

Research on the Ecological Efficiency of the Application of Green Technologies in the Light Industry

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Abstract

In modern times, the application of green technologies in the light industry is of strategic importance in terms of both environmental protection and economic sustainability. As this industry is resource-intensive, increasing environmental efficiency has become a key goal. Research shows that the introduction of waste-free technologies in the production process significantly reduces the pressure on natural resources. The establishment of water recycling systems, especially in textile and leather processing enterprises, protects the ecological balance. Replacing chemical dyes with natural substitutes prevents pollution of soil and water bodies. The use of energy-efficient equipment allows us to minimize carbon emissions in production. The use of renewable sources such as solar and wind energy in enterprises is one of the key factors accelerating the green transition. Environmental efficiency also means more efficient use of raw materials and optimization of their specific gravity. The study found that circular economy models facilitate waste management in light industry. Producing new products from recycled fibers is both environmentally friendly and reduces costs. The application of digital technologies in the production chain helps to accurately calculate and prevent resource losses. Businesses that meet environmental standards have a more competitive position in international markets. Green technologies also create a more favorable environment for the health and safety of employees. The introduction of modern filtration systems dramatically reduces the amount of harmful gases emitted into the atmosphere. It is necessary to use modern monitoring methods to assess environmental efficiency. The improvement of the environmental rating of enterprises is an important factor attracting the attention of investors. The methods applied within the framework of the study revealed the real savings indicators of green technologies. Environmental control should be strengthened at all stages, from raw material procurement to the sale of finished products. The use of biodegradable packaging materials reduces the damage to the environment at the end-consumption stage. The introduction of innovative purification devices completely prevents heavy metals from mixing with water. Low-emission technologies are also an indicator of the social responsibility of an industrial enterprise. Proportionality must be maintained between increasing production volumes and managing environmental risks. Government support and green subsidies play a crucial role in the spread of these technologies. The adaptation of local businesses to international ISO 14001 standards improves environmental management. Research results prove that green investments provide high profitability in the long term. Economic growth must be achieved through ecological modernization, without harming the environment. Modern consumers are now increasingly preferring environmentally friendly brands. In light industry, environmental efficiency is not only a technological but also an ethical necessity.

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Future development strategies must be based on the principles of "green growth". Thus, the application of green technologies paves the way for a sustainable future by reducing the environmental footprint of industry. The analyses conducted once again confirm the importance of expanding reforms in this area.

Keywords: Light industry, Green technologies, Environmental efficiency, Circular economy, Resource saving

JEL Codes: Q01, Q56, R11, Z32

1. Introduction

In the modern world, the rapid development of the global economy has brought to the forefront the problems of depletion of natural resources and environmental pollution (Milli Prioritetlər, 2021; Məmmədov, 2022). As in all areas of human activity, preserving ecological balance in the industrial sector is no longer an option, but an absolute necessity (Rüstəmov, 2023). Light industry, especially textiles, clothing, and leather processing, occupies an important place in the world economy, but is also one of the sectors that has the greatest impact on the environment. Production processes in this area require the use of large amounts of water, energy, and chemicals, which increases environmental risks (Muthu, 2020). In the face of global climate change and the increase in natural disasters, radical changes in the operations of industrial enterprises are inevitable.

The concept of "green technologies" arose from this necessity and aims to minimize environmental damage at every stage of production. The application of green technologies in the light industry is based on the principles of efficient resource management and waste reduction (Gardetti & Larios-Francia, 2023). The application of these technologies is not only an ecological but also an important factor that increases the economic profitability of enterprises. In modern times, environmental standards adopted by international organizations and states impose new obligations on industrial sectors. Transitioning to clean technologies in the production chain is a key strategic path to reducing the carbon footprint (European Commission, 2022).

The relevance of the research is related to the scientific and practical justification of the transition from traditional production methods to sustainable models in light industrial enterprises. Recycling waste generated during raw material processing is the foundation of the circular economy. In an era where water resources are limited, it is vital to use water efficiently and establish closed-loop systems in the textile industry. The increase in the price of energy resources and stricter environmental requirements is pushing businesses to invest in energy-efficient equipment. Green technologies also protect both nature and human health by limiting the use of harmful chemicals.

