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COMPLEX ECOLOGICAL SUSTAINABILITY ANALYSIS: LEATHER PRODUCT REPAIR AND RECYCLING PROCESSES

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Annotation

This article discusses environmental aspects aimed at reducing the negative impact of the leather industry on the environment through the recycling and reuse of leather products. The impact on health and ecosystems of resource consumption, wastewater pollution, and the production and disposal of leather products is analyzed. Special attention is paid to modern recycling methods and sustainable technological solutions, including bio-duplication, closed-loop water management systems and bio-alternatives for natural leather. Using the example of Kazakhstan, the current situation in the field of waste recycling is analyzed, and recommendations are made to improve the environmental efficiency of the industry. The work is based on modern statistical data and international experience, which allows us to conclude that it is necessary to move to a circular economy and sustainable management of leather waste.

Keywords: leather industry, waste recycling, eco-efficiency, sustainable development, waste.

Аңдатпа

Бұл мақалада былғары бұйымдарын қайта өңдеу және қайта пайдалану арқылы былғары өнеркәсібінің қоршаған ортаға теріс әсерін азайту мақсатында экологиялық аспектілер қарастырылады. Ресурстарды тұтыну, ағынды сулардың ластануы, сондай-ақ былғары бұйымдарын өндіру және жою кезінде денсаулыққа және экожүйелерге әсері талданған. Әсіресе қазіргі заманғы рециклинг әдістеріне және тұрақты технологиялық шешімдерге, оның ішінде биодублеу, тұйықталған су пайдалану жүйелері және табиғи былғарыға биоальтернативаларға ерекше назар аударылған. Қазақстан мысалында қалдықтарды қайта өңдеу саласындағы қазіргі жағдай талданып, саланың экологиялық тиімділігін арттыру бойынша ұсыныстар берілген. Жұмыс заманауи статистикалық деректер мен халықаралық тәжірибелерге негізделген, бұл циркулярлық экономикаға және былғары қалдықтарын тұрақты басқаруға көшу қажеттілігі туралы қорытынды жасауға мүмкіндік береді.

Негізгі сөздер: былғары өнеркәсібі, қайта өңдеу, экологиялық тиімділік, тұрақты даму, қалдықтар.

Аннотация

В данной статье рассматриваются экологические аспекты переработки и повторного использования кожаных изделий с целью снижения негативного воздействия кожевенной промышленности на окружающую среду. Проведён анализ потребления ресурсов, загрязнения сточных вод, а также воздействия на здоровье и экосистемы при производстве и утилизации кожаных изделий. Особое внимание уделено современным методам рециклинга и устойчивым технологическим решениям, включая биодублирование, замкнутые системы водопользования и биоальтернативы натуральной коже. На примере Казахстана проанализирована текущая ситуация в сфере переработки отходов и даны рекомендации по повышению экологической эффективности отрасли. Работа основана на актуальных статистических данных и международных практиках, что позволяет сделать вывод о необходимости перехода к циркулярной экономике и устойчивому управлению кожевенными отходами.

Ключевые слова: кожевенная промышленность, переработка отходов, экологическая эффективность, устойчивое развитие, отходы.

1 Introduction

The leather industry traditionally occupies an important place in the global economy, providing the population with leather and products made from it, which are used in footwear, clothing, furniture, dry goods and other industries. Despite its significant contribution to socio-economic development, this sector is one of the most environmentally unfriendly industries. Its operation is accompanied by high resource intensity, the use of many chemical reagents and the generation of a significant amount of waste. The production of leather products is considered one of the most resource-intensive and environmentally unfriendly production processes. It has a significant impact on the environment at all stages of the life cycle - from animal husbandry to the disposal of the finished product. This is reflected in the high consumption of water, energy and chemicals, especially at the oxidation and finishing stages. The use of toxic substances such as chromium compounds, acids and dyes without adequate purification leads to soil and water pollution and harms ecosystems and human health. In addition, the production process generates a significant amount of solid and liquid waste containing hazardous compounds. This problem is especially acute in developing countries with a low level of environmental control. The leather production process includes several stages:

