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INNOVATIVE APPROACHES IN WASTE MANAGEMENT FROM PAST TO PRESENT

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ABSTRACT

Today, waste management is becoming increasingly important in terms of environmental sustainability and economic efficiency. Increasing population, industrialization and changes in consumption habits necessitate the development of new approaches in the field of waste management and the rethinking of existing systems. In this context, innovations and innovative approaches in waste management from past to present play a critical role in the transformation of waste management. Developments around the world encourage the adoption of innovative solutions and approaches in waste management. In particular, concepts such as zero waste targets, circular economy principles and waste reduction strategies are gaining more importance in international platforms and in the domestic policies of countries. In addition, technological advances offer more efficient and effective solutions in waste management. Developments in smart sensors, automatic classification systems and recycling technologies make it possible to manage waste more effectively.

In this context, these developments in the field of waste management worldwide are an important driving force for the further development and implementation of waste management strategies and policies. In this study, innovative approaches in waste management from past to present are discussed, and it aims to be an important resource for understanding the effects of global developments on waste management and for creating more sustainable waste management systems in the future.

Keywords*: waste management, innovative approaches, environmental sustainability*

INTRODUCTION

Increasingly, waste management has become very important in terms of environmental sustainability and economic efficiency. Population growth, industrialization and changes in consumption habits necessitate the rethinking of existing systems in waste management and the development of new approaches. In this context, innovations and innovative approaches in waste management from past to present play a critical role in the transformation of waste management. In order to reduce the pressure of increasing waste on the environment due to human activities and industrialization, solutions have been

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sought at local, regional and national levels since the 1960s. Initially aiming to find solutions to environmental pollution, these social movements have transformed into an approach focused on preventing problems over time. In this context, disposal of waste and its use in the economy have become important in waste management. Within the scope of efforts to transition from a consumer society to an ecological society, the use of waste as an input to the economy constitutes one of the basic elements of sustainable waste management (Acungil, 2019).

Global developments are encouraging the adoption of innovative solutions and approaches in waste management. Concepts such as zero waste targets, circular economy principles and waste reduction strategies are gaining more importance in international platforms and in the domestic policies of countries. Developments in smart sensors, automatic separation systems and recycling technologies enable more effective waste management practices (Balbay *et al.*, 2021).

This article aims to examine and evaluate innovative approaches in waste management from past to present and aims to contribute to the knowledge in this field by revealing the historical development and current effects of innovative methods, technologies and strategies used in waste management. The importance of the article is based on the aim that innovative approaches in waste management contribute to the protection of natural resources by reducing environmental pollution, to increasing economic efficiency by recycling waste into the economy, to raising awareness of society on waste management and to more sustainable behaviours. It also helps to develop effective and sustainable waste management strategies for policy makers and decision makers, and to enrich the knowledge in the field of waste management and inspire new research as a valuable resource for academic research and industrial applications.

WASTE MANAGEMENT

Waste management is a major environmental problem faced by modern societies and plays a critical role in terms of sustainability. Waste management is a term that defines the management of waste generated as a result of our daily activities; it is structured in a way that is compatible with the benefits of the circular economy with the aim of protecting the environment and preserving natural resources (Anonymous, 2015). This process also includes reducing the potential harms of waste to human health, increasing economic values and supporting social welfare. Waste management is carried out by applying the basic principles of the waste management hierarchy (Öktem, 2016). These principles aim to reduce and prevent waste from the point of its creation, to reuse or recycle it, when possible, to evaluate energy recovery and finally to dispose of it safely (Parker, 2010). This systematic approach ensures that waste management is carried out effectively in terms of sustainability, environmental protection and resource efficiency.

The waste management hierarchy aims to ensure that waste is managed hierarchically at the highest level and that resources are used as efficiently as possible. This approach is an important guide to reduce environmental impacts and act in accordance with sustainability principles (Anonymous, 2024).

Waste Management Hierarchy

The waste management hierarchy is a framework that organizes the steps to be implemented in waste management in order of priority. This hierarchy includes steps such as minimizing waste, reusing, recycling, energy recovery and finally safe disposal (Öktem, 2016). Its aim is to minimize environmental impacts, protect natural resources and ensure efficient use of resources for a sustainable future. The waste management hierarchy provides guidance for both individuals and businesses to manage waste responsibly and encourages them to act in accordance with the principles of a circular economy. A visual representation of the waste management hierarchy is provided in Figure 1. The hierarchical steps consist of the following steps:

