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A Study on the Current Status of Landfill in Seoul and the Solutions to Future Generation Landfill Problems

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Abstract

Purpose: A resource circulation management system can be established by operating and managing power generation facilities using landfill gas, and economic feasibility can be confirmed through the impact of landfill gas on climate change and the absolute value that can be used as a resource. **Research design, data and methodology:** After investigating the generation of landfill gas by visiting Nanjido and metropolitan landfill sites in Seoul, the environmental impact and economic evaluation can be conducted through the emission coefficient of whether it can be used as an energy resource. **Results:** Currently, the Nanji landfill was completed in 1993 and is being used as a Nanji camping site after stabilization work such as cover and water curtain was completed to solve environmental problems that have occurred. The Seoul metropolitan area landfill was selected after the completion of the Nanji landfill, and the landfill has been underway so far, and unlike Nanji landfill, it aims to implement eco-friendly treatment facilities. **Conclusions:** Waste generated in future generations also inevitably needs to be disposed of, so you can expect an optimized management plan to reduce the disgust of local residents and maximize the need by changing the perception of landfill as an eco-friendly space rather than a simple waste disposal facility.

Keywords : Landfill, Greenhouse gas, Climate change

JEL Classification Code : Q24, Q26, Q54

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1. Introduction

In the course of daily life, waste is inevitably generated. Recyclable materials, such as paper, metal, and plastic, are reused, while non-recyclable waste is either incinerated for intermediate treatment before landfill disposal or directly landfilled.

Landfilling is a method of final disposal used when waste is no longer economically viable. It requires designated landfill sites, and once the capacity of a site is exceeded, further landfill operations become impossible.

In the early 1960s, waste was disposed of randomly without designated areas, leading to significant environmental issues in affected regions. To address this, dedicated landfill sites were designated by the late 1970s. Once landfilling in these areas was completed in the 1970s, Seoul began searching for a new landfill site. In 1978, the Nanjido Landfill, located near Seoul with convenient transportation and accessibility, was chosen.

From March 1978 to March 1993, the Nanjido Landfill accepted waste from 10 million Seoul citizens for 15 years, handling approximately 78% of the household waste generated in Seoul. After the Nanjido Landfill reached its capacity, landfill operations were transferred to the Sudokwon Landfill, which spans Incheon and Gimpo, where waste from Seoul is currently disposed of.

Materials generated during landfilling include methane, carbon dioxide, volatile organic compounds (VOCs), and hydrogen sulfide, collectively referred to as landfill gas. Unlike incineration facilities, which generate acute pollutants immediately during combustion, landfills produce chronic pollution over the long term due to anaerobic digestion and leachate formation.

As time passes, the greenhouse gases emitted from landfills persist for extended periods, impacting the environment and contributing significantly to climate change, one of the most pressing international issues. Therefore, measures to treat these greenhouse gases are necessary. Instead of merely reducing emissions, a resource-recycling management system can be established by utilizing landfill gas for power generation facilities.

Lastly, landfills, along with incineration facilities, are recognized as representative nuisance facilities. While waste generation continues to increase, the locations available for waste disposal are limited, making the selection of landfill sites an unavoidable issue for human life.

Thus, identifying ways to utilize landfills to benefit human life and fostering public awareness about these sites can serve as a starting point for selecting and establishing future landfill sites to accommodate the waste that will inevitably be generated.

2. Literature Review

Looking at the historical characteristics of waste landfill management in Seoul, in the early 1960s, there were no designated waste disposal sites in the city. As a result, household waste was disposed of in areas such as residential development zones and low-lying wetlands. In 1964, when Seoul secured its first dedicated landfills, areas such as Gunja-dong, Sangwolgok-dong, Eungam-dong, and Yeomchang-dong were utilized as landfill sites. During the period from 1976 to 1977, other areas, including Bangbae-dong, Apgujeong-dong, Janghan-dong, Guui-dong, Cheongdam-dong, and Songjeong-dong, served as dedicated landfill sites.