preparation of raw materials, tanning, dyeing and finishing. Each stage requires a large amount of water, energy and chemicals - chromium, sulfides, dyes, oil compositions. As a result, wastewater with a high content of organic and toxic compounds is discharged into the environment, polluting the soil and atmospheric air. According to international studies, leather production can consume 30-40 liters of water for processing one kilogram of raw materials, and the amount of heavy metals in wastewater is several times higher than the permissible maximum concentration. The negative impact of the leather industry is manifested not only in environmental pollution, but also in the threat to human health. Enterprise employees are exposed to toxic substances, and the surrounding population suffers from the deterioration of air and water quality. These factors create the need to find new ways to organize production aimed at the principles of sustainable development. In this regard, recycling and reuse of leather products are becoming important measures to reduce the environmental burden [1,2,10]. Such approaches allow to extend the service life of materials, reduce waste and reduce resource consumption. In addition to environmental benefits, leather recycling contributes to the introduction of a circular economy and can support the development of small businesses and job creation. For the effective implementation of such solutions, a comprehensive analysis is required, covering environmental, resource, energy and socio-economic aspects. Thus, the relevance of the study is due to the need to analyze the resource costs and environmental risks of the leather industry, as well as consider the possibilities of their reduction through the introduction of recycling technologies and the rational use of nature.

2 Methods and Materials

This research work has a complex analytical nature and is aimed at a comprehensive consideration of the impact of the leather industry on the environment. The main object of study is the resource costs and environmental hazards of natural leather production, as well as recycling and alternative technologies used to reduce them.

2.1 Methods

Several scientific methods were used in the study:

- Literature review method. Literature sources based on international experience were reviewed to study modern trends in leather production and recycling.
- Comparative analysis method. The environmental indicators of natural leather were compared with their synthetic counterparts, and their advantages and disadvantages were identified.
- Statistical analysis method. Quantitative data were systematized and presented in the form of tables and diagrams. This made it possible to clearly demonstrate the volume of production, the amount of waste and the level of recycling.
- Systematic approach. Ecological, resource, social and economic aspects were considered in a comprehensive manner, and their interrelationships were identified.
- Case study method. Specific examples of the leather industry in Kazakhstan were studied, their environmental problems and development opportunities were analyzed.

2.2 Materials

The following materials were used for the study:

- Reports and presentations of international organizations - data published by the Food and Agriculture Organization of the United Nations (FAO), the United Nations Environment Program (UNEP), the World Bank. These sources made it possible to determine the global environmental burden of leather production.
- Scientific literature - articles in international and foreign peer-reviewed journals. They describe methods for reducing the impact of production processes on the environment.
- Kazakhstani sources - statistical data, official reports and national strategies related to the ecology and natural resources of the Republic of Kazakhstan. They reflect the actual state of leather production in Kazakhstan.
- Comparative data - statistics on production volumes, energy consumption, water consumption and carbon dioxide emissions were used to compare the production of natural leather with synthetic materials (polyurethane, PVC).

The information obtained was processed qualitatively and quantitatively. Quantitative data (water consumption, energy consumption, CO₂ emissions) were entered into comparative tables. Qualitative data (waste management practices, recycling efficiency) were systematized and textual analysis was performed. Diagrams and graphs were used to make the results understandable. The use of these methods allowed us to achieve the main goal of the study - a comprehensive assessment of the environmental burden of the leather industry and the proposal of ways to reduce it. The literature review allowed us to summarize scientific views, comparative analysis to highlight specific differences, statistical analysis to provide a quantitative basis, and case studies to draw conclusions adapted to the situation in Kazakhstan.

3 Results

Leather production is an environmentally-intensive industry. This production process uses a lot of natural resources, especially water and energy, and also increases greenhouse gas emissions. According to recent studies, the production of 1 kg of natural cowhide produces 24 kg of CO₂ equivalent, which is equivalent to the production of synthetic alternatives such as polyurethane (PU) and polyvinyl chloride (PVC).

