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Waste Management Policies in Light of Integrating Artificial Intelligence Applications: The Case Study of South Korea

سياسات إدارة النفايات في ظل إدماج تطبيقات الذكاء الاصطناعي: دراسة حالة
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Abstract:

This study aims to highlight South Korea's model for integrating artificial intelligence applications into waste management policies, it seeks to explore and implement effective global solutions for smart waste management, facilitating knowledge sharing and capacity building for most countries worldwide, including developing and Arab nation such as Algeria. This will help them adopt more effective smart solutions for efficient waste management in the future.

This study concluded that South Korea has become a global leader in this field, making significant strides towards achieving zero waste, establishing a clean society, and creating a more sustainable environment and planet. This success is attributed to the nature of its transformative policies: clearly defined, achievable, and practically and effectively implemented within a specific timeframe. These policies are distinguished by their comprehensive and mandatory nature, combining incentives and deterrents while maintaining a balance between them. This has allowed South Korea to be recognized as a global model that most countries can emulate by adopting similar applications.

Keywords: waste management; Artificial Intelligence; Smart waste management; Internet of Things; Environmental Sustainability.

الملخص:

تهدف هذه الدراسة إلى تسليط الضوء على نموذج كوريا الجنوبية لإدماج تطبيقات الذكاء الاصطناعي في سياسات إدارة النفايات لاستكشاف وتطبيق حلول عالمية فعالة للإدارة الذكية للنفايات لتبادل المعرفة وبناء القدرات لمعظم دول العالم، من بينها الدول النامية والعربية، من ضمنها الجزائر، وذلك لمساعدتها على تبني حلولاً ذكية أكثر فعالية لترشيد إدارة النفايات مستقبلاً.

وتوصلت الدراسة إلى أن دولة كوريا الجنوبية أصبحت دولة رائدة عالمياً في هذا المجال، وقطعت أشواط كبيرة في مسار الاتجاه لبلوغ غاية صفر نفايات وإرساء مجتمع نظيف وخلق بيئة وكوكب أكثر إستدامة، وتمكنت من تحقيق ذلك، بفضل طبيعة سياساتها التحولية الواضحة الأهداف والقابلة للتحقق والتطبيق الواقعي والفعال ضمن إطار زمني محدد، والتي تتميز عن غيرها بطابعها الشامل والإلزامي والجمع بين سياستي التحفيز والتخويف، والموازنة بينهما، ما سمح بتصنيفها كنموذج يحتذى به عالمياً يمكن أن تستفيد منه معظم دول العالم بتبنيها لتطبيقات مماثلة.

الكلمات المفتاحية: إدارة النفايات؛ الذكاء الاصطناعي؛ الإدارة الذكية للنفايات؛ أنترنت الأشياء؛ الإستدامة البيئية.

1. INTRODUCTION

The issue of waste management constitutes one of the top priorities of the international development agenda for the twenty-first century, as it has become a challenge for the international community that is not limited to developed countries, but also includes developed countries, due to the many repercussions associated with it related to ecological issues and environmental sustainability.

In light of the growing and increasing international issue that has become a real international dilemma threatening environmental balance and stability, on the one hand, and the growing and increasing technological and digital revolution, and the accompanying technological development of artificial intelligence application, on the other hand, many countries of the world, including South Korea, have turned to integration artificial intelligence applications

into the public policy for waste management policies as smart transformative mechanism to rationalize and streamline the public policy for waste management in order to reach the goal of zero waste and create a clean society and a more sustainable environment, in order to achieve sustainable development environmental, sustainability and principles of the circular economy.

In light of the above, the following problem can be posed:

How did South Korea integrate artificial intelligence into its waste management policies to achieve environmental sustainability? And what lessons have been learned?

This problem includes several sub-questions:

- What is the concept of waste management and artificial intelligence?

- What does the smart waste management mean?

- What are the stages of development of South Korea's public waste management policy?

- What are the characteristics of South Korea's smart waste management policies? And what distinguishes them from other strategies?

- What lessons can be learned from the South Korean model of smart waste management?

This study will highlight South Korea's model for smart waste management policies, South Korea was chosen as the focus of this study because it is a leading global model in smart waste management, particularly in food waste recycling, and strives to keep pace with global development in waste management by integrating artificial intelligence applications as a transformative tool.

The study aims to explore and implement effective smart waste management solutions to share knowledge and build capacity in most countries worldwide, including developing and Arab countries such as Algeria, by helping them adopt more effective smart waste management solutions in the future.