2.1. Nanjido Landfill

By the late 1970s, rapid population growth in Seoul led to a significant increase in waste generation. Additionally, the development of apartment complexes and residential zones left no space within the city for waste disposal. As a result, waste generated by Seoul's residents was landfilled at Nanjido, a location on the city's outskirts with convenient transportation access.

From March 1978 to March 1993, over a span of 15 years, Nanjido served as the landfill for waste generated in Seoul. Unlike the sanitary practices used in modern landfills like the Metropolitan Landfill Site, Nanjido employed unsanitary, simple landfill methods (dumping waste without any preventive measures). This landfill covered an area of 2,720,000 square meters (approximately 823,000 pyeong). The waste was piled to a height of 13 meters above sea level for flat landfilling and up to 92–98 meters above sea level for elevated landfilling, accommodating a total of 91.972 million cubic meters of waste.

Figure 1: Nanjido Landfill

The Nanjido Landfill, which covered an area of approximately 2,720,000 square meters (similar in size to Yeouido) and contained 92 million cubic meters of waste, completed flat (low-lying) landfilling by December 1985. Starting in 1985, the landfill was divided into the No. 1 and No. 2 landfills (now the Noeul Park and Haneul Park in World Cup Park) and transitioned to vertical landfilling. Initially, the plan was to limit the landfill height to 45 meters, which is the standard for international landfills (the Metropolitan Landfill Site, for example, has an eight-layer structure reaching 40 meters). However, delays in the construction of the Gimpo Metropolitan Landfill forced the continued accumulation of waste, resulting in two massive garbage mounds reaching approximately 100 meters in height.

During its operation, Nanjido was notorious for its dust, foul odors, and flies, earning it the nickname "Samdado" (Island of Three Many: many dust, many odors, many flies). Approximately 3,000 waste collectors lived and worked in the area, salvaging items like paper, bottles, and cans from the landfill. The harmful gases, particularly methane, emitted from the waste piles caused a total of about 1,390 fires over the 15-year period.

Table 1: Seoul's Household Waste Management (1978–1992)

Category	Proportion (%)	Remarks
Nanjido Landfill	77.7	
Used for Han River Embankment Filling	5.1	Coal ash, Han River Comprehensive Development Project (1982–1985)
Other Treatments	17.2	Guui-dong, incineration (Yangcheon & Nowon Resource Recovery Facilities)

The current Nanjido landfill, after ceasing waste disposal operations in March 1993, faced several environmental issues due to unsanitary and simple landfilling methods. These problems included soil and groundwater contamination from leachate, slope instability, air pollution caused by landfill gases, and its role as an obstacle to the balanced development of Seoul.

To address these challenges, stabilization measures were implemented, such as covering the landfill with soil, slope stabilization, leachate treatment, landfill gas collection and recycling, and the installation of impermeable barriers.

Today, the Nanjido site has been transformed into the Nanjido Camping Ground and World Cup Park, serving as recreational areas. However, the landfill still functions as a reactor for the decomposition of waste buried during its operational period.

Figure 2: World Cup Park View

2.2. Metropolitan Landfill

The Metropolitan Landfill Site was established after the completion of the Nanjido landfill and has been in operation ever since. Unlike the Nanjido landfill, it aims to implement eco-friendly waste management facilities.

The Metropolitan Landfill Site is located in Geomdan-dong and Geoman-dong of Seo-gu, Incheon, as well as Yangchon-myeon, Gimpo-si, Gyeonggi Province. It covers an area of 15.4 million square meters (approximately 4.66 million pyeong).

The site accepts waste from 58 municipalities across the Seoul metropolitan area, including all districts of Seoul and 23 cities in Gyeonggi Province. The landfill's licensing period initially spanned from 1992 to 2016.

The landfill’s estimated capacity is 228 million tons, with an additional potential capacity of 86 million tons in the 3rd and 4th landfill sections, making landfilling feasible until approximately 2060.

It operates under a **sanitary landfill system** and is managed by the Metropolitan Landfill Site Management Corporation.

