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IN DEVELOPING COUNTRIES NEW APPROACHES TO RECYCLING IN THIER ECONOMY COSTS AND FINANCING MECHANISMS,

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ANNOTATION:

Recycling has evolved from a basic waste-management practice into a strategic pillar of the circular economy. This article examines new approaches to recycling, analyzes the economic costs involved, and explores how developing countries can allocate and mobilize funds for the recycling sector. Drawing on global data and existing literature, the study highlights recycling as a tool for sustainable development, job creation, and resource efficiency. The paper also reviews financing models suitable for low- and middle-income economies. Recycling is more than waste management — it's a driver of circular economic growth**:** It reduces raw material costs and commodity price risks. For example, recycled materials can be cheaper than virgin inputs in many products, improving profitability for local businesses. It creates jobs: estimates suggest recycling industries in developing countries can create 15–40 jobs per $1 million invested. It reduces environmental degradation (GHG emissions, pollution, landfills) and provides public health benefits from cleaner cities.It can make national industries more resilient and competitive internationally.

Key words: Circular Economy ,Resource Recovery, AI & IoT sorting systems, Blockchain & tokenization models, environmental degradation, raw material costs, Green bonds **,** carbon markets, Public-private partnerships (PPPs)

В РАЗВИВАЮЩИХСЯ СТРАНАХ НОВЫЕ ПОДХОДЫ К ПЕРЕРАБОТКЕ ОТХОДОВ В ИХ ЭКОНОМИКЕ, ЗАТРАТЫ И МЕХАНИЗМЫ ФИНАНСИРОВАНИЯ

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АННОТАЦИЯ

Переработка отходов превратилась из базовой практики управления отходами в стратегический столп экономики замкнутого цикла. В этой статье рассматриваются новые подходы к переработке, анализируются связанные с этим экономические издержки и исследуется, как развивающиеся страны могут распределять и мобилизовать средства для сектора переработки. Опираясь на глобальные данные и существующую литературу, исследование подчеркивает роль переработки как инструмента устойчивого развития, создания рабочих мест и повышения эффективности использования ресурсов. В статье также рассматриваются модели финансирования, подходящие для стран с низким и средним уровнем дохода. Переработка — это больше, чем просто управление отходами, это движущая сила роста экономики замкнутого цикла: она снижает затраты на сырье и риски, связанные с ценами на товары. Например, переработанные материалы могут быть дешевле, чем первичное сырье во многих продуктах, что повышает прибыльность местных предприятий. Она создает рабочие места: по оценкам, предприятия по переработке отходов в развивающихся странах могут создать 15–40 рабочих мест на каждый миллион долларов инвестиций. Она снижает деградацию окружающей среды (выбросы парниковых газов, загрязнение, свалки) и

обеспечивает пользу для общественного здравоохранения благодаря более чистым городам. Она может сделать национальные отрасли промышленности более устойчивыми и конкурентоспособными на международ ном уровне.

Ключевые слова: Циркулярная экономика, переработка ресурсов, системы сортировки на основе ИИ и Интернета вещей, блокчейн и модели токенизации, деградация окружающей среды, стоимость сырья, зеленые облигации, углеродные рынки, государственно-частное партнерство (ГЧП)

RIVOJLANAYOTGAN MAMLAKATLARDA QAYTA ISHLASH SOHASIGA YANGI YONDASHUVLAR: IQTISODIY XARAJATLAR VA MOLIYALASHTIRISH MEXANIZMLARI