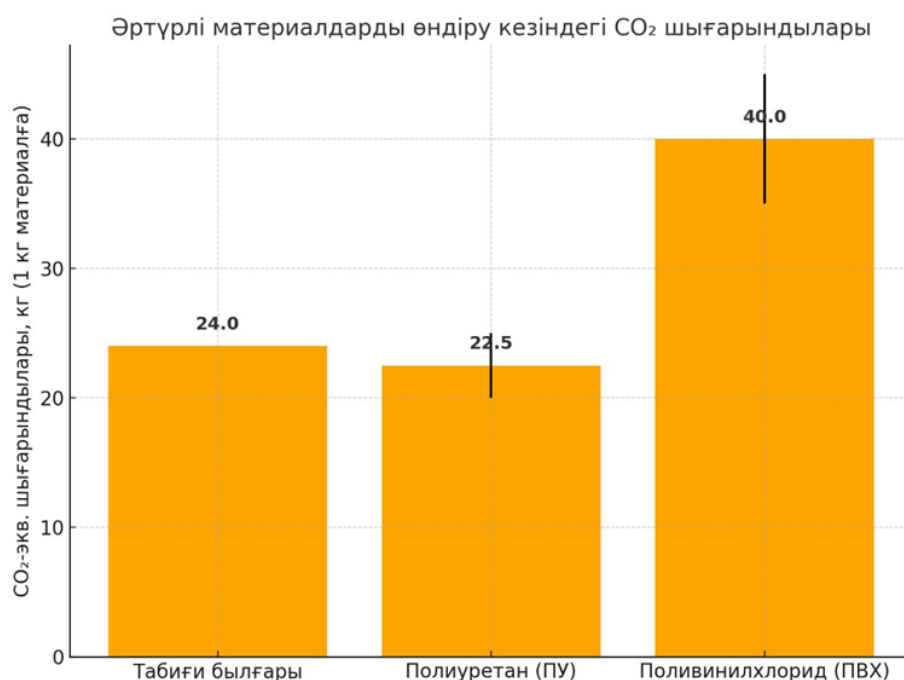


Figure 1. During the production of natural leather, polyurethane, polyvinyl chloride

Since this industry is particularly closely linked to livestock farming, its greenhouse gas emissions account for about 19% [2]. This issue is important in combating climate change and the increase in greenhouse gases. The environmental impact of the leather industry is evident not only in terms of its carbon footprint, but also in terms of water use and chemical pollution. The amount of water consumed is surprisingly high, as an average of 12.4 m³ of water is required to produce 1 kg of leather. Most of this water is used in the livestock farming process. For example, in Bangladesh, the production of 1 ton of leather requires [3]:

- 6,845 m³ of green water
- 6,091 m³ of blue water
- 21,124 m³ of grey water

Green water is rainwater used for plant growth. Green water does not usually directly affect the ecosystem or natural resources, if it is a natural process. Blue water is water taken from natural water bodies, such as rivers, lakes, groundwater. Blue water is part of the water resources used for irrigation, industrial needs and other purposes. Unlike green water, blue water can be a burden on ecosystems, especially if water bodies are used inefficiently. Grey water is water used to dilute

pollutants (for example, wastewater). It is used to reduce the impact of pollution generated during industrial or agricultural activities. It is essentially used water that requires treatment before being returned to the ecosystem or reused.) This data is truly alarming, given the water shortages and environmental crises in countries.