Table 2: Current Status of Landfill Site in the Seoul Metropolitan Area

Category	Total	Landfill No. 1	Landfill No. 2	Landfill No. 3	Landfill No. 4	Other Facilities
Site Area (10,000 m²)	1,540	404	356	307	338	135
Landfill Area (10,000 m²)	901	251	248	221	181	-
Landfill Capacity (10,000 tons)	22,800	6,400	7,800	8,600	-	-
Landfill Period	'92.2~	'92.2~'00.10	'00.10~'16.12	-	-	-
Landfill Utilization Rate	55%	100%	8.3%	-	-	-

Figure 3: Distribution of Landfill Site in the Seoul metropolitan area

With rapid economic growth and population increases during the 1980s, the volume of waste generated also rose significantly. Waste from the Seoul metropolitan area accounted for 58% of the nation's total waste, further exacerbating the severity of the issue. As the Nanjido landfill, which handled waste disposal for Seoul, reached capacity, it became necessary to secure a new landfill to handle the massive amount of waste.

The Metropolitan Landfill Site was established in 1985, while waste was still being deposited at Nanjido. Recognizing the need for a long-term solution after Nanjido's closure, the government formulated and implemented a plan for the construction of the Metropolitan Coastal Landfill Project, based on feasibility studies conducted under a presidential directive and at the request of the Seoul Metropolitan Government for a large-scale landfill.

The Ministry of Environment pursued a regional landfill solution to suppress environmental pollution caused by waste and reduce inconvenience for citizens by ensuring long-term sanitary waste disposal. Although the Seoul Metropolitan Government spearheaded the development of the landfill facilities, the site's location in Seo-gu, Incheon, and Yangchon-myeon, Gimpo County, Gyeonggi Province, sparked significant opposition and protests from nearby residents.

From 1992 to 2010, the Metropolitan Landfill Site received a total of 120 million tons of waste, averaging 6.33 million tons annually. Waste volumes decreased from 1995 to 1999 due to the introduction of the volume-based waste fee system. However, construction waste led to an increase from 2000 onward, before policies promoting waste reduction and recycling caused another decline starting in 2003. Slight increases were observed in 2006, 2007, 2011, and 2013.

2.2.1. Implementation of Eco-Friendly Treatment Facilities at the Metropolitan Landfill Site

To prevent the entry of illegal waste, diverse monitoring activities are carried out by local residents and landfill staff. These efforts include conducting detailed inspections of waste to proactively prevent the concealment and unauthorized disposal of waste, thereby safeguarding against environmental pollution.

Additionally, the landfill has been developed as a safe and sanitary facility, effectively preventing environmental contamination caused by leachate generated from waste. The landfill employs hygienic methods during the disposal process to reduce odor, prevent scattering, and control the proliferation of pests. Furthermore, advanced leachate treatment systems ensure the consistent maintenance of stable discharge water quality.

2.2.2. Establishment of a Resource-Circulating Management System at the Metropolitan Landfill Site

The landfill operates and manages a **9.88 MW power generation facility** that utilizes landfill gas. Additionally, a **50 MW power plant** is under construction, targeted for completion by 2006. These facilities not only recycle landfill gas as a resource but also help reduce odor in surrounding areas, mitigate greenhouse gas emissions (such as methane and carbon dioxide), and support the nation's efforts to meet international climate change agreements.

- **9.88 MW Power Generation Facility**: Produces electricity equivalent to the needs of 35,000 households, used for internal power consumption.
- **50 MW Power Plant**: Will generate electricity for 180,000 households, with plans for commercialization.

The **Eco-Clean Resource Circulation Center** introduces an environmentally efficient system that diversifies waste treatment methods by converting landfill waste into resources. It supplies energy required for operations, supports local recycling businesses, and promotes regional economic development by integrating waste management with community development plans.

2.2.3. Future Management Directions for the Metropolitan Landfill Site

The **Dream Park Project** envisions transforming the landfill from a simple waste disposal site into an eco-friendly ecological and cultural space. This initiative establishes a cooperative framework with local residents and shifts the focus from reactive environmental management aimed at mitigating pollution to proactive management through waste resource recovery. The project seeks to position the Metropolitan Landfill Site as a leading waste resource recovery facility and one of the world's best Dream Parks.

