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# Energy Recovery Potential of Municipal Solid Waste Generated in Georgia

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***Abstract* – According to the waste hierarchy, waste recovery is prioritized over landfilling. However, in Georgia, over 90 % of waste is landfilled, causing social, economic, and environmental issues. To ensure sustainable waste management, Waste-to-Energy should complement recycling and reuse efforts. The amount of municipal waste disposed of in landfills has significantly increased. The National Statistics Office of Georgia reports that landfill waste rose from 774.4 thousand tons in 2015 to 1184 thousand tons in 2024. The calorific value of municipal waste in Georgia is crucial for energy recovery. For efficient energy use, waste should have a minimum lower calorific value of 7 MJ/kg. Plastic, paper, and textiles have the highest calorific values. Notably, municipal waste in Georgia contains 13–14 % plastic, 10–11 % paper and cardboard, and over 4 % textiles. However, these materials are essential for recycling, which conserves natural resources and should remain a priority. This paper aims to examine the possibilities for implementing Waste-to-Energy approaches at the municipal level in Georgia. It should be noted that the composition of municipal waste has not been sufficiently studied. The existence of such data is essential for assessing the potential for Waste-to-Energy systems, as well as for improving the effectiveness of planning and implementing municipal waste management. At present, Georgia also faces a lack of experience and technical expertise needed for the introduction of Waste-to-Energy approaches.**

***Keywords* – Caloric value; energy recovery; organic waste; paper; plastic; textile; waste hierarchy, Waste-to-Energy (WtE).**

| **Nomenclature** | |
|---|---|
| WtE | Waste-to-Energy |
| MSW | Municipal solid waste |
| GHG | Greenhouse gas |
| LCV | Lower calorific value |
| CV | Calorific value |
| RDF | Refuse-Derived Fuel |
| SRF | Solid Recovered Fuel |
| MC | Moisture content |
| VC | Volatile components |
| FC | Fixed carbon |
| PET | Polyethylene Terephthalate |

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| | |
|---|---|
| LCA | Life Cycle Assessment |
| TEA | Techno-Economic Analysis |

## 1. INTRODUCTION

The growing dynamic of waste generation remains a pressing issue, not only locally but also on a global scale as well. The impact of municipal waste, even when considered solely from an environmental perspective, is evident in global challenges such as climate change, biodiversity loss, and pollution [1]. The global annual generation of solid municipal waste reached 2.1 billion tons in 2020. Considering the current rates of economic development and population growth, it is expected that global municipal waste generation will increase by 56 % by 2050, reaching 3.8 billion tons [1].

According to available information, landfills, open dumps, and wastewater account for 20 % of global anthropogenic methane emissions [2], where the anaerobic decomposition of organic waste results in the production of greenhouse gases such as methane. This accounts for 4 % of total anthropogenic greenhouse gas emissions.

As a developing country, Georgia faces waste management challenges. The waste management sector is one of the key contributors to GHG emissions. According to [3], the country's overall emission trends from 2001 to 2022 were as follows:

- Minimum emissions in 2001: 9514 Gg of $CO_2$ equivalent.
- Emissions in 2022: 20 096 Gg of $CO_2$ equivalent.

It is noteworthy that the contribution of waste to greenhouse gas emissions in Georgia has been steadily increasing, and by 2022, it amounted to 1995.9 Gg of $CO_2$ equivalent, which accounts for approximately 9.9 % of total emissions for the same year. For reference, the composition of greenhouse gases was as follows (2022): $CO_2$ – 63.9 %, $CH_4$ – 29.4 %, $N_2O$ – 4.4 % [3].

Municipal waste generation in Georgia has growing dynamics. According to the National Statistics Office of Georgia, in 2024, municipal waste generation amounted to more than 1184 thousand tons, up 6 % from the previous year, 2023, and 44 % higher compared with the data from 2015 (Fig. 1). In the waste sector, emissions are expected to increase by approximately 33 % to up to 1.85 $MtCO_{2e}$ in 2030 [19]. Despite the reforms implemented, GHG emissions in the waste sector continue to increase. To transform the waste sector, it is important to adopt systems similar to those used in the world's most developed countries. The major challenges in the sector are as follows: outdated landfills and dumping a significant part of municipal waste in landfills. More than 90 % of municipal waste generated will still be disposed of in landfills, which means that a large amount of secondary resources are not being used beneficially, particularly in recycling and recovery.