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ANNOTATSIYA

Qayta ishlash dastlab chiqindilarni boshqarishning oddiy usuli bo‘lgan bo‘lsa, bugungi kunda u aylana (tsirkulyar) iqtisodiyotning muhim strategik ustuniga aylandi. Ushbu maqolada qayta ishlash sohasidagi yangi yondashuvlar tahlil qilinadi, u bilan bog‘liq iqtisodiy xarajatlar o‘rganiladi hamda rivojlanayotgan mamlakatlarda qayta ishlash sektorini moliyalashtirish va zarur mablag‘larni safarbar etish mexanizmlari ko‘rib chiqiladi. Tadqiqot global ma’lumotlar va mavjud ilmiy adabiyotlarga asoslanib, qayta ishlashni barqaror rivojlanish, bandlikni oshirish va resurslardan samarali foydalanish vositasi sifatida yoritadi. Shuningdek, maqolada past va o‘rta daromadli mamlakatlar uchun mos bo‘lgan moliyalashtirish modellari tahlil qilinadi. Qayta ishlash faqat chiqindilarni boshqarish emas, balki aylana iqtisodiy o‘sishning muhim harakatlantiruvchi kuchidir: u xomashyo xarajatlarini kamaytiradi va tovar narxlaridagi beqarorlik xavfini pasaytiradi. Masalan, ko‘plab mahsulotlarda qayta ishlangan materiallar birlamchi xomashyoga nisbatan arzon bo‘lib, mahalliy korxonalar rentabelligini oshiradi. Qayta ishlash yangi ish o‘rinlarini yaratadi: hisob-kitoblarga ko‘ra, rivojlanayotgan mamlakatlarda qayta ishlash sanoati har 1 million AQSh dollari investitsiya evaziga 15–40 ta ish o‘rnini yaratishi mumkin. Bundan tashqari, u atrof-muhitga yetkaziladigan zararni (issiqxona gazlari chiqindilari, ifloslanish, poligonlar hajmi) kamaytiradi va shaharlarning tozaligi orqali aholi salomatligiga ijobiy ta’sir ko‘rsatadi. Qayta ishlash milliy sanoatning barqarorligini oshirib, uni xalqaro miqyosda raqobatbardoshroq qilishi mumkin.

Kalit so‘zlar: Aylana iqtisodiyot, resurslarni qayta tiklash, AI va IoT asosidagi saralash tizimlari, blokcheyn va tokenizatsiya modellari, atrof-muhit degradatsiyasi, xomashyo xarajatlari, yashil obligatsiyalar, uglerod bozorlari, davlat-xususiy sheriklik (DXSh).

INTRODUCTION

Innovative recycling systems increasingly rely on digital technologies to address the growing challenges of waste generation, resource scarcity, and environmental degradation. Traditional recycling systems often suffer from inefficiencies such as poor waste segregation, high operational costs, lack of transparency, and low recycling rates. Digital technologies offer new solutions by improving efficiency, traceability, data-driven decision-making, and stakeholder engagement. As a result, digitalization has become a key driver of modern, sustainable, and circular recycling systems. Digital technologies transform recycling systems across the entire value chain, from waste generation and collection to sorting, processing, and secondary material markets. These technologies enable real-time monitoring, automation, and optimization, making recycling systems more effective and economically viable. AI & IoT sorting systems improve material separation, raising recycling efficiency and quality. Smart bins with sensors can monitor real-time collection and trigger pickups.

Blockchain & tokenization models are being explored to incentivize citizens (e.g., tokens or reward credits for recycling), linking them to market pricing and potentially carbon credits.These digital systems reduce operational costs long-term by increasing recovery yield and lowering contamination. The Internet of Things (IoT) plays a crucial role in innovative recycling systems through the use of sensors and connected devices.

Smart bins equipped with sensors monitor fill levels, waste type, and contamination rates.Data collected in real time helps municipalities optimize collection routes, reducing fuel consumption, labor costs, and greenhouse gas emissions.Predictive analytics based on IoT data allows authorities to plan collection schedules more efficiently and avoid overflows.Studies show that smart collection systems can reduce waste collection costs by 20–40% while improving service quality. Artificial Intelligence (AI) and Automated Sorting, artificial intelligence is transforming waste sorting and material recovery facilities:Machine vision systems identify different materials (plastics, metals, paper, glass) based on shape, color, and composition.Robotic arms powered by AI separate waste at high speed and with high accuracy.AI systems reduce human error and contamination, leading to higher-quality recycled materials.Automated AI-based sorting can increase material recovery rates by 20–30% and significantly improve the market value of recycled outputs. Big Data Analytics and Decision Support Systems **.**Big data analytics enables recycling systems to move from reactive to proactive management:Large volumes of data from collection, sorting, and processing stages are analyzed to identify inefficiencies. Governments and companies can forecast waste generation trends and plan infrastructure investments accordingly. Data-driven decision-making improves policy design, such as determining optimal recycling targets and incentive structures Circular Economy Business Models **.**Examples around the world show recyclers turning waste into valuable products or services: *Waste Concern* in Bangladesh demonstrates how waste can be transformed into sales-driven recycling entrepreneurship. Community-centric models like waste banks in Indonesia involve households depositing sorted waste for credit, improving collection rates and engagement.These help build local recycling markets and empower low-income participants. Countries are experimenting with policy and pricing tools:

- Deposit Return Systems (DRS) (e.g., Romania) dramatically boost recycling rates — with up to 94% bottle returns in some months after implementation.
- Taxes on virgin materials or waste export bans encourage domestic recycling investment. For example, UK reports link £800 million of private investment and ~5,400 new jobs to plastic recycling facility build-outs if waste exports are reduced.

These measures make recycling economically attractive for both investors and consumers. Economic Costs of Recycling. Direct Processing & Infrastructure Recycling often requires **sorting,** collection, and processing infrastructure — specialized plants, equipment (balers, sorters), and logistics.According to the International Energy Agency, advanced recycling costs can exceed $500 per tonne of waste processed (varies by material and region) but come with health and climate co-benefits.Informal recycling sectors (like in India or Bangladesh) often handle large portions of waste without safety or formal remuneration — integrating these workers into formal systems requires training, safety equipment, and social protections.Adopting automation and digital tools requires upfront capital that may be prohibitive without external financing — which is why funding strategies are critical. How Developing Countries Can Finance Recycling. Developing economies often struggle with limited budgets, but there are multiple viable ways to finance recycling industries:Public Budget Allocation Governments can designate specific environmental or zero waste budget lines to recycling infrastructure (vehicles, sorting stations, plants).Example: Some “green economy” national strategies include financing frameworks geared toward waste management and sustainability, and banks are

now building ESG-aligned credit lines.International Development Finance Major development institutions are already mobilizing resources:The World Bank is using instruments like sustainability-linked bonds — e.g., a $100 million bond financing plastic recycling projects in Ghana and Indonesia (180,000 ton recycling capacity; ~230,000 ton plastic collection).IFC sustainability loans and MIGA guarantees help build material recovery facilities and waste-to-energy plants.These risk-sharing mechanisms reduce financial burden on local governments. Private & Impact Investment. Recycling projects can be structured to appeal to:Impact investors interested in environmental, social, and governance (ESG) returns.Public-private partnerships (PPPs) where governments provide land or tax incentives and private firms build and operate facilities.Green bonds and carbon markets — where recycled materials generate credits sold for climate mitigation value. Example: In India, recycling equipment markets are forecast to expand to over $2.64 billion by 2030, signaling strong investor interest. India's recycling equipment market projected to reach $2,641 .Local and Micro-Funding.Local recycling cooperatives, social enterprises, and community schemes can be funded through:

- Micro-credits for small recyclers.
- Community crowdfunding.
- Municipal bonds earmarked for green infrastructure.

Models like waste banks demonstrate how small-scale finance can mobilize large volumes of sorted waste.Rapid urbanization, population growth, and rising consumption have significantly increased solid waste generation worldwide. According to the World Bank, global municipal solid waste generation exceeded 2.2 billion tonnes in 2020 and is projected to rise to 3.4 billion tonnes by 2050**,** with the fastest growth occurring in developing countries. At the same time, only about 13–15% of global waste is recycled**,** indicating a large untapped economic potential. In response, many economies are shifting from a traditional "linear" model (take–make–dispose) to a **circular economy**, where materials are reused, recycled, and reintegrated into production systems. Recycling has become a key component of this transition, particularly for developing countries seeking sustainable growth with limited natural resources. New Approaches to Recycling in the Modern Economy Circular Economy and Resource Recovery. The most significant new approach to recycling is its integration into the circular economy framework**.** Rather than treating waste as an environmental burden, modern systems view it as a secondary raw material**.** The Ellen MacArthur Foundation estimates that circular economy strategies, including recycling, could generate economic benefits of up to USD 4.5 trillion globally by 2030**.**

Recycling metals, plastics, paper, and organic waste reduces dependence on virgin materials. For example, recycling aluminum saves up to 95% of the energy required for primary production, while recycled plastics can save 30–80% of energy, depending on the process. Digital and Technological Innovations

New recycling approaches increasingly rely on digital technologies**,** such as:

- Artificial intelligence (AI**)** for automated waste sorting,
- Internet of Things (IoT) sensors for smart collection systems,
- Digital tracking platforms to monitor material flows.