In this study, we adopted the case study approach as a fundamental method for the study, due to its suitability to its nature, which requires delving into the study of waste management policies in South Korea in light of the integration of artificial intelligence applications. This is with the aim of reaching scientific results related to smart waste management policies that allow us to draw a set of lessons learned that most countries of the world can benefit from, including developing and Arab countries, including Algeria, as it is a similar unit in terms of its suffering from the waste crisis, even if the national conditions are not identical, but this does not negate the existence of commonalities between them.

To achieve the study's objectives, address the research questions, and provide a comprehensive analysis, we will rely on the following elements :

- Artificial Intelligence and Waste Management: A conceptual Approach.

- Artificial Intelligence as a Modern Smart Technology for Waste Management.

- Stages of Development of Public policy for Waste Management in South Korea.

- Lessons Learned from Smart Waste Management Policies in South Korea.

2. Artificial Intelligence and Waste Management: A conceptual Approach

2.1 The concept of Artificial Intelligence

The historical beginnings the concept of Artificial Intelligence can be traced back to the contributions of researchers in the 1940s and 1950s, most notably: (Marvin Minsky), (John McCarthy), (Shannon Claude), and (Nathaniel Rochester) who participated in the participated in the Dartmouth Conference held in the United States in 1956s, that paved the way and laid the foundations for the birth of the term "Artificial Intelligence" and its establishment as a new independent scientific branch¹.

With the dawn of the 1990s and third millennium, the concept of artificial intelligence deepened, and its fields of use expanded, especially in light of the information revolution media and

communication technology, and the beginning of the era “Big Data”.

It has now become a specialized scientific field and one of the most prominent disciplines taught in most major universities worldwide, and is in high demand. It is a central focus for most countries around the world, which are moving towards employing artificial intelligence as a new and effective tool to support current human cognitive capabilities, foster innovation and scientific research, and develop national strategies and encourage training in this field to achieve sustainable and comprehensive development.

The concept of Artificial Intelligence appeared in the literature of international organizations including the of “Economic Co-operation and Development” (OECD), which defined it in 2019 as a: « Machine based system capable within a specific set of objectives defined by humans, of providing predictions, recommendations and decisions, that affect real and virtual environment, and the Artificial Intelligence designed to operate at varying levels of autonomy »².

Which the European Parliament summarizes it as: « the ability of a machine to simulate human behaviors such as thinking, planning and creativity »³.

So it is clear from these two definitions that Artificial Intelligence is designed to simulate human ability to think, learns and analyzes.

This is confirmed by numerous academic studies. Researcher “Kodjovi Lotchi” defines Artificial Intelligence as a: «branch of computer science, concerned with creating of performing tasks that typically require human intelligence. These tasks can be complex, such a reasoning, learning problem-solving, perception, natural language understanding, and independent action»⁴.

The academic definition shows that Artificial Intelligence is a multidisciplinary field, and a new independent branch of computer science, centered on developing the ability of computers to automatically

mimic human intelligence by employing a set of algorithms and designing and integrating intelligent technologies, applications programs, methods and tools that are capable of performing various tasks in all areas of life, just like humans and developing them to keep pace with the information revolution and the technology that characterizes the 21st century.

Studies agree that Artificial Intelligence relies on complex and composite algorithms, and the analysis of massive databases to use them for developing the performance of technical systems to achieve the highest level of efficiency. This allows it to perceive its environment, manage these perceptions, solve problems and take the necessary actions to achieve a specific goal. The computer receives a specific data (either pre-prepared or collected through its sensors, such as a camera...), analyzes it and responds to it. On this basis, AI-equipped systems can adapt their behaviors by analyzing the effects resulting from their previous actions to operate independently.⁵

According to the European Parliament, Artificial Intelligence has become the key technology of the future, because it is a modern digital technology that has invaded all areas of life, since the late twentieth and the beginning of the twenty-first century.

. Its use and integration have deepened in nearly all fields and in our daily lives, current international system. Its main areas include machine learning, natural language processing, computer vision, robotics and others⁶.

2.2 The concept of Waste Management

As for the concept of waste management, many studies according to the researchers “Ebikapade Amasuomo, and Jim Baird” emphasize that: « waste is a direct result of human environment interaction (Human activities), and it consists of materials that their owners no longer need. A material considered waste by one person may be a resource for another; therefore a material can be only considered waste when its owner classifies it as such»⁷.