The modern approach of waste management policy is based on the waste hierarchy with priority orders such as prevention, preparing for reuse, recycling, and other recovery, e.g., energy recovery and disposal. The National Waste Management Strategy of Georgia, adopted in 2016, is based on similar approaches. The waste hierarchy defines the most prioritized approaches in the waste management process, as well as the least desirable methods. In particular, it should be noted that the most desirable approaches, in order, are: prevention, preparing for reuse, recycling, while other recovery, e.g., energy recovery, is better than disposal. Overall, the national waste management strategy should aim to minimize the waste going to landfill.

One of the approaches, which ranks fourth in terms of priority in the waste hierarchy, is recovery, which also includes energy recovery. Along with reuse and recycling, Waste-to-

Energy (WtE) can be a solution that will help facilitate sustainable waste management programs by diverting waste from landfills for energy production.

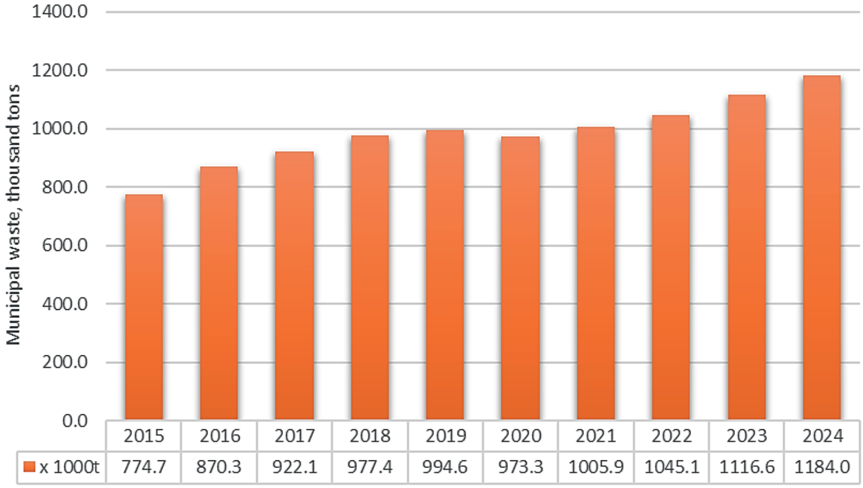



Fig. 1. Municipal waste generation in Georgia, 2015–2024. Source: National Statistics Office of Georgia, www.geostat.ge.

According to the Intergovernmental Panel on Climate Change (IPCC) "waste incineration and other thermal processes avoid most GHG generation" [4].

Although WtE disposal is a linear use of resources, as the materials that are burned can never be recovered and reused, it is a possible alternative method for municipal waste management. The calorific value of municipal solid waste has a significant impact on the application of WtE methods. The calorific value of different waste streams is determined by the thermal and chemical properties of the waste, which include their elemental composition (carbon, sulfur, hydrogen, oxygen), moisture content (MC), volatile components (VC), fixed carbon (FC), and ash content.

WtE technologies are widely used in some industrialized countries. For example, Denmark has made significant contributions to a sustainable WM infrastructure by incorporating WtE technologies. Particularly noteworthy is Denmark's experience, where only 3 % of Copenhagen's trash goes to landfills. 54 % is used in incinerators to create heat and electricity. 97 % of all city residents receive their energy as excess heat produced by their waste incinerators. According to the Swedish Waste Management Association, in 2021, Sweden generated approximately 4.9 million tons of municipal waste, with more than 50 % being incinerated to produce energy [6]. Germany is recognized as one of the leading countries in WtE implementation with 91 facilities. Residual waste thermally treated – 25 million tons which is the largest value from European countries [7]. France is among the lead countries according to the numbers of the WtE plants in Europe with 116 plants, but residual waste thermally treated is only 14.0 million tons [7].

Totally in European countries there were 498 Waste-to-Energy plants for 2022 [7], with generation of electricity for 20 million people and providing heat for about 17 million people per year. About 10 % of European district heating comes from WtE – 99 billion kWh of heat [5].

