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THE ENVIRONMENTAL IMPACT OF INDUSTRIAL ENTERPRISES DEVELOPMENT

DSc, prof. ***Isadjanov Abduvali***
International Islamic Academy of Uzbekistan
ORCID: 0000-0001-8307-3966
a.isadjanov@iiau.uz
Mansurova Iqbolxon
International Islamic Academy of Uzbekistan
ORCID: 0009-0009-2219-5615
iqboloymansurova1987@gmail.com

Abstract. *This article provides recommendations for developing innovative methods to assess the environmental impact of industrial enterprise development by examining international experiences, various methodologies, regulatory frameworks, and advanced global practices in environmental impact assessment. It also analyzes key global indicators related to industry and waste management, as well as year-by-year statistical data on pollutant emissions released into the atmosphere by industrial enterprises in Uzbekistan. Furthermore, the article identifies several systemic challenges in the process of reducing the environmental impact of industrial enterprises in Uzbekistan and offers recommendations for addressing these issues.*

Keywords: *circular economy, degradation, environment, IoT sensors, online monitoring systems, resource efficiency, zero-waste production, waste, carbon footprint.*

SANOAT KORXONALARI RIVOJLANISHINING ATROF-MUHITGA TA’SIRI

i.f.d., prof. ***Isadjanov Abduvali***
O‘zbekiston xalqaro islomshunoslik akademiyasi
Mansurova Iqbolxon
O‘zbekiston xalqaro islomshunoslik akademiyasi

Annotatsiya. *Ushbu maqola sanoat korxonalarining atrof-muhitga ta’sirini baholash bo‘yicha xorijiy tajribalarni o‘rganish, turli metodologiyalar, me’yoriy-huquqiy bazalar va global miqyosda qo‘llaniladigan ilg‘or tajribalarni tahlil qilgan holda sanoat korxonalari rivojlanishining atrof-muhitga ta’sirini baholashning innovatsion usullarini ishlab chiqish bo‘yicha tavsiyalar beradi. Shuningdek Jahon bo‘yicha sanoat va chiqindilarni boshqarish bo‘yicha muhim ko‘rsatkichlar hamda O‘zbekistonda sanoat korxonalaridan atmosferaga chiqarilgan ifloslantiruvchi moddalarning yillar kesimida statistik ma’lumotlari tahlil qilingan. O‘zbekistondagi sanoat korxonalarining ekologik ta’sirini kamaytirish jarayonida bir qator tizimli muammolar va ularni bartaraf etish bo‘yicha tavsiyalar keltirilgan.*

Kalit so‘zlar: *sirkulyar iqtisodiyot, degradatsiya, atrof-muhit, IoT sensorlar, onlayn nazorat tizimlari, resurs tejamkorligi, chiqindisiz ishlab chiqarish, chiqindi, karbon izi.*

ВОЗДЕЙСТВИЕ РАЗВИТИЯ ПРОМЫШЛЕННЫХ ПРЕДПРИЯТИЙ НА ОКРУЖАЮЩУЮ СРЕДУ

д.э.н., проф. ***Исаджанов Абдували***
Международная исламская академия Узбекистана
Мансурова Икболхон
Международная исламская академия Узбекистана

Аннотация. *В статье представлены рекомендации по разработке инновационных методов оценки воздействия развития промышленных предприятий на окружающую среду на основе изучения международного опыта, различных методологий, нормативно-правовых механизмов и передовой мировой практики в сфере оценки воздействия на окружающую среду. Также проанализированы ключевые глобальные показатели, связанные с промышленностью и управлением отходами, а также статистические данные о выбросах загрязняющих веществ в атмосферу промышленными предприятиями Республики Узбекистан. Кроме того, в статье выявлены основные системные проблемы в процессе снижения негативного воздействия промышленных предприятий на окружающую среду в Узбекистане и предложены рекомендации по их решению.*

Ключевые слова: *циркулярная экономика, деградация, окружающая среда, IoT-датчики, системы онлайн-мониторинга, ресурсная эффективность, безотходное производство, отходы, углеродный след.*

Introduction.

The objective necessity of using resources efficiently and combating climate change in countries around the world requires a transition to the circular economy model. The core idea of the circular economy is a model based on the efficient use of resources in the production and consumption of goods, as well as reducing the volume of waste through the reuse of resources.