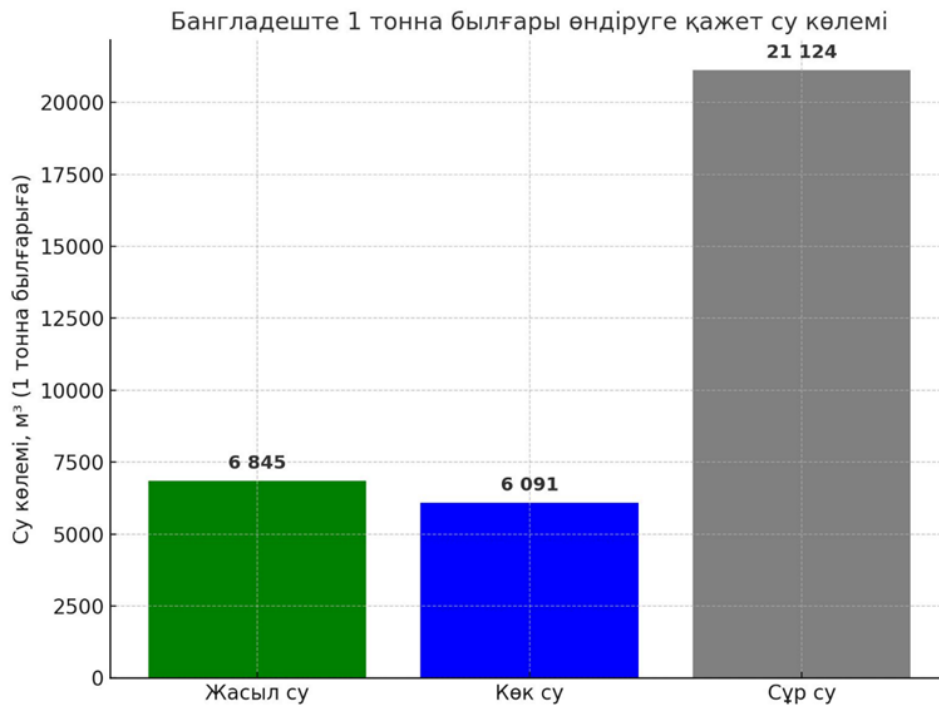


Figure 2. Water consumption per ton of leather in Bangladesh

In addition to water consumption, leather production is characterized by high levels of chemical pollution. The chrome tanning process is particularly hazardous, as 66,000 tons of chromium compounds are used annually, but only 21,000 tons of them remain in the finished product, the rest is lost to wastewater. These chromium compounds, heavy metals, acids, dyes, and other chemicals pollute soil and water, harm ecosystems and human health. Chromium, in particular, is highly toxic and can cause serious diseases, including cancer, accumulate in the body, and cause long-term environmental changes. The abundance of chemicals and the increasing amount of waste generated during production are also of concern [4]. According to FAO, for every 1 ton of leather processed, 195 kg of scrap, waste, and chips, 217 kg of chrome sludge, sludge, and dust, and 35 kg of paint and finishing waste are generated.

1 тонна былғарыны өңдеуден шығатын қалдықтар (FAO деректері бойынша)

