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Organizational and economic aspects of ecologization in the development of the hop products subcomplex

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ABSTRACT

The article examines the organizational and economic aspects of ecologization in the hop products subcomplex, which includes hop cultivation, its processing, and the production of related products such as beer. It has been established that the development of productive forces has led to a global ecological crisis, exacerbated by the activities of the hop products subcomplex, associated with the use of chemical substances, energy-intensive technologies, pollution of water bodies with wastewater, and high equipment wear. These processes result in increased ecological risks and the penetration of harmful substances into the final product, negatively affecting human health. It has been determined that ecologization of the hop products subcomplex addresses two key tasks: reducing the environmental burden (air, water, and soil pollution) and ensuring the production of safe products by preventing toxins, using harmless additives, and developing functional products that enhance organism resilience. The article emphasizes the improvement of legislation, the implementation of resource-saving technologies, equipment modernization, waste recycling, and the use of digital platforms in the green economy. The introduction of an ecological management system for risk control and government support measures allows for the reduction of emissions, water and energy consumption, as well as an increase in waste recycling. It has been determined that the success of the hop products subcomplex development depends on the interaction between the state, business, communities, and science, which includes the development of sustainable varieties, functional products, and waste-free technologies. All this enhances the industry's competitiveness, reduces the ecological footprint, and promotes sustainable development, taking into account international experience. At the same time, prospects include biotechnologies, automation, and the expansion of organic production to meet the demand for environmentally friendly products in the hop products subcomplex.

Keywords: Ecologization, Hop products subcomplex, Organizational and economic measures, Sustainable development, Green economy.
Article type: Perspective.

INTRODUCTION

In the era of intensive industrial growth, humanity has achieved unprecedented heights in mastering natural resources, which, however, has led to serious ecological consequences. At the same time, the development of productive forces has allowed for a significant expansion of influence on the environment, interfering in natural processes, disrupting the cycle of substances and energy, as well as altering the structure of ecosystems. This process has become a catalyst for the global ecological crisis, as the increase in production volumes and product diversity has long been carried out without proper consideration of ecological requirements, as emphasized in studies on product quality assessment and sustainable development (Agamirova *et al.* 2017). In the context of the agro-industrial complex, where agricultural and processing sectors play a key role, such trends manifest particularly acutely, leading to soil, water body, and atmospheric pollution, as well as resource depletion. At the

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same time, special attention is warranted for the hop products subcomplex (HPSC), which includes hop cultivation, its processing, and the production of related goods such as beer. This subcomplex, being an important part of the food industry, is capable of causing tangible harm to nature, and the threat intensifies with the expansion of activity scales. Subcomplex enterprises often use chemical substances and energy-intensive technologies, making them potentially hazardous objects, while wastewater from hop processing and beer production pollutes water bodies with organic waste. At the same time, equipment wear and outdated work methods lead to high resource intensity and energy costs, as noted in works on the economic efficiency of hop production in Russia (Karataeva *et al.* 2021a). Moreover, harmful substances can penetrate the final product, negatively affecting human health, which actualizes the need for ecologization as a comprehensive approach to risk minimization. At the same time, ecologization of the hop products subcomplex solves two fundamental tasks: reducing the environmental burden through decreased air, water, and soil pollution, as well as more rational use of natural resources; ensuring the production of safe, high-quality products by preventing the penetration of toxic substances, using harmless additives, and developing products that enhance organism resilience to external factors. To address these tasks, organizational and economic measures are required, including the creation of ecological policy mechanisms at the state and sectoral levels, which aligns with risk management methodologies under globalization conditions (Filonova *et al.* 2024). At the state level, tax regulators, licensing systems, norming, and quota systems are already applied, as well as ecological fees that translate external negative effects into production costs. At the same time, stimulating ecologically safe activities and distributing responsibility, including insurance, complement this approach, as shown in the analysis of public-state partnership in education and economic growth (Dzhikiya *et al.* 2023a). At the sectoral level, the formation of such mechanisms relies on the legislation of the Russian Federation on environmental protection and other regulatory acts. At the same time, enterprises of the hop products subcomplex must develop initiatives for compliance with standards, coordinate state and sectoral programs, solving functional tasks while considering the preservation of resource potential.