According to UN estimates, approximately 110 billion tons of minerals are extracted from the Earth's crust each year. Up to 40% of the world's land has been degraded, and nearly half of the global GDP (around 44 trillion USD) is at risk due to land degradation. Experts warn that if no action is taken, this figure may reach 55% by 2050. Specialists emphasize that restoring degraded land can be achieved by transforming agricultural practices — in particular, adopting terraced and contour farming, planting nutritious cover crops, collecting and storing rainwater, or replanting trees to prevent soil erosion (Yuldashev, 2025).

By 2030, humanity is expected to need 50% more food and 30% more water compared to today. Due to population growth and global economic development, global energy consumption is projected to increase by approximately 53% by 2035 (Yuldashev, 2025).

In Uzbekistan, the wide implementation of circular economy technologies in the development of industrial enterprises is also considered an important priority. As a key indicator of introducing the circular economy, significant attention is being given to waste recycling and reducing their environmental impact. The Decree of the President of the Republic of Uzbekistan No. PF-16 dated January 30, 2025, "On the State Program for the Implementation of the 'Uzbekistan – 2030' Strategy in the Year of Environmental Protection and the Green Economy," outlines several important tasks, including "…reducing the enterprise's environmental impact, preventing environmental violations, and introducing an online monitoring system for atmospheric emissions," as well as "…implementing the principles of the circular economy ('7R') into production processes" (Farmon, 2025).

The Decree of the President of the Republic of Uzbekistan No. PF-5863 dated October 30, 2019, "On Approving the Concept for Environmental Protection of the Republic of

Uzbekistan until 2030," places significant emphasis on addressing the environmental impact of industrial enterprise development, as well as enhancing the economic mechanisms for managing environmental pollution and waste disposal at the current stage of the country's development. This decree also approved the "Strategy for Managing Municipal Solid Waste in the Republic of Uzbekistan for 2019–2028," which aims to establish an efficient and modern system for municipal solid waste management. The strategy sets targeted objectives, including ensuring the recycling of at least 60% of generated municipal solid waste, increasing the processing of waste with specific characteristics to 25%, and reducing the amount of municipal solid waste buried in landfills by 60% (Farmon, 2019).

The Decree of the President of the Republic of Uzbekistan No. PF-5863 dated October 30, 2019, "On Approving the Concept for Environmental Protection of the Republic of Uzbekistan until 2030," places significant emphasis on addressing the environmental impact of industrial enterprise development, as well as improving the economic mechanisms for managing environmental pollution and waste disposal at the current stage of the country's development. This decree also approved the "Strategy for Managing Municipal Solid Waste in the Republic of Uzbekistan for 2019–2028," which envisages the creation of an efficient and modern system for municipal solid waste management. The strategy aims to achieve specific targets, including processing at least 60% of generated municipal solid waste, increasing the recycling of certain types of waste with unique characteristics to 25%, and reducing the amount of municipal solid waste buried in landfills by 60% (Farmon, 2019).

The Decree of the President of the Republic of Uzbekistan No. PF-149 dated September 26, 2024, "On Measures to Ensure Transparency in the Fields of Ecology and Environmental Protection and to Further Improve the Management System," laid the foundation for the establishment of the Agency for Waste Management and Circular Economy Development (Farmon, 2024).

Furthermore, in the Resolution of the President of the Republic of Uzbekistan No. PQ-436 dated December 2, 2022, "On Measures to Enhance the Effectiveness of Reforms Aimed at Transitioning the Republic of Uzbekistan to a 'Green' Economy by 2030," several key tasks were outlined, including "…developing a strategic environmental assessment system for major sectors of the economy that may have harmful impacts on the environment," and "…transitioning economic sectors to 'green' technologies, particularly those that enable resource efficiency, zero-waste production, waste recycling, the use of safe chemicals, and the adoption of renewable energy technologies, as well as studying and implementing these technologies in practice." Implementing the tasks set out in the above decree and resolution, including the development of innovative methods for assessing the environmental impact of industrial enterprise development, remains one of the most pressing issues (Qaror, 2022).

Literature review.

Annually, 2.01 billion tons of municipal solid waste are generated worldwide, at least 33% of which — in a very conservative estimate — is not managed in an environmentally safe manner. On average, each person generates 0.74 kilograms of waste per day globally, although this figure ranges widely from 0.11 to 4.54 kilograms. Although high-income countries account for only 16% of the world's population, they produce approximately 34% of global waste, or 683 million tons (WB, 2018).

