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Review

Towards Zero Waste: An In-Depth Analysis of National Policies, Strategies, and Case Studies in Waste Minimisation

Mohammed Almansour and Mohammad Akrami *

Department of Engineering, University of Exeter, Exeter EX4 4QF, UK; ma1003@exeter.ac.uk
* Correspondence: m.akrami@exeter.ac.uk

Abstract: This review provides a detailed analysis of zero waste (ZW) initiatives, focusing on national policies, strategies, and case studies aimed at minimising municipal solid waste (MSW). It evaluates the environmental, social, and economic impacts of waste and explores the transition from conventional landfill reliance to sustainable waste management practices. Key ZW approaches, including circular economy frameworks and extended producer responsibility (EPR), are examined through case studies from countries such as China, Germany, and the United States. The review highlights advancements in waste-to-energy (WTE) technologies, the development of zero waste cities, and the critical role of policies in achieving significant MSW reduction. Additionally, it identifies key challenges such as infrastructure gaps and regulatory weaknesses and offers practical solutions to overcome these barriers. This study serves as a valuable resource for policymakers aiming to implement effective waste reduction strategies and enhance sustainable waste management systems globally.

Keywords: municipal solid waste (MSW); zero waste (ZW); national policies; waste-to-energy (WTE); circular economy; sustainable waste management; waste reduction strategies

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1. Introduction

Waste, regardless of it is type or location, is often recognised as an environmental concern. However, it also carries significant social and financial implications [1]. Every instance of discarding a basic consumable food item, a damaged toy, a replaced electronic device, or any other form of disposal contributes to resource depletion and exacerbates environmental challenges globally [2]. When an item is discarded and classified as waste, a unique set of challenges emerges in terms of its management and treatment. Several factors contribute to waste generation, with one key factor being the production of items with limited lifespans, such as perishable foods, electronic devices, clothing, and furniture. Additionally, large agricultural areas are devoted to growing crops that are eventually wasted [1]. Waste production has historically been a result of human behaviour. Municipal solid waste (MSW) includes materials no longer wanted by the individual or entity that generated them, such as food and agricultural waste, along with discarded consumer products and their packaging. Once MSW is generated, it typically accumulates before being processed. Waste management involves the handling and treating of materials that may be reused, recovered, or disposed of [3]. The escalating production of MSW has become a more urgent concern worldwide, especially in newly developing and emerging nations. In these areas, current facilities and MSW management practices often struggle to cope with the growing amount of MSW caused by an increasing population, economic expansion, and rising urbanisation [4].

The global average waste production is 0.74 kg per person per day, while individual country rates vary significantly, ranging from 0.11 to 4.54 kg per person daily. Waste production numbers are often linked to income levels and rates of urbanisation [5]. In 2012, urban areas globally produced around 1.3 billion tonnes of MSW annually [6], and this amount is projected to rise to 3.4 billion tonnes by 2050. Additionally, the total amount of waste produced in low-income nations is projected to more than triple by 2050. Middle-income countries currently generate around 61% of global waste, while high- and low-income nations contribute about 34% and 5%, respectively. Organic waste constitutes approximately 50% of waste in low- to middle- incomes. In high-income nations, although the absolute volume of organic matter is similar, due to larger amounts of packaging and other inorganic waste, the proportion of organic material is around 32%. The proportion of recyclable waste varies significantly, ranging from 16% in low-income countries, and including paper, cardboard, plastic, metal, and glass, to over 50% in high-income nations. As nations' income levels increase, the volume of recyclable waste rises, with a particularly notable increase in paper waste, of which over one third is recovered through composting and recycling [5]. A summary of the global waste composition and quantities is presented in Table 1.

Table 1. Summary of worldwide MSW amount and composition.

