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Theoretical and Practical Aspects of Solid Waste Recycling Efficiency in Industrial Enterprises of Uzbekistan

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Abstract: Industrial waste management has come to be widely recognised as a prerequisite to any viable economy with the present conditions of widespread industrialisation. With the growth of industrialization in Uzbekistan, implementation of the Strategy of Uzbekistan – 2030 has changed the attitude towards waste disposal fate from a one-type more complex disposal and regenerated as a secondary resource. Nevertheless, there still exists a lag between the contemporary management practises and circular economy principles necessary for a “Green Economy” to be realised. In response, this research adopts a multi-method approach, using SWOT analysis and economic modeling to assess recycling efficiency in most economic sectors–industrial enterprises. We make an important contribution by introducing a unique efficiency function (Eres) that quantifies recycling by cost, volume of waste, and potentially implementable technology in order to better understand how much economic and resource saving potential is available from recycling. The report expects the recycling rate of industrial waste to increase from 21% in 2024 to 65% in 2030 and the recycling rate of landfill to fall to 35%. The Emissions Reduction Fund will trigger the transition to this ‘Zero Waste’ strategy, providing \$350 million in economic savings and the possibility of expanding sector employment from 8,000 to more than 50,000 jobs. The research also found that industrial symbiosis, which is a practice that utilizes the waste of one enterprise as raw materials for others, could be applied to reduce the cost of industrial products by 10–15% and decrease imports of raw materials by 25%. Our results indicate that modernizing industrial waste infrastructure in Uzbekistan, where the high investments available are scarce, is economically viable in order to improve the overall attractiveness for investments.

Keywords: Industrial waste, circular economy, Uzbekistan-2030 Strategy, industrial symbiosis, green economy, resource efficiency, forecasting.

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1. Introduction

Under the conditions of global industrialization, industrial waste management has emerged as a fundamental factor in economic stability. Globally, more than 2 billion tons of waste are generated annually, a significant portion of which is attributed to industrial sectors. The modern industrial sector faces a dual challenge: increasing production volumes while minimizing negative environmental impacts. According to international statistics, industrial activities account for more than 50% of the world's total solid waste [1]. As the share of industry in Uzbekistan's economy continues to grow, transitioning from mere disposal to reintegrating waste into production as a secondary resource has become a priority of the “Uzbekistan – 2030” Strategy. The objective of this study is to analyze cost-reduction mechanisms through the implementation of the “Zero

Waste” principle in industrial enterprises. While the “Uzbekistan – 2030” Strategy outlines ambitious goals for environmental protection and the transition to a “Green Economy” a theoretical gap remains between current waste management practices and the requirements of a circular economy [2]. This research aims to bridge this gap by evaluating recycling efficiency in industrial enterprises and proposing a localized model.

2. Methodology

This research employs a multi-methodological approach, including SWOT analysis, monographic observation, systematic and comparative analysis, the extrapolation method, regression and correlation analysis, and economic modeling. Consequently, the experiences of Germany (EPR system) and South Korea (Eco-Industrial Parks) were projected onto Uzbekistan's manufacturing conditions, and the investment attractiveness and Return on Investment (ROI) of waste recycling were analyzed [3]. Based on statistical data, dynamic growth forecasts up to 2030 were developed for the future.

The theoretical foundations of the circular economy were pioneered by Pearce and Turner, who focused on closed-loop systems in resource utilization. Contemporary scholars such as Stahel argue that waste is a “design flaw” [4]. Furthermore, Bilitewski identifies the lack of necessary infrastructure as a primary barrier to recycling efficiency. While local researchers in Uzbekistan have primarily focused on environmental aspects, this study proposes a forecast of the waste-to-resource ratio up to 2030 using a specific efficiency function. The proposed efficiency function is designed to mathematically represent both the economic and resource-saving efficiency of industrial waste recycling.

$$E_{res} = \sum_{2024}^{2030} \frac{(V_w * P_r) - (C_{op} + I_t)}{V_{total}}$$

The proposed efficiency function is defined by the following variables: V_w – Volume of waste; P_r – Price of secondary raw materials; C_{op} – Operational costs; I_t – Technological investments.