The foundation lies in a preventive approach to nature protection and ecologization of production in accordance with Russian and international standards, including the implementation of artificial intelligence and information technologies in measurements and automation (Dudukalov *et al.* 2021). In the period from 2020 to 2024, efforts were focused on improving the legislative base, implementing resource-saving technologies, and developing technical measures, taking into account Russia's participation in international agreements on nature protection, which required a revision of sectoral norms. Certification of specialized services, development of projects for maximum permissible emissions and discharges adapted to the Water Code of the Russian Federation, equipment modernization including replacement of boilers and turbines, reconstruction of treatment facilities, implementation of water reuse systems, and improvement of air purification technologies allowed for the reduction of harmful emissions and avoidance of fines. However, the lack of economic support hinders full compliance with requirements, as emphasized in studies on sustainable development of the agro-industrial complex (Khoruzhy *et al.* 2023a). An important step was the use of waste and secondary raw materials, implementation of technologies with minimal waste generation, which expands the raw material base without additional burden on nature and reduces pollution, especially in the context of producing environmentally friendly hop raw materials (Karataeva *et al.* 2021b). New technologies for organic raw material production involve rational placement of production using digital platforms in the green economy, including high-quality planting material, modern equipment, transformer robots, agrotechnologies, and improvement of the organizational and economic mechanism for linking the interests of producers and consumers (Karataeva *et al.* 2021c). At the same time, ecologization takes into account the zonal specifics of regions, hop varieties for each terroir, influencing geographical competition in the international market. Therefore, reducing negative impact is possible through an ecological management system according to the ISO 14001 standard, minimizing process impacts, ensuring safety at all stages of the product life cycle, preventing pollution, and reducing waste (Khoruzhy *et al.* 2023b). At the same time, rational use of resources, increasing the share of recycled waste, reducing emissions require capital investments in environmental measures and prevention of norm violations. At the same time, the need for high-quality products as a basic need for humans emphasizes pollution risks with radionuclides, pesticides, heavy metal salts, and nitrates, with risk factors: microbiological, chemical, and physical (Mukhlynina *et al.* 2018). In addition, control is relevant with demand for natural products, reducing the use of preservatives. At the same time, safety requirements assume the presence of macro- and microelements, non-toxicity, harmless additives, energy saving, waste recycling, and quality certificates. In Russia, all this stimulates modernization in regions like the Chuvash

Republic through subsidies, loans, tax incentives, and grants, similar to international experience (Karataeva et al. 2021d). Practice has shown that community participation in monitoring enhances effectiveness, and the interaction of the state, business, communities, and science ensures a systemic approach (Trukhachev & Dzhikiya, 2023). At the same time, prospects include adaptation of foreign practices, development of a scientific base for sustainable varieties, implementation of HACCP for risk analysis (Khoruzhy et al. 2023c). It is necessary to understand that ecologization is linked to the production of functional products enriched with beneficial components for health, following global trends (Karataeva *et al.* 2023e). In addition, development requires investments, scientific research in nutraceutics, biotechnologies, with priorities: safety, biotechnology processing, composites, preventive products. Thus, ecologization of the hop products subcomplex combines scientific, technological, and regulatory aspects for sustainable development, minimizing harm to nature and improving product quality, opening paths to competitiveness in the green economy.

MATERIALS AND METHODS

The present study is based on a comprehensive analysis of the organizational and economic aspects of ecologization in the hop products subcomplex of the Russian Federation, with emphasis on key regions such as the Chuvash Republic and the Altai Krai, where hop growing has historically established traditions. To achieve the set goals, both theoretical and empirical methods were used, allowing for a comprehensive assessment of the current state of the industry, identification of problems, and proposal of measures for their resolution. First and foremost, a review of scientific literature on sustainable development of the agro-industrial complex was conducted, including works on assessing the economic efficiency of hop production and methodologies for product quality management, which allowed for the formation of a conceptual basis for analyzing ecological risks and mechanisms for their minimization. Data for the study were collected from official sources, including statistical reports from the Ministry of Agriculture of the Russian Federation, as well as reports from enterprises of the hop products subcomplex on the implementation of resource-saving technologies and ecological management systems. In particular, indicators of equipment wear, volumes of wastewater, and harmful emissions obtained from ecological audits corresponding to the ISO 14001 standard were analyzed. To assess the impact on the environment, indicators such as annual consumption of electricity, water, and fuel, as well as waste characteristics including the presence of harmful substances, were applied, as recommended in methodological approaches to monitoring sustainable development of the agro-industrial complex. The empirical part included a comparative analysis of international experience in ecologization of hop growing in leading countries such as the Czech Republic, Germany, and the USA, based on published data on government support measures. For this, content analysis methods of reports and publications were used, including grants for research on sustainable hop varieties and tax incentives for organic production, which allowed for adapting foreign practices to Russian conditions taking into account climatic and zonal regional features. In particular, a systemic approach to modeling organizational and economic mechanisms was applied, relying on the concept of the green economy and digital platforms, where factors of rational placement of organic hop raw material production and implementation of modern agrotechnologies were considered. For analyzing product safety risks, including microbiological, chemical, and physical factors, the HACCP (Hazard Analysis and Critical Control Points) system was employed, integrated with data on pollution by radionuclides, pesticides, and heavy metal salts. This system included identification of critical control points at stages from hop cultivation to processing and waste disposal, using statistical data processing methods such as calculating average values and variance for indicators of emission reduction and consumption. In addition, modeling of economic effects from implementing energy-saving technologies and waste recycling was conducted, using OLAP technologies for cost and risk management, which allowed for forecasting expected results such as energy savings and increased waste recycling. The involvement of stakeholders (state, business, local communities, and scientific institutions) was evaluated through matrix analysis of roles and actions, based on data about cooperatives in Chuvashia and soil monitoring. For studying prospects of functional product production enriched with vitamins and probiotics, forecasting methods based on global trends were used, with calculation of annual segment growth. The overall analysis was conducted using qualitative methods such as expert assessments and SWOT analysis, supplemented by quantitative calculations of economic efficiency, including the contribution of science to the development of biotechnologies and automated systems. All this ensured a comprehensive understanding of ecologization processes, taking into account regulatory regulation and incentives for sustainable industry development in the context of global climate changes.