For WtE implementation, it is quite crucial to know the characteristics of the waste to allow the application of the right technology for optimal use of WtE system.

This study seeks to estimate the expected thermal potential of municipal solid waste generated in Georgia to evaluate the feasibility of advanced waste management options, particularly energy recovery through WtE technologies. At present, the composition of MSW in Georgia remains inadequately characterized, especially with respect to the effects of climatic conditions, seasonal variability, socio-economic factors, and cultural practices, all of which exert a significant influence on waste characteristics and calorific value.

## 2. Methods and Methodology

The methods used for this paper's purpose included a case study of the relevant materials, such as reports, scientific articles, and data on the municipal waste in general, and experience on WtE of the developed and developing countries. A case study involved collecting and reviewing the existing strategic reports and their contents. Statistical information existing on national and municipal levels on waste management in Georgia was collected and analysed.

The experience of the leading countries in the field of energy recovery was studied and analysed. Other related information was reviewed and connected to the existing needs.

Currently, there is no available information about the use of energy recovery methods in Georgia.

Also, the waste composition studies are currently available for very limited number of the municipalities of Georgia. It should be noted that Georgia with a population of 3.727 million people, includes 69 municipalities, which differ in their location, population size, local customs, which affects the volume and composition of municipal waste generation as well.

Comparative LCA/TEA, as an integrated methodology for evaluating possible scenarios of existing practices, was used for the evaluation of the following options such as landfilling, recycling, and WtE pathways for Georgia. The scenarios were comparatively assessed using a multi-criteria framework incorporating environmental performance indicators (including GHG emissions, resource efficiency, and pollution reduction), economic parameters (capital costs, revenue potential, operational viability).

Energy recovery potential has been analysed according to the regions using the low, medium and high LCV for each fraction of MSW generated in Georgia's regions during 2024.

Empirical studies show that the overall waste calorific value strongly depends on waste composition and moisture content [19]. The calorific value thresholds commonly referenced for WtE systems are applicable under specific technical and operational conditions. In particular, an average LCV of at least 7 MJ/kg [26], without the minimum falling below 6 MJ/kg, is generally required for efficient operation [15]**.** These values are especially relevant when mixed MSW is intended for direct combustion in mass-burn incineration or other high-temperature thermal treatment systems. The typical LCV of each fraction of MSW was taken from the references [22], [26].

## 3. Results

### *3.1. Composition of Municipal Solid Waste Generated in Georgia*

According to the data of the National Waste Management Strategy of Georgia [8], the typical composition of generated waste streams and the shares of different components in them show that municipal waste includes organic waste (54.7 %), plastic waste (13.8 %), paper and cardboard (10.6 %), textiles (4.1 %), construction and demolition waste (2.5 %), glass (2.3 %), metal (1.4 %) and other waste (11 %), (Fig. 2). It is also important to have detailed information about the composition of solid waste generated in various municipalities of the country. It should be noted that the composition of municipal waste across municipalities and regions in Georgia has not been comprehensively studied, and reliable information is available for only a few cities and municipalities. The limited existing data primarily reflect waste composition studies conducted at municipal or regional landfills.

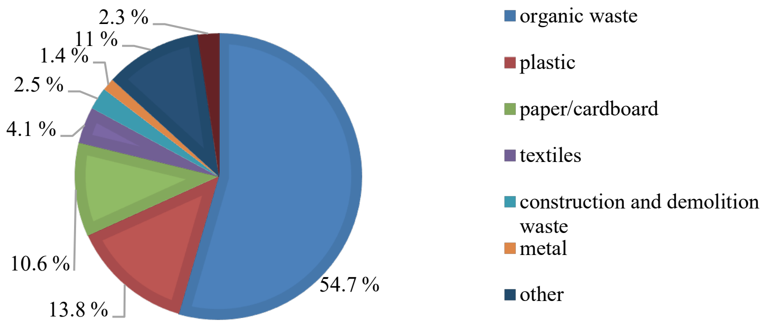



Fig. 2. Waste composition totally generated in Georgia (according to [8]).