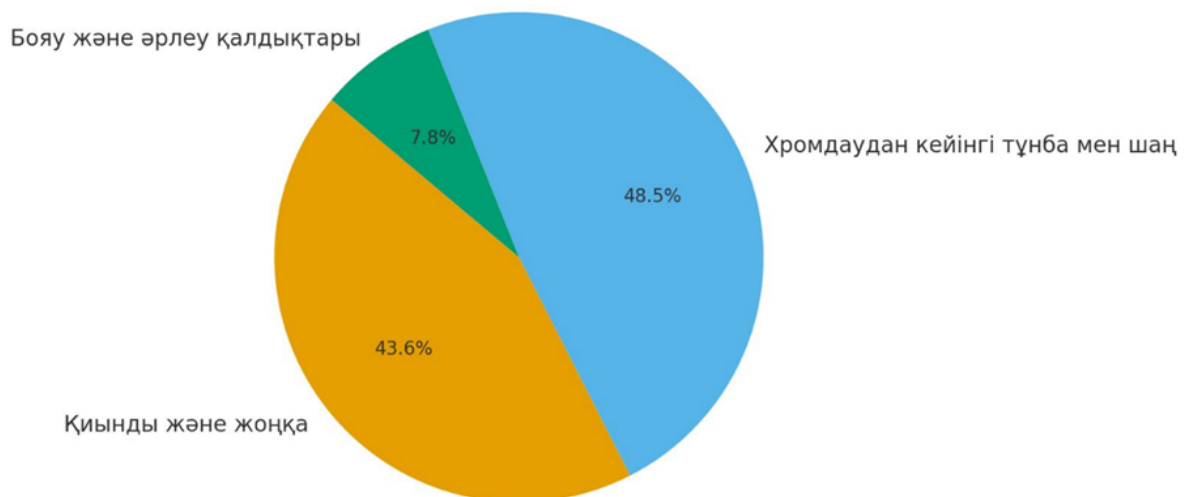


Figure 3. Percentage of waste generated during leather processing

In addition, from 25 to 85 m³ of toxic wastewater is generated during the processing of 1 ton of raw materials, which contains chromium, sulfides, ammonia and other hazardous substances [5]. These waters are very difficult to treat, and they cause long-term damage to ecosystems, natural resources and public health. All these factors indicate that the environmental burden of the leather industry is heavy. In many countries, especially developing countries, environmental control systems are insufficient, which is why these problems are becoming more and more complex. To solve this problem, it is necessary to introduce production technologies based on the principles of sustainable development and a closed economy. To solve the above environmental problems, it is necessary to introduce new technologies into the leather industry, develop recycling processes and use environmentally friendly production methods. For example, the bio-dubbing process requires the use of environmentally friendly and natural materials.

Тері өңдеу кезінде пайда болатын улы ағынды сулардың құрамындағы ластағыштар

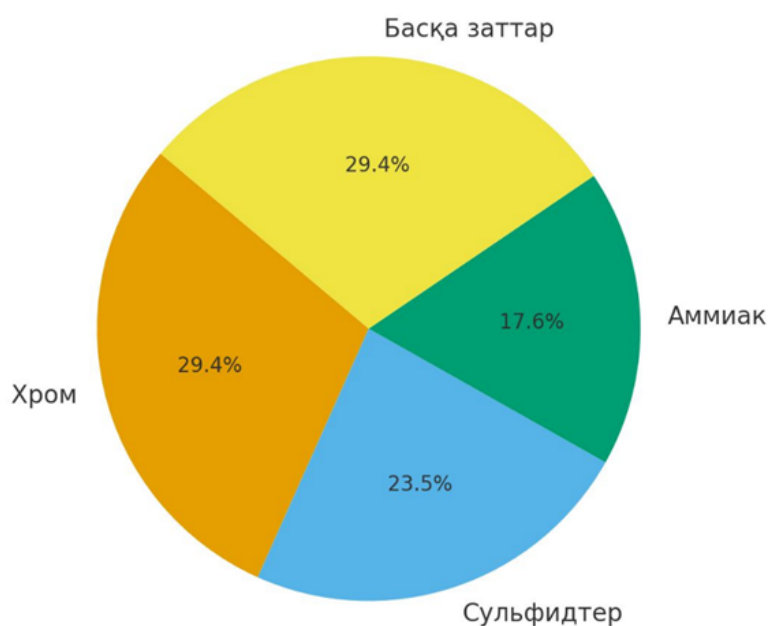


Figure 4. Percentage of pollutants in the water discharged from leather processing

This approach involves the use of natural plants and other organic substances instead of chromium. In addition, it is necessary to introduce closed systems that allow saving water resources. These technologies not only reduce the environmental load, but also increase the economic efficiency of the industry.