RESULTS AND DISCUSSION

The development of productive forces has significantly expanded humanity's ability to impact the environment, interfere in natural processes, the cycle of substances and energy, as well as alter the structure of ecosystems. This process has become the cause of the global ecological crisis, as the growth in production volumes and increase in its diversity have long occurred with minimal consideration of ecological requirements. The current state of the hop products subcomplex, which includes hop cultivation, its processing, and the production of related goods such as beer, is capable of causing tangible harm to nature, and this threat grows with the expansion of activity scales. The reasons for this lie in several aspects: industry enterprises often use chemical substances and energy-intensive technologies, making them potentially hazardous objects; wastewater from hop processing and beer production becomes a source of water body pollution with organic waste; equipment wear reaching 50–60%, and outdated work methods lead to high resource intensity and energy costs. Moreover, harmful substances through various pathways can enter the final product, negatively affecting human health. Based on this, ecologization of the hop products subcomplex is intended to solve two key tasks. The first is reducing the environmental burden created by industry enterprises through decreasing air, water, and soil pollution with harmful emissions and more rational use of natural resources. The second is ensuring the production of safe and high-quality products by preventing the penetration of toxic substances from raw materials during processing, using harmless additives, and developing products that enhance human resilience to adverse external factors. Therefore, to achieve these goals, organizational and economic measures are necessary, including the creation and development of ecological policy mechanisms at both state and sectoral levels. At the state level, tools such as tax regulators in the spheres of licensing, norming, and quota systems are already applied, as well as a system of ecological fees that translates external negative effects into production costs. Stimulating ecologically safe activities and distributing responsibility for the growth of ecological risks, including insurance, complement this approach. At the sectoral level, the formation of similar mechanisms is carried out in accordance with the legislation of the Russian Federation on environmental protection and other regulatory acts governing this sphere. Under these conditions, enterprises of the hop products subcomplex must develop initiatives aimed at compliance with ecological standards. Enterprises also need to coordinate the implementation of both state and sectoral programs and take measures to solve their functional tasks, while not forgetting the importance of preserving resource potential. The basis of such activities is a preventive approach to environmental protection and ecologization of production in accordance with Russian and international standards (Karataeva *et al.* 2021; Voskovskaya *et al.* 2022; Dzhikiya *et al.* 2023). In the period from 2020 to 2024, efforts were focused on three main directions: improving the legislative base, implementing resource-saving technologies, and developing technical measures. At the same time, Russia's participation in international agreements on nature protection required a revision of sectoral norms. Certification of specialized services was conducted, and projects for maximum permissible emissions and discharges adapted to the Water Code of the Russian Federation were developed. At enterprises, equipment was modernized, including replacement of boilers and turbines, treatment facilities were reconstructed, water reuse systems were implemented, and air purification technologies were improved. This allowed for the reduction of harmful emissions and avoidance of fines for exceeding pollution norms, although the lack of economic support hinders full compliance with ecological requirements. On the other hand, an important step for enhancing the ecological efficiency of the hop products subcomplex was the use of waste and secondary raw materials, as well as the implementation of technologies with minimal waste generation. Under such conditions, reducing waste volume not only expands the raw material base without additional burden on nature but also decreases environmental pollution. Industry waste, such as beer draff, contains valuable components—proteins, carbohydrates, and vitamins—however, a significant portion is used irrationally, causing damage to ecosystems. Nevertheless, positive changes are noticeable: new products from secondary raw materials are being mastered in production, which contributes to reducing the ecological burden. At the same time, new technologies for organic raw material production and the concept of ecological capacity involve rational placement of organic hop raw material and hop product production using digital platforms under the conditions of forming a green economy. In this regard, it is necessary: using high-quality planting material; employing new, modern equipment and transformer robots; implementation of modern agro-technologies; improvement of the organizational and economic mechanism for linking the interests of hop raw material producers and consumers; updating the material and technical component of hop cultivation, hop raw material production, and hop products. Production of