Modern concepts of the circular economy have been studied internationally by scholars such as MacArthur (2014), Geetha (2025), who focused on innovations in resource restoration and process redesign within the circular economy, Lifset and Anex (2009), who explored theoretical models of the circular economy, and Ilina (2022), who investigated conceptual approaches and implementation mechanisms in the circular economy, among others. These

studies are primarily aimed at the comparative analysis of theoretical approaches in the field, as well as addressing the challenges associated with the transition to a green economy.

The formation of the green economy concept, its stages of development, the necessity of transitioning to this model, its factors, principles, and indicators, as well as the main problems and proposals, prospects, priority directions, and development phases have been analyzed in detail in studies (Yuldashev, 2025; Jumashev and Ktaybekov, 2024; Mirzayev and Usmonov, 2025; WB, 2021).

The interconnection between ecology and the economy, as well as the environmental impact and outcomes of the country's economic activities, have been examined (Turayeva et al., 2023). According to Gutberlet (1996), global industrial development relies on the provision of resources and production factors by the environment. As a result, it leads to environmental pollution, including issues such as air, water, and soil contamination. While industry serves as a driving force for the economy, it also forms the foundation for sustainable development aimed at preventing environmental degradation. The main objectives of industry should include improving quality of life, reducing poverty, and preserving the environment. Emerging directions in sustainable production, widely discussed under the concept of industrial ecology, offer solutions to existing environmental problems.

In the studies by Gurieva and others (2019), proposals were made to address the complex ecological modernization of economic growth within the framework of the "green" economy. These proposals include: digital technologies (tracking and monitoring resource use and waste disposal, modeling product durability, and optimizing the use of raw materials and inputs); biotechnology (using living organisms and their components, which are key factors in creating an environmentally friendly world, to solve production and disposal challenges); resource-saving technologies (reducing the volume of industrial waste generated and reusing production and consumption waste); and industrial symbiosis (creating innovative industrial clusters and technological platforms that facilitate the formation of logistics chains and contribute to the development of regional and national potential).

According to the British scientist Gosawi (2021), the increase in industrialization is one of the serious problems that has negatively affected the entire environment. He argues that the main reason for the formation of environmentally polluting industries is negligence and the pursuit of material interests. According to him, a high level of industrialization has a negative impact across all sectors of industry.

The sectors having the greatest impact on the environment are thermal power plants and cement production enterprises. Currently, there are 12 thermal power plants in the country, including the coal-specialized "Angren" and "New Angren" thermal power plants. In addition, there are 36 cement manufacturing enterprises, 15 oil and gas processing facilities, and 4 metallurgical industries (Turg'unov, 2023).

In our country, consistent efforts are being made to protect the environment, particularly by reducing the environmental impact of industrial enterprises to improve ecological conditions. At the same time, the results of the analyses conducted indicate the necessity of implementing effective and modern methods for a comprehensive approach and strategic planning in addressing environmental protection issues within industrial enterprises.

Research methodology.

In this article, a comprehensive methodological approach was applied to study in depth the environmental impacts arising from the development of industrial enterprises and to develop innovative methods for their assessment. The research methodology consists of several stages and includes both quantitative and qualitative analysis methods. A mixed-methods approach was employed in the study. These approaches are aimed at identifying quantitative relationships between environmental indicators and industrial production. This is

considered the most effective approach for a comprehensive assessment of the environmental impact of industry.

The article utilized the following secondary statistical sources for the period 2010–2024: data from the Ministry of Ecology and the State Statistics Committee of the Republic of Uzbekistan, as well as reports from the World Bank (More Growth, Less Garbage), the OECD (Global Plastics Outlook), and the IEA (International Energy Agency).

Innovative Methods for Assessing the Environmental Impact of Industrial Enterprises Recently, CO_2 (carbon dioxide) emissions have been decreasing in sectors that implement sustainable practices. The line graph here illustrates the reduction in emissions, highlighting the positive environmental impact of sustainable practices over time.

Currently, the extraction and use of raw material resources account for 70% of global greenhouse gas emissions. Through more efficient use of key industrial materials (cement, steel, plastics, and aluminum) and circular economy practices, it is possible to reduce global greenhouse gas emissions by 40% by 2050. In the food industry, circular economy approaches could lead to a 49% reduction in global harmful gas emissions. According to the Circular Gap Report, the circular economy currently constitutes 7.2% of the global economy.