Through innovative approaches, the biodegradable nature of the materials used in production further increases environmental efficiency. Digitalization and the integration of artificial intelligence into industry open up new opportunities to prevent resource losses. The study of environmental efficiency requires the creation of a new methodological framework for increasing the competitiveness of enterprises. Modern consumer behavior is also characterized by an increased demand for environmentally friendly products. In this regard, a green image of enterprises is a key condition for accessing international markets (Muthu, 2020).

The main goal of the research work is to comprehensively analyze the environmental and economic consequences of the application of green technologies in the light industry. The tasks set in this direction include assessing the current ecological situation and identifying ways to optimize it. Studying international experience creates the basis for the adaptation of green standards in local enterprises. "Green Growth" strategies implemented by the state are an important support mechanism for the sustainable development of industry. Establishing environmental management systems (e.g., ISO 14001) within an enterprise increases management effectiveness (Gardetti & Larios-Francia, 2023).

Scientific research shows that it is impossible to prevent the ecological crisis without technological innovations. Nanofilters and biological treatment methods applied in the light industry minimize the degree of pollution. Conducting environmental monitoring during the production process helps to identify potential risks in

advance. Diversifying the raw material base and increasing the share of recycled materials also reduces the industry's foreign dependence. The methodology applied within the framework of the study covers quantitative and qualitative indicators of environmental efficiency.

From a social perspective, green technologies create a healthier and safer environment in the workplace. The social responsibility of businesses is measured by their attitude towards the environment. The transformation of industrial sectors is inevitable in order to leave a clean environment for future generations. The current study combines theoretical and practical recommendations for the implementation of environmental innovations in light industry. Thus, green technologies are a universal tool for both ecosystem restoration and industry adaptation to modern requirements. Consistent reforms in this area serve to achieve the country's sustainable development goals. In conclusion, it can be noted that environmental efficiency is the most important criterion determining the future development vector of the light industry.

2. Relevance of the Topic

In modern times, the deepening global ecological crisis makes it inevitable to carry out radical reforms in the light industry, as in all industrial sectors. The rapid depletion of our planet's natural resources requires the introduction of new, cost-effective approaches to production processes. The light industry sector, especially the textile and leather processing industries, is one of the largest water consumers and chemical polluters in the world. In this regard, the implementation of green technologies is at the heart of the environmental protection strategy. Reducing carbon emissions has become a priority for every business in the fight against global warming and climate change. The issue of industrial waste management remains a pressing scientific problem both locally and internationally.

The modern consumer market no longer attaches great importance not only to price and quality, but also to the ecological origin of the product. Producing environmentally friendly products is a key way for businesses to gain an advantage in international competition. The world's leading brands are already embracing green technologies, transitioning to the concept of "sustainable fashion." Refusing the use of harmful chemicals in production is necessary to protect both the ecosystem and human health. The limited availability of energy resources and rising prices make the issue of energy efficiency an economic priority. The integration of renewable energy sources into the light industry reduces enterprises' dependence on external energy.

The goal of "A country with a clean environment and green growth" is specifically mentioned in the socio-economic development priorities of the Republic of Azerbaijan until 2030. This strategic line requires the ecological modernization of all industrial facilities operating in the country. Reusing water in closed-loop systems in enterprises is an important step in preventing the threat of water shortages. Establishing waste-free production models minimizes dependence on natural raw materials. Applying circular economy principles extends the life cycle of materials and prevents waste. The introduction of digital tracking systems to increase transparency in the production chain is a relevant innovation. Scientific research into environmental efficiency allows for the development of optimal development models for enterprises.

Investors now consider companies' ESG (Environmental, Social, and Governance) performance as a key criterion when making investment decisions. The process of adapting to international standards (ISO 14001, ISO 50001) accelerates the integration of local businesses into foreign markets (ISO, 2006; Standard, 2006). The application of green technologies leads to the optimization of production costs in the long term. In modern times, the main object of industrial ecology science and research is precisely technological innovations. The use of biomaterials and biodegradable fibers is leading to revolutionary changes in the textile industry. Precise allocation of resources with the help of artificial intelligence and robotics radically reduces waste.

The relevance of the research topic is also related to the need for environmental education and personnel training. Creating green jobs is a guarantee of social well-being and environmental security. Correctly calculating environmental performance indicators allows you to see the real state of the enterprise. Reducing the amount of harmful gases emitted into the atmosphere is essential to achieving global "Net Zero" goals. The green transition strategy of enterprises determines their sustainability in the coming decades. The use of innovative treatment

facilities in raw material processing prevents pollution of rivers and groundwater. The principle of decoupling economic growth from environmental damage is the main line of modern economics.