3 Discussion of the results

The results of the study show that the leather industry has a significant anthropogenic impact on the environment. In particular, leather production requires the use of a large amount of fresh water, chemical reagents (sodium sulfate, lime, chromium compounds, etc.), and is also accompanied by the formation of solid and liquid waste. All this creates significant environmental hazards in the form of heavy metal pollution of water bodies, soil degradation, deterioration of air quality and a threat to public health. However, the analysis shows that the introduction of waste recycling technologies can radically change the situation. The recycling of leather raw materials and by-products can significantly reduce the load on natural resources. For example, recycling chromium from production waste reduces the need to extract primary ore resources and reduces toxic emissions. As a result, enterprises can simultaneously reduce environmental costs and save raw materials. In addition, recycling contributes to the formation of a new sector of the economy - secondary production. Collagen, gelatin, biopolymers, organomineral fertilizers, feed additives and even building materials can be obtained from leather waste. This opens up prospects for diversifying the industry and expanding the market for environmentally friendly goods. Thus, leather waste turns from a problem

into a potentially valuable resource. World experience confirms the effectiveness of this approach. For example, in a number of European countries, up to 80% of leather industry waste is recycled, which has allowed us to significantly reduce the burden on the environment and move to the principles of the "Green Economy" [4, 5, 10]. This experience is especially relevant for Kazakhstan, since the country's leather industry is energy and resource-intensive, and environmental standards are still at the development stage.

Based on the analysis, several main areas of improvement in the industry can be identified:

- Technological modernization. Introduction of closed water circulation systems, modern methods of wastewater treatment and safe disposal of chromium-containing compounds.
- Economic incentives. Provision of tax breaks and subsidies to enterprises that introduce recycling and environmentally friendly technologies.
- Regulatory and legal regulation. Tightening environmental requirements, introducing mandatory recycling of certain categories of waste, as well as harmonizing national standards with international standards.
- Scientific and educational. Development of innovative processing methods in cooperation with universities and research centers, training new specialists for the industry.

Thus, the discussion of the results confirms that the recycling of leather industry waste is a strategically important direction that ensures a balance between economic development and environmental protection. This will simultaneously reduce the negative impact on ecosystems, increase the efficiency of resource use and contribute to the transition of Kazakhstan to a sustainable development model. It is important to develop the process of recycling raw materials to reduce recycling and waste. The creation of new products by processing leather waste, especially with environmentally friendly methods, allows for a reduction in production volumes and the conservation of natural resources. In addition, the market demand for products made from recycled leather waste is also increasing. These measures help to significantly reduce the environmental burden of the leather industry and reduce environmental risks in this sector. Recycling and reusing leather products can significantly reduce the negative impact on the environment. Reuse reduces the need to produce new leather, thereby reducing water, chemical and energy consumption. Recycling leather reduces the need for raw materials, water and energy resources, as well as pollution associated with tanning and other stages of leather production. For example, using old leather products as raw materials for furniture upholstery, shoes or accessories can reduce the carbon footprint by 35–55% compared to the same products made from new leather, within the framework of the circular economy concept. This will contribute to the promotion of sustainable consumption and production models, the formation of a secondary raw material market and the reduction of the overall environmental footprint of the industry. In addition, leather recycling plays an important role in socio-economic terms. It contributes to job creation and the development of small businesses, especially in low- and middle-income countries, where recycling can be an affordable source of income. Thus, a comprehensive approach to assessing the effectiveness of leather recycling should take into account not only environmental indicators, but also socio-economic sustainability.

The field of recycling and sustainable waste management remains a relevant and problematic area in Kazakhstan.

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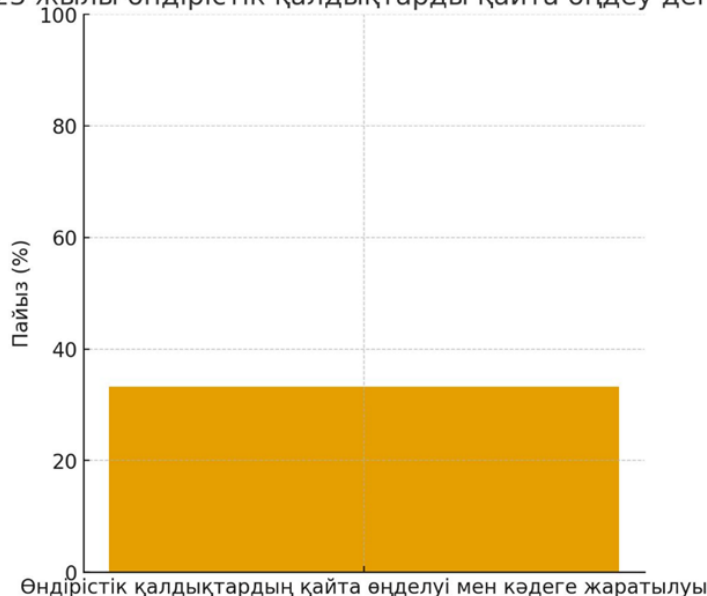