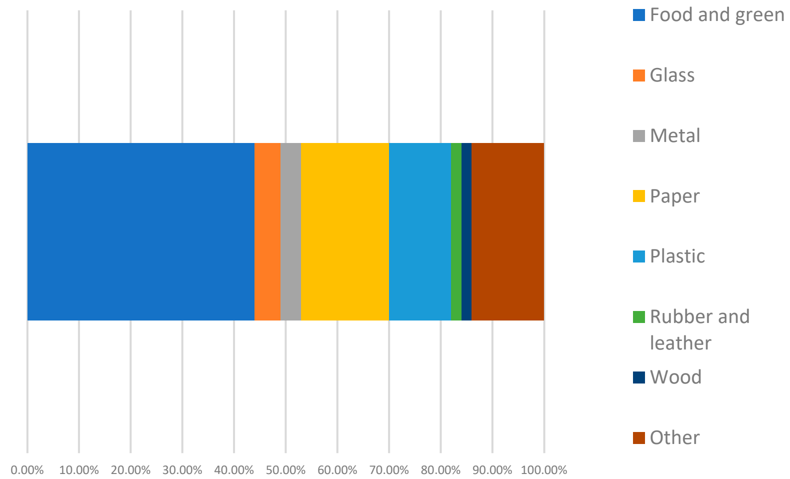
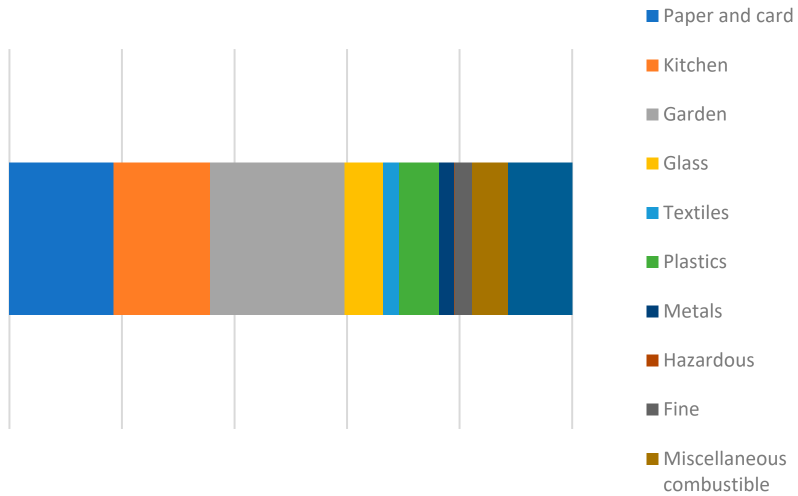
Location	MSW Amount (Million Tonnes)	MSW Composition	Since Year	Ref.
Worldwide	2010		2016	[5]
United Kingdom	25.691		2022	[7,8]