Key Plans for the Dream Park Project:

- **Landfill No. 1**: Development of recreational sports facilities, accommodating up to 1,800 visitors per day, with a sports park.
- **Landfill No. 2**: Establishment of waste resource recovery facilities.
- **Landfill No. 3**: Creation of a resource recovery facility complex, along with a temporary nursery and flower cultivation area.
- **Landfill No. 4**: Development of an ecological park and sports park centered around the Anamdo watershed.

2.3. Metropolitan Landfill

2.3.1. Stage 1: Initial Adjustment Phase

In this phase, biodegradable organic materials in the waste are decomposed by microorganisms, converting them into CO_2. This process consumes the oxygen within the landfill.

2.3.2. Stage 2: Transition Phase

As oxygen is depleted within the landfill layers, anaerobic conditions begin. Acid-producing microorganisms generate fatty acids, CO_2, and H_2 under anaerobic conditions, marking the onset of the initial acid formation phase.

2.3.3. Stage 3: Acid Formation Phase

Microbial activity initiated in Stage 2 leads to a rapid increase in the production of organic acids. Concurrently, the levels of CO_2 and H_2 gradually begin to decrease.

2.3.4. Stage 4: Methane Formation Phase

In this phase, acetic acid and H_2 produced during the acid formation phase (Stage 3) are converted by microorganisms into CH_4 (methane) and CO_2. The conversion rate of CH_4 and CO_2 increases significantly, resulting in a sharp decline in acid production.

2.3.5. Stabilization Phase

This phase occurs after biodegradable organic materials have been converted into CH_4 and CO_2 in Stage 4. Moisture continues to be supplied through the waste layers, and slowly decomposing organic materials are broken down into CH_4 and CO_2 over an extended period.

3. Research Methods

This study aims to analyze the current status of waste landfilling and landfill gas emissions at the Metropolitan Landfill Site, which manages waste from Seoul and Gyeonggi Province. To calculate greenhouse gas emissions, data on the total waste intake and direct landfill volumes for 2024 were utilized, based on information disclosed by the Metropolitan Landfill Site Management Corporation.

Table 3: 2024 Quarterly Waste Management Data at the Metropolitan Landfill Site

Category	Waste Intake (tons)	Direct Landfill (tons)	Waste for Resource Recovery (tons)	Landfill Ratio (%)	Resource Recovery Ratio (%)
1st Quarter 2024	256,791	132,662	124,128	51.66%	48.34%
2nd Quarter 2024	297,029	193,118	103,911	65.02%	34.98%
3rd Quarter 2024	229,826	116,643	113,183	50.75%	49.25%

When landfilling is conducted, waste undergoes decomposition through five stages, during which microbial activity intensifies and landfill gas is generated.

This study aims to determine the amount of landfill gas collected from each landfill section between 2020 and 2022. Additionally, the proportion of greenhouse gases within the collected gas is calculated to estimate the total greenhouse gas emissions from the landfill site.

Based on the **Managed Landfill Investigation Report** issued by the Metropolitan Landfill Site Management Corporation, the landfill gas collected over the past three years is as follows:

Table 4: Landfill Gas Collection Data (2020–2022)

Year	Landfill No. 1 (m^3)	Landfill No. 2 (m^3)	Landfill No. 3 (m^3)	Total (m^3)
2020	16,249,800	170,881,320	21,139,632	195,939,300
2021	16,089,849	152,070,966	37,221,198	205,382,054
2022	14,532,322	143,530,083	51,155,473	209,217,878

The composition of landfill gas generated from each landfill section during 2020–2022 is as follows. Greenhouse gases such as **CH_4 (methane)** and **CO_2 (carbon dioxide)** constitute the majority of the landfill gas.

Table 5: Composition Ratios of Landfill Gas (2020–2022)

Year	Landfill Section	CH_4 (%)	O_2 (%)	CO_2 (%)	N_2 (%)
2020	Landfill No. 1	43.6	1.3	37.4	17.7
	Landfill No. 2	46.7	1.0	38.1	14.2
	Landfill No. 3	49.0	0.024	38.3	11.8
2021	Landfill No. 1	42.9	1.0	28.1	28.1
	Landfill No. 2	46.0	0.7	37.2	16.0
	Landfill No. 3	50.3	10.6	40.6	9.1
2022	Landfill No. 1	37.5	1.5	21.2	39.8
	Landfill No. 2	46.4	0.6	36.8	16.2
	Landfill No. 3	50.4	0.0	41.8	7.7

Meanwhile, to evaluate the economic viability of landfill gas generated at the site, the energy facilities' power generation and electricity sales status, which convert landfill gas into electrical energy for utilization, were analyzed.