- ***Reduction and Prevention:*** This step, which is at the top of the hierarchy, aims to minimize the generation of waste. Using less material in production processes, designing long-lasting products and avoiding unnecessary consumption are the basic strategies of this stage. This approach is the most effective method to minimize the environmental impact of waste (Kaza *et al.*, 2018).
- ***Reuse:*** This step aims to extend the life of products and materials. Repairing, refurbishing or otherwise reusing used products reduces waste generation (Gündüzalp and Güven, 2019).
- ***Recycle***: It is the process of reprocessing waste to obtain new products or materials. Recycling prevents materials from going directly to landfill and contributes to the conservation of natural resources. Materials such as paper, plastic, glass and metal are commonly recycled waste types (Kaypak, 2018).
- ***Energy Recovery:*** The use of waste for energy production enables the energy content of waste to be utilized. This process involves the production of energy through burning or biodegradation of waste. Energy recovery is a recovery method that can reduce the volume of waste while also meeting the energy need.
- ***Disposal:*** This step, at the bottom of the hierarchy, involves the safe disposal of waste. This is usually done by burying the waste in landfills or burning it. Disposal is considered a last resort when all other options have been exhausted and is the least preferred method of waste management (Öktem, 2016).

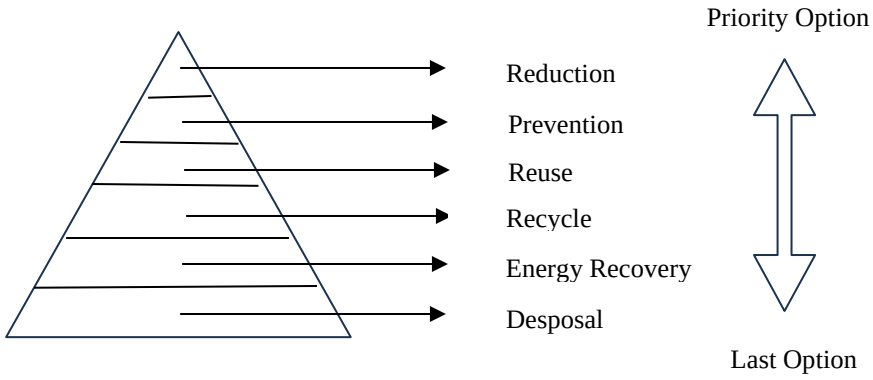

Figure 1. Waste Management Hierarchy
Source: Simon (2019)

WASTE MANAGEMENT FROM PAST TO PRESENT

From past to present, waste management has been shaped by the lifestyles of societies, technological developments and the evolution of environmental awareness, and has undergone a wide range of transformations, from simple waste disposal methods to complex and sustainable systems. This process has been approached with a different understanding and approach in every period of human history, and in the modern era, it has gained a more environmentally friendly and efficient structure in line with the principles of circular economy and sustainability.

In the early ages, waste management was not a significant problem because people lived in small and nomadic communities. Waste was directly released into nature and recycled through natural processes (Bilgili, 2021). In ancient times, more populous and settled societies began to form. For example, in Ancient Rome, arrangements such as sewage systems and garbage collection services were made. In the Roman Empire, the large sewage system called "cloaca maxima" was used to remove waste from the city and was known as one of the most advanced waste management solutions of the period (Güçlü, 2024).

In the Middle Ages, waste management problems became more apparent. As cities grew and populations increased, streets and public spaces began to fill up with waste. The unregulated accumulation of waste paved the way for epidemics such as plague to spread. The Black Death, which ravaged Europe in the 14th century, has gone down in history as an example of the dramatic consequences of poor hygiene and waste management. During this period, it was common practice to dump waste outside cities or into streams (Isen, 2005).

The Industrial Revolution marked the beginning of a new era in terms of waste management. The Industrial Revolution, which began in the late 18th and early 19th centuries, caused radical changes in production and consumption habits. Industrialization led to the production of large amounts of waste, and the management of this waste became an increasingly complex problem. The accumulation of waste in large cities became a threat to public health (İsen, 2005). For example, the "Great Stink" incident in London in the 19th century showed that the unregulated accumulation of waste caused serious health and quality of life problems. During this period, methods such as burning waste and burying it in regular landfills began to become widespread (Mumford, 2007).

In the 20th century, especially after World War II, waste management became more important. The proliferation of plastics and other synthetic materials created new challenges in waste management. From the 1950s onwards, plastic production increased rapidly worldwide, causing plastic waste to become a major environmental problem. During this period, landfills and incinerators became the most common disposal methods. However, with the increase in environmental awareness, recycling and waste reduction measures began to gain importance. In the 1970s, especially with the rise of environmental movements, sustainable practices such as recycling and reuse came to the fore (İsen, 2005). Earth Day celebrations were organized in the United States in 1970 to increase environmental awareness and draw attention to waste management problems.