Table 1. *Cont.*

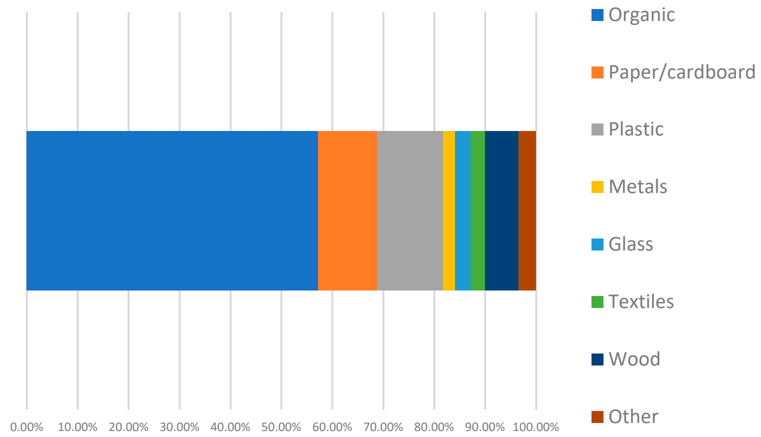
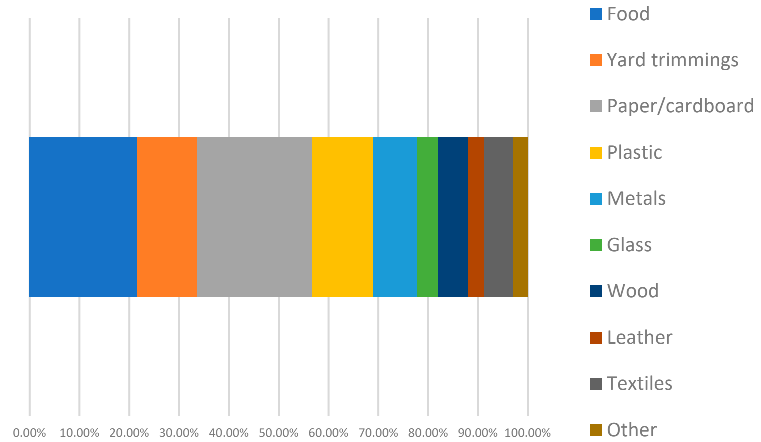
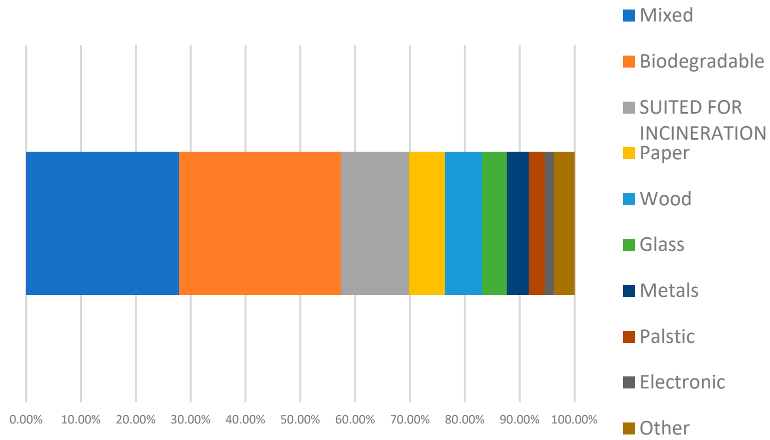
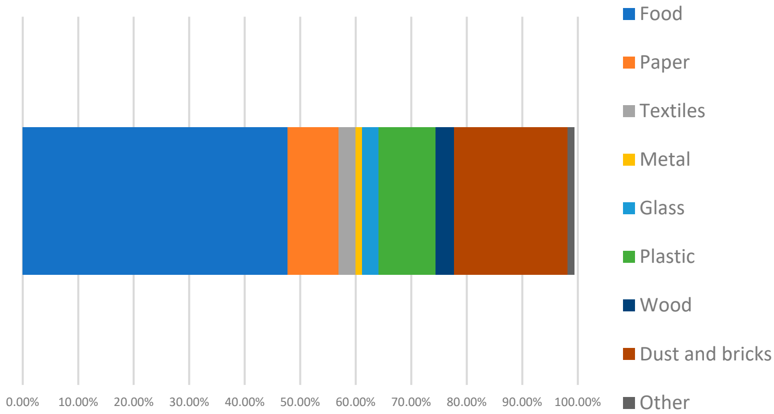
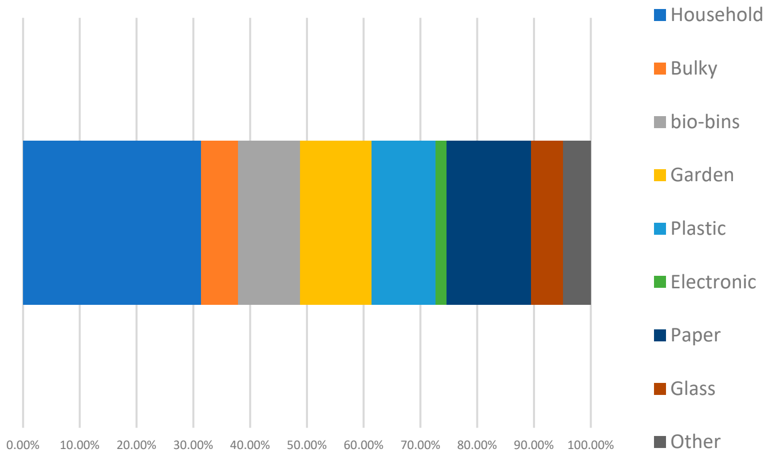
Location	MSW Amount (Million Tonnes)	MSW Composition	Since Year	Ref.
Saudi Arabia	16		2016	[9,10]
United States of America	292.4		2018	[11]
Denmark	12.2		2022	[12]

Table 1. *Cont.*

Location	MSW Amount (Million Tonnes)	MSW Composition	Since Year	Ref.
China	242		2020	[13,14]
Germany	356.1		2020	[15]