These innovations improve efficiency, reduce contamination, and lower long-term operational costs. Studies indicate that AI-based sorting can increase material recovery rates by 20–30% compared to manual systems.Social and Community-Based Recycling Model**s**In many developing countries, informal waste pickers already play a critical role, collecting up to 60% of recyclable materials in some cities. New approaches aim to formalize and integrate these workers into organized

recycling systems through cooperatives, waste banks, and social enterprises. Evidence from countries such as India, Brazil, and Bangladesh shows that such models improve incomes, working conditions, and recycling rates simultaneously. Economic Costs of Recycling.Despite its benefits, recycling involves several types of costs: Capital CostsInitial investments are required for:Collection vehicles,Sorting facilities,Recycling plants and machinery.The cost of establishing a basic material recovery facility in a developing country typically ranges from USD 1–5 million, while advanced recycling plants may exceed USD 20–50 million**,** depending on scale and technology. Operational and Social Costs .Operational costs include labor, maintenance, energy, and transportation. In addition, integrating informal workers requires spending on training, safety equipment, and social protection. However, studies show that these costs are often offset by job creation, reduced landfill expenses, and public health benefits**.** Cost–Benefit Perspective. The World Bank estimates that every USD 1 invested in recycling and waste management can generate USD 3–4 in economic and social benefits, particularly in urban areas where landfill costs and environmental damage are high. Financing the Recycling Sector in Developing Countries**.**Developing countries often face fiscal constraints, but several financing mechanisms are available:Public Budget Allocation.Governments can allocate funds through: National environmental budgets, Municipal solid waste programs, Dedicated green or climate funds. Even allocating 0.3–0.5% of GDP to waste management and recycling can significantly improve infrastructure and service coverage in low-income countries**.** Public–Private Partnerships (PPPs) .PPPs allow governments to share risks and costs with private investors. In such models:

- The public sector provides land, policy support, or guarantees,
- The private sector finances and operates recycling facilities.

This approach has been successfully used in countries such as Indonesia, South Africa, and Vietnam. International and Climate Finance.International institutions play a key role in financing recycling:The World Bank and regional development banks provide concessional loans and grants.Green Climate Fund (GCF) and Global Environment Facility (GEF) support recycling projects with climate and environmental benefits.Between 2018 and 2023, international development finance institutions committed **over** USD 5 billion globally to waste management and recycling projects. Local and Micro-Finance Mechanisms. At the community level, recycling can be financed through:

- Micro-credit schemes for small recyclers,
- Cooperative financing,
- Waste-bank models that reward households for sorted waste.

Such decentralized financing is particularly effective in low-income urban areas.

LITERATURE REVIEW AND DISCUSSION.

The literature consistently emphasizes that recycling contributes to:

- Employment creation (10–40 jobs per 1,000 tonnes of waste recycled),
- Lower greenhouse gas emissions**,**
- Reduced public health costs**.**

However, researchers also highlight challenges such as weak governance, low public awareness, and limited access to finance. Successful case studies stress the importance of policy coherence**,** financial incentives**,** and institutional capacity building**.** Conclusion recycling is no longer merely an environmental necessity but a strategic economic opportunity, particularly for developing countries. New approaches grounded in the circular economy, supported by technology and inclusive social models, can transform waste into value. While recycling requires upfront investment, the long-term economic, social, and environmental returns outweigh the costs. For developing countries, a mixed financing strategy combining public funds, private investment, and international support offers

the most effective pathway to building a sustainable recycling sector and advancing broader development goals.

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