The Role of Digital Technologies (AI, IoT) in Optimizing Waste Management and Resource Efficiency in South Korea

Presented by SANA TERRA

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Table of Contents

EXECUTIVE SUMMARY

South Korea is a global leader in waste management, with one of the highest recycling rates in the world. However, the country faces challenges such as increasing waste generation, population growth, rapid urbanisation, and the need for more efficient resource recovery. Digital technologies, particularly Artificial Intelligence (AI) and the Internet of Things (IoT), are playing a transformative role in addressing these challenges. This report explores how AI and IoT are being integrated into South Korea's waste management systems, highlights successful case studies, and provides recommendations for further improvement. By leveraging these technologies, South Korea can enhance its waste management systems, improve resource efficiency, and achieve its sustainability goals.

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INTRODUCTION

Background

South Korea is a resource-constrained nation with limited natural endowments, yet its economy is heavily reliant on energy and raw materials. To sustain its industrial and economic activities, the country depends significantly on international imports, sourcing approximately 96% of its energy and 90% of its mineral resources from overseas markets. As a result of rapid economic development, waste generation in South Korea saw a consistent rise, particularly in industrial waste. In 2017, the total waste produced reached 429,531 tons per day, with household waste contributing 53,490 tons per day (12.5%) and industrial waste accounting for 376,041 tons per day (87.5%) (Yoo, 2020).

South Korea has made significant progress in waste management, achieving a recycling and composting rate of over 60% in recent years (Belcher, 2022). The country has implemented effective waste management systems to address its waste-related challenges. Key initiatives include the Volume-based Waste Fee (VBWF) system, the Pay-As-You-Throw (PAYT) program, and the Extended Producer Responsibility (EPR) scheme, all of which have contributed to reducing waste and promoting sustainable practices (Saraswati, 2023). However, South Korea faces pressures on existing waste management infrastructure driven by population growth, rapid economic development, and accelerated urbanisation consumption. Digital technologies like AI and IoT offer innovative solutions to enhance efficiency, reduce costs, and minimise environmental impact.

Objectives

- To analyse the challenges in South Korea's waste management systems.
- To explore the applications of AI and IoT in optimising waste management in South Korea.
- To examine the advantages and impediments of adopting these technologies.
- To provide actionable recommendations for stakeholders in South Korea.

CURRENT CHALLENGES IN WASTE MANAGEMENT IN SOUTH KOREA

a. Waste Generation Trends

In 2023, South Korea produced an estimated 176 million tons of waste, with construction and industrial sectors contributing significantly to this figure. Additionally, the average daily municipal waste generation per capita was approximately 1.2 kilograms (H. Yoo, 2025b). This high level of waste generation is driven by rapid urbanisation, a growing population, and increasing consumption patterns. Despite the significant challenges associated with managing large quantities of waste, South Korea has achieved remarkable advancements in recycling. In 2023, an impressive 86% of the total waste generated was recycled, while only approximately 6% was incinerated (Statista, 2023) (see Figure 1). This high recycling rate is supported by a thriving recycling industry, which included over 6,900 companies providing waste recycling services in the country that year—a notable increase of more than 1,000 companies since 2017 (Yoo, 2025b).

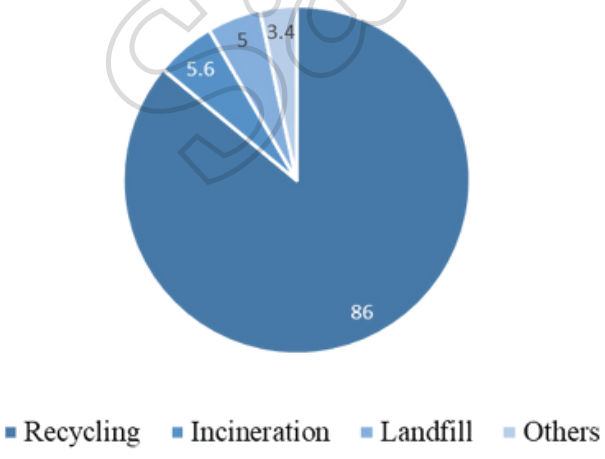


Figure 1: Waste Disposal Methods in Korea in 2023

b. Inefficiencies in Traditional Systems

Until the mid-1990s, waste disposal services in South Korea relied on the traditional method of "collection and landfilling," a practice common among developing nations at the time. However, this traditional approach became increasingly inefficient in managing the rapidly growing volumes of municipal solid waste (MSW) caused by industrialization and urbanization United Nations Development Programme, 2017).

Numerous waste management issues occurred due to the surge in per capita plastic consumption, urban population increase leading to waste generation, limited landfill space and environmental concerns related to incineration (Mohammed bin Rashid Centre for Government Innovation, 2023; Waste Met Asia, 2020; S.-J. Yoo, 2020). To address these issues, various policies aimed at promoting sustainable resource management were legislated, with a focus on waste reduction and resource recirculation. As a result, the management of Municipal Solid Waste (MSW) has seen substantial improvement, characterized by high recycling rates and a significant reduction in landfilling (United Nations Development Programme (UNDP), 2017).

c. Environmental and Economic Impacts

With a population density of 480 inhabitants per square kilometre, the Republic of Korea ranks among the countries with the highest population densities globally. The capital city, Seoul, has the highest density, nearing 20,000 inhabitants per square kilometre, while Cheju Province has the lowest density, with fewer than 284 inhabitants per square kilometre (UNFAO, 2016). Finding suitable locations for new landfills or incinerators has grown increasingly challenging due to strong opposition from local communities and South Korea's geographic constraints, including its limited land area and high population density. By 2025, Seoul, Incheon, and Gyeonggi Province are projected to encounter major difficulties in securing alternative landfill sites to replace the current Sudokwon Landfill Site (SLS), according to environmental engineering experts. The SLS currently occupies 8.9 square kilometres, and the remaining 5.83 square kilometres cannot be utilized until the Incheon Metropolitan Government grants the necessary permits (Kim, 2020).

Landfills have significant environmental and economic impacts. Greenhouse emission is the most prominent environmental problems arise from landfill as it is a major source of methane, which is 84 times more potent than CO2 in trapping heat (Danthurebandara, Passel, Van Passel, et al., 2013; Vasarhelyi, 2021). Another issue is leachate production, which leak through landfill liners, polluting groundwater and connected water sources and leading to eutrophication and the creation of “catastrophic zones” in marine ecosystems. In addition, the construction of landfill often results in the disappearance of natural habitats, with the U.S. alone losing over 1,800,000 acres of habitat due to landfill sites (recykal, 2024; Vasarhelyi, 2021). In terms of economic impacts, property vales are decreased by proximity to landfills, with studies indicating 12.9% decrease for large landfills and 2.5% for smaller ones (Granzier-Nakajima, 2023; Vasarhelyi, 2021). Communities near landfill suffer increased health risks, including a 12% higher risk of congenital malformations in children. This leads to to higher healthcareexpenditures and decrease in quality of life (Danthurebandara, Passel, Nelen, et al., 2013; Vasarhelyi, 2021). These challenges highlight the need for innovative solutions to optimise waste management and resource efficiency.

4. DIGITAL TECHNOLOGIES IN WASTE MANAGEMENT: SOUTH KOREA'S APPROACH

a. Waste Generation Trends

South Korea is a global leader in technology adoption, with a strong focus on AI and IoT. The country is the first country in the world to legislate a Smart City (Park, 2024), which includes the smart waste solutions. These technologies are being integrated into various aspect of smart city plan, including the waste management, from collection and sorting to resource recovery and energy generation.

The country has been at the forefront of integrating Artificial Intelligence (AI) and Internet of Things (IoT) technologies into its waste management systems, significantly improving efficiency, sustainability, and environmental outcomes. For instance, IoT-enabled Smart Garbage Systems (SGS) have been deployed to address food wastechallenges. In a pilot project in Gangnam, Seoul, smart garbage bins (SGBs) equipped with IoT sensors monitored waste levels and communicated data through wireless mesh networks. This system optimized collection schedules and reduced food waste by 33% within a year. The SGS also incorporated Radio Frequency Identification (RFID) technology to track resident participation and improve accountability, demonstrating how IoT can enhance user convenience while reducing costs for both residents and the government (Hong et al., 2014; Roy et al., 2022).

b. Case Studies

IoT-Enabled Smart Waste Bins

Due to insufficient numbers of public waste bin and frequency of waste collection, the Seoul metropolitan government struggled to manage waste management and collection. Also, as the city planners had no real-time data on bin capacity or fill rates, recycling bins are overflowed with plastic bottles and paper cups which the waste collection staff normally had to face. Therefore, to solve the problem, in 2014, the Seoul municipality collaborated with a Ecube Labs, a South Korean company that manufactures smart and connected garbage bins and solar-powered waste compactors, installing 85 Clean Cubes in highly congested areas of the city centre to manage general waste and recyclables. Clean Cubes are solar-powered waste compaction bins equipped with embedded sensors. These sensors measure the bin's fill level in real time and activate automated waste compaction, boosting the bin's capacity by 500% to 700%. The public cleanliness department utilized Clean City Networks (CCN) to monitor the fill levels and operational status of Ecube Labs' Clean Cubes, enabling them to track collection efficiency across Seoul. According to Seoul Metropolitan government, the shift from traditional waste and recycling collection methods to Ecube Labs' monitoring system has cut the collection costs by 83% and removed the waste overflow issues in Seoul City (Tomás, 2017).

AI-Powered Waste Sorting System

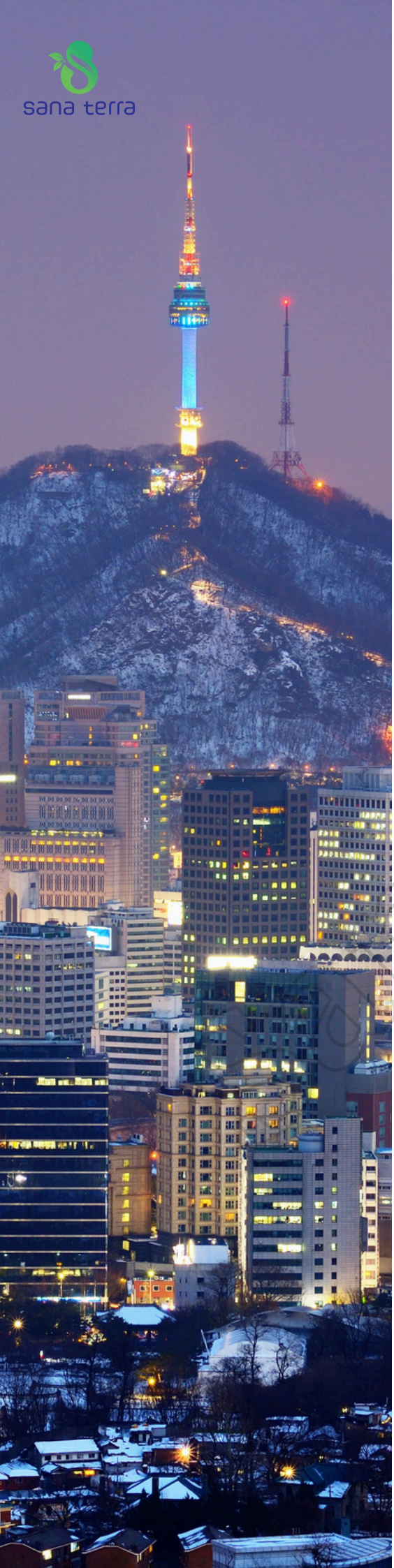
South Korean's startup Superbin's "Nephron" utilised AI to distinguish recyclable and non-recyclable items, reducing sorting time and contamination risks. It also compressed items for efficient processing and directly delivers to recycling factories. Also, users can earn points that can be transformed into cash (Kim, 2019; Miller, 2021). AI-enabled recycling bins, such as those deployed across the Seoul Metropolitan Area, can identify and sort plastic bottles within seconds. These bins process up to 600 kilograms of plastic monthly and reward users with redeemable points, incentivizing recycling behaviour. Over 1,000 such bins have retrieved at least 500 million plastic bottles in a year (Bastille Post Global, 2024).

SK Ecoplant's AI and Digital Transformation Initiatives

SK Ecoplant, a leading environmental services company in South Korea, has been actively integrating digital technologies into its waste management processes. In collaborating with Amazon Web Services (AWS), SK Ecoplant developed an "Eco-Friendly Incinerator AI Solution" to enhance the operational efficiency of waste incinerators while minimizing pollutant emissions.

Furthermore, SK Ecoplant is developing a digital platform to gather and analyze data from all stages of waste treatment in real-time, with a launch targeted for the second half of the year. The company is also collaborating with "RECO", which provides a data-based integrated waste resource management solution called "Upbox".

The AI and Digital Transformation (DT) technologies secured through SK Ecoplant's in-house development and collaboratives play a crucial role in the company's acquisition of a 30% stake in Cenviro, Malaysia's largest integrated environmental company (SK Ecoplant, 2022).



Hanam's Smart Solution: Integrating Waste and Public Space

In 2007, South Korea's Ministry of Land, Infrastructure and Transportation initiated a large-scale housing development project in Hanam City, aiming to create apartments for roughly 94,000 residents. The Korea Land and Housing Corporation, the state-owned developer, undertook the project between 2009 and 2016, and was tasked with managing the increased waste and sewage. Rather than construct new, separate facilities, the LH opted to fund Hanam City's modernization of its existing infrastructure. This led to the creation of the Hanam Union Park, an underground complex housing an upgraded sewage treatment plant, an incinerator, a food waste processing plant, and recycling and sludge treatment facilities. To mitigate potential resident complaints, all waste and sewage processing was located underground, integrated with public parks and sports areas, and featuring the Union Tower. The facilities manage waste solely from the new apartment complex, while the sewage plant handles wastewater for the entire city. Employing advanced technologies to control odor, the Union Park has successfully avoided resident complaints and become a model for smart infrastructure, effectively addressing the NIMBY issue and attracting attention from local government officials seeking to replicate its success (Yoo, 2020).

5. BENEFITS OF DIGITAL TECHNOLOGIES IN SOUTH KOREA

The integration of digital technologies such as Artificial Intelligence (AI) and the Internet of Things (IoT) into waste management systems has brought numerous benefits to South Korea, transforming traditional practices into efficient, sustainable, and cost-effective solutions. AI-powered systems enhance recycling quality by reducing contamination and increasing the grade of recycled materials, which boosts revenue while preserving natural resources. Machine learning algorithms automate waste sorting processes, improving accuracy and reducing landfill dependency, thereby lowering greenhouse gas emissions. Predictive analytics optimize waste collection routes, minimizing fuel consumption and operational costs. IoT-enabled smart bins equipped with sensors monitor fill levels in real-time, ensuring timely collection and reducing overflow issues. These technologies also improve transparency by providing actionable insights that prevent illegal dumping and enhance compliance with regulations (Addas et al., 2024; Cochran, 2024; Lettieri, 2023; Mule, 2024).

Economically, these innovations reduce hardware dependency and labour costs while enabling predictive maintenance to avoid costly downtime. Public engagement is strengthened through incentive programs that encourage recycling participation. Furthermore, AI-driven robotics eliminate the need for humans to perform hazardous tasks like sorting toxic e-waste. However, challenges remain, including high initial investment costs for infrastructure, data privacy concerns related to IoT systems, and reliance on consistent public participation for success (Addas et al., 2024; Cochran, 2024)

Looking ahead, South Korea aims to expand the use of AI-powered systems in rural areas and enhance IoT platforms with advanced analytics for predictive maintenance. International collaboration is also being pursued to share best practices globally. These efforts align with sustainability goals and position South Korea as a leader in smart waste management (Addas et al., 2024; Com4, 2024; Mule, 2024). By integrating cutting-edge technologies into its infrastructure, the nation sets a benchmark for sustainable urban development while offering valuable lessons for other countries seeking similar solutions.

Challenges and Barriers in the South Korean Context

South Korea's adoption of digital technologies like AI and IoT in waste management has been transformative, but several challenges hinder their full implementation and scalability.

a. High Initial Cost

The deployment of smart waste management systems, such as IoT-enabled bins and AI-driven recycling platforms, requires significant upfront investment. Infrastructure costs for sensors, data processing platforms, and advanced robotics can be prohibitive, especially for smaller municipalities and rural areas (Fang et al., 2023; Yoo, 2020).

b. Public Engagement and Behavioural Challenges

Despite the availability of advanced systems like IoT-based smart garbage bins and AI-powered recycling tools, public participation still needs to be encouraged as effective waste management depends heavily on individual behaviour, such as proper sorting of recyclables (Yoo, 2020). Limited awareness campaigns and insufficient incentives for residents pose barriers to success for the smart waste management (Seoul Solution, 2014).

c. Scalability Issues

While urban centres like Seoul have successfully implemented systems such as Clean Cubes and Clean City Networks to optimize waste collection, scaling these technologies to less densely populated or rural areas presents logistical difficulties. These regions often lack the infrastructure or financial resources needed to support such initiatives.

d. Data Privacy Concerns

IoT systems collect vast amounts of data on waste generation patterns and individual behaviours. This raises concerns about data privacy and security, particularly in densely populated urban areas like Seoul (Tomás, 2017). Ensuring compliance with privacy regulations while maintaining system functionality is a complex challenge.

e. Regulatory Enforcement

llegal dumping and improper disposal practices persist despite strict regulations. Monitoring compliance at scale is challenging, even with advanced digital tools, as loopholes in enforcement mechanisms can undermine the effectiveness of these technologies (Kwon, 2019; Yoo, 2025a).

f. Resource Optimization

While IoT-enabled systems reduce unnecessary fuel consumption by optimizing collection routes, they require constant maintenance and updates to remain effective. Battery-operated devices like smart bins also face limitations in energy efficiency over time (Hong et al., 2014; Tomás, 2017).

Addressing these challenges will require increased investment in infrastructure, enhanced public education campaigns, stronger regulatory frameworks, and continuous technological innovation to ensure that AI and IoT solutions can meet South Korea's ambitious goals for waste management and resource efficiency.

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Recommendations for South Korea

To address the challenges and further optimize the role of digital technologies in waste management and resource efficiency in South Korea, the following recommendations can be considered:

a. Enhance Public Engagement and Awareness

- **Expand Education Campaigns:** Develop comprehensive and targeted public awareness campaigns to educate residents about the benefits of AI and IoT-based waste management systems. Highlight the environmental and economic impacts of proper waste disposal and recycling.
- **Incentivize Participation:** Introduce stronger incentive programs, such as redeemable points or financial rewards, to encourage consistent participation in recycling and proper waste sorting. These incentives can be integrated with IoT-based systems to track and reward individual contributions.

b. Invest in Scalable Infrastructure

- **Rural Area Focus:** Allocate resources to extend AI and IoT technologies to rural and less densely populated areas. This can be achieved through government subsidies or public-private partnerships to reduce the financial burden on smaller municipalities.
- **Cost-Effective Solutions:** Explore cost-effective IoT and AI solutions, such as low-power sensors and modular systems, to make smart waste management more accessible to regions with limited budgets.

c. Strengthen Data Privacy and Security

- **Robust Data Policies:** Implement stringent data privacy regulations to protect the information collected by IoT systems. Ensure transparency in how data is used and stored, and provide residents with control over their personal information.
- **Cybersecurity Measures:** Invest in advanced cybersecurity measures to safeguard IoT platforms from potential breaches, ensuring the integrity and reliability of waste management systems.

d. Improve Regulatory Enforcement

- **Stricter Monitoring:** Enhance monitoring mechanisms to ensure compliance with waste management regulations. Use AI-driven analytics to detect and prevent illegal dumping or improper disposal practices.

- **Community Involvement:** Establish resident support consultative committees to foster dialogue between local governments and communities. This can help address NIMBY (Not in My Backyard) concerns and ensure smoother implementation of waste disposal facilities.

e. Foster International Collaboration

- **Knowledge Sharing:** Collaborate with other countries to share best practices and lessons learned in waste management. Participate in global initiatives to promote sustainable urban development and resource efficiency.

- **Policy Exchange:** Engage in policy exchanges to adopt successful strategies from other nations, such as advanced recycling programs or waste-to-energy projects.

f. Promote Technological Innovation

- **Research and Development:** Invest in R&D to develop AI and IoT technologies capable of handling complex waste streams, such as e-waste. Encourage collaboration between academia, industry, and government to drive innovation.

- **Predictive Maintenance:** Enhance IoT platforms with predictive maintenance capabilities to reduce downtime and improve the efficiency of waste management systems.

By implementing these recommendations, South Korea can further leverage digital technologies to optimize waste management, enhance resource efficiency, and set a global standard for sustainable urban development.

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CONCLUSION

South Korea's commitment to technological innovation, coupled with robust policy frameworks and active public engagement, positions it as a leading example in smart waste management. The nation's achievements demonstrate that a holistic, technology-driven approach can significantly enhance urban sustainability and livability. By addressing existing challenges and fostering ongoing innovation, South Korea not only secures its own enviornmental future but also provides a dynamic blueprint for global cities seeking to transform their waste management practices. The lessons learned here extend beyond waste management; they underscore the potential for digital transformation to drive comprehensive, sustainable urban development, inspiring other nations to adopt similar integrated strategies in their pursuit of environmental stewardship.

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