The Great Pacific Garbage Patch, currently spanning 1,760,000 square kilometres, 12 times the size of Bangladesh, continues to experience a daily increase in waste accumulation [16]. Waste production rates in lower-income countries are expected to more than double over the next two decades. However, waste generation is not a new phenomenon; it dates back to the earliest stages of modern civilisation. In contemporary society, waste highlights inefficiencies and the misallocation of resources. The production of waste depletes natural resources, consumes energy and water, puts pressure on land, pollutes the environment, and ultimately, adds an economic burden due to the costs associated with waste management [16]. The improper handling of organic waste poses significant risks to human health, primarily through direct exposure to disease-causing microorganisms and the proliferation of disease-carrying organisms such as insects and rodents [3]. Another major environmental consequence of waste is the release of greenhouse gases (GHGs) into the atmosphere, which accelerates global warming and contributes to climate change. Landfills are a primary source of methane and other GHG emissions during waste treatment processes [16]. Preventing the disposal of untreated waste in landfills, or ensuring it is properly treated, is crucial for protecting human health and minimising the environmental impact. This would halt the release of landfill gases, primarily, methane and carbon dioxide. Furthermore, the contamination of groundwater by harmful leachate from landfill waste disposal is a serious concern [17]. The over-dependence on landfill sites has created a more urgent need for waste management solutions, mostly owing to limitations in available land and the accompanying environmental, health, and safety concerns [18]. In the long run, recycling and reusing materials instead of sending waste to landfills reduces pollution [16].

Collecting waste and categorising, processing, reusing, and converting it into resources and energy are all main elements of sustainable waste management [19].

Progress in solid waste management has focused on the development of novel solutions that enhance resource recovery, minimise environmental impact, and improve sustainability. For instance, research conducted by Mo et al. [20], presents a novel method for biomass steam gasification using a fly ash-based catalyst processed through a combination of washing and calcination. This technique significantly improves the production of hydrogen-rich syngas, a valuable resource for sustainable energy. The results include extended hydrogen release and a substantial increase in syngas output and cold gas efficiency compared to the absence of a catalyst. This method enhances syngas production while facilitating a more efficient use of biomass and solid waste. The research establishes a basis for the efficient use of waste biomass and fly ash. Furthermore, another advancement in waste management research investigates the production of bioenergy from non-food biomass. This study emphasises the quantification of bioenergetic, emission, and biochar efficiencies of ginger (Zingiber officinale) pyrolysis. It highlights the demand for alternatives to fossil fuels and provides a method to decrease the solid waste generated by ginger processing, which is often disposed of via landfilling or incineration. Utilising this inexpensive and readily available biomass offers potential for generating cost-effective and environmentally sustainable bioenergy and chemicals [20].

An analysis of national policies and regulations globally is provided in this paper, including an outline of the historical background of waste management. The notion of zero waste (ZW) is examined as a sustainability paradigm that precisely tackles the fundamental issues of the worldwide waste management system. The aim of this review is to chronicle the progression of ZW efforts across time, offering a comprehensive summary of their growth. Therefore, this analysis will be beneficial for public officials responsible for formulating plans and enhancing regulations about zero waste. In addition, the research analyses the difficulties, risks, obstacles, and possibilities associated with shifting from conventional waste management methods to zero waste methods. Highlighted are the lessons derived from successful waste reduction initiatives, which indicate the potential and strategic approaches in the construction of efficient waste minimisation management infrastructure.

2. Historical Context of Waste Management

The demand for the proper disposal and treatment of waste emerged when people transitioned from scattered geographical regions to concentrated settlements. The increased populations of cities and towns led to an increase in waste, which became a troublesome issue [21]. The Greeks established the first recognised ‘municipal landfills’ in the Western World and enacted the first documented prohibiting of the disposal of waste in the streets in 500 BC [3]. The first evidence of waste being incinerated as a means of disposal may be traced back to the beginning of the first millennium in Palestine. During the Middle Ages, the issue of waste disposal persisted as a troublesome problem for urban inhabitants. Litter was often discarded into the streets, resulting in unpleasant odours and promoting the proliferation of pests and diseases [21]. The Cold War saw the emergence of academic interest in consumer history as a topic at the centre of the political and ideological struggle between communism and capitalism. From that point on, consumption was seen as a key factor in economic development [16]. The amount of waste generated these days is much higher compared with the late 19th century; this is due to the introduction of one-time-use products into market such as razors and canned foods, among others. As a result, it places significant pressure on authorities, who must handle it effectively [22].