The 21st century has been a period of major changes in waste management. Circular economy and sustainability concepts have become central to waste management policies. Practices such as waste reduction,

reuse, recycling and energy recovery have become widespread. Advanced recycling technologies and smart waste management systems have begun to optimize waste collection and processing processes (Bilgili, 2021). For example, "zero waste" policies implemented in Scandinavian countries have come to the fore with the aim of recycling and reusing waste as much as possible. At the same time, issues such as combating plastic pollution and managing e-waste (electronic waste) have become important agenda items at the international level.

As a result, waste management has evolved in parallel with social and technological changes throughout history and has now become more complex and advanced in the context of sustainability and circular economy. In this process, minimizing environmental impacts and efficient use of resources have become the main objectives of waste management policies.

EXAMPLES OF WASTE MANAGEMENT INNOVATIONS

The examples of waste management include different waste management strategies and projects implemented in various countries and regions around the world. These examples illustrate the efforts of local authorities, governments, businesses and individuals to reduce, reuse, recycle and safely dispose of waste. Waste management plays a critical role in achieving the goals of protecting the environment, sustainably using natural resources and improving public health. Various waste management policies and projects implemented in different geographical regions and cultural contexts provide insight into innovative solutions and best practices in this area. Below, we will examine some of the prominent waste management examples and practices from around the world.

İZAYDAŞ
İzmit Waste Incineration and Storage Joint Stock Company
Türkiye

In Turkey, solutions to solid waste management began in the 1990s, and important steps were taken with the EU in the 2000s (Doğru, 2006). Kocaeli is one of the most industrially intensive provinces in Turkey, and this situation increases both job opportunities and migration, leading to a continuous increase in the population. The rapidly growing population has made waste management an important problem in Kocaeli. However, population growth is not the only effective factor; socio-economic characteristics, consumption habits, seasonal changes, industrial activities, agriculture, trade and tourism are also factors that shape the amount and type of solid waste. İZAYDAŞ, the first solid waste disposal facility established in Turkey, was established in Kocaeli in 1996 and still produces energy from waste together with regular storage areas (Menteşe and Kızılçam, 2021).

İZAYDAŞ adopts an integrated approach in waste management and energy production processes in Kocaeli (Doğru, 2006). Firstly, waste collection and transportation operations are carried out regularly from various municipalities and industrial facilities in Kocaeli. Collected wastes are subjected to separation and classification processes in the facilities; this process ensures the separation of recyclable materials and the processing of wastes according to their types. Separated recyclable materials are processed in recycling facilities and reused, thus contributing to the protection of natural resources and the reduction of waste amounts. Non-recyclable waste is used

for energy production; it is burned in modern facilities to produce electricity and heat energy, which helps to reduce environmental impacts and meet energy needs. The remaining waste after separation and recycling processes is buried in regular storage areas and environmental safety measures are taken in these areas. İZAYDAŞ constantly monitors the environmental impacts of its facilities, keeping air quality, water pollution and other factors under control. In addition, various educational projects are carried out to raise public awareness about waste management. This holistic approach aims to minimize environmental impacts and use resources efficiently by ensuring that İZAYDAŞ achieves its sustainable waste management and energy production goals (Menteşe and Kızılçam, 2021).

NEWATER (Singapur)

NEWATER is known as an international company that offers innovative solutions in the water management and treatment sector. The company responds to global needs for protecting and improving water resources by using modern technologies and advanced engineering methods. NEWATER is a pioneer in optimizing water treatment processes, recycling wastewater and sustainable water management practices. Its innovative products and services aim to improve water quality and reduce environmental impacts in a wide range of areas from industrial facilities to residential areas. The company continues its mission to provide cleaner and safer water resources worldwide by continuously innovating in water treatment technologies with its strong research and development team (Corporation, 2004).

NEWATER makes a significant difference from traditional treatment methods with its innovative methods in the field of water treatment and recovery. The company improves the quality of water by using physical, chemical and biological treatment processes in an integrated manner, while also minimizing environmental impacts. Traditional treatment methods usually target only certain pollutants and can consume large amounts of energy and chemicals. The physical treatment applied by NEWATER ensures the effective removal of large particles and pollutants; chemical treatment uses optimized chemical processes for the separation of dissolved pollutants and toxins. Biological treatment, on the other hand, allows the separation of organic substances by microorganisms, but NEWATER uses advanced technologies that make this process more efficient. The company also promotes water reuse beyond traditional methods with high-performance filtration methods such as membrane technologies, reverse osmosis and nanofiltration, and recycles wastewater in high quality (Anonymous, 2020). The visual of the working principle of the NEWATER facility is given in Figure 2.