So waste refers to human residues resulting from daily activities and interactions with the environment. These are diverse materials varying according to their physical states, source and impacts on the environment human and the economy equally. Its concept differs from one individual to another; there are many classifications of waste. In general they are classified into three main types according to their physical states into solid, liquid and gaseous waste and according to their source into household, industrial, agriculture, commercial, demolition and construction, and mining waste and also according to their environmental impact into hazardous and non-hazardous waste⁸.

The concept of waste management generally refers to: « the activities and procedures that deal with waste including and waste collection, transportation, treatment and disposal. Waste prevention, recycling, reuse, and recovery are important waste management strategies that reduce the burden on landfills, conserve natural resources and save energy»⁹.

Meaning that it encompasses the overall public policies waste management set by government and countries to manage and regulate the waste sector, making it a fundamental pillar for establishing and consolidating a circular economy on the one hand and reducing its impact on the environment and humans on the other. It includes laws, plans, programs procedures and activities related to the methods of waste collection transportation treatment separation sorting recycling valorization and disposal.

3. Artificial Intelligence as a Modern Smart Technology for Waste Management

3.1 Adopting Smart Waste Management Policies

In light of technological development and the distinctive information revolution of the present era, the era of Artificial Intelligence the latter has become a pivotal factor in shaping contemporary human society's day by day through its penetration into all areas of life, including the field of

waste management. It has become a modern intelligent digital technology for managing waste as most countries in the world are moving towards developing the field of waste management by drawing up public policies based on integrating artificial intelligence technologies and applications into waste management processes to identify separate and sort waste in the shortest possible time to reduce costs by minimizing the generated waste and the resulting pollution achieving maximum efficiency by utilizing natural resources and designing and producing new goods to the point of reaching zero waste, in line with the orientations of the international community regarding achieving sustainable development by the year 2030.

These recent changes and developments, along with the integration of Artificial Intelligence technologies and applications into waste management policies and their employment in many countries around the world, have contributed to causing fundamental transformation in traditional waste management systems characterized by fixed guidance and manual monitoring of containers and central dispatching¹⁰.

These traditional systems have proven to be ineffective especially in urban areas experiencing rapid urban expansion and population growth, which has led to an increase in the amount of waste generated in both developing and developed countries, increasing over recent decades. This has led to the emergence of new concepts widely discussed in the international and academic arenas, which can be considered a real revolution towards achieving the goal of "zero waste" stage. At the forefront of these concepts is the concept of "Smart Waste Management" as a new mechanism to address the contemporary and complex challenges facing human's societies in the field of waste management to achieve environmental sustainability, a circular economy and sustainable development.

Smart Waste Management is defined as: «the development or improvement of

traditional waste management methods, meaning upgrading them using information technology»¹¹.

Where this term includes: « any strategy that utilizes and operates information and communication technologies to enhance the efficiency of waste disposal by improving factors related to time, cost and environmental impact»¹².

3.2 Employing Internet of Things Systems

In this smart waste management system, the internet is considered a fundamental element¹³, as the literature related to artificial intelligence in waste management emphasizes the impedance of “Internet of Things ” (IoT) technologies¹⁴, a concept that emerged in the late 1990s and the beginning of the third millennium, thanks to the contributions of researcher “Kevin Ashton” who first introduced it in 1999s and described it as a : « set of connected devices that can be uniquely identified using Radio Frequency Identification (RFID) technology¹⁵.

Nonetheless, the precise definition of the internet of things is still in the process of formation and development and is subject to different viewpoints. Generally, the internet of things is defined as a: « dynamic global network infrastructure with self-configuring capabilities, based on standard and communication protocols». To this day, many technologies are used in the internet of things. Among them: wireless sensor networks (WSNs), Barcodes, Intelligent Sensing, Radio Frequency Identification (RFID), Near Field communication (NFC) technology, Low Energy Wireless Communications, and cloud computing¹⁶.

IoT sensors when coupled with artificial intelligence, allow real-time monitoring of waste containers, enabling a more dynamic and efficient waste collection waste process¹⁷, and improving its management by achieving higher recycling rates. AI algorithms can analyze data to provide insights for optimizing collection routes based on waste generation patterns¹⁸, thereby enhancing the efficiency and effectiveness of waste management systems.