During the period between 1750 and 1850, the industrial revolution in Europe resulted in a significant migration of people from rural regions to urban centres. This led to a substantial growth in the urban population and, therefore, a rise in the amount of waste generated. The rise in home waste generation was accompanied by an associated rise in waste from industries resulting from the rapid growth of large-scale manufacturing operations. The waste that was produced consisted of various elements including shattered glass, corroded metal, food remnants, and human excrement. This waste constituted a significant risk to human health and attracted flies, rodents, and other pests, which, in turn, might potentially spread diseases. Consequently, there was a growing recognition of the connection between the environment and public health. The first European Union (EU) policy paper on waste, known as the "Community strategy for waste Management", was created in 1989 as a component of the Fourth Environmental Action Programme (1987-92). The policy outlines the concepts of the management of waste hierarchy, which include the employment of clean and advanced technology to avoid waste, waste reutilisation and recycling, and the optimisation of ultimate disposal methods. The idea of proximity, which states that waste should be managed as close to its origin as feasible, together with the objective of achieving self-reliance in the management and disposal of waste, were highlighted. In 1996, the European Environment Ministers approved a new waste strategy, which was a reassessment of the 1989 document. It also emphasised the importance of implementing precise emission criteria for waste incineration and effectively regulating waste landfills. The following Landfill of Waste Directive (1999) and the Incineration of Waste Directive (2000) put specific rules into effect. The management planning of waste on a regional and local scale, as well as suggestions for cross-border waste exports, were also included in the strategy [21].

In terms of waste produced from packaging products, the obligation to take care of it in Germany was previously mandated by the Packaging Ordinance (VerpackV) in 1991. The document includes regulations about the responsibility of manufacturers and distributors to obligate and recycle discarded packaging. Retailers may fulfil this responsibility by engaging in a program that facilitates the gathering and reprocessing of that waste. In 1993, Germany implemented a collection and disposal system that was in line with the existing regulations. Consequently, there was a notable decrease in the percentage of packaging found in municipal waste. The Federal Environment Ministry of Germany implemented a program that includes a voluntary agreement to steadily enhance the recycling rate of paper waste since 1994. From 2001, Germany has made efforts to maintain a consistent rate of 80%. As of 1 June 2005, it is no longer permissible to dispose of waste in landfills without it undergoing pre-treatment. The pre-treatment process occurs in either incineration facilities or mechanical biological processing facilities. Also, it is required that the waste be treated to prevent degradation inside a landfill. Prior to landfilling, it is necessary to extract recoverable recyclables, and the energy produced from the wastes must be used. In 2010, Germany obtained an impressive overall recovery percentage of nearly 85% for packaging waste. Furthermore, Germany has implemented a waste management strategy during the last two decades that relies on closed cycles and distributes the responsibility of disposing of items to producers and distributors. It has heightened people's awareness of the need to segregate waste, prompted the implementation of novel waste disposal methods, and bolstered recycling capabilities [17]. A 65% waste recycling target was announced by government through the Circular Economy Act of 2012. Germany far exceeded the target long ago, with a projected recycling rate of around 67% in 2019 [23]. In 2020, the COVID-19 pandemic caused disruptions in recycling efforts. Several recycling depots either stopped or restricted their services, resulting in interruptions in certain waste management cycles. Additionally, there were provisional modifications in waste separation. The Federal Ministry of Environment instructed families with COVID-19 cases to suspend waste separation and dispose of all waste through residual waste disposal [24]. The government implements a deposit refund system (DRS). Containers eligible for recycling are appropriately branded within the plan. Customers paid a down payment when purchasing the bottles, which varies from EUR 0.08 to EUR 0.25. This sum is refunded upon the return of the empty container to a retail establishment. DRS has shown remarkable efficacy in nations such as Germany, with an impressive 98.4% return rate since the implementation of the program. The strategy to address the increasing waste output nationwide has been recently amended, and it has been declared that, beginning in 2024, every container for dairy goods and milk will be included in the DRS scheme [23].