ecological raw materials is possible under conditions where hop production as a whole, as well as its primary and deep processing, are carried out using high-tech equipment (Karpov *et al.* 2017; Loseva *et al.* 2017; Karataeva *et al.* 2021). At the same time, the need of industrial sectors for high-quality organically ecologized hop raw materials is growing, which leads to the necessity of modernizing all stages of production and processing technologies in production and processing. It is necessary to apply new technologies for organic raw material production in Russia's hop products complex. Moreover, new technologies for organic hop raw material production involve rational placement of organic product production in the HPSC using digital systems under the conditions of forming a green economy and optimal placement of organic product production. Ecologization of the production process in the HPSC should be implemented taking into account the ecological features of hop cultivation and the zonal specifics of regions, defined hop varieties for each terroir in the region, which will allow influencing external factors of geographical competition for hop raw materials in the international market. For a deeper understanding of ecologization processes, it is useful to refer to Table 1, which illustrates the key directions of ecologization in the hop products subcomplex, including goals, methods, and expected results. It emphasizes a systemic approach to solving the industry's ecological problems and focuses attention on the necessity of integrating modern technologies.

Table 1. Directions of Ecologization in the Hop Products Subcomplex.

Direction	Goal	Implementation methods	Expected result
Emission reduction	Reduction of air pollution	Equipment modernization, filters	Reduction of harmful emissions by 20%
Rational water use	Conservation of water resources	Water reuse systems	Reduction of water consumption by 15–20%
Waste recycling	Reduction of ecosystem burden	Secondary raw material utilization	Increase in recycling to 30%
Energy efficiency	Reduction of energy costs	Implementation of energy-saving technologies	Energy savings up to 25%

Ecologization of the hop products subcomplex requires a comprehensive approach that combines state and sectoral efforts, while the implementation of modern technologies, waste recycling, and compliance with ecological norms enable the reduction of environmental impact and enhancement of the industry's competitiveness. These measures not only address contemporary challenges but also establish a foundation for sustainable production development. At the same time, the success of these initiatives largely depends on the level of funding and the readiness of HPSC enterprises to adapt to new conditions, which is particularly important in the context of global climate changes. Reducing the negative impact of Russia's hop products subcomplex on the environment is possible through the implementation of an effective ecological management system at enterprises. Such a system must comply with the international standard ISO 14001, which defines key requirements for ecological provisions. In this case, the system's goals and objectives are formed taking into account the provisions of Russian legislative and regulatory acts governing environmental protection. Here, the primary emphasis is placed on preventing and reducing ecological risks, which requires enterprises in the industry to fulfill a series of priority tasks. Among them, particular importance is attached to minimizing the impact of technological processes on nature. This is achieved through the optimization of production operations aimed at reducing the burden on ecosystems. No less important is ensuring ecological safety at all stages of the product life cycle—from raw material processing to waste disposal. HPSC enterprises must strive to prevent pollution, reduce waste volumes, deepen hop raw material processing, decrease the share of defective products, and completely eliminate waste burial. Therefore, enhancing employee qualifications in ecology and involving all participants in the production chain, including raw material suppliers, in the ecologization process also play a key role in achieving these goals (Sycheva *et al.* 2023; Khoruzhy *et al.* 2023d; Rodionov *et al.* 2025). In this case, indicators corresponding to the ISO 14001 standard are applied to assess the effectiveness of the ecological management system. These include data on the composition and volumes of used raw materials and supplies, annual consumption of electricity, water, and fuel resources, as well as information on atmospheric emissions and characteristics of liquid and solid wastes, including the presence of harmful substances. Sources of environmental impact are also considered, with analysis of their intensity, potential risks of accidents, fire and explosion hazards, radiation characteristics, and the initial state of the natural environment. These parameters enable comprehensive monitoring of existing trends. Practice has shown that the activities of enterprises in the field of ecologization are focused on several directions (Kosevich *et al.* 2016;