The trend toward adopting AI-based waste management policies aligns closely with the circular economy model, which encourages the reuse, recycling, and recovery of materials to reduce environment impact through the development and modernization of the waste management process¹⁹, in line with the 17 sustainable development goals achieving environmental sustainability by 2030 particularly Goal 11: Sustainable Cities and Communities, Goal 12: Responsible Consumption and Production and Goal 13: Climate Action²⁰.

3.3 Integrating Artificial Intelligence Applications into Waste Management Policies

Most researchers specializing in the field of smart waste management policy agree that artificial intelligence in waste management has multiple and diverse applications and technologies. However, there is confusion between applications and technologies, while reality confirms that there is a significant difference between them. In our studies, we will focus on the main applications, which can be summarized in the following points:

Smart waste Bins: These are bins designated for waste and recycling equipped with advanced technologies, such as sensors, data systems and control applications, designed to support smarter, more sustainable cities²¹, including the ultrasonic sensor, which is used to measure the capacity of the waste bin and verify it by calculating the distance to an object. They also monitor the environmental conditions of smart bin by installing humidity and temperature sensors, especially for organic waste. The humidity sensor is used to determine the amount of water in a specific material and the smoke sensor detects the presence of gas in the trash bin²².

Monitoring bin fill levels encourages better sorting habits and improves collection processes, thanks to the Internet of Things (IoT) and real-time data, resulting in a qualitative transformation of traditional waste management into a more efficient and responsive system²³, by improving waste

collection routes using advanced algorithms such as the “Ant Colony System” and “the Genetic Algorithm”²⁴, Which is a search and optimization technique based on inference, is applied on the principal of genetic selection²⁵, which allows reducing the distances traveled leading to fuel saving and lowering carbon dioxide emissions²⁶, by helping waste collection trucks choose the most efficient route, thereby reducing waste collection costs, thanks to equipping the trucks with a Global Positioning System (GPS) unit and cameras for real-time tracking and monitoring²⁷.

For example but not limited to, we mention the metroSTOR smart bins, which includes sensing technology that monitors the fill levels of the bins and sends alerts when there is a need to empty them, and it enhance access control features, such as the metroKEY application, managing waste safely and orderly the electronic portal allows officials to track the status of units analyze usage data and communicate with users through targeted messages resulting in cleaner more efficient and data-driven management of public waste processing and recycling facilities²⁸.

Automated waste sorting process: AI-powered robots and machine waste sorting robots, which operate with artificial intelligence and machine vision systems, automate the process of sorting and classifying waste improving the efficiency and accuracy of recycling operations²⁹, Automated waste classification relies on the use of computer vision techniques³⁰, and artificial neural network, which are computational models for machine learning that mimic the behavior of neurons in the human brain. They consist of input layers, hidden layers and interconnected output layers. These networks receive signification attention in the field of waste management because they allow storing information across all layers of nodes, work with missing information even if some node layers are defective and can perform multiple tasks simultaneously³¹.

Thus, they represent an important

development that enables these systems to accurately identify recyclable materials, reducing human effort and improving recycling quality by minimizing cross-contamination at processing plants³². The application of automated waste sorting or classification has been adopted since 2011, which witnessed the emergence of the Finnish company “Zen Robotics” for the first it in the field of waste management and automatic classification. Its projects use a mix of computer vision techniques and machine learning, where it employs advanced robotic weapons to sort and extract recyclable materials³³.

Predictive Analytics: research related to waste generation prediction models has recently gained increasing attention and various models been proposed to better predict the amount of waste generated. These include statistical models, machine learning and fuzzy models. Artificial Intelligence Algorithms are considered the most advanced models for reliable waste generation prediction as they possess unique abilities in data input, learning and powerful prediction³⁴.

AI Algorithms analyze data to predict waste generation patterns³⁵, meaning they monitor and anticipate waste production urban system management, and the accuracy of predictive models depends greatly on the reliability and quality of input date, and the successful application of these systems requires ensuring the proper installation of Internet of Things sensors and their standards and that the collected data is consistent and representative of the environment in which it is applied³⁶.

Monitoring waste: Monitoring waste: Monitoring is an essential part of waste management, as it helps the relevant authorities make decisions and improve future performance, for example, a study by “Silviani Lionita Claudya Manik” and others emphasize the possibility of using a centralized monitoring system in the form of web pages that display all the data required to be recorded in the waste management system. This system is classified into three

categories: the main page, the monitoring page and the contact page. This centralized monitoring system consists of information related to the status of all installed smart waste bins and their collection locations by the trucks. Early information about the type of waste can be used, using image segmentation technology to determine the appropriate treatment for the collected waste, thereby improving the entire waste management process³⁷.