There was a lack of standardised methods for managing waste in England. Waste was incinerated in uncontrolled household fires or thrown into the street. In 1297, a legislation was enacted mandating homeowners to maintain the area in front of their residence free from obstructions. However, this regulation was often disregarded. Consequently, there was a widespread presence of illness and vermin. From 1348 to 1349, a majority of London's population perished due to the Black Death. During the beginning 1400s, it became mandatory to store waste from home inside until it was taken away by individuals known as rakers. In terms of waste, the circumstances deteriorated in the 18th century with the onset of the Industrial Revolution. Products were manufactured at a low cost, leading to a surge in output and prompting people to migrate to urban areas. The initiation of waste control began with the enactment of the first Public Health Law in 1848. Waste was extracted from residences and deposited in adjacent excavations. Once the holes were completely filled, they were excavated, and it was transported away using a horse and waggon. Starting in 1875, homeowners were obligated to store waste in portable containers or dustbins, while municipal authorities were responsible for the disposal and collection of waste [25]. Moreover, specialised MSW incinerators were first used in the UK around the late 1870s. There were more than 300 incineration plants in 1912, out of which 76 were equipped with some form of electricity generating. In 1936, a law was regulated in place to govern the dumping of waste into water and identified the legal nuisance caused by any sort of company, manufacturing, or operation that might potentially harm public health or degrade the surrounding area [21]. The management of MSW underwent substantial changes during the last two decades. Prior to 2009, the predominant portion of MSW produced in the UK was disposed of in landfills. The proportion of MSW landfilled decreased markedly over the first 10 years of the century, down from 80% in 2001 to 49% in 2010. Recycling, both inorganic and organic, had a significant growth throughout the same timeframe. In 2010, the UK government pledged to enhance the alignment of MSW reporting with the EU's standards for MSW, ensuring a more uniform incorporation of business trash akin to residential waste [26]. The 2011 Laws mandate that all parties engaged in the management of waste and production in England (and Wales) must, upon the disposal of waste, implement all reasonable steps to adhere to the order of priority established in the waste hierarchy (prevent, reuse, and recycle). The government implemented the Household Reward and Recognition Program in 2012/13 and has collaborated with councils to enhance the amount and standard of waste collections, facilitating recycling and promoting award systems to boost recycling efforts. In 2018, the Resources and Waste Strategy was presented to provide an objective for conserving materials through waste reduction, enhancing sustainability, and advancing into a circular economy [27].

The COVID-19 pandemic significantly influenced waste management procedures and policies in the UK, as the government prioritised recycling and residual waste disposal, maintaining about 90% and 100% of collections, respectively, throughout the crisis. Additionally, more than 90% of Household Waste Recycling Centres (HWRCs) had to close temporarily during the first phases of the epidemic. A growing proportion of councils have ceased collections of bulky items (50% of councils) and garden waste (30% of councils). Security measures, lockdowns, and changes in consumer behaviour resulted in substantial modifications to waste content. The UK prepared for managing a heightened amount of medical waste. WTE plants were seen as a viable and efficient option for the disposal of this waste. The Waste Industry Safety and Health Forum (WISH) has established new guidelines to enhance worker safety, namely, for collection crews and waste management personnel [28]. The UK's recycling rate for residential waste, including incineration bottom ash metal, was 44.1% in 2022, down from 44.6% in 2021. The quantity of biodegradable municipal waste (BMW) sent to landfills in the UK decreased to 6.3 million tonnes in 2022, down from 6.7 million tonnes in 2021. In 2020, "Recycling and other recovery" was the predominant final waste management method in the UK, accounting for 52.3% of total waste, while landfill was the next most common method, representing 24.2% of waste disposal. By using tools like eco-design and Extended Producer Responsibility (EPR), the UK government aims to reduce waste and integrate circular economy principles into legislation through the Environmental Act of 2021 [29]. After reaching 62.4% in 2022, the recycling rate for packaging waste in the UK increased to 64.8% in 2023 [7]. The goal of a new program is to make recycling easier by requiring local governments to collect all recyclables from residents' homes, rather than just certain kinds. In April 2024, the landfill taxation is going up, which means it will not be as cost-effective to keep using landfills to dispose of waste. A number of sectors are now attempting to limit or outright prohibit the use of single-use items; for example, beginning in 2024, wet wipes will no longer be sold in England [30].