Table 6: Landfill Gas Utilization and Energy Production (2024)

Category	Landfill Gas Usage (1,000 m^3)	Electricity Generation (kWh)	Electricity Sales (kWh)	Self-Consumption (kWh)
1st Quarter 2024	42,208	57,487	46,763	10,329
2nd Quarter 2024	37,773	49,905	40,538	9,021
3rd Quarter 2024	34,017	38,811	35,999	2,634

Through this process, the Metropolitan Landfill Site utilizes the landfill gas generated to produce electricity. After deducting the self-consumed electricity for internal operations, the remaining generated power is sold to nearby apartment complexes and local citizens.

4. Results and Discussion

Currently, half of the waste brought into the Metropolitan Landfill Site is directly landfilled, while the other half is utilized for energy recovery and resource recycling. However, greenhouse gas emissions were identified through the composition of the landfill gas being utilized.

An analysis of the composition ratios of landfill gas collected from 2020 to 2022 shows that the majority of the landfill gas consists of **CH_4 (methane)** and **CO_2 (carbon dioxide)**. This indicates that these gases are the byproducts released at the final stage of the landfill gas generation process.

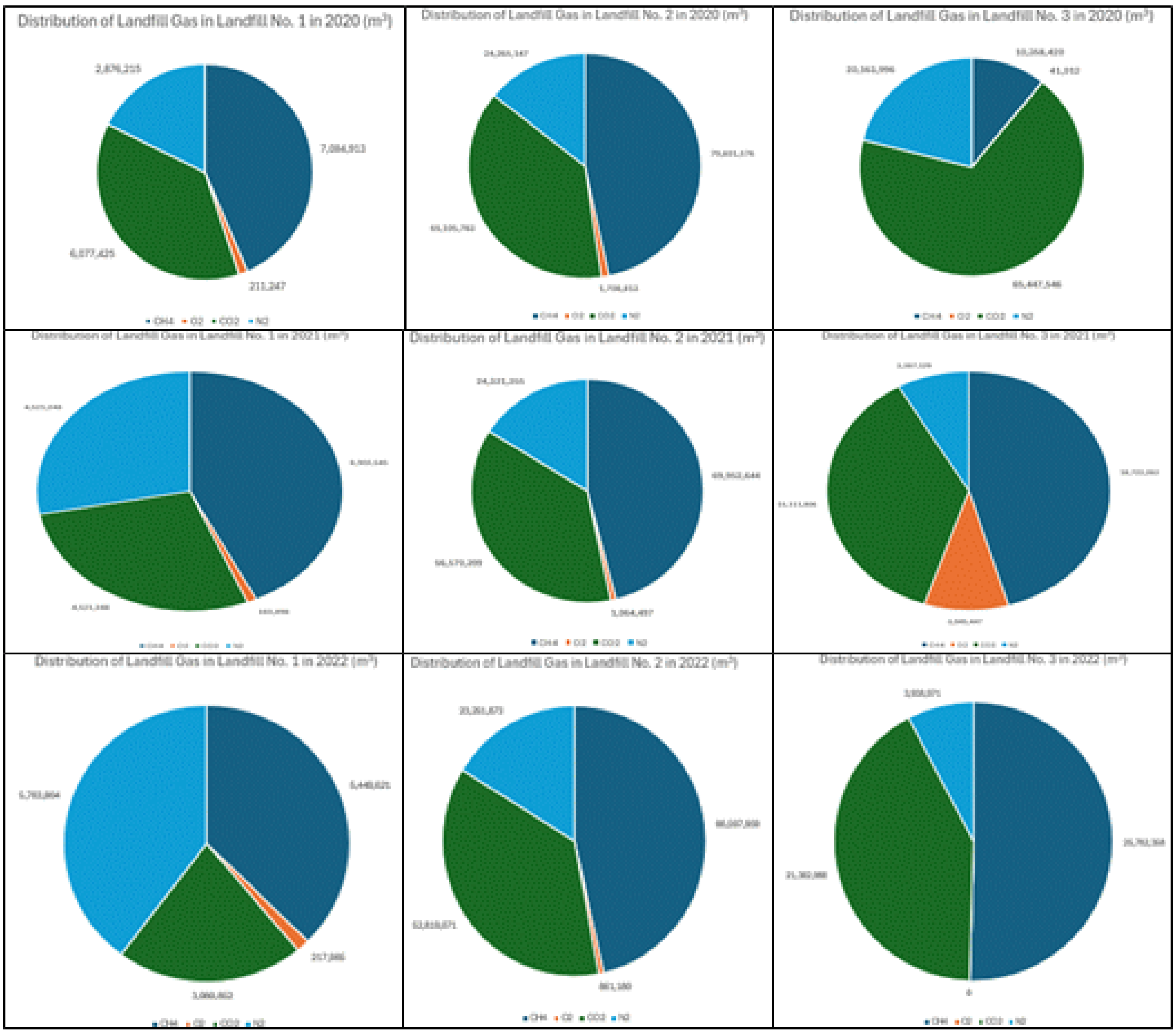

Figure 4: Gas Composition Distribution by Landfill and Substance (2020–2022)

As illustrated in the graph, the volume of landfill gas emissions is significant when compared to the **654.5 million tons of greenhouse gas emissions** preliminarily estimated for 2022 across the country.

These gases, classified as the **six major greenhouse gases under the Kyoto Protocol**, would contribute directly to the greenhouse effect if released untreated into the atmosphere. This would trap heat, raise surface temperatures, and accelerate climate change, highlighting the urgent need for their proper management.

Additionally, the **per capita electricity consumption in 2022** was **10,652 kWh**. By utilizing landfill gas for energy generation, an average of **40,000 kWh of electricity** can be produced through recycling, rather than relying on fossil fuels. This makes the process not only **economical** but also **productive**, offering a sustainable alternative to conventional energy sources.

5. Conclusions

Despite the growing trend of waste recycling, half of the waste entering landfills is still directly landfilled without pre-treatment. Therefore, it is essential to assess the greenhouse gas emissions and environmental impacts caused by landfills and establish effective countermeasures.