For the purpose of comparing the composition of municipal solid waste, data from different distinct regions were selected. Specifically, the city of Kutaisi and the Tsageri and Lentekhi municipalities were examined, as they differ in geographical location, population size, and the volume of MSW generated.

Kutaisi is one of the largest cities in Georgia, with a population of 125.6 thousand (as of 2024). The generation of waste increases annually, despite a general decline in the population of Kutaisi (for comparison, in 2015, the population of Kutaisi was over 147 thousand). Despite a decrease in the population, municipal waste generation in Kutaisi between 2020 and 2024 has shown a growing trend [19]. In 2015, the city generated 47 thousand tons of municipal waste, which increased to approximately 55 thousand tons by 2024 (Fig. 3).

The first study on the composition of municipal waste generated in Kutaisi (Georgia, Imereti Region) was conducted in 2010–2011 [9]. For determining the composition of unprocessed MSW, it was based on main standard test methods, such as ISO 14780 “Solid biofuels – Method for sample preparation”; ASTM D5231-92 “Standard Test Method for Determination of the Composition of Unprocessed MSW”; ASTM D4687-95 “Standard Guide for General Planning of Waste Sampling” and the experience of the Kaunas University of Technology (Lithuania). Mixed MSW flow from multifamily apartment complexes, single family homes, office buildings, and streets was used for sampling by the authors [9]. The quantitative extent of seasonal variation was determined by methods of descriptive statistics. The amount of the variation in waste management data was assessed by calculating the variation in the mean percentage by which the monthly quantities differ from the average. Time series analyses were applied to the MSW fraction generation data with the aim to describe and forecast its seasonal behaviour. As a result, the average annual composition of household waste in Kutaisi was as follows: plastic – 13.5 %, paper – 10.72 %, metals – 3 %, glass – 4.02 %, and food waste – 43.7 %.

When waste generation is examined with consideration of the seasonal component, shows that the least amount of waste is produced in February, and, for example, according to observations in 2010–2011, it was 15.4 kg per capita. The maximum level of waste generation was observed in August (21.7 kg per capita, 2010–2011). The study conducted in Kutaisi (Georgia) illustrates a seasonal trend in waste generation. The proportion of food waste in the total amount of waste in Kutaisi is the most affected by seasonal aspects. Its share is high in July-August, while also being affected by the number of holidays, festive days, and fasting days per month. The number of hot days and festive days also affects the plastic fraction [9].

Unlike the location of Kutaisi, it should be noted that the Lentekhi and Tsageri municipalities are located in the mountainous region of Western Georgia, within the Racha-Lechkhumi and Kvemo Svaneti regions. The populations of the municipalities in 2018–2019 were as follows: 4200 in Lentekhi municipality and between 9100 and 9400 in Tsageri municipality.

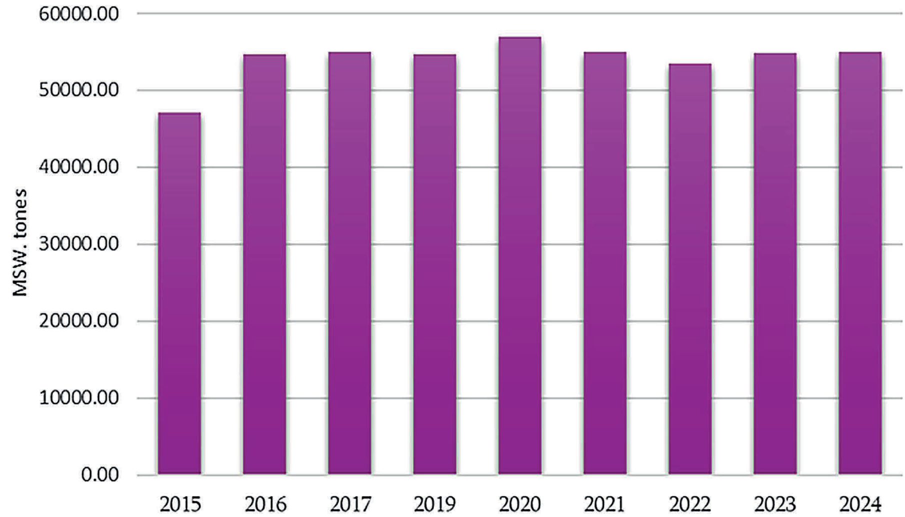



Fig. 3. Municipal waste generation in Kutaisi, Georgia, 2015–2024.

