AMERICAN JOURNAL OF BIOLOGY AND NATURAL SCIENCES
https://biojournals.us/index.php/AJBNS
ISSN: 2997-7185

Article

Assessment Of The Environmental And Economic Efficiency Of Waste Management And Recycling Technologies In Bukhara Region, Uzbekistan

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Citation: Kobulova Barno Bakhriddin kizi. Assessment Of The Environmental And Economic Efficiency Of Waste Management And Recycling Technologies In Bukhara Region, Uzbekistan. American Journal of Biology and Natural Sciences 2026, 3(11), 118-124.

Received: 10th Jun 2026
Revised: 11th Sep 2026
Accepted: 20thOct 2026
Published: 21stNov 2026

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Abstract: The assessment of environmental and economic efficiency is an essential component of sustainable waste management. Increasing municipal solid waste generation requires regional authorities to introduce technologically effective, economically viable, and environmentally responsible waste treatment systems. This article investigates the potential environmental and economic efficiency of waste management and recycling technologies in Bukhara Region, Uzbekistan. The research aims to identify the main factors influencing the performance of waste treatment systems, examine the relationship between recycling technologies and resource efficiency, and develop an integrated framework for evaluating waste management performance. The study applies comparative, analytical, and systematic approaches based on international environmental publications and national waste management policy documents. Particular attention is given to waste sorting, mechanical recycling, organic waste composting, material recovery, and landfill management. The proposed assessment framework incorporates environmental indicators, including recycling rates, landfill diversion, pollution prevention, and resource conservation, alongside economic indicators such as operational costs, investment requirements, revenue from recovered materials, and cost-effectiveness. The findings suggest that combining appropriate recycling technologies with effective institutional management can improve regional waste management performance. The article concludes that an integrated environmental-economic assessment model can support evidence-based decision-making and sustainable waste management planning in Bukhara Region.

Keywords: waste management, recycling technologies, environmental efficiency, economic efficiency, cost-effectiveness, solid waste, resource recovery, circular economy, Bukhara Region.

1. Introduction

Waste management is an increasingly important component of sustainable regional development. The growth of urban populations, expansion of economic activities, and increasing consumption of material goods have resulted in a continuous increase in municipal solid waste generation. These developments require the introduction of effective technological solutions that can reduce environmental pollution while ensuring the economic sustainability of waste management systems [1].

According to the United Nations Environment Programme, global municipal solid waste generation is expected to increase from approximately 2.1 billion tonnes in 2023 to 3.8 billion tonnes by 2050. This trend highlights the importance of developing economically and environmentally efficient waste management technologies [2].

Traditional waste management systems are largely based on collection, transportation, and landfill disposal. Although these activities are necessary for maintaining sanitary conditions, they do not fully utilise the economic value of recyclable materials. Modern waste management strategies therefore emphasise waste prevention, material recovery, recycling, and the development of circular economy systems.

The World Bank identifies waste management planning, institutional coordination, operational efficiency, and financial sustainability as important conditions for improving municipal waste management systems [3].

In Uzbekistan, the Solid Waste Management Strategy for 2019–2028 provides a policy framework for improving waste collection, transportation, recycling, and disposal systems. The strategy also emphasises the reduction of landfill dependency and the development of recycling capacities [4].

Bukhara Region requires particular attention in this context because of its urban development, tourism sector, agricultural activities, and increasing demand for environmental services. The region needs waste management technologies that are not only environmentally safe but also financially sustainable and suitable for local economic conditions [5].

The economic efficiency of recycling technologies depends on several factors, including the composition of waste, collection costs, transportation distances, energy consumption, technological capacity, market demand for secondary raw materials, and the availability of investment.

At the same time, environmental efficiency must be assessed through measurable indicators such as reductions in landfill disposal, resource conservation, emissions prevention, and the reduction of pollution risks.

The main purpose of this research is to develop an integrated framework for assessing the environmental and economic efficiency of waste management and recycling technologies in Bukhara Region [6].

The specific objectives are:

1. To examine the main technological approaches used in modern waste management.
2. To identify the environmental and economic indicators relevant to recycling efficiency.
3. To analyse the potential application of different recycling technologies in Bukhara Region.
4. To develop an integrated framework for evaluating waste management performance.
5. To formulate recommendations for improving regional environmental and economic efficiency.