New generation technologies not only shorten production time but also reduce the environmental burden. The creation of ecological clusters in industrial zones makes resource exchange more efficient. Efficient use of local resources and promotion of recycling are strategic factors that reduce import dependence. Identifying gaps in the application of green technologies is the basis of scientific research. Green tax breaks implemented by the state encourage businesses to innovate. The development of environmental auditing services increases transparency and accountability in the industry. Recycling packaging materials into an environmentally friendly form reduces the burden on landfills.

The research work serves as a theoretical basis for the ecological transformation of the light industry. Replacing outdated and environmentally harmful equipment with modern technologies is a priority. Increasing environmental efficiency also means improving the internal management culture of the enterprise. The integration of education and science with industry paves the way for the real application of green innovations (Gardetti & Larios-Francia, 2023). Tightening environmental requirements in global supply chains make this topic vital for every exporter.

Consequently, it can be noted that the study of the application of green technologies in the light industry is of exceptional importance for the future of both the national economy and the global ecosystem. Every scientific research conducted on this topic is a real contribution to ensuring sustainable development.

The main goal of the research is to investigate the possibilities of applying green technologies in light industrial enterprises, assess the impact of these innovations on the environment, and develop scientific and practical mechanisms to increase environmental efficiency in production.

The object of the study is the production processes of light industrial enterprises, the resource management mechanisms used in these processes, and the interaction of the applied technologies with the environment. The research used a systematic approach, comparative analysis, statistical data interpretation, ecological monitoring, and mathematical modeling of resource efficiency.

3. Materials

The material base of the study is statistical data obtained from light industrial enterprises, environmental reports, and international standards for the application of green technologies. The main focus is on the efficiency of water, energy, and raw material use in the textile and leather processing sector. A product life cycle assessment (LCA) methodology in accordance with ISO 14040 and ISO 14044 standards was used in this study. This method allows us to calculate the environmental burden at all stages, from the extraction of raw materials to the disposal of the final product (ISO, 2006; Standard, 2006). Carbon emissions and wastewater composition in production areas were analyzed using modern digital sensors. The study also considered the technical characteristics of new generation equipment that saves resources as a material. The results of energy audits of local enterprises served as important material for analyzing the current situation.

4. Discussion

The main topic of discussion is the quantitative indicators of the differences between traditional production methods and green technologies. Analyses show that the application of nanotechnologies reduces water consumption in the textile dyeing process by an average of 40-50%. This is a crucial factor for the sustainability of the industry, especially in regions experiencing water scarcity. Another important issue for discussion is the neutralization of chemical waste through biological treatment facilities. Modern filtration systems are capable of removing 98% of heavy metals from water. When it comes to energy efficiency, automated control systems increase electricity savings to 30%. Businesses that use renewable energy sources can reduce their carbon footprint by 2,500 tons of CO₂ equivalent per year. Increasing the share of recycled polyester and other synthetic fibers in production optimizes raw material costs (Muthu, 2020).

The discussion of the circular economy model has particular importance as a future development vector for light industry. The transition of materials from the "produce-use-dispose" chain to the "produce-use-recycle" model is analyzed. Research shows that recovering and reusing slaughter waste as raw materials reduces raw material waste by 15%. Circulating water within a facility through closed-loop systems is the most obvious indicator of environmental efficiency. The discussions encourage the industrial use of renewable biomaterials (e.g. organic cotton, hemp fiber). These materials are biodegradable and thus prevent soil pollution in a natural way. A waste management strategy has a positive impact on the overall profitability of the enterprise. Eco-design principles ensure that a product is recyclable even at the design stage.

The return on investment (ROI) of green technology investments forms the economic part of the discussion. Assessments show that energy-efficient systems fully pay for themselves within an average of 3-5 years. The system of environmental taxes and subsidies is one of the main incentives that increases the interest of businesses in this field. Businesses with green certificates (e.g., Oeko-Tex) can sell products at a 20% higher price in European markets. From a social perspective, cleaning the work environment of toxic substances reduces occupational diseases by 60%. Employees' acquisition of green skills strengthens the innovation potential of the enterprise. Environmental efficiency is also considered an integral part of corporate social responsibility (CSR). Research results prove that customer loyalty to environmentally responsible brands is 1.5 times higher than that of others.