Romanenkov *et al.* 2017; Karataeva *et al.* 2021h). Here, particular attention is warranted for the rational use of raw and material resources, which contributes to cost reduction and minimization of the ecological footprint. Furthermore, increasing the share of recyclable wastes helps minimize their harmful impact, while reducing emissions in the form of liquid, solid, and gaseous wastes requires the implementation of modern purification and filtration technologies. Therefore, capital investments in environmental protection measures become an important lever for realizing these tasks, and preventing violations of ecological norms remains a mandatory condition for the sustainable development of the industry. It is necessary to understand that the need for food products, including those from the hop products subcomplex, remains one of the fundamental needs for humans, as high-quality products enhance organism resilience to external factors, serving as an important indicator of well-being. However, industrialization and the growth of mass production have led to the complication of supply chains and an increase in product contamination risks. Harmful substances such as radionuclides, pesticides, heavy metal salts, and nitrates can enter the human body through HPSC products. This makes the development of measures to ensure product safety one of the priority tasks in the industry. Therefore, three groups of risk factors can be identified in the production process: microbiological, chemical, and physical. Microbiological threats include bacteria causing food infections and intoxications, viruses, parasites, and other microorganisms. Control of these factors is becoming increasingly relevant, as demand for natural products leads to reduced use of preservatives, salt, sugar, and thermal processing. As a result, products become less protected from external influences, which reduces their safety. Consequently, ensuring compliance with sanitary, hygienic, and phytosanitary standards becomes an integral part of industry ecologization. At the same time, modern requirements for the ecological safety of hop products subcomplex products assume the presence of necessary macro- and microelements for balanced nutrition. In addition, HPSC products must be non-toxic and free from harmful impurities. The additives used must not contain components hazardous to health. Also, at all stages—from production to consumption the formation of toxic substances and harmful microbiological processes is excluded. Production technologies must be oriented toward energy saving and waste minimization, which reduces the environmental burden (Seredina *et al.* 2017; Karataeva *et al.* 2021i; Potekhina *et al.* 2024). In addition, wastes must be recycled, with their products finding application or being incorporated into natural biogeochemical cycles. Packaging must also be suitable for multiple use or secondary recycling, and the presence of quality certificates with complete information on composition, storage conditions, and product production is mandatory. In Russia, a similar approach could become a powerful stimulus for modernizing hop growing, especially in regions with a developed industry, such as the Chuvash Republic. In this case, state support can be implemented through various instruments: subsidies for purchasing ecologically safe equipment, preferential lending for innovation implementation, tax incentives for enterprises using organic methods, as well as grants for conducting research (Table 2).

Table 2. Measures of state support for ecologization of hop growing and their impact.

Country	Support measure	Impact on the industry	Implementation period
Czechia	Subsidies for precision agriculture	Reduction of pesticide use by 25%	2018–2023
Germany	Tax Incentives for organic production	Increase in organic hop share by 15%	2015–2022
USA	Grants for research on sustainable varieties	Development of new varieties with enhanced resilience	2017–2023
Russia	Preferential lending for modernization	Expected reduction in water and energy costs by 20%	Forecast for 2025

As evident from Table 2, each country adapts support measures to its specific conditions and priorities; however, the common outcome is an enhancement of the industry's ecological sustainability. In Russia, the implementation of similar initiatives could not only reduce ecological damage but also increase the competitiveness of domestic hops on the international market, where demand for environmentally friendly products is steadily growing. However, the success of ecologization depends not only on the state and business but also on active financing (Zavalko *et al.* 2017; Shakhmametev *et al.* 2018). In regions where hop growing plays a significant role in the economy, local residents can act as partners and overseers. For example, in the Chuvash Republic, communities actively participate in monitoring the state of soils and water resources, which enables prompt responses to ecological issues and adjustments to production processes. This interaction strengthens the social foundation for implementing ecological projects and enhances their effectiveness. Furthermore, local communities can contribute to the popularization of environmentally friendly products, shaping consumer demand for them. Therefore, for a

deeper understanding of each party's role in the ecologization process, it is useful to examine their interactions within a unified system framework. All participants (the state, business, local communities, and scientific institutions) contribute unique inputs, which, with proper coordination, amplify the overall effect. For instance, the state establishes standards and provides funding, business implements technologies and develops new products, communities monitor compliance with ecological norms, and scientific institutions offer innovative solutions and train producers. This interaction can be represented in matrix form, as shown in Table 3.