An important study on the composition of municipal waste was conducted in September 2018, May 2019, and August 2019 in the Lentekhi and Tsageri municipalities of upper Georgia within the Integrated SWM project of Kutaisi [10]. A characteristic feature of the mountainous regions of Georgia is the low population density. The waste compositions were analyzed separately for the different territorial structures, such as commercial areas and rural areas of both Tsageri and Lentekhi municipalities (Georgia). As a result of the conducted studies, it was found that the share of recyclable materials such as glass, metal, paper/cardboard, textiles, and plastics is higher in urban areas and the commercial centers of towns than that in rural settlements. At the same time, the share of biogenic fractions is equally high in all waste samples in urban and rural settlements [10], (Fig. 4).

Taking into account that a small number of studies have been conducted on the composition of municipal waste in Georgia and scarce data is available, the studies of Kutaisi city and Lentekhi and Tsageri municipalities [9], [10] provide an opportunity for some generalization.

Other important data for applying WtE approaches is the quantity of MSW generated by the regions of Georgia, particularly, 37.5 % of generated waste comes from Tbilisi, which has a population of 1.33 million, which is capital city of Georgia. This is followed by the regions of Adjara (12.5 %) and Imereti (11 %). Waste generation in the other regions is comparatively lower (Fig. 5).

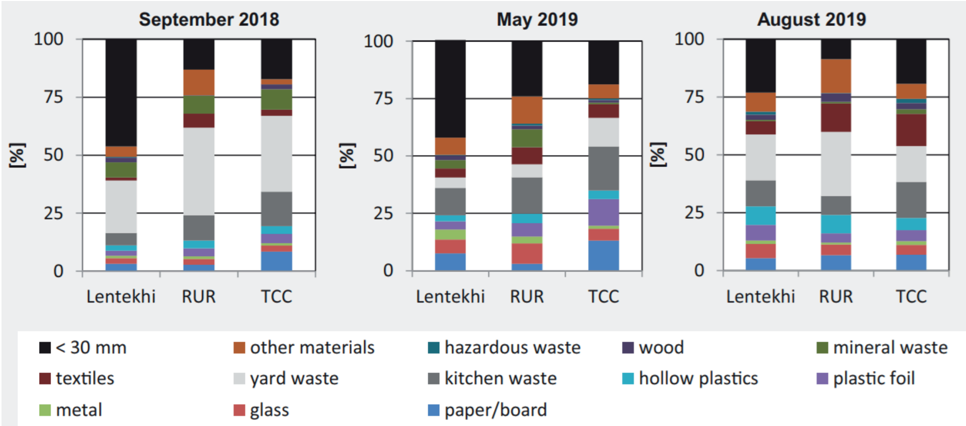



Fig. 4. Waste composition according the studies conducted in Lenthekhi and Tsageri municipalities of Georgia [10]. (The designations introduced by the authors of the study are as follows: TCC – commercial area and RUR – rural areas of the Tsageri and Lentekhi municipalities).

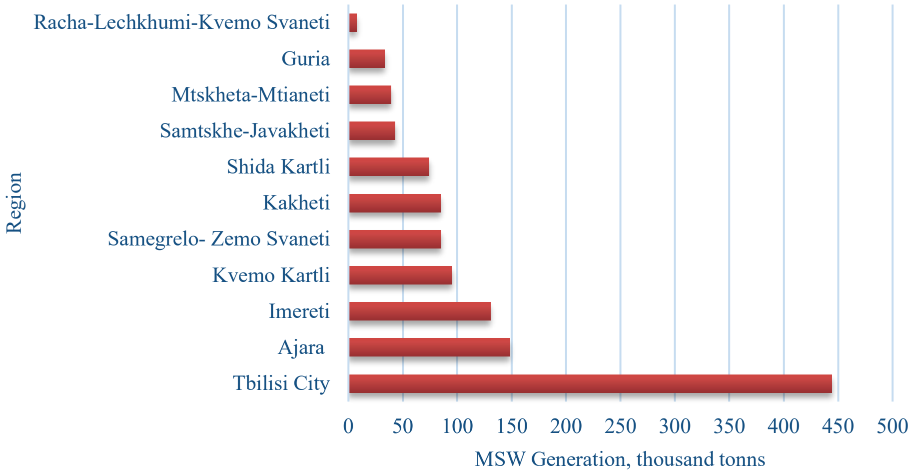



Fig. 5. Regional waste generation in Georgia, 2024.