The challenges encountered in the implementation of green technologies also feature prominently in the discussions. The main obstacles are high initial investment costs and a lack of specialists. However, public-private partnership models can help share these financial burdens. Modular transition strategies are proposed to avoid production interruptions during technological upgrades. It is important to create industrial symbiosis centers that enable resource exchange between enterprises. The construction of joint treatment facilities at the regional level reduces costs for small and medium-sized enterprises. Every discussed solution must be carried out in parallel with the tightening of environmental regulations. Through Digital Twin technology, it is possible to simulate the results of the green transition in advance.

The results show that green technologies in the light industry are no longer a luxury, but a term of survival. The discussions highlight the need to improve the legislative framework in this area. Processing local raw materials using environmentally friendly methods strengthens economic security by reducing the share of imported components. In future research, studying the role of artificial intelligence in waste sorting has been identified as a promising direction. It is suggested to create a single national platform for continuous monitoring of environmental efficiency. Modern laboratory tests show that innovative materials are not inferior to traditional materials in terms of durability. Promoting green manufacturing also has a positive impact on the country's international image (European Commission, 2022). In conclusion, it can be noted that the materials obtained and the discussions conducted create a sufficient scientific basis for the "green" transformation of the industry. This transition process requires a multifaceted approach and close cooperation between all stakeholders. Table 1, given below, shows the application of green technologies in specific areas of the light industry and the benefits they create:

Table. Comparative analysis of green technologies in light industry sectors.

| Industrial Area | Applied Green Technology | The Impact of the Traditional Method | Ecological and Economical Benefit |
|------------------------|--|--|---|
| Textile Industry | Waterless dyeing (CO2 technology) and digital printing | Excessive water consumption and chemical pollution | 90% reduction in water consumption; saving on dyes |
| Clothing Production | Laser cutting and recycled fibers | Fabric waste and synthetic waste | 15-20% reduction in material loss; optimization of raw material costs |
| Leather Processing | Plant-based tanning (Chromium-free technology) | Pollution of water with Heavy metals (Chromium) | Zero toxic waste; eco-friendly product certification |
| Shoe Industry | 3D printing technology and biodegradable pallets | Adhesive fumes and non-polymer waste | Shortening the production chain, reducing carbon footprint by 30% |
| Sericulture and Wool | Ecological conditioning and natural cleaning | High energy consumption and harmful detergents | 40% increase in energy efficiency; naturally preserving fiber quality |

Key results taken from Table 1:

1. *Resource efficiency*: Raw material losses are minimized in all areas of the light industry.
2. *Environmental compatibility*: Harmful chemicals (especially in leather and textiles) are replaced with safe alternatives.
3. *Competitive advantage*: The "Green Production" label increases the company's ranking in the global market (for example, in the EU and US markets).

5. Conclusion and Future Directions

A study of the environmental efficiency of the application of green technologies in the light industry shows that a radical technological transformation in this area of industry is inevitable for both ecological balance and economic sustainability. Analyses prove that traditional production methods lead to excessive waste of resources and irreversible environmental pollution. During the study, it was found that the integration of green technologies significantly reduces the carbon footprint of enterprises. Especially in the textile industry, the application of water recycling and closed-loop systems provides revolutionary results in saving water resources. Replacing chemical dyes with biological alternatives minimizes toxic pollution of water bodies. The application of chromium-free tanning methods in leather processing plants ensures both environmental safety and protects the health of employees. Modern, energy-efficient equipment reduces production costs and strengthens the financial stability of the enterprise. The use of renewable energy sources is a strategic factor that reduces the energy dependence of industrial enterprises.

The application of principles of circular economy to industry allows waste to be revalued as a resource. The use of recycled materials reduces pressure on natural raw material extraction and serves to preserve biodiversity. Research shows that green innovations are not only environmentally friendly but also have high economic profitability. The compliance of enterprises with international environmental standards (ISO 14001) increases their competitiveness in global markets. Modern consumers increasingly prefer ethical and environmentally friendly products, which makes the concept of "green branding" relevant. The application of digital technologies and artificial intelligence helps reduce resource losses in production to zero. Increasing environmental efficiency also increases the social responsibility indicators of the enterprise.