The waste regulation and policy in South Africa is initiated by the Environmental Conservation Act of 1989. It established the criteria for waste management and introduced a legal description of waste. However, the main emphasis was on the regulation, supervision, and administration of waste disposal facilities. The objective was to mitigate the environmental consequences linked to several inadequately managed landfills, a significant portion of which were essentially dumpsites (both regulated and unregulated) [31]. The waste management history in South Africa starts with four stages over 30 years, as presented in Figure 1. It starts with period of using the landfill in 1989, which is referred to as "The Age of Landfilling". The second phase began in 2001 with the introduction of recycling. Nevertheless, the government has achieved a mere 10% diversion of recyclables from disposal to recycling. In 2008, the third stage started with the introduction of new waste laws aimed at largely controlling the waste and secondary resources sector. In 2008, the last phase was implemented to enforce tyre manufacturers' obligations for the disposal of used tyres. This was done via the implementation of a compulsory EPR programme [31].

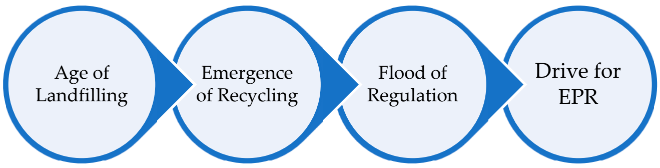


Figure 1. The phases of a waste economy in South Africa [31].

Prior to the Industrial Revolution in the US, waste was typically collected and disposed above ground or buried underground. Waste produced from humans and animals was utilised as fertiliser for land, and there were instances when waste was burned and used like fuel. Animals were often given leftover food. Additionally, open water sources, including rivers, lakes, and the ocean, were used as disposal sites for waste. During the 1870s, concerns over the negative impact on public health prompted local governments (municipalities) to assume responsibility for waste management in major cities across America. Initial efforts coordinated street cleaning, waste collection, and transportation to the nearest municipal landfill for dumping on land or in water [3]. A waste management law was implemented in the 1795 by the Corporation of Georgetown, Washington DC. The act explicitly outlawed the placement of waste on roads and mandated that individuals either personally eliminate their waste or use commercial companies to do so. By 1856, Washington had implemented a comprehensive waste management system over the whole city, which was funded by tax revenues. In 1878, the Mayor of Memphis orchestrated the collecting of household and commercial waste, and its transportation to locations situated outside the city limits. In 1885, the earliest MSW incineration plants were established in Allegheny, Pennsylvania [21]. In the 1890s, American towns faced health hazards due to the presence of industrial solid waste, municipal refuse, large quantities of manure, and deceased horses. Traditional methods of waste disposal included land or water dumping, use as animal feed or fertiliser on farms, and incinerating [3]. Through 1914, the US had around 300 plants for waste incineration. Nevertheless, a significant number of these waste incinerators were characterised by their small size, manual feeding systems, inadequate design, and lack of proper management. Consequently, their operation was inefficient in terms of cost. By 1915, half of the most cities had implemented a system for waste collection, and in 1930, this number had increased to 100% [21].