Another study by “Bingbing Fang” and the others emphasizes that AI-based system can monitor the recycling process to search for complex recycling situation, such as incorrect material sorting or material contamination, and alert the relevant staff to take the necessary measures to improve the recycling process, where this can help ensure that materials are recycled as efficiently and effectively as possible³⁸.

Based on the above ; it is clear that integrating artificial intelligence (AI) as a modern smart technology for waste management requires adopting the concept of smart waste management and integrating it into public policy for waste management. This concept is fundamentally based on employing Internet of Things (IoT) systems and key applications of artificial intelligence as smart transformative tools³⁹ that contribute to streamlining waste management policies to achieve environmental sustainability. The most important of these applications include: Smart Waste Bins, Automated Waste Sorting Processes, Predictive analytics, and Monitoring Waste.

4. Stages of Development of public policy for waste management in South Korea.

Anyone who follows the public policy for waste management in South Korea will find that it has gone through two main phases, as explained below:

4.1 Phase1: Before the integration of artificial intelligence applications into public policy for waste management (1995 to 2012)

This period saw South Korea adopt a series of public policies for waste

management since the mid-1990s to address the crisis of that time. The most important of these policies are decades-long separate disposal system for recyclable wastes and volume-based garbage fees for general and food wastes, which are considered two fundamental pillars of waste management in the country. In addition, there is the extended producer responsibility (EPR) system, which requires manufacturers to collect and recycle waste generated by their products⁴⁰.

The volume-based garbage fees for general and food wastes has contributed to reducing the amount of waste and increasing recyclable resources, while the EPR System had encouraged the recycling of packaging materials. Furthermore, the implementation of a waste to energy system, the establishment of waste disposal facilities, and anti-dumping policies have all contributed to the advancement of South Korea’s waste management systems⁴¹.

Since 1995, South Korea has implemented the Volume- Based Waste Fee system (VBWF), a policy that charges users based on the amount of waste they dispose of, thus encouraging waste reduction and recycling⁴². It also implemented the Jongnyangje system for efficient waste collection, sorting, and resource reuse. These systems embody the principals of “Polluter pays”, “pay by the amount”, and “reduce, reuse, and recycle”. This has helped train South Korean citizens to accurately and correctly sort their waste into basic categories: general waste, food waste, recyclables, bulky waste, business waste, and construction waste. Color-coded bags are used for general waste and food waste, and special labels, and cards based on the amount of waste produced, recyclables are collected free of rewards are given to those who report violations. This has contributed to reducing the waste crisis and improving the overall situation⁴³. Its management efficiency during this period.

4.2 Phase Two: Developing smart waste management policies (2012 to 2025)

In recent years, Policies to manage

resources throughout their entire life cycle have been newly introduced and implemented with the aim of building a circular economy where resources are reused and recycled instead of ending up in a dump⁴⁴. This is thanks to the integration of artificial intelligence applications and the successful integration of "Internet of Things" technologies. South Korea's smart systems enable real-time monitoring of waste levels, optimization of collection routes and ensuring efficient recycling processes according to official statistics for 2017 approximately 86% of waste is recycled and converted into resources⁴⁵, and about 95% of its food waste is recycled⁴⁶.

These practices have significantly contributed to reducing reliance on landfills and improving resource efficiency. This has led to South Korea being ranked a global leader in waste management quality and waste reduction, according to the 2025 Global Waste Index. South Korea ranked second highest in recycling rates among the 38 countries included in the index⁴⁷, a result that can be attributed to its increasing focus on employing artificial intelligence applications in waste management. South Korea adopted several policies to integrate artificial intelligence into waste management during the third millennium, a period that witnessed intensified efforts to embody smart waste management in the era of information and communication technology and artificial intelligence, which led to the establishment of a national strategy for smart waste management based on drawing up multiple smart public policies, the most important of which are summarized in the following policies:

Smart trash bins using renewable energy: In 2012, South Korea saw the installation of 70 smart trash cans which use renewable energy at four universities in Seoul National, Korea, Yonsei and Dongguk. 3000 Clean Cube trash compactors and Clean Flex in Seoul and throughout Korea, a solar-powered trash compactor using wireless technology, using solar energy batteries Clean Cube-attached

trash bins detect the quantity of waste they collect and can hold up to eight times more trash than.