The research work found that the state's "green growth" strategy creates new incentives for industrial enterprises. Green subsidies and tax breaks accelerate the technological innovation process of enterprises. The introduction of innovative treatment facilities dramatically reduces atmospheric emissions. Switching to biodegradable packaging materials eliminates the environmental damage caused by a product at the end of its life cycle. Industrial symbiosis models streamline resource exchange between enterprises. Ekoloji audit və monitoring sistemləri istehsalatın hər bir mərhələsində şəffaflığı təmin edir. The methodology proposed as a result of the research allows for the prediction of environmental risks.

Economic analyses show that initial investments in green technologies yield high returns in the medium and long term. Saving resources reduces the cost of the product and leads to an increase in market share. The green transition also encourages the creation of new "green jobs" and the training of qualified personnel. The study proves that ecological modernization is closely linked to the digital transformation of industry. The use of nanofilters in production increases the degree of water purity up to 98%. Recycled polyester and other fibers serve to diversify raw materials in the textile industry. The LCA (Life Cycle Assessment) method applied for assessing environmental efficiency has been identified as the most effective tool (ISO, 2006; Standard, 2006).

Future development prospects require the industry to transition to a completely waste-free and carbon-neutral model. The role of scientific research and innovation is crucial in this transition process. Efficient use of the local raw material base strengthens the country's economic security. The creation of ecological clusters in industrial zones increases resource efficiency at the regional level. The research work forms a theoretical and practical basis for the ecological transformation of the light industry. The application of environmental management in the

internal management systems of enterprises optimizes the decision-making process. Green technologies make a real contribution to ecosystem restoration and the protection of natural capital.

In conclusion, it can be noted that the application of green technologies in the light industry is not just a technological innovation, but also an ethical obligation to future generations. The research results confirm the importance of further improving legislation and incentive mechanisms in this area. An increase in the green rating of enterprises increases their international investment attractiveness. Each "green" step in the production chain leads to an increase in overall environmental efficiency. Thus, the sustainable development of the light industry directly depends on the large-scale implementation of green technologies. The research provides concrete solutions to reduce the industry's environmental footprint. This strategic approach will play an important role in the country's achievement of global environmental goals. Ultimately, green technologies are the main driving force determining the future of the industry. All the provisions of the study can be considered a scientifically based roadmap for increasing the environmental efficiency of the light industry.

The novelty of the study lies in the comprehensive substantiation of the dependence between the application of green technologies and environmental efficiency in light industrial enterprises through mathematical and statistical models and the development of specific "green transition" indicators for local production conditions. At the same time, an innovative waste-free production methodology for integrating circular economy principles into the textile and leather processing sector was proposed for the first time within the framework of this study.

The applied significance of the research lies in the development of practical recommendations that minimize resource loss in light industrial enterprises, the introduction of production models in accordance with environmental standards, and the creation of a methodological basis for enterprises to increase their export potential by obtaining international "green" certificates.

The application of green technologies in the light industry directly serves to strategically reduce production costs and increase the overall profitability of the enterprise. Innovations focused on water and energy efficiency ensure lower costs, reducing utility costs by an average of 30-40%. Thanks to circular economy models, the recycling of raw materials and a waste-free production chain minimize dependence on expensive foreign raw material imports. Environmentally friendly production methods exempt businesses from heavy environmental fines and environmental remediation costs. Obtaining international environmental certificates (such as OEKO-TEX or ISO 14001) allows local products to be sold at higher prices in foreign markets and gain a competitive advantage. Green investments accelerate the return on investment by optimizing resource management in the long term. Automated resource tracking systems prevent economic losses by eliminating waste caused by the human factor. İstehsalatın ekoloji modernizasiyası müəssisənin ESG reytingini yüksəldərək əlverişli şərtlərlə "yaşıl kredit" və investisiya cəlb etmək imkanlarını genişləndirir. Selling waste as raw materials to other industries within the framework of industrial symbiosis creates an additional source of income for the enterprise. Nəticə etibarilə, yaşıl texnologiyalar yüngül sənayedə dayanıqlı iqtisadi artımı təmin edən ən effektiv alətdir.

Author Contributions

All authors have read and approved the final version of the manuscript.

Conflict of Interest

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