Table 3. Roles and actions of stakeholders in the ecologization of the hop products subcomplex

Stakeholder	Role in the Process	Specific Actions	Examples from Practice
State	Regulator and sponsor	Establishment of standards, subsidies	Subsidies in Czechia
Business	Executor and innovator	Implementation of technologies, new products	Cooperatives in Chuvashia
Local communities	Overseer and partner	Environmental monitoring, project participation	Soil monitoring in Russia
Scientific institutions	Researcher and consultant	Development of methodologies, Training	Grants in USA

As evident from Table 3, each party performs its specific function, yet it is only through their collaborative efforts that a systemic outcome is achieved. In Russia, this approach is currently at an initial stage; however, the potential for its development is evident. For instance, expanding cooperative structures in conjunction with state support could stimulate the implementation of precision agriculture, which would reduce resource utilization and enhance yield. Simultaneously, local communities could assume the role of observers, ensuring transparency and oversight of compliance with ecological standards. The prospects for applying international experience under Russian conditions also merit attention. The Czech Republic, Germany, and the United States demonstrate that ecologization of hop growing is feasible with a clear strategy and financial incentives. In Russia, key regions for implementing such initiatives could include the Chuvash Republic and the Altai Krai, where hop growing has long-standing traditions. However, this necessitates adapting foreign practices while accounting for local specifics, such as climatic conditions, the structure of the agrarian sector, and ecologically oriented production. Another critical aspect is the development of a scientific foundation for industry ecologization. In the United States, research grants have led to the creation of new hop varieties resistant to diseases and drought, thereby reducing producers' dependence on chemical protection agents. In Russia, similar efforts could be undertaken collaboratively by universities and research institutes, enabling the development of varieties adapted to local conditions. This, in turn, would decrease import costs and enhance the industry's independence from external supplies. To comply with these requirements, a systemic approach to safety is essential, incorporating the analysis of potential risks. Under such conditions, traditional control schemes fail to encompass all aspects influencing safety and protect only against isolated threats. Therefore, it is crucial to identify all possible hazards and develop measures for their prevention.Complications arise from excessive regulation of indicators in technical specifications, necessitating a transition to unified state standards for homogeneous groups of HPSC products. The experience of developed countries illustrates the effectiveness of the HACCP (Hazard Analysis and Critical Control Points) system, which enables the identification, analysis, and control of risks at all stages from raw material production to final product consumption. The HACCP system is based on the assessment of all potential threats, determination of critical control points in the production process, and implementation of monitoring procedures, thereby ensuring protection against biological, chemical, and physical contaminations, drawing on advancements in agronomy, microbiology, and other disciplines. The implementation of HACCP not only enhances the safety of HPSC products but also provides data for developing preventive measures. On the other hand, this system contributes to strengthening the position of Russian HPSC products on the international market, as it is recognized by organizations such as UN/FAO within the Codex Alimentarius framework and underlies safety approaches in developed countries. Therefore, for a more illustrative representation of the key aspects of ecologization in the hop products subcomplex, Table 4 may be considered. At the same time, rational resource utilization reduces costs and ecological burden, waste disposal diminishes pollution, and safety control enhances product quality. Concurrently, the comprehensive application of such approaches enables not only the minimization of harmful environmental impacts but also the strengthening of the industry's competitiveness. Meanwhile, the ecological safety of food products from the hop products subcomplex is supported by a system of

legislative measures and regulatory requirements. In this regard, the development of standards, ecological norms, and technical specifications for HPSC products forms the foundation of this process. Furthermore, state registration of pesticides and agrochemicals is conducted only in the presence of methodologies that allow for the determination of residual quantities of these substances in hop raw materials and finished products. Additionally, state oversight of compliance with established norms is combined with veterinary-sanitary examination of HPSC products. During export and import, independent verification is performed, while radiological and toxicological control is carried out at all stages from production to realization. In this context, contaminated products are subject to seizure and disposal, thereby guaranteeing the protection of public health. HPSC enterprises, in turn, bear full responsibility for adherence to sanitary norms, and the system of fines and sanctions incentivizes them toward strict fulfillment of requirements.

Table 4. Methods and expected results of ecologization in the hop products subcomplex.