The following innovative approaches are considered most effective in reducing the environmental impact of industrial enterprise development:

- Implementation of circular economy systems – extending product life cycles, reducing waste, recycling, and reusing resources significantly decrease the ecological footprint of industry.
- Digitalization of environmental monitoring – IoT sensors, online monitoring systems, digital mapping, and AI-based monitoring enhance real-time tracking and management of pollutants.
- Modernization of the recycling industry – converting waste into energy, establishing large sorting centers, applying biotechnological solutions, and using production waste as secondary raw materials increase resource efficiency.
- Green energy and zero-waste technologies – utilizing solar, wind, biogas, and other renewable energy sources reduces the carbon footprint of industry.

Strengthening the regulatory and legal framework – enhancing the regulatory and legal framework improves the effectiveness of environmental protection measures.

In Uzbekistan as well, the “Green Economy Transition Strategy for 2019–2030,” the Environmental Policy Concept, and initiatives for modernizing regional industrial zones as sustainable infrastructure require accurate, digital, and transparent assessment of industrial enterprises’ environmental impacts (OECD, 2027).

Reports of international organizations (UNIDO, UNEP, the World Bank, ADB, OECD, UNECE) on Uzbekistan for 2024–2025 highlight the need to deepen industrial decarbonization, resource efficiency, and the circular economy (UNIDO, 2024).

Innovative methods – life cycle assessment (LCA), carbon/water/resource footprints, digital twins, soft-sensor technologies, remote sensing, and ESG instruments – provide opportunities to assess environmental impacts of industrial enterprises in ways that are accurate and digital, dynamic and scenario-based, as well as transparent for investors and the public.

Through the specific directions outlined in these innovative methods, it is advisable for industrial enterprises in Uzbekistan to implement the following key tasks:

1. Introduce clear environmental KPIs based on national “green economy” and environmental policy documents;
2. Gradually adopt ISO 14001/50001, LCA, and ESG reporting;
3. Establish monitoring systems in major enterprises based on digital twins, IoT, and remote sensing;

4. Develop eco-industrial parks and industrial symbiosis projects;
5. Transfer innovative eco-technologies and assessment methods using international financial and technical assistance programs.

Through these measures, industrial development and environmental protection will become mutually reinforcing directions, strengthening Uzbekistan's ability to achieve its sustainable development and "green economy" goals set for 2030.

Analysis and discussion of results.

Efficient resource use and combating global warming and climate change have become pressing issues worldwide. According to the official UN report, approximately 100 billion tons of minerals and other resources are extracted annually, and 40% of the Earth's surface is degraded, putting nearly half of the global GDP at risk (OECD, 2019).

The generation of waste is increasing annually worldwide. In 2020, a total of 2.24 billion tons of solid waste was produced globally, of which only 17% was recycled. By 2050, due to rapid population growth and urbanization, annual waste generation is expected to increase by 73% compared to 2020, reaching 3.88 billion tons. Therefore, several countries around the world are taking necessary measures to reduce the generation of municipal solid waste and to promote product reuse or recycling. For example, the Netherlands aims to reduce resource use by 50% by 2030 and achieve a fully circular economy without waste by 2050. In France, a roadmap for the circular economy has been developed, including 50 measures to achieve a 100% circular economy (WB, 2018).