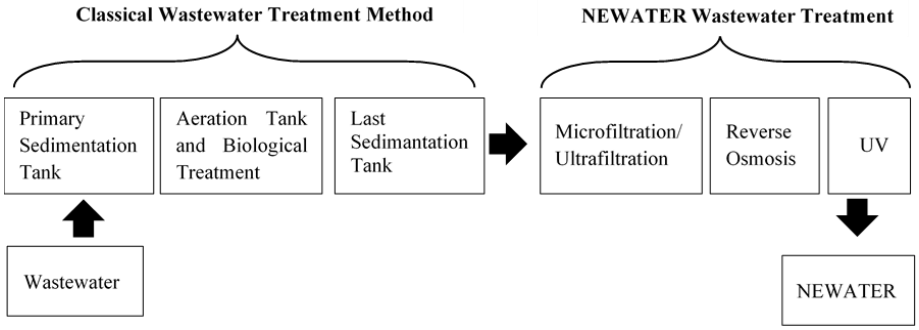

Figure 2. NEWATER Working Principle
Source: Anonymous (2020)

In the future, with the decreasing water resources and increasing water pollution, these advanced technologies offered by NEWATER will become even more important. Considering the limitations and environmental impacts of traditional treatment methods, the integrated and highly efficient treatment methods offered by NEWATER will play a critical role in ensuring sustainable water management. These technologies will play a leading role in water management in the future by improving water quality and making significant contributions to achieving the goals of protecting and reusing water resources.

Clean Cubes Waste Compression Boxes and Sensor Application (South Korea)

In 2018, South Korea introduced an innovative waste management solution that offers smart solutions equipped with Clean Cubes waste compression bins and advanced sensor technology. These smart bins represent a significant advancement in urban waste management, integrating compression mechanisms and real-time monitoring capabilities. Clean Cubes waste compression boxes increase the capacity of the box by compressing waste and reduce collection frequency. This compression process is carried out through a mechanical system that turns waste into a more manageable form, thus using the space inside the box more efficiently and minimizing overflow problems, thus saving money (Bülbül, 2019).

An important feature of these boxes is the integration of sensor technology. The sensors monitor various parameters such as the filling level of the box, the type of waste, and the operating status of the compression mechanism (Gürcan and Açıksöz, 2023). This real-time data is transmitted to a central management system so that waste management authorities can remotely monitor the status of the box and plan collection operations more efficiently according to real needs, rather than according to fixed schedules.

The implementation of Clean Cubes boxes in South Korea aims to increase waste collection efficiency, reduce operational costs, and improve overall urban cleanliness. By using smart technology, these boxes help minimize waste-related problems, contributing to more sustainable waste management practices (Bülbül, 2019).

The implementation of such technologies is seen as part of South Korea's efforts to develop smart city initiatives and increase environmental sustainability. The Clean Cubes project exemplifies how integrating

technology with traditional waste management practices can lead to significant improvements in efficiency and effectiveness.

CONCLUSIONS

Innovative approaches to waste management have evolved with technological developments to increase environmental sustainability. Advanced technologies such as Newater enable wastewater to be recycled and reused as drinking water, while reducing environmental impacts by providing a solution to water scarcity. İZAYDAŞ, as an important example of waste management in Turkey, plays a leading role in the disposal of solid waste and the production of energy from this waste. This facility constitutes an important model for the circular economy by demonstrating that waste can be used to produce energy rather than just being stored. Smart waste compression bins such as Clean Cubes contribute to cleaner and more orderly cities by optimizing waste collection processes, while also saving energy and resources.

Within the framework of the waste hierarchy, these innovative solutions both support environmental sustainability and provide economic gains. With the opportunities provided by technology, more efficient and environmentally friendly methods have been developed in waste management, which has made a great contribution to the protection of natural resources and the reduction of environmental impacts. In the future, with the spread of such innovative solutions, more integrated and sustainable waste management will make significant contributions to the solution of global environmental problems. Various suggestions can be made to make waste management more effective. First of all, it is of great importance to encourage technological innovation; smart waste management systems, sensor technologies and high-performance treatment methods need to be continuously developed. Research and development projects to be carried out in cooperation with the state and private sector can increase the dissemination and effectiveness of these technologies. In addition, strengthening recycling and waste reduction strategies is one of the most important steps in this area. Encouraging recycling in society through education and awareness campaigns and spreading waste reduction practices can help adopt sustainable habits.

In developing countries, strengthening the waste management infrastructure and increasing management capacity are also foreseen as a critical need. Establishing modern waste disposal facilities and equipping existing facilities with capacity-enhancing innovations contribute to solving this problem. In addition, comprehensive policies and legal regulations need to be established and implemented for effective waste management; within this framework, clear legal standards should be determined and effective supervision should be provided. Common solutions to global waste problems should be developed with international cooperation. Finally, public awareness and education are critical factors for the success of waste management. Increasing the knowledge and awareness of society on waste management can contribute to reducing waste and increasing recycling rates by ensuring that individuals adopt sustainable habits. The implementation of these recommendations is important in enabling waste management to be carried out in a more efficient and environmentally friendly manner.

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