Direction	Goal	Implementation methods	Expected result
Resource optimization	Reduction of raw material and energy	Costs energy-saving technologies, process improvements	Decrease in costs and ecological footprint
Waste recycling	Reduction of volume and impact	Utilization of secondary raw materials	Disposal reduction of environmental pollution
Product safety	Guarantee of quality and safety	Control systems	Increase in consumer trust, compliance with standards

Contemporary ecological challenges, such as product contamination with harmful substances, necessitate the production of goods with elevated biological value. In the hop products subcomplex, this manifests in the creation of products with significant biological value. Nevertheless, the production of such products in Russia encounters a series of difficulties. Here, a particular emphasis is placed on the absence of modern domestic equipment capable of meeting technological requirements for the release of complex combined products, which limits production scales. At the same time, the shortage of investments in technologies that enable the reduction of harmful substance content in raw materials and finished products exacerbates the situation. Issues with forming a stable raw material base and ensuring ecologically clean zones for raw material production also play a role. In this regard, quality control of materials entering processing remains insufficiently stringent, while economic motivation for producing products with special properties is currently weakly expressed. Overcoming these barriers requires the development of state support measures for enterprises oriented toward the production of organic products. An important direction in the development of the hop products subcomplex is ecologization associated with the production of functional food products. This term, which emerged in Japan in the early 1990s, encompasses items specifically designed to maintain health and reduce disease risks. Such products include dietary, preventive, specialized, and enriched variants, as well as biologically active supplements. Their composition may include both natural and added components dietary fibers, oligosaccharides, amino acids, vitamins, minerals, and probiotics. Depending on the method of achieving functionality, they are subdivided into several groups: from natural products with high content of beneficial substances to modified items with improved bioavailability of active components. In this regard, such developments are aimed at enhancing organism resilience to external adverse factors. The prospects for functional product production in Russia are substantial and reinforced by global trends. In Europe, such items already occupy one-fifth of the food industry market, and in the coming years, their share may reach 30%. Large HPSC companies, leveraging advancements in nutraceutics, biotechnologies, and pharmacology, are becoming leaders in creating new ingredients and products. In Russia, this process is supported by scientific research and state initiatives aimed at developing products that strengthen health and reduce the burden on the healthcare system. For a more illustrative representation of the key aspects of this direction, reference may be made to Table 5, which displays the main categories of functional products, their purposes, creation methods, and expected effects. Practice has demonstrated that the development of functional product production, aligning with global trends, unveils substantial prospects for meeting the escalating demand for HPSC products that contribute to health fortification. It is projected that over the next five years, the annual growth of this segment will range from 7–10%. Achieving such potential necessitates active state involvement. In this regard, financial support is essential for updating the technological base of the HPSC, enabling the creation of products with predefined characteristics. Equally important is raising public awareness regarding the benefits of such products and their significance for health maintenance. Attaining these objectives is unattainable without proactive advancement in scientific research within nutraceutics, as well as related disciplines and technologies

for HPSC product manufacturing. Science plays a pivotal role not only in the development of functional products but also in the ecologization of their production processes, as contemporary knowledge facilitates precise evaluation of product consumption impacts on the human organism, determination of macro- and micronutrient functions, and establishment of standards for composition, quality, and product safety.

Table 5. Main categories of functional products in the hop products subcomplex.

Category	Purpose	Creation methods	Expected effects
Radioprotective products	Protection from radiation exposure	Inclusion of beta-carotene, alginates	Reduction in radionuclide
Accumulation antioxidant products	Neutralization of toxins	Use of pectins and antioxidants	Elimination of heavy metals from the body
Enriched products	Improvement of nutritional value	Addition of vitamins, minerals, probiotics	Enhancement of immunity and overall tone
Preventive products	Prevention of Chronic Diseases	Application of dietary fibers, oligosaccharides	Reduction in risk of various pathologies