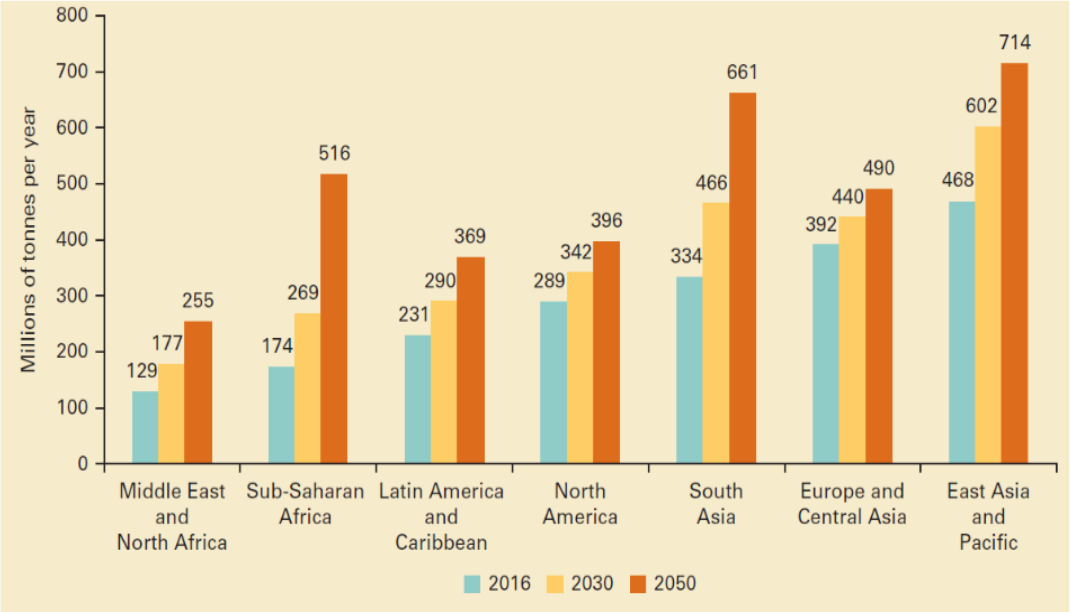
Key global indicators for industrial and waste management are presented in Table 1:

Table 1.

Key global indicators for industrial and waste management (WB, 2021; OECD, 2022; IEA, 2022)

Indicator	2020	2050 prognoz	Source
Volume of solid waste	2.24 billion tons	3.88 billion tons	According to World Bank report (*More Growth, Less Garbage*)
Recycling rate	17%	35–40%	According to OECD report (*Global Plastics Outlook*)
Global carbon emissions	36.4 billion tons	Expected to decrease	According to IEA (International Energy Agency) report

According to the official World Bank report, the projected amount of waste by region is expected to increase by 2050. This is primarily due to population growth, the expansion of industrial enterprises, and other factors (Figure 1).



Picture 1. Projected waste generation by region (million tons per year) (WB, 2018).

Looking ahead, global waste is expected to reach 3.40 billion tons by 2050, which is twice the rate of population growth during the same period. Overall, there is a positive correlation between waste generation and income levels. In high-income countries, per capita daily waste generation is projected to increase by 19% by 2050, while in low- and middle-income countries, this figure is expected to rise by approximately 40% or more. Waste generation initially decreases at the lowest income levels and then accelerates more rapidly at low-income levels with additional income changes compared to high-income levels. In low-income countries, the total amount of waste generated is expected to increase more than threefold by 2050. The East Asia and Pacific region accounts for the largest share of global waste, producing 23%, whereas the Middle East and North Africa region produces the least in absolute terms, only 6%. However, the fastest-growing regions are Sub-Saharan Africa, South Asia, and the Middle East and North Africa, where total waste volumes are expected to increase threefold, twofold, and twofold, respectively, by 2050. In these regions, more than half of the waste is currently openly dumped, and the projected growth trajectories pose significant environmental, health, and well-being challenges (WB, 2018).

Uzbekistan, one of the leading countries in Central Asia, faces challenges in waste management. A diversified economy based on abundant natural resources and rapidly developing industry generates a large variety of wastes that require specialized management. According to the latest data from the Ministry of Ecology, approximately 14 million tons of waste are generated annually in Uzbekistan, of which 10.3% is plastic. However, only 4–5% of this waste is recycled. More than 7 million tons of greenhouse gases are released into the atmosphere, and 43 thousand tons of toxic leachate from landfills seep into the soil. The largest consumers of plastic are the packaging, transport, and construction sectors. A significant increase in these wastes has been observed (Sputnik Uzbekistan, 2024).

A strategy for transitioning to a "green" economy is being implemented in the country to ensure environmental safety, promote rational use of natural resources, and reduce the environmental pressure from industrial enterprises.

Statistical data on pollutants released into the atmosphere from industrial enterprises in Uzbekistan over the years are presented in table form (Table 2).

Table 2.