In 2015, the Ecube developed Clean Flex, an ultrasonic fill-level sensor attachable to any trash can that monitors the quantity of contained waste quantity through ultrasonic waves and detects fire hazard.

Clean Flex collects waste data and sends them wirelessly to the CCN users can remotely check the volume of collected waste using the internet, resulting in lower cost thanks to using the shortest routes to collect waste and fewer visits to garbage containers⁴⁸.

The new way of managing our bins using Ecube Labs monitoring system: To achieve urban development and reduce waste collection costs, South Korea implemented a waste container management system using the Ecube Labs monitoring system. This was done in partnership with Ecube Labs, a company specializing in the design of smart, IoT-connected waste containers equipped with sensors capable of monitoring their fill levels and status. Eighty-five Clean Cube bins for household waste and recyclables were installed in Seoul, the capital city. Public hygiene officials used the Clean City Networks (CCN) platform (though the status and fill-level information provided by CCN) to monitor the status and fill levels of the Clean Cube bins, as well as to track the collection process through the city⁴⁹.

CCN is web and cloud-based management and data analytics platform, that provides the monitoring environment, smart dashboard, analytics, and center in one comprehensive and easy to-use package, allowing for complete control and comprehensive visibility of waste management operations and cost reduction⁵⁰.

The Clean Cube system was implemented at Everland, the premier theme park in South Korea, to eliminate the problem of overflowing waste containers. This system was installed, and its waste compression feature allowed for the

postponement of collection operation until the evening. The Clean City Network system also enabled city employees to identify and address overflowing waste containers during the day immediately, keeping waste out of sight of visitors⁵¹.

This system has also made Seoul's Seodaemun district the best neighborhood to live in. Since the implementation of the Clean Cube system, the district has been able to significantly reduce the frequency of garbage collection, quickly address the problem of garbage accumulation, and maximize work efficiency by reducing costs and workload for both administrative staff and waste collection personnel⁵².

For its part, Bukchon traditional village had known the application of smart waste containers (ClearCAP) since 2017. It is famous traditional tourist village in Seoul, where it includes many traditional houses dating back to the early twentieth century, which have become used as cultural centers, restaurant and cafes that work to preserve the rich history of Seoul. The village witnessed the installation of container fill level sensors (CleanCAP fill level sensors in the area) to reduce the problem of accumulated waste due to the influx of local and international tourists. (The CleanCAP is an ultrasonic level sensor that measure the amount of trash in waste bins, it can be attached to existing receptacles / containers to detect any type of trash, in Bukchon, the CleanCAPs were installed on three 3 different types of waste bins)⁵³.

In Bukchon, CleanCAP devices were installed on three different types of waste containers significantly improving waste collection efficiency. Waste collectors can now travel to designated area with prior knowledge of the locations they need to visit, As a result, unnecessary collections have decreased, and collection costs have dropped by 43%. This achievement is attributed to the use of a data collection and analysis platform (CCN) to determine optimal collection paths⁵⁴.

Lotte Department Store, which provides retail services and manages cultural

centers exhibitions, and event halls, has installed more than 20 smart, Solar-powered waste containers to maximize the chopping experience for its customers. After installing this system, the number of waste collections decreased to once a day after closing hours, down from four times a day on weekdays and seven times a day on weekends. The system's advertising board also contributed to a 15% increase in customer engagement and participation in store events⁵⁵.

Smart food waste management system: South Korea is a leading country in the field of food waste recycling at the global level, as it was a pioneer in adopting a series of transformative policies to reduce food waste since the mid-1990s to confront the acute waste crisis that it witnessed at that time, with the beginning of the third millennium, it turned to employing and integrating technology to manage food waste with high efficiency. In 2013⁵⁶, it was able to develop food waste inlets with weight-based pricing pay- as -you- throw model (PAYT) as a solution for food waste management⁵⁷. This achieved using bins equipped with RFID technology for precise tracking and billing⁵⁸.