This model is primarily based on the “net profit-to-resource ratio” principle. It evaluates the difference between the economic value generated during the waste recycling process and the costs incurred, relative to the total volume. The first component of the formula, $(V_w * P_r)$ represents the gross revenue derived from converting waste into raw materials by multiplying the volume of recycled waste by its market price. In this context, waste is treated not merely as a liability but as a strategic asset (resource). To determine the net efficiency of the process, operational expenses (energy, labor, and transport) and technological investments (new equipment and innovations) are subtracted from $(C_{op} + I_t)$ the gross revenue. This reflects the Return on Investment (ROI) and the self-sufficiency of the recycling system [5]. Dividing this result by the total volume V_{total} provides a normalized indicator of how “clean” and efficient the system is, calculating the economic and environmental benefit per unit of waste. The representation of the formula in a summation ($\sum$) form allows for the observation of temporal dynamics over the period of 2024–2030. Utilizing this model, it is possible to forecast how overall efficiency increases as technological investments lead to a reduction in operational costs and as the market price of secondary raw materials rises. Consequently, this function serves as a critical indicator for defining waste management strategies at both the corporate and national levels.

3. Results and Discussion

As part of the study, a comparative analysis of international practices, specifically European Union (EU) statistical indicators, was conducted to evaluate the efficiency of

solid waste recycling in Uzbekistan's industrial enterprises [6]. As of 2022, the EU generated a total of 83,4 million tonnes of packaging waste, equivalent to 186,5 kg per capita. The fact that this figure has increased by 31,7 kg compared to 2012 indicates a continuous growth in waste volumes within industrialized societies. The composition of all packaging waste generated in the European Union is distributed as follows: 41% paper and cardboard, 19% plastic, 19% glass, 16% wood, 5% metal [7].

In 2022, an average of 36,1 kg of plastic packaging waste was generated per person living in the EU, of which 14,7 kg was recycled. Between 2012 and 2022, the amount of plastic packaging waste generated per capita increased by 7,6 kg, while the volume of recycled plastic rose by 4,0 kg [8] (Figure 1).