Pollutants released into the atmosphere (thousand tons) (Statistika agentligi, n.d.**).**

Regions	2020	2021	2022	2023	2024
Republic of Uzbekistan	924.4	908.7	873.6	763.2	866.7
Republic of Karakalpakstan	28.9	31.4	21.1	9.8	10.5
Andijan	11.5	4.9	17.3	10.5	32.6
Bukhara	37.1	44.8	35.6	30.7	35.4
Jizzakh	3.4	2.9	27.0	29.5	33.1
Kashkadarya	128.1	132.2	115.7	117.7	88.6
Navoi	48.4	68.6	41.6	35.0	39.2
Namangan	15.0	24.0	7.4	5.0	4.4
Samarkand	52.7	39.4	38.7	39.4	47.4
Surkhandarya	6.5	7.1	7.3	7.4	10.8
Syrdarya	71.8	45.7	49.1	3.1	42.5
Tashkent	430.0	425.4	438.0	430.1	465.0
Fergana	50.5	46.5	49.5	26.4	26.2
Khorezm	6.8	7.2	4.5	3.4	9.9
Tashkent Sity	33.7	28.6	20.8	15.2	21.1

According to analyses, nearly 14 million tons of waste are generated annually in Uzbekistan, of which only 4–5% is recycled. Current waste management practices at landfills lead to the release of more than 7 million tons of greenhouse gases and the leakage of 43,000 tons of toxic leachate into the ground. In Andijan and Tashkent regions, 4,000 tons of waste are recycled daily, producing 630 million kilowatt-hours of electricity per year. In Samarkand and Kashkadarya regions, 3,000 tons of waste are processed daily, generating 480 million kilowatt-hours of electricity annually. In Bukhara and Navoi regions, 1,500 tons of waste are recycled daily, and with an investment of 200 million dollars, 363 million kilowatt-hours of electricity are produced. Through the implementation of a circular economy in the country, it is planned to incinerate over 4.7 million tons of waste, generate 2.1 billion kilowatt-hours of electricity, and save 152 million cubic meters of natural gas by efficiently utilizing municipal solid waste. This approach could reduce harmful gas emissions from waste by 2.4 million tons and create 1,200 new jobs.

There are a number of systemic challenges in the process of reducing the environmental impact of industrial enterprises in Uzbekistan, and addressing them step by step is one of the key requirements of modern environmental management. Firstly, the insufficient development of digital waste monitoring systems reduces the effectiveness of environmental control. In many enterprises, the composition, volume, and emission levels of waste are not recorded in real time, which makes it difficult to detect problems early and take prompt action. The implementation of digital sensors, IoT devices, and automated management systems could significantly reduce environmental risks.

Additionally, the insufficient implementation of environmental management systems in industrial enterprises is another significant issue. Most enterprises do not operate according to the ISO 14001 standard, resulting in unstructured environmental activities, and inadequate planning and audit mechanisms. This leads to a weak strategic approach to assessing environmental risks and mitigating them.

The lack of investment in the modernization of recycling technologies remains a pressing issue. In many production facilities, outdated equipment results in high energy consumption and large amounts of waste. Transitioning to modern, energy-efficient

technologies that minimize waste generation would not only provide significant economic benefits but also substantially reduce the environmental burden.

Furthermore, the slow development of qualified personnel in the field of circular economy hinders the progress of this sector. The lack of skilled specialists in areas such as converting waste into resources, environmentally optimized product design, and recycling logistics makes it difficult for industrial enterprises to transition to a "green" model.

Therefore, the implementation of IoT technologies, smart sensor systems, "green energy" sources, zero-waste technologies, and circular economy principles in production processes not only ensures environmental safety but also creates long-term economic efficiency for enterprises. A modernized, digitalized, and sustainable production model also contributes to enhancing the global competitiveness of Uzbekistan's industry.

Conclusion and suggestions.

Innovative approaches are essential to improve environmental management systems in industrial enterprises in Uzbekistan. In particular:

Implementation of circular economy technologies can extend product life cycles, reduce waste, recycle and reuse resources, and significantly decrease the environmental footprint of industry.

Digitalization of environmental monitoring enables online control systems, digital mapping, and AI-based monitoring, enhancing real-time supervision and management of pollutants.

Development of the recycling industry allows waste-to-energy conversion, establishment of large sorting centers, application of biotechnological solutions, and use of production waste as secondary raw materials, increasing resource efficiency.

Adoption of green energy technologies—including solar, wind, biogas, and other renewable sources—contributes to the reduction of the industrial carbon footprint.

Strengthening the regulatory and legal framework enhances the effectiveness of environmental protection measures.

These approaches support the sustainable development of industrial enterprises, ensure environmental safety, and improve economic efficiency.

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