Turning waste into wealth: evaluating the macroeconomic benefits of recycling and pyrolysis in Armenia

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Abstract. Solid waste management represents a significant yet underutilized economic opportunity for developing economies, particularly Armenia. This study examines the macroeconomic potential of solid waste recycling and polymer pyrolysis, evaluating their capacity to contribute to GDP growth while promoting environmental sustainability. Quantitative analysis estimates the revenue potential from recycling major solid waste streams and converting polymer waste into fuel through industrial pyrolysis. The economic value added through these waste valorization methods is benchmarked against Armenia's GDP to assess macroeconomic impacts. Results indicate that implementing systematic waste collection, recycling, and pyrolysis technologies could yield substantial economic benefits, including GDP growth, reduced fuel import dependence, employment generation, and increased fiscal revenues. Beyond direct financial returns, waste-to-energy conversion offers environmental advantages through pollution reduction and decreased landfill reliance. The analysis further identifies multiplier effects supporting regional development and industrial diversification. These findings demonstrate the strategic value of incorporating advanced waste management systems into national economic planning as a pathway toward circular economy implementation and sustainable development in Armenia.

1 Introduction

Numerous contemporary studies forecast the end of the 21st century as a period of potential ecological collapse, a scenario largely attributed to the rapid and unsustainable growth in solid waste generation. This trend threatens not only specific species of flora and fauna but the entire natural ecosystem of which humanity is an inseparable part. Among the most urgent environmental challenges is the management of solid waste, which poses complex ecological, economic, and social risks. Waste management has been a relevant and pressing issue since the mid-20th century when industrial-scale incineration plants began to be

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constructed and operated. Although the first waste incineration facility was established in Nottingham as early as 1874, it was not until the second half of the 20th century that such facilities became widespread in the United Kingdom, primarily due to the increasing accumulation of polymer-based waste. While industrial enterprises were initially the principal source of polymer waste, household consumption has since become an equally significant contributor.

Modern polymer materials (comprising various plastics, elastomers, and synthetic fibers) are now extensively used in trade, healthcare, agriculture, and various aspects of daily life. The uncontrolled incineration of these materials results in the release of harmful gases, thereby exacerbating environmental degradation. In contrast, systematic recycling has the potential to mitigate not only environmental harm but also contribute to economic efficiency and social well-being. However, many high-performance polymers currently in use are less compatible with environmental goals and are often economically unviable to recycle, creating a paradox between technological advancement and ecological responsibility.

Not all solid waste is equally suitable for recycling. Some materials, particularly complex plastics and micro-components, are more cost-effectively neutralized through controlled incineration. Meanwhile, relatively simple waste types such as polyethylene, metals, paper, and glass are widely recyclable and are processed in many countries. More complex waste streams, including used automotive engine oils and oily wastewater from marine transport, present additional technical and economic challenges that limit recycling feasibility. These limitations are often compounded by insufficient sorting infrastructure and limited public awareness.

As a small and open economy, Armenia faces a wide range of challenges, including exposure to external shocks [1], food security [2], import dependency [3], balanced and inclusive regional development [4], social welfare [5], efficient agricultural production [6], labor market dynamics, and migration pressures [7]. Environmental concerns and waste management are no exception to these challenges, particularly in light of Armenia's commitment to the United Nations Sustainable Development Goals (SDGs), where environmental sustainability has been identified as a national priority[8].The economic rationale behind solid waste processing is increasingly viewed through the lens of resource recovery and macroeconomic benefit. Accordingly, this study aims to assess the potential macroeconomic impact of solid waste management in Armenia, with a particular focus on the collection of polymer-based waste and its conversion into fuel through pyrolysis. The study estimates the monetary value of fuel produced via pyrolysis, excluding production costs, and compares this value to the country's GDP to determine its potential contribution to economic growth.

More broadly, the study evaluates the volume and structure of solid waste generated through economic and household activities, identifies key recyclable categories by weight, estimates the potential revenue from recycling efforts, and calculates the expected annual GDP growth from these activities. This comprehensive analysis integrates both traditional recycling strategies and advanced waste-to-energy conversion scenarios to offer a holistic view of the economic feasibility of sustainable waste management practices.