Figure 5. Percentage of pollutants in the water from leather processing

Despite the announced state initiatives, the level of recycling and utilization of industrial waste in the country in 2023 was only 32–34.5%, while earlier the Ministry of Ecology, Geology and Natural Resources of the Republic of Kazakhstan aimed to increase this figure to 45%.

This indicates the existence of systemic difficulties: insufficient recycling infrastructure, weak business incentives, and limited information about the possibilities of resource reuse among the population and producers. The situation is even more complicated in the context of light industry, including in the production of leather goods. Over the past 30 years, the volume of light industry production has decreased by 6 times, and footwear production by 35 times. This industry is experiencing not only a severe decline, but also a loss of production and technological potential, which limits the development of a sustainable chain of materials recycling in Kazakhstan, including leather and textiles [7].

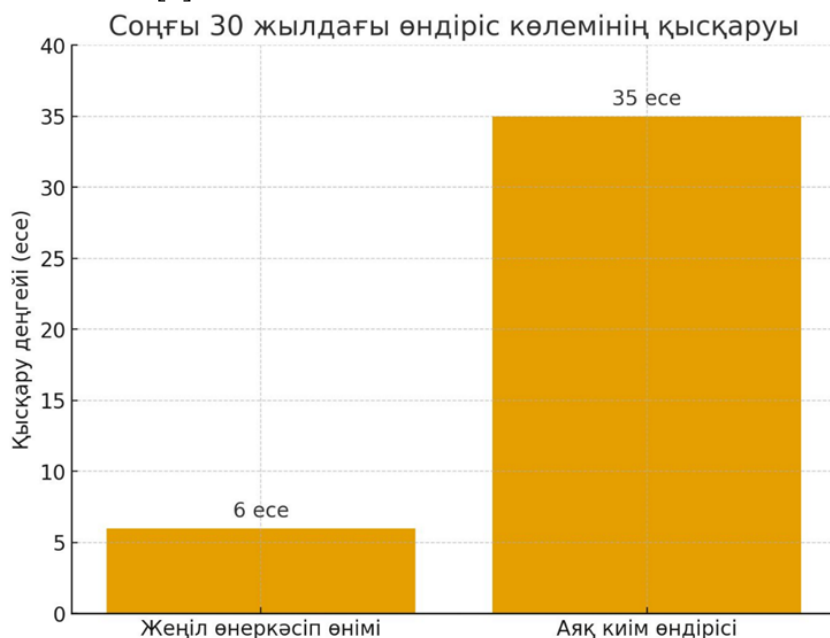


Figure 6. Production decline over the past 30 years

The decline of traditional leather production has increased the country's dependence on imports for raw materials and finished products, increasing the environmental and economic burden. However, against the background of these problems, Kazakhstan is witnessing the development of innovative and sustainable business forms. For example, eco-startups are emerging that offer