### *3.2. Expected Potential for Waste-to-Energy in Municipal Waste Generated in Georgia*

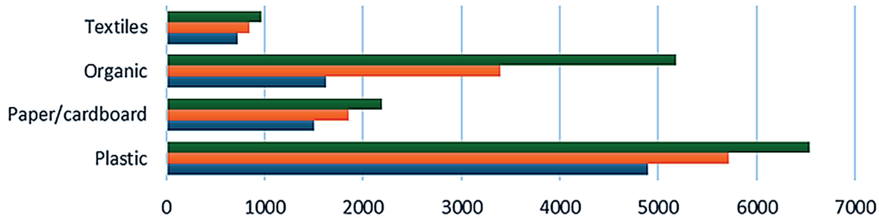
WtE refers to technologies that convert residual waste into energy (electricity, heat, fuels) while reducing waste volume and mitigating methane emissions from landfills. Main categories of WtE used globally are described in Table 1.

For the application of WtE technologies, a key determining factor is the energy potential of the waste fractions used as feedstock. This potential is primarily defined by the LCV of the material, which governs the efficiency of energy recovery during the incineration process. The energy potentials should be determined by using the LCV values of each fraction of MW and fraction percentages. The energy potential for each fraction of MSW can be quantified as follows:

$E = LCV \times m$, where *LCV* refers to the lower calorific value of each fraction, expressed as low, medium, and high values (in MJ/kg) and *m* is the mass of accordance fraction (in kg).

TABLE 1. FOUR MAIN CATEGORIES OF WASTE-TO-ENERGY APPROACHES

| Technology | Type of waste | Main outputs |
|---|---|---|
| Mass-Burn Incineration | Residual municipal solid waste | Electricity, District heating |
| Anaerobic Digestion | Food waste, agricultural residues, sewage sludge | Biogas, biomethane, digestate |
| Gasification & Pyrolysis | Gasification: RDF/SRF, plastics, biomass | Syngas |
| | Pyrolysis: Plastics, rubber, RDF | Pyrolysis oil, char, syngas |
| Refuse-Derived Fuel (RDF) / Solid Recovered Fuel (SRF) Co-Incineration | Pre-treated waste (RDF/SRF) | Heat, steam (industrial) |




| | Plastic | Paper/cardboard | Organic | Textiles |
|---|---|---|---|---|
| High, TJ | 6535.68 | 2196.32 | 5181.184 | 970.88 |
| Medium,TJ | 5718.72 | 1851.184 | 3400.152 | 849.52 |
| Low, TJ | 4901.76 | 1506.048 | 1619.12 | 728.16 |

**Energy Potential, TJ**

High, TJ  Medium,TJ  Low, TJ

Fig. 6. Expected energy recovery potential from MSW, Georgia, 2024.

For a country like Georgia, where more than 1 million tons of municipal waste is accumulated annually, the optimistic expected energy potential for the waste generated in Georgia in 2024 is approximately 14 880 TJ. The highest estimated energy potential is found in plastic waste with more than 6530 TJ, which is primarily due to the high calorific value of plastic (30–40 MJ/kg). The organic energy potential was calculated as more than 5180 TJ according to the optimistic scenario, despite the fact that the amount of organic waste far exceeds other types of waste (more than 647 thousand tons). This is due to the very low calorific value of organic waste 2.5–8 MJ/kg.

To account for variability in waste composition and calorific value, the energy potential for municipal waste was estimated using low (8 MJ/kg), medium (10 MJ/kg), and high (12 MJ/kg) LCV scenarios. Table 2 summarizes the resulting energy potentials for each region of Georgia. The results indicate that Tbilisi city contributes the largest share of potential energy due to its high waste generation, while smaller regions such as Racha-Lechkhumi have limited energy potential.