2 Literature review

The economic benefits of waste management are widely discussed in the literature. Studies show that in developing markets waste management practices have a wide range of benefits such as financial stability, job creation, and community cohesion [9].Efficient waste management practices significantly contribute to employment opportunities. In the United States, the recycling industry supports over a million jobs, with the collection, processing, and manufacturing of recycled materials creating 6-13 times more jobs per 1,000 tons of waste compared to traditional landfill disposal. Similarly, in the European Union, full implementation of waste legislation is projected to create over 400,000 jobs by 2020. Implementing effective waste management can lead to substantial cost savings and revenue generation at the micro level and municipality [10]. The sale of recyclable materials such as paper, plastics, and metals can generate significant revenue streams. Efficient waste management reduces expenses related to waste disposal, landfill use, and raw material procurement by promoting resource recovery and reuse [11].

Beyond economic advantages, effective waste management contributes to environmental protection and social well-being [12]. Proper waste disposal and recycling reduce pollution, mitigate greenhouse gas emissions, and conserve natural resources. Socially, waste management initiatives can enhance community health, provide dignified employment, and promote social inclusion, particularly for marginalized groups involved in informal waste collection. Waste management is integral to the development of a circular economy, where materials are reused, repurposed, and recycled in closed-loop systems. This approach reduces dependence on virgin materials, conserves resources, and stimulates local economic activity [13].

Waste management, especially when aligned with circular economy principles, delivers substantial economic benefits by creating jobs, reducing costs, fostering innovation, and supporting financial stability for both communities and businesses. These advantages make waste management a key driver of sustainable economic growth [14]. These advantages make waste management a key driver of sustainable economic growth.

In recent years, public awareness regarding solid waste management has increased due to economic growth, which has influenced poor waste management practices. The majority of the generated waste has been disposed of without undergoing any form of processing, often ending up in open dumps and landfills. These methods are unhygienic and adversely affect public health, the environment, and the economy of the country [15]. This assessment summarizes the current situation and outlines the potential economic impacts of effective waste management.

Armenia's waste management primarily focuses on collection, transportation, and disposal, with minimal emphasis on recycling, prevention, or reduction [16]. Secondary use and utilization of waste are almost nonexistent [17]. There is an absence of a comprehensive policy concept for municipal solid waste (MSW), inconsistent legal and administrative frameworks, and a lack of reliable data on waste generation and management. Financial resources for sector improvement are also limited [18]. Given the reviewed literature, it is imperative to address the existing research gap concerning the economic benefits of improving waste management in Armenia.

3 Methodology

The article employs a combination of quantitative and qualitative research methods, including time series analysis, regression analysis, and other relevant approaches. It considers the volume of solid waste generated by both economic and household activities. The study provides an overall estimate of the potential economic benefits that could have been realized if the portion of waste classified as recyclable had been properly processed. Specifically, the main categories of recyclable waste are identified based on their relative weights, and their estimated market value is calculated following the sorting phase. The estimated volumes and values of all recyclable outputs are then aggregated and compared with national GDP figures to assess their potential macroeconomic impact.

In addition, the methodology incorporates a scenario-based assessment grounded in the assumption that all polymer-based waste is subjected to pyrolysis, which is a thermochemical process that converts waste into fuel [19]. The potential value of the fuel generated through pyrolysis is estimated without accounting for production costs. This hypothetical fuel value is also compared to GDP to determine the possible percentage contribution such waste-to-energy conversion could make to overall economic output. This dual approach allows for a comprehensive evaluation of both conventional recycling and advanced energy recovery strategies in the context of Armenia's economy.

4 Results and Discussion

In the pursuit of economic growth, humanity generates an increasing amount of waste per unit of GDP. In developed countries, however, industrial waste per unit of GDP tends to stabilize or even decline alongside economic growth. In these countries, waste management is regulated through technological advancement, the implementation of circular economy models, environmental policies, and, in some cases, the relocation of environmentally harmful industries to developing nations. In developing countries, there exists a strong positive correlation between GDP growth and industrial waste generation: each unit increase in GDP leads to a corresponding increase in industrial waste. This pattern is also observed in our republic. Empirical data indicate a direct relationship between economic activity and waste generation in industrially developed countries. A closer examination of the GDP and municipal waste generation (used as an approximate indicator of partial resource consumption) across various European countries illustrates this trend (see Fig. 1).