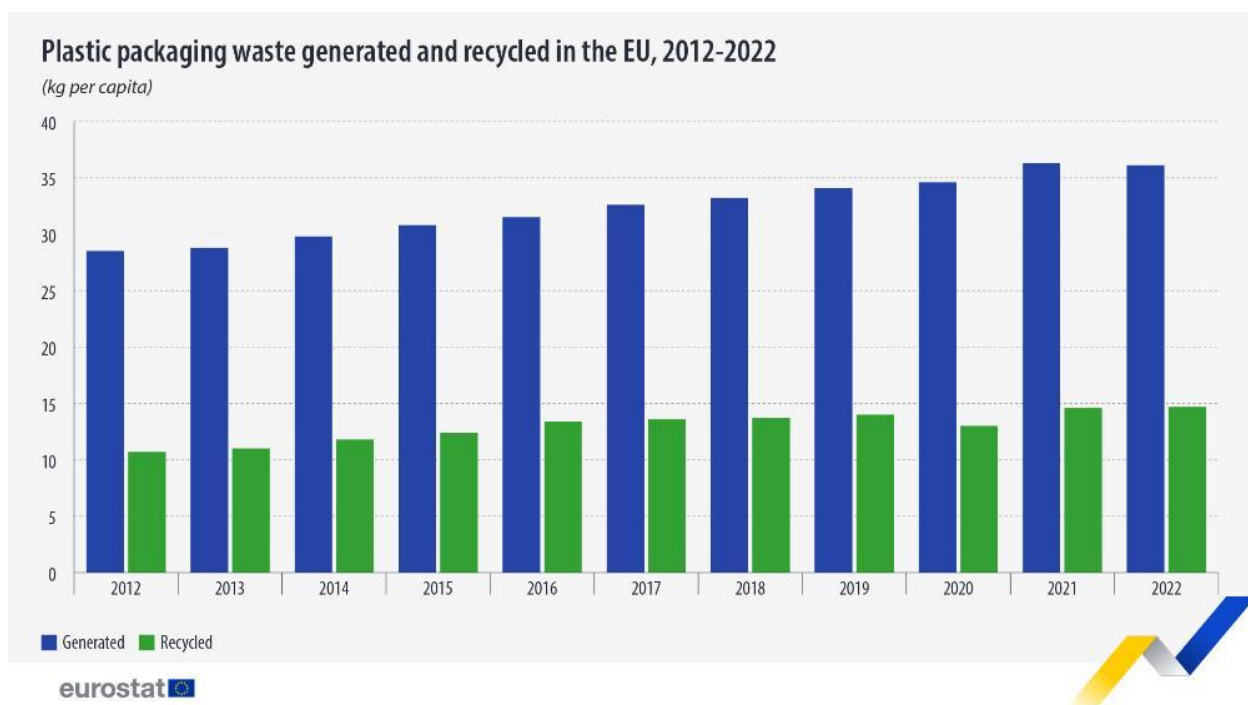


Figure 1. plastic packaging waste generated and recycled in the EU.

The average recycling rate of industrial waste in Uzbekistan currently stands at 15-20%. Based on the “Uzbekistan-2030” strategy, the following development forecast for the industrial sector has been developed [9].

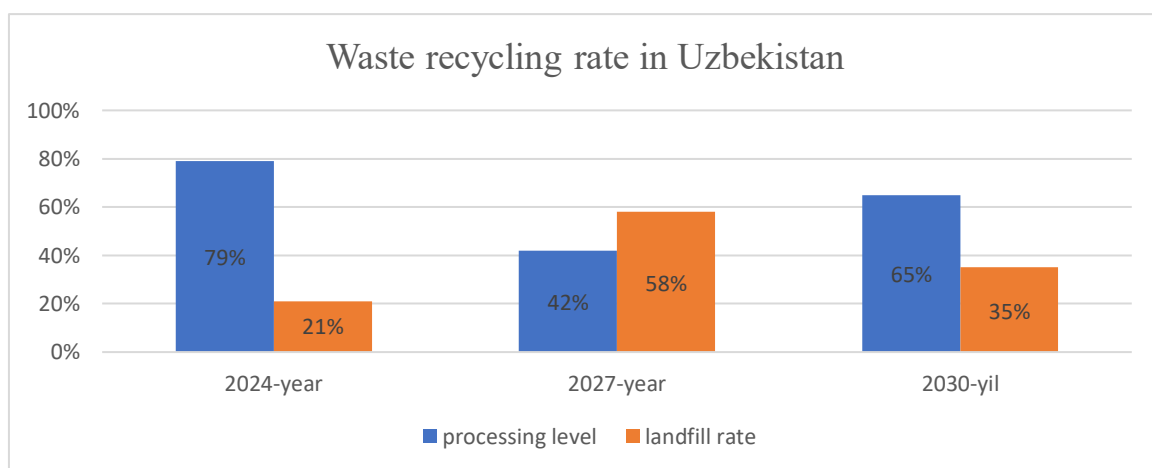


Figure 2. Waste recycling rate in Uzbekistan.

According to the data presented in Figure 2, the majority of waste in 2024 (79%) was disposed of in traditional landfills, while the recycling rate stood at 21%. By 2027, the share of recycling is projected to double, reaching 42%, whereas landfill disposal is expected to decrease to 58%. By 2030, recycling is anticipated to become the primary management method, accounting for 65% of total waste, with the landfill disposal rate dropping to 35%. These figures indicate that significant transformations are expected in the field of solid waste management [10].