alternative materials to natural leather. One of them is vegan leather made from coffee waste, which has high biodegradability, UV resistance and a profitability of up to 68% [6]. Such innovations demonstrate the potential of local entrepreneurship to implement the principles of turning waste into a valuable resource. In addition, Kazakhstan has the potential to integrate international practices in the field of recycling and reuse of leather products. The development of specialized enterprises, the creation of mechanisms to stimulate recycling, and the support of startups and local brands working with recycled materials can make a significant contribution to the development of new economic segments aimed at reducing the environmental burden and sustainability. Thus, despite the decline and difficulties of traditional leather production, Kazakhstan has the prerequisites for the formation of a sustainable infrastructure for the recycling of leather waste. This requires comprehensive support from the state, business and the scientific community aimed at developing green technologies, encouraging recycling and introducing closed production cycles. In turn, it is necessary to introduce systematic and multi-layered measures to increase the environmental sustainability of leather production in Kazakhstan and minimize its negative impact on the environment, which should cover both production and consumption. One of these areas is the active promotion of the recycling of leather products and the introduction of the principle of extended producer responsibility (EPR), which provides for a system of measures that oblige businesses to dispose of products after their life cycle ends. This model can be effectively used in developed countries and become the basis for environmentally responsible regulation of the industry. Another important task is to invest in wastewater treatment technologies used in leather processing, especially at the tanning and finishing stages. The introduction of modern methods, such as electrocoagulation, ultraviolet treatment and membrane filtration systems, will significantly reduce water resources from pollution and reduce the toxicity of effluents. Another important area that needs to be addressed is the development of closed water use systems and energy-efficient technological solutions that allow for multiple use of water and heat in the production process. Such approaches contribute not only to reducing the environmental burden, but also to increasing the economic efficiency of enterprises. Support for ecological startups and the introduction of bioalternatives to natural leather (for example, the Urapk project of Kazakhstan, a project to produce eco-leather from coffee waste) should become a priority of state and private investment policy. Grants, tax incentives for such projects and their inclusion in national sustainable development programs can accelerate the formation of a new sector with an ecological focus. Finally, attracting consumers plays an important role. The formation of a culture of conscious consumption, the development of a secondary market, the repair of leather goods and their extension of their service life - all this is part of the concept of sustainable fashion and is consistent with the global goals of reducing the ecological footprint of the textile and leather industry [6-9]. Thus, the sustainable development of the leather industry requires an inter-sectoral approach, carried out with the participation of the state, business, the scientific community and citizens, as well as the introduction of technological and behavioral solutions aimed at long-term reduction of the environmental burden.

4 Conclusion

The study revealed that the leather industry is one of the most resource-intensive and environmentally hazardous industries. Its activities are accompanied by high consumption of water, energy and chemical reagents, resulting in the formation of a significant amount of solid and liquid waste. These factors have a negative impact on ecosystems and public health, especially in the context of an underdeveloped environmental control system. In addition, the analysis showed that the introduction of waste processing technologies can significantly change the situation. The processing of leather raw materials not only reduces the burden on the environment, but also opens up new economic opportunities: the production of secondary materials, feed additives, fertilizers and biopolymers. Thus, waste can be considered not only as an environmental problem, but also as a valuable resource. The results of the work confirm the need for the Kazakh leather industry to transition to innovative, environmentally friendly technologies. This requires an integrated approach that includes the modernization of production processes, state support for processing enterprises and the development of the regulatory framework. Only in this case can the industry ensure sustainable

development by reducing environmental risks and increasing competitiveness in the international market. In this context, leather recycling is not only environmentally important, but also an economically viable strategy that can give impetus to the development of new markets, small-scale industries, craft sectors, and environmentally-oriented innovative solutions. In the case of Kazakhstan, unlocking this potential requires a systematic and cross-sectoral approach. Issues such as the low level of waste processing, the decline of light industry, and the lack of infrastructure for the disposal of leather materials require comprehensive measures from government agencies, business, and the scientific community. It is necessary to modernize existing production capacities, introduce deep processing technologies, introduce the principle of Extended Production Responsibility (EPR), as well as create a favorable investment environment for eco-startups and projects offering bio-alternatives to natural leather. An important element of the sustainable transformation of the industry is the active involvement of consumers: developing a culture of conscious consumption, expanding the secondary market, and popularizing the concept of sustainable fashion. Thanks to coordinated actions at all levels — from production policy to consumer behavior, leather product recycling can become an integral part of the sustainable development and ecological modernization of Kazakhstan. Thus, the main conclusion of the study is that the rational use of leather industry resources and waste recycling is a strategic path to environmental safety and economic efficiency.

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