To manage closed landfills effectively, various processes are required. **Leachate treatment** involves installing impermeable barriers underground around the landfill and collection wells within the barriers to safely collect and treat leachate before discharging it into nearby water bodies like the Han River. **Landfill gas treatment** includes installing gas extraction wells connected to pipelines to collect landfill gas, which can then be used as boiler fuel to generate heat for nearby apartments, providing economic value. **Surface capping** prevents water infiltration and suppresses landfill gas emissions by covering the landfill with soil and impermeable liners. **Slope stabilization** ensures the stability of waste mounds by adjusting slopes and planting vegetation to create an ecological environment for wildlife.

Landfill gas can be converted into electricity and heat, supplying nearby apartments and residents. This falls under energy recovery and recycling, making it economical and environmentally friendly. Raising awareness about the utility of landfills as energy resources and improving public perceptions can reduce stigma and maximize their value.

A prime example of effective landfill management is the **Nanjido landfill**, where stabilization efforts began in 1996. The site was restored to an environment where plants and animals could thrive, culminating in its transformation into **World Cup Park** in May 2002. This serves as a living example of environmental restoration and can inspire future projects.

Currently, **Landfill Nos. 1 and 2** are closed, **Landfill No. 3** is operational, and **Landfill No. 4** is planned for future use. As space is limited and waste generation will continue to grow, close cooperation and understanding between local residents and municipalities are essential.

Additionally, considering the significant costs and environmental impacts, reducing the generation of waste itself for future generations is a critical part of the **zero-waste strategy**. By fostering mutual understanding and collaboration, society can find solutions within this challenge, sharing the benefits and addressing difficulties together to leave a cleaner environment for future generations.

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