TABLE 2. EXPECTED ENERGY POTENTIAL BY THE REGIONS OF GEORGIA, 2024

| Region | Low Potential, TJ | Medium Potential, TJ | High Potential, TJ |
|---|---|---|---|
| Tbilisi City | 3554.4 | 4443 | 5331.6 |
| Ajara | 1185.6 | 1482 | 1778.4 |
| Imereti | 1043.2 | 1304 | 1564.8 |
| Kvemo Kartli | 760 | 950 | 1140 |
| Samegrelo- Zemo Svaneti | 680 | 850 | 1020 |
| Kakheti | 677.6 | 847 | 1016.4 |
| Shida Kartli | 593.6 | 742 | 890.4 |
| Samtskhe-Javakheti | 341.6 | 427 | 512.4 |
| Mtskheta-Mtianeti | 312 | 390 | 468 |
| Guria | 264 | 330 | 396 |
| Racha-Lechkhumi-Kvemo Svaneti | 60 | 75 | 90 |

Different waste management scenarios were evaluated based on the prevailing MSW practices in Georgia and the long-term strategic objectives of the sector, in alignment with national policy priorities and EU waste management principles. The comparative results of the scenario analysis are presented in Table 3.

TABLE 3. COMPARATIVE LCA/TEA OF WASTE MANAGEMENT SCENARIOS

| WM Scenarios | GHG Emission | Air Pollution | Energy Yield | Costs |
|---|---|---|---|---|
| Landfill (without methane capture) | High | Low-moderate | 0 | Low |
| Landfill (with methane capture) | Medium | Moderate | Moderate | Medium |
| Recycling | Low | Low | Minimal | Medium |
| Anaerobic Digestion (AD) for organics | Low | Low | Moderate | Medium |
| Mechanical-Biological Treatment (MBT) | Medium | Medium | Low–Moderate | Medium–High |
| WtE (Incineration with energy recovery) | Medium-Low | Medium | High | High |
| WtE (Gasification) | Medium-Low | Medium-Low | High | High |

The WtE provides an intermediate solution in terms of environmental and resource performance. Compared to landfilling, WtE significantly reduces GHG emissions and enables energy recovery from residual, non-recyclable waste fractions. However, it remains a linear resource use pathway, as material recovery is limited once waste is thermally treated. Economically, WtE systems involve the highest capital investments, particularly for thermal processing and flue gas treatment technologies, but offer high revenue potential through electricity and heat generation, especially when integrated into district heating systems. Operational feasibility is highly dependent on waste composition and requires a minimum lower calorific value to ensure efficient plant performance. In addition, for the optimal operation of WtE facilities, the supply of combustible MSW should be at least 100 000 tons [26]. Only three regions of Georgia meet this requirement: Tbilisi City, Adjara AR, and the Imereti region.

## 4. CONCLUSION

Energy recovery approaches are not yet used in Georgia. Energy recovery is the recommended waste treatment for residual household and similar waste that remains after waste prevention, recycling, and organic waste treatment. The main goal of the National Waste Management Strategy 2026–2030 and other official documents is to achieve recycling rates for recyclable waste, which aligns with the priority approaches of the waste hierarchy. However, in addition, it is desirable to utilize the potential of non-recyclable waste for energy recovery purposes, which would further improve the climate change mitigation policy in the country, along with the associated economic, social, and environmental benefits. The comparative assessment of the municipal solid waste management scenarios demonstrates significant differences in environmental performance, resource efficiency, and economic viability.

Plastic wastes such as PP, HDPE and PET, as well as paper/cardboard, have the highest energy potential for energy extraction. However, this type of waste is a very important material for recycling technologies. So, priority should be given to the recycling of these types of waste, which, among other benefits, is a source of the conservation of natural resources.

The introduction of WtE methods for non-recyclable municipal waste that should be landfilled will avoid pollution caused by landfills and, more importantly, emissions of methane as a greenhouse gas.

To summarize, we can determine that key challenges for WtE in Georgia are as follows:

- Absence of a WtE-specific regulations on the national level. WtE approaches have not yet been applied in practice.
- Lack of the information about waste composition at the municipal level.
- The virtual absence of research on waste calorific value hinders the implementation of WtE approaches.

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