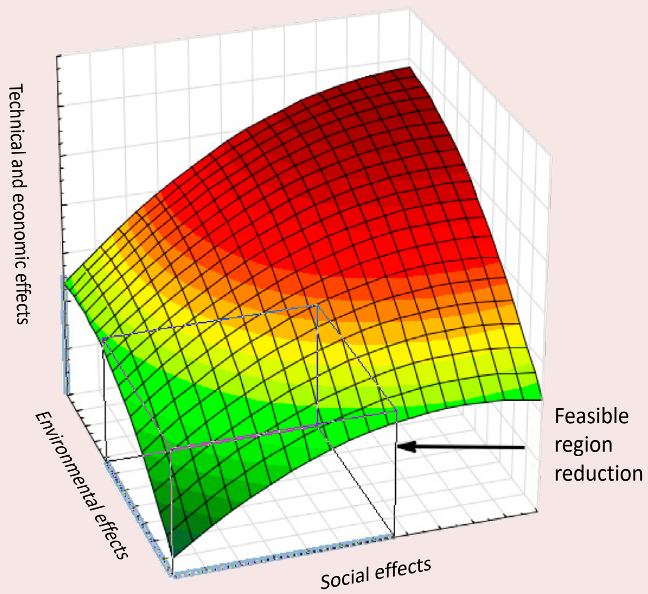
Some forest enterprises, using the model under consideration and their own business data, can obtain more information about development opportunities and the effects of participating in social and environmental activities. Therefore, the presented model serves as a basis for developing

Figure 3. 3D model depicting effects of forest enterprise activity



Source: own compilation.

Figure 4. Feasible region reduction if conditions of designed model are not met



Source: own compilation.

business strategies with taking into account their changing priorities (from economic to balanced). Implementing this model in enterprises' activity requires a preliminary review of all possible effects, resources, and restrictions; their correlation, and a set of calculations to assess the effectiveness of potential transformations. The widespread implementation of this approach requires a detailed methodology, the development of which is the next step of the authors' work.

Approbation and evaluation of the effects of using the above model is a complex task that requires, even for a single enterprise, a comprehensive study with access to a variety of data constituting a trade secret. The authors analyzed the practice of implementing certain principles of sustainable development by one of the leading timber enterprises of the Krasnoyarsk Territory. Based on the results of the practical study, it was revealed that the changes are associated with the transformation of the technological scheme, introduction of several units of high-performance equipment with less environmental impact, improved working conditions for personnel, partial modernization of infrastructure, and the output of new products based on previously unused wood waste. The resulting effects are associated with an increase in production and economic performance, an increase in staff salaries, a decrease in environmental impact and a number of other positive changes.

Conclusion

The research developed a model for optimizing forest enterprises' activities, considering the movement into sustainable development. The model includes a range of effects that impact the resulting economic parameter (profit) through the use of various resources. Enterprises are affected by a set of restrictions, that limit the feasible region of effects if these restrictions are not complied with. The authors' model takes this into account and represents the novelty of the research.

The research presents a graphical model of resource flows at a forest enterprise. The model summarizes generally accepted approaches to describing the activities of an enterprise, including assessment of the external environment, production factors, recyclables etc. The model emphasizes the resources, restrictions and effects obtained by forest enterprises. The designed model, along with the description of some external environment components, can be used for further research on interactions and the development of its components.

The main finding confirms the thesis that great efforts are needed to encourage businesses to implement sustainable development. These efforts should be based on tightening existing complimentary restrictions and developing measures to encourage businesses. The mathematical framework presented reflects the technical, economic, environmental, and social dependencies in the activity processes of forest enterprises. The presented mathematical framework reflects the technical, economic, environmental and social dependencies in the business processes of forest enterprises.

The presented results may be valuable to researchers of the forest sector economy and to the industry. In the applied aspect, the federal authorities can practically use the results to implement sustainable development programs and create industrial policy. Taking into account the prospects of transitioning to sustainable development, the presented results will be useful for the heads of forest businesses, especially large ones, in developing relevant strategies and development plans.

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