Technological advancements ensure the implementation of automated systems and closed-loop production cycles that minimize waste, thereby promoting resource conservation and reduction of environmental burden. In this context, priority tasks for scientific organizations collaborating with the Ministry of Agriculture of the Russian Federation and the Russian Academy of Sciences include the development of energy-saving solutions, prevention of product contamination at all stages of its creation, and the release of functional products. The National Academy of Sciences of Russia perpetuates the traditions established by the eminent scientist V.I. Vernadsky, making a significant contribution to the ecologization of the hop products subcomplex. For instance, ultrasonic cleaning devices, equipment for grinding, drying, and sterilization utilizing ultra-high-frequency fields, as well as automated packaging systems have been developed. Such solutions exemplify how science can integrate production efficiency with environmental stewardship. Collaborative efforts among scientific institutes have resulted in the creation of technological complexes for the manufacture of therapeutic-prophylactic HPSC products. In particular, ecologically pure natural-origin dyes are produced, illustrating the commitment to waste-free practices and rational resource utilization. Particular attention is devoted to resource-saving approaches. For example, the use of dryers operating on various fuel types enables substantial reduction in energy expenditures. Concurrently, the prospects for further development of the hop products subcomplex are associated with several key directions. Primarily, this encompasses ensuring the safety and quality control of raw materials and finished products. A significant position herein is occupied by the refinement of biotechnological processing methods, as well as storage and transportation technologies that preserve product properties. In this regard, the development of composites and biologically active additives with specified characteristics supplements this list. Finally, the creation of products for prophylactic purposes remains one of the priority tasks. In this context, the interaction between producers and scientists ensures the implementation of cutting-edge advancements in biochemistry, thermophysics, and biotechnologies, aimed at prudent utilization of natural resources, which is critically important for the sustainable development of the industry. Furthermore, ecologization of the hop products subcomplex demands a modern material and technical base, well-considered regulatory framework, and a system of incentives for ecologically responsible activities. Under such conditions, an innovative development model and support for science and education also play a decisive role. Fundamental principles herein include strict adherence to quality and safety requirements at all stages from production to realization, producer accountability for their products reinforced by a control system, as well as state regulation through norming, certification, and monitoring. Concurrently, public informing about product quality and the efficacy of oversight measures, as well as the withdrawal from circulation of hazardous HPSC products with subsequent disposal, complement this approach.

For a more illustrative representation of the key aspects of ecologization in the hop products subcomplex, reference may be made to Table 6, which systematizes the primary research directions, their objectives, implementation methods, and expected effects, underscoring a comprehensive approach to addressing industry challenges. Thus, the development of the hop products subcomplex in Russia entails a combination of scientific advancements, technological innovations, and state support. This not only bolsters the industry's market position but also contributes to enhancing the population's quality of life while simultaneously preserving natural resources for future generations. On one hand, the refinement of the legislative framework and quality control ensures

product safety. On the other hand, the implementation of innovative technologies and the expansion of the functional product assortment opens new opportunities for improving the population's quality of life.

Table 6. Methods and expected effects of ecologization in the hop products subcomplex.

Direction	Goal	Implementation methods	Expected effect
Product Safety	Guarantee of quality and protection	Raw material analysis, certification	Reduction of risks for consumers
Energy Efficiency	Reduction of resource costs	Implementation of new technologies	Decrease in ecological burden
Waste-Free Production	Rational raw material use	Waste recycling	Enhancement of production sustainability
Functional Products	Improvement of public health	Addition of active substances	Expansion of beneficial product assortment

CONCLUSION

The investigation into the organizational and economic aspects of ecologization in the hop products subcomplex has revealed that the contemporary development of the industry, encompassing hop cultivation, its processing, and the production of related goods, confronts significant ecological challenges, such as environmental pollution by chemical substances, wastewater, and energy-intensive processes, exacerbated by equipment wear. These factors not only intensify the global crisis but also pose threats to consumer health through the infiltration of harmful substances into products, underscoring the necessity of transitioning to sustainable practices. In this regard, ecologization addresses two primary tasks: minimizing the burden on nature through emission reduction, rational resource utilization, and waste recycling, as well as ensuring product safety and quality by preventing contaminations, employing harmless additives, and developing functional products enriched with beneficial components to enhance organism resilience. It has been established that organizational and economic measures, including tax regulators, ecological fees, and risk insurance at the state level, should be complemented by sectoral initiatives in accordance with Russian Federation legislation, thereby promoting a preventive approach and adherence to ISO 14001 and HACCP standards. The analysis has also demonstrated positive shifts in the refinement of the legislative base, equipment modernization, implementation of water reuse systems, and technologies with minimal waste, which enables the reduction of harmful emissions, water and energy consumption, as well as an increase in waste recycling. The utilization of secondary raw materials, such as beer draff, expands the raw material base without additional ecosystem damage, while new organic production technologies incorporating digital platforms and regional zonal specifics enhance competitiveness in the international market. In this context, the engagement of stakeholders forms a systemic approach, adapting experiences from the Czech Republic, Germany, and the United States to Russian conditions, particularly in the Chuvash Republic and Altai Krai. This not only mitigates ecological risks but also stimulates the release of functional products, forecasting segment growth at 7–10% annually, thereby contributing to population health improvement and alleviation of the healthcare system burden. Ultimately, ecologization of the hop products subcomplex represents a key factor in sustainable development, integrating economic efficiency with nature conservation. In this regard, prospects are linked to further modernization, investments in science and education, which will enable overcoming barriers such as the absence of modern equipment and weak motivation, ensuring resource preservation for future generations and strengthening the hop products subcomplex's position in the green economy.

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