The origins of modern MSW management in the US may be traced back to the implementation of George Waring's processes by the New York City Sanitation Department in 1895. The unit operations approach has been used in waste management and to explore strategies for extracting materials and revenue from MSW. During the period from the 1920s to the 1960s, there was a formalisation of sanitary engineering processes and improvement of unit operating techniques. This led to the development of a management framework that remains in use nowadays. Sanitary engineering emphasises the collection and assessment of data in the creation, building, and operation of waste management facilities. Municipal organisations introduced cutting-edge equipment, including motorised collection trucks, street cleaners, and updated incinerator technology. Between 1941 and 1945, recycling was implemented as a significant initiative in the majority of cities nationwide. In the 1960s, the rate of MSW generated per person was three pounds per day. Paper and other packaging materials that are produced in large quantities have become significant components of the waste stream, displacing ash and food wastes. The Solid Waste Disposal Act was enacted in 1965, representing the first implementation of contemporary solid waste legislation in America. It concentrated the methods used for getting rid of solid waste and was enhanced by the first nationwide investigation of solid waste management techniques in the US. Subsequently, in 1970, legislation was enacted that redirected attention from dumping to the recovering of energy and material resources. This legislation and its previous versions prioritise extensive study on its implementation. The Resource Conservation and Recovery Act (RCRA) of 1976 ultimately superseded the first RCRA. The RCRA now serves as the primary law governing the management of MSW. Since the late 1980s, technological and based-on-performance criteria for MSW management plants under the RCRA have been in effect [3,21]. San Francisco has an extensive background in waste collecting systems, starting with the unofficial recycling of waste in the beginning of 20th century and evolving into the advanced systems that operate today. Additionally, it is at the forefront of sustainability activism on a global scale; it was the city that spearheaded the Urban Environmental Accords Programme (UNEP) [16]. In 2009, the United States Environmental Protection Agency's (EPA) Office of Resource Conservation and Recovery (ORCR) implemented a sustainable materials management (SMM) scheme grounded in life-cycle thinking to preserve natural resources and support governments in implementing the scheme for conservation programs. The advent of SMM signifies a transition from conventional end-of-life disposal methods to a voluntary methodology for sourcing, utilising, and overseeing natural resources, aimed at fostering economic development, resilience, and job creation while mitigating adverse environmental and health effects. SMM involves enterprises, governmental entities at all tiers, non-profit organisations, and academic institutions to improve the economy and the environment. The objective of SMM is to cultivate creative behaviours within societies that minimise material consumption at the point of production and/or collect and repurpose potential valuable substances from waste compotation [32]. In 2018, San Francisco revised its waste management objectives to include decreasing MSW production by 15% and reducing landfill or incinerator disposal by 50% by 2030 [33].

In 1995, China enacted and enforced legislation aimed for avoiding and controlling pollution to the environment caused by solid waste. Since then, it has also used incineration units for MSW as a substitute for landfills since 1995 [34,35]. Guo et al. [34] conducted a study for solid waste management policies in China from 2004 to 2019. This law was updated on two occasions, in 2004 and 2020. Between 2004 and 2019, China's major approach to managing residential waste shifted progressively from sanitary landfilling to waste incineration. 85.2% of China's harmless treatment went into sanitary landfills, whereas 5.6% went into incineration in 2004. However, the waste treatment process for sanitary landfills has been progressively decreasing since 2016, reaching 82%, while the incineration load has decreased by 73%. When looking at the overall quantity for 2019, 45.6% of it went to landfills for household garbage, while 50.7% was incinerated. No comprehensive data are available for China's waste from the home recycling programme. Many people and organisations in China engaged in solid waste recycling that was not affiliated with the government. Moreover, there is a growing trend of incinerating MSW, but landfill sites continue to be the primary method of discarding waste in China. Approximately 60% of MSW was disposed of in landfills in 2017. However, the predominant use of landfill sites as the primary method for waste disposal is linked to a variety of issues, such as the land requirement, the harmful environmental impact caused by emissions like carbon dioxide (CO_2) and Methane (CH_4), and land and underground contamination from leachate leakage [18]. In December 2018, the ZW cities initiative was presented by the government. That policy demonstrates the growing focus on transitioning from fossil fuels to sustainable energy, aimed at decreasing China's carbon emissions, minimising waste generation, and optimising recycling [36]. China's waste management policy underwent substantial changes throughout the COVID-19 epidemic, primarily due to the heightened production of waste. In response to this increase, China enacted urgent measures, including the construction of additional treatment plants and the deployment of 46 mobile treatment units. These modifications underscore the nation's efforts to enhance its waste disposal infrastructure due to the unparalleled waste catastrophe triggered by the epidemic. The COVID-19 pandemic intensified the attention on waste disposal facilities and policies, highlighting the need for resilient systems adept at managing both regular and emergency waste [37].

The quantity of MSW produced in Japan had a consistent upward trend until around 2000. Waste production had a significant surge during the time of fast economic expansion (1960s to 1970s) and during a period of economic prosperity (late