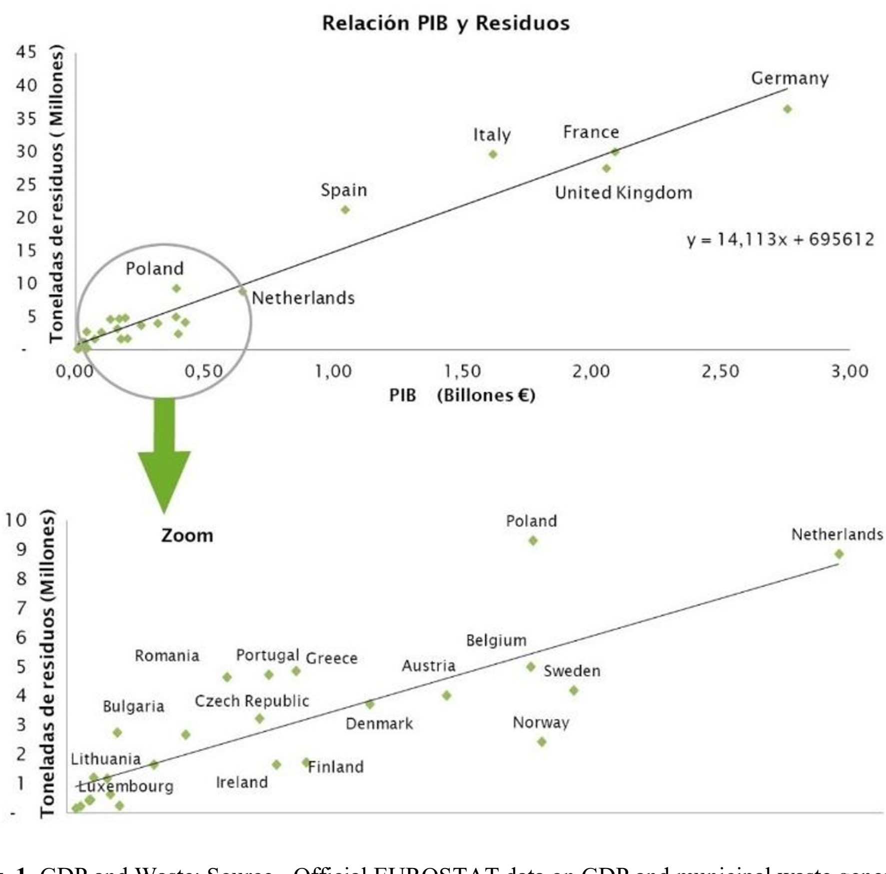

Fig. 1. GDP and Waste: Source - Official EUROSTAT data on GDP and municipal waste generation.

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The graph clearly illustrates a general trend: the higher a country's wealth or level of development (measured by GDP) [20], the greater its waste generation.

For instance, if Spain, with a GDP of 1 trillion euros and an annual production of 21 million tons of municipal waste, were to increase its GDP by an additional 1 trillion euros, reaching the level of the United Kingdom, its municipal waste generation would rise by more than 71 million tons annually.This projection is based on Spain's GDP-to-waste ratio, which is described by the linear equation Y=14.113x+695612where:

- Y denotes GDP,
- and x represents the quantity of waste in million tons.

According to this relationship, if Spain were to double its GDP, the volume of municipal waste would increase by over 71 million tons per year.

Due to the global scarcity of natural resources, many of which are non-renewable, the issue of material overexploitation has become one of the leading priorities on the international environmental agenda.

When evaluating the potential economic benefits of solid waste collection, recycling, and pyrolysis, it is essential to consider the fact that approximately 469,000 tons of waste are generated annually in Armenia [21]. Of this amount, only about 15% is currently recycled or neutralized [22]. Consequently, nearly 398,000 tons of waste remain untreated, essentially a "gift" to nature, which could have been recycled, thereby not only preventing environmental harm but also generating economic value.

On average, around 35% of total waste is considered recyclable. In Armenia's case, this corresponds to approximately 164,150 tons of recyclable waste. Of this, 25% is plastic, 15% is glass, 30% is paper, 15% is metal, and 5% is wood waste. These proportions translate to roughly 41,000 tons of plastic, 24,600 tons of glass, 49,250 tons of paper, 24,600 tons of metal, and 8,200 tons of wood, respectively [22].

When evaluating the potential economic losses incurred through materials that could otherwise have been converted into revenue, a conservative estimate begins with the calculation of the intrinsic material value, that is, the product of quantity and unit price.