As a result of strategic reforms in Uzbekistan, the following indicators are projected to be achieved:



Figure 3. Forecast indicators of industrial waste processing (2024-2030).

Figure 3 reflects the strategic plan for the development of the industrial waste recycling sector in Uzbekistan for the 2024–2030 period. While the recycling efficiency was at a low level of 21% in 2024, the target is to reach 65% by 2030. This signifies a transition of industrial enterprises toward the “Zero Waste” principle, increasing the waste reuse rate threefold rather than relying on landfill disposal.

The recovery of secondary raw materials is expected to reduce raw material imports by 25%, enabling the preservation of national foreign exchange reserves and more efficient use of local resources [11]. Sectoral modernization will also drive job creation, with employment projected to grow from 8,000 positions in 2024 to over 50,000 by 2030. This indicates the emergence of new “green” professions that ensure both environmental and social stability [12].

Data analysis forecasts more than a fourfold increase in environmental efficiency (from 15% to 65%) between 2023 and 2030, leading to economic savings of \$350 million. Although industrial expansion is expected to increase total waste volume from 120 million to 150 million tonnes, the most significant change will occur in the recycling share. This reflects the widespread implementation of circular economy principles and modern utilization technologies. The value of saved raw materials is projected to grow much faster than waste volume, increasing 7.7-fold (from \$45 million to \$350 million). By 2030, Uzbekistan plans to increase the number of industrial clusters operating on the “Zero Waste” principle, which is estimated to reduce the cost of industrial products by 10–15% due to resource efficiency [13].

Discussion

International experience demonstrates that efficiency is achieved not only through technology but also via legislative reforms. The following advanced global solutions are proposed for the successful implementation of the “Uzbekistan – 2030” Strategy:

1. South Korean Model: Establishing “Eco-Industrial Parks” in the Tashkent and Navoi regions, where the thermal energy or wastewater of one plant serves as a resource for another.
2. German Model: Implementing Blockchain technology to monitor waste movement, which eliminates illegal dumping. Additionally, introducing Green Bonds to provide low-interest “ecological loans” for enterprises purchasing recycling technologies.
3. Japanese Model: Creating a platform for the B2B sale of industrial by-products (e.g., thermal energy or metallurgical slag). Implementing Extended Producer Responsibility (EPR) encourages the circular economy by making producers financially responsible for their product packaging and waste [14].

Practical application is already evident at the Navoi Mining and Metallurgical Company, where technogenic waste (sludge) processing has been successfully implemented. By extracting gold and associated metals from old tailings, the company reduced production costs by 35% compared to primary ore mining, enhancing its competitiveness on global exchanges. Similarly, while only 12% of the phosphogypsum produced by “Uzkimyosanoat” JSC is currently recycled, our forecast suggests that converting this waste into construction materials (gypsum board) could generate an additional \$15-20 million in annual revenue by 2030 [15].

4. Conclusion

To increase the efficiency of solid waste recycling in Uzbekistan's industrial enterprises, it is essential to fully transition to a circular economy model and implement industrial symbiosis. This requires a system where one enterprise's waste becomes another's raw material—such as utilizing metallurgical and energy waste for construction materials. To accelerate this, the foundation of economic stimulation should include “green” subsidies, tax incentives for importers of recycling technologies, and preferential status in public procurement for manufacturers using recycled materials.

Furthermore, digitalization through electronic exchanges for real-time waste monitoring will facilitate resource sharing between enterprises. Technologically, the adoption of innovative methods such as pyrolysis and plasma gasification for waste-to-energy conversion, the construction of automated sorting points in industrial zones, and the establishment of Regional Recycling Hubs to reduce logistics costs are required. Such a comprehensive approach will not only alleviate the environmental burden but also significantly increase the economic profitability of the industrial sector through secondary resources.

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