2. Materials And Methods

The research is based on a qualitative and analytical approach that combines the examination of international scientific literature, environmental reports, national policy documents, and established waste management assessment principles.

The geographical scope of the research is Bukhara Region, Uzbekistan.

The study focuses on five major technological approaches:

1. Mechanical sorting and separation of municipal solid waste.
2. Plastic recycling and material recovery.
3. Paper and cardboard recycling.
4. Glass and metal recovery.
5. Biological treatment and composting of organic waste.

The following methods were applied.

Analytical method

International publications and national policy documents were analysed to identify the main technological and organisational factors affecting waste management efficiency.

Comparative method

Different waste treatment technologies were compared according to their environmental benefits, operational requirements, economic potential, and suitability for regional implementation.

Systematic approach

Waste management was examined as an integrated process involving waste generation, collection, transportation, sorting, processing, recovery, and final disposal.

Environmental-economic assessment

A set of quantitative indicators was proposed to evaluate the environmental and economic performance of recycling technologies.

The following formulas provide a basis for subsequent empirical assessment.

3. Results

The analysis indicates that the environmental and economic performance of waste management technologies depends on the integration of technological capacity, resource recovery, operational costs, and institutional organization [7].

Comparative assessment of waste recycling technologies

Different recycling technologies provide different environmental and economic benefits. Their effectiveness depends on waste composition, processing capacity, infrastructure availability, and market demand for recovered materials.

Table 1. Comparative characteristics of waste management and recycling technologies

Technology	Environmental efficiency	Economic potential	Main limitation
Mechanical sorting	Reduces mixed waste disposal	Produces marketable secondary materials	Requires investment in equipment
Plastic recycling	Reduces plastic waste accumulation	Generates recycled plastic materials	Depends on material quality and market demand
Paper recycling	Reduces demand for virgin fibres	Supports secondary paper production	Requires clean and sorted paper
Glass recycling	Conserves raw materials	Enables repeated material recovery	Transportation and processing costs
Metal recycling	Reduces demand for primary metals	Offers potential material revenue	Requires appropriate separation
Organic composting	Supports organic waste recovery	Produces compost for suitable applications	Requires contamination control

Source: Compiled by the author based on [8].

The comparison demonstrates that no single technology can address all waste management challenges. A combination of sorting, recycling, and biological treatment technologies is more appropriate for developing an integrated regional waste management system.

Environmental efficiency assessment

Environmental efficiency should be determined by measuring the extent to which waste treatment technologies reduce environmental pressure.

The main assessment indicators include:

1. Reduction in the amount of waste transported to landfills.
2. Reduction in uncontrolled waste disposal.
3. Decrease in the demand for primary raw materials.
4. Improvement in material recovery.
5. Reduction in pollution risks.
6. Efficient utilisation of organic waste [9].

The UNEP emphasises that waste prevention and reuse should be prioritised, followed by recycling and other appropriate recovery methods [10].

For Bukhara Region, these principles suggest the importance of establishing separate collection and treatment systems for different categories of waste.

Economic efficiency assessment

Economic efficiency is determined by the relationship between the financial resources invested in waste management and the measurable economic benefits obtained [11].

The principal expenditure categories include:

1. Waste collection and transportation.
2. Sorting and separation operations.
3. Equipment installation and maintenance.
4. Electricity and water consumption.
5. Labour and administrative expenses.
6. Waste treatment and residual disposal.

Potential economic benefits include:

- Revenue from recyclable materials.
- Reduced landfill transportation and disposal costs.
- Recovery of reusable raw materials.
- Production and sale of quality-controlled compost.
- Employment opportunities in recycling enterprises.

The World Bank notes that financial planning, operational management, and cost recovery are important components of sustainable waste management systems [12].

Proposed integrated environmental-economic assessment model

Based on the reviewed literature, an integrated assessment model is proposed for evaluating waste management technologies in Bukhara Region.

Table 2. Integrated indicators for evaluating waste management efficiency

Assessment dimension	Indicator	Measurement unit
Environmental	Recycling rate	Percentage (%)
Environmental	Landfill diversion rate	Percentage (%)
Environmental	Material recovery volume	Tonnes/year
Environmental	Greenhouse gas emissions	Tonnes of CO_2-equivalent
Environmental	Energy consumption	kWh/tonne
Economic	Investment costs	UZS
Economic	Operational costs	UZS/year
Economic	Revenue from recycled materials	UZS/year
Economic	Net economic benefit	UZS/year
Economic	Cost per tonne processed	UZS/tonne
Institutional	Collection service coverage	Percentage (%)
Institutional	Public participation	Percentage (%)

Source: Developed by the author based on [13].

The proposed model makes it possible to examine environmental and economic performance simultaneously. It also provides a basis for comparing different technological alternatives under regional conditions.

Regional opportunities for Bukhara Region

The regional application of recycling technologies should consider the specific economic and geographical characteristics of Bukhara Region.

Several opportunities can be identified.

First, the development of sorting facilities in urban areas could improve the separation and recovery of recyclable materials.

Second, cooperation with hotels, restaurants, markets, and tourism enterprises could reduce the quantity of mixed municipal waste and improve source separation.

Third, agricultural waste and biodegradable municipal waste could be considered for composting and other biological treatment methods, subject to technical and environmental feasibility assessments.

Fourth, cooperation between local authorities and private recycling enterprises could encourage investment in waste processing infrastructure.

Finally, digital monitoring systems could improve the collection and analysis of information on waste generation, transportation, treatment, and disposal [14].

4. Discussion

The results suggest that the assessment of waste management technologies should not be limited to recycling volumes or financial returns. A comprehensive approach must consider environmental impacts, operational performance, investment requirements, and long-term economic sustainability.

One of the most important findings is that the environmental and economic dimensions of waste management are closely interconnected.

For example, improved waste sorting can increase the quality of recovered materials, reduce contamination, and improve the economic value of recyclable products. Similarly, efficient transportation planning can reduce fuel consumption and operational expenses.

However, the implementation of recycling technologies requires careful economic planning. The purchase of advanced equipment does not automatically guarantee financial efficiency. Investment decisions should be based on reliable information concerning waste composition, processing capacity, transportation distances, electricity costs, and market demand.

For Bukhara Region, the selection of technologies should therefore follow a region-specific assessment rather than relying exclusively on technological solutions implemented in other countries.

The following strategic measures are recommended:

1. Establishment of regional waste sorting infrastructure.

Separate collection and sorting facilities should be developed to improve the recovery of recyclable materials.

2. Promotion of public-private partnerships.

Cooperation between local government institutions and private enterprises could facilitate investment in recycling infrastructure and improve operational management.

3. Development of organic waste processing.

Composting facilities could be introduced where sufficient quantities of suitable organic waste are available.

4. Introduction of economic monitoring indicators.

Waste management enterprises should systematically monitor operational expenditure, recycling revenues, material recovery rates, and cost per tonne processed.

5. Strengthening environmental monitoring.

The environmental performance of recycling and disposal facilities should be evaluated through regular monitoring of air, soil, and groundwater quality where relevant.

6. Digitalisation of waste management.

A regional information system could provide data on waste collection, transportation, recycling, and disposal, supporting more transparent decision-making.

It is also important to consider the limitations of the proposed assessment. The economic performance of recycling technologies depends on changing market prices, transportation costs,

energy prices, and the quality of recovered materials. Environmental benefits also require appropriate life-cycle assessment to avoid transferring pollution from one stage of waste management to another.
Therefore, the proposed framework should be applied using verified regional statistical data and direct measurements in future empirical research [15].

5. Conclusion

The assessment of environmental and economic efficiency is essential for improving waste management systems and supporting sustainable regional development.
The research demonstrates that mechanical sorting, plastic recycling, paper recovery, glass and metal processing, and organic waste composting can contribute to improving resource utilisation and reducing environmental pressure when they are implemented under appropriate technical and economic conditions.
For Bukhara Region, the development of an integrated waste management system requires the coordination of technological, financial, institutional, and environmental measures.
The proposed assessment framework combines environmental indicators, including recycling rates, landfill diversion, material recovery, and emissions, with economic indicators such as investment costs, operational expenditure, recycling revenues, and net economic benefits.
The study highlights that technological modernisation should be accompanied by effective financial planning, institutional cooperation, public participation, and environmental monitoring.
It is recommended that future research conduct a detailed regional waste composition analysis, collect primary operational and financial data from waste management enterprises, and apply life-cycle assessment to determine the actual environmental performance of different recycling technologies.
The implementation of these measures could provide a scientific basis for selecting economically viable and environmentally sustainable waste management technologies in Bukhara Region.

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