- Plastic: 41,000,000 kg × 100 AMD = 4.1 billion AMD
- Glass: 24,600,000 kg × 5 AMD = 123 million AMD
- Paper: 49,250,000 kg × 45 AMD = 2.21625 billion AMD
- Metal: 24,600,000 kg × 50 AMD = 1.23 billion AMD
- Wood: 8,200,000 kg = 117,143 cubic meters × 10,000 AMD = 1.17143 billion AMD

The total estimated material value will be 8.89925 billion AMD. Comparing this to Armenia's GDP in 2018, which stood at 6.0170352 trillion AMD, the value of these materials would amount to approximately:

$$8,899,250,000/6,017,035,200,000=0.148\%$$

Thus, the following formula can be applied to quantify the share of recoverable waste value within GDP:

$$Q = \Sigma(nP_x(t) + nP_y(t) + nP_z(t) + \ldots + nP_N(t)) / GDP(t)$$

Where: Q = Contribution of solid waste materials to GDP
X, Y, Z, N = Types of solid waste
n = Generated quantity
P = Average market price at respective collection/recycling sites
Σ = Total aggregate value

This implies that even solely through the collection and classification of solid waste as raw materials, Armenia's GDP could have increased by 0.148%. Furthermore, the potential for GDP growth would multiply significantly if these materials were recycled rather than merely sorted and sold. Annually, approximately 469,000 tons of waste are generated in Armenia, of which only about 15% is recycled or neutralized. Roughly 398,000 tons of waste remain untreated, representing not only an environmental burden but also a missed economic opportunity. On average, about 35% of total waste is recyclable. In Armenia's case, this equates to 164,150 tons, of which the composition is approximately:

- Plastic: 25% = 41,000 tons
- Glass: 15% = 24,600 tons
- Paper: 30% = 49,250 tons
- Metal: 15% = 24,600 tons
- Wood: 5% = 8,200 tons

Reiterating the earlier valuation using material prices:

- Plastic: 4.1 billion AMD
- Glass: 123 million AMD
- Paper: 2.21625 billion AMD
- Metal: 1.23 billion AMD
- Wood: 1.17143 billion AMD

Totaling 8.89925 billion AMD, again equivalent to 0.148% of 2018 GDP. Now consider the case where plastic waste undergoes pyrolysis. From 41,000 tons of plastic, pyrolysis can provide:

- Oil derivatives: approx. 65% = 26,650 tons
- Carbon black pigment: approx. 10% = 4,100 tons
- Oxidized material (gaseous byproducts): approx. 25%

Assuming a conversion rate of 1 liter per kilogram, 26,650 tons equates to 26.65 million liters of oil. At an average price of 300 AMD per liter, the potential revenue is:

$$26{,}650{,}000 \text{ liters} \times 300 \text{ AMD} = 8.0 \text{ billion AMD}$$
$$8{,}000{,}000{,}000 / 6{,}017{,}035{,}200{,}000 = 0.13\%$$

This constitutes an additional 0.13% of GDP. Combining this with the previous estimate (excluding the plastic raw material value already accounted for):

$$(8.89925 - 4.1 + 8.0) \text{ billion AMD} = 13.9 \text{ billion AMD}$$
$$13.9 \text{ billion} / 6.0170352 \text{ trillion AMD} = 0.23\%$$

Through the structured collection, sorting, and pyrolytic processing of plastic waste, Armenia could potentially increase its GDP by an additional 0.23%, independently of developments in other sectors of the economy.

5 Conclusion

As in many countries around the world, solid waste collection and sorting remain among the primary challenges of recycling in Armenia. Without proper infrastructure for collection and classification, large-scale recycling becomes unfeasible. The calculations presented in this article clearly demonstrate that solid waste collection and recycling are not only environmentally beneficial but also hold considerable economic potential. In particular, the mere act of systematic waste collection contributes to GDP growth, as quantified in this study.

The establishment of a new industrial sector based on the pyrolysis of polymer waste could have a significant macroeconomic impact. Beyond contributing to GDP growth (estimated at approximately 13.9 billion AMD in direct value) this sector has the potential to generate new jobs and increase public revenues. Moreover, by reducing reliance on imported petroleum products through partial substitution with locally produced fuel, Armenia could strengthen its economic security and improve its regional economic multiplier. This, in turn, would generate positive spillover effects across other sectors of the economy and enhance the country's overall growth potential.

Importantly, the development of this sector serves not only financial objectives but also critical environmental goals. In resource-constrained countries such as Armenia, where there are no domestic oil reserves, the production of alternative fuels from recycled waste offers a promising path toward both energy diversification and ecological sustainability. This dual benefit highlights the strategic importance of waste-to-energy conversion as a long-term policy priority. Furthermore, if the environmental benefits of waste management were quantified in monetary terms, for example, through the avoided costs of plastic damage mitigation or government expenditures on waste removal, then the actual impact on the economy would far exceed the initial estimates. Considering these multiplier effects and indirect gains, the true contribution of polymer waste recycling to Armenia's economic and ecological systems is substantially greater than the direct output alone suggests. Ultimately, these findings underscore the untapped potential of solid waste as a resource for sustainable development, fiscal resilience, and environmental protection.

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