Envac's Automated Waste Collection System: The Envac's Automated Waste Collection System (AWCS) is a pioneering smart waste management project in South Korea, aiming to achieve urban development and realize the goal of "Smart Cities". This system is based on replacing the traditional track-based waste collection system with an underground pipe network, thus eliminating the need for traditional waste trucks, reducing carbon emissions and improving efficiency⁵⁹. This system was developed by Envac Korea, company that has revolutionized smart waste management in South Korea by installing more than 50 automated waste collection systems in 11 cities and completing 16 large-scale urban projects. Among these project are the Sejong City Development, which boasts the world's largest automated waste collection system; The H Fiestier I park (Gaepo, Seoul), which utilized the latest automated waste collection

technology; and Haeundae LCT (Bursan). Bursan integrates smart waste management solutions, and Gwacheon Sci (Gwacheon City)⁶⁰.

It is clear from the above that South Korea has integrated artificial intelligence into its urban waste management policies, contributing to the emergence of what are called "Smart Cities". This international has not been limited to urban areas, but has extended to villages, entertainment and play centers, large stores, and many universities, making it a global model to be emulated.

5. RESULTS AND DISCUSSION

Lessons Learned from Smart Waste Management Policies in South Korea

South Korea is a global leader in smart waste management, possessing one of the world's most advanced waste management systems. Its model deserves careful study and in-depth analysis to learn from it, especially considering that it was one of the countries most affected by the waste management crisis in the 1990s due to its small size, high population, and other economic factors related to exports. This is similar to the situation faced by many countries worldwide today, including developing and Arab nations such as Algeria. This makes South Korea a model to emulate, as these developments demonstrate the potential for most countries, including Algeria to adopt similar smart applications. This aligns with the research objective of exploring and implementing effective smart waste management solutions, Algeria and other countries can address their waste management challenges by:

- Employing Internet of Things (IoT) systems and adopting smart city policies;
- Developing an underground waste collection policy, specifically underground pipeline network, to replace the traditional truck-based system;
- Replacing traditional containers with smart bins equipped with Radio Frequency Identification (RFID) technology for waste tracking and billing;
- Developing an online platform for waste management data analysis, providing an

integrated monitoring environment for container status and fill levels. This will offer a comprehensive view of waste management operations and reduce costs;

-Installing container fill level sensors to mitigate the problem of accumulated waste. These ultrasonic sensors measure the amount of waste in containers and can be installed on existing containers to detect any type of waste;

- Implementing a volume-based waste they generate. This will be facilitated through the introduction of dedicated smart bins, with fines for violators and incentives for reporting violations;

- Developing a smart food waste recycling policy to reduce food waste, especially bread;

- Promoting resource recovery and circular economy by transforming waste into value products.

6. CONCLUSION

South Korea is a global leader in developing smart waste management policies, particularly for food waste. It has become a model for the world, boasting one of the most advanced waste management systems globally, as it strives towards achieving "zero waste" and establishing a clean, waste free society and a more sustainable environment.

This was achieved thanks to its adoption of the concept of smart waste management and its practical application through intensified national efforts to integrate artificial intelligence into waste management policies since the beginning of the third millennium. It adopted several transformative policies with clear objectives, achievable goals, and practical and effective implementation within a defined timeframe.

These policies are distinguished from those of other countries pursuing similar approaches by their comprehensive and mandatory nature, the most important of these include: Smart trash bins using renewable energy; The new way of managing our bins using Ecube Labs monitoring system; Envac's automated waste collection system; Smart food waste

management system and other. These collectively contributed to promoting a culture of organized waste sorting and collection, and resource recovery, in line with the principles of the circular economy. This is achieved by transforming waste into value products or disposing of non-recyclable products in a safe and environmentally friendly manner. The country is committed to implementing these policies in its own unique way, combining incentives and deterrents. This includes imposing fees based on the quantity of waste produced, fines for violators and providing incentives, for those who report violations in waste disposal methods.

Today, South Korea continues to work diligently to maintain its gains by striving to solidify these policies into a distinctive behavioral culture within South Korea society, aiming to achieve environmental sustainability, establish a circular economy, and reach a "zero waste" stage to contribute to creating a more sustainable planet.

After studying the South Korean model for integrating artificial intelligence applications into waste management policies, the study concludes with a set of lessons that most countries worldwide, including developing and Arab countries, such as Algeria (as previously mentioned), can benefit from. However, this cannot be achieved without genuine political will to formulate smart waste management policies characterized by:

- Comprehensive and mandatory nature;
- Combining incentive (reward) policies to promote positive environmental behaviors with deterrent (punishment) policies to limit negative environmental behaviors, and balancing the two;
- Clean short - term and long- term objectives;
- Feasibility and practical, effective implementation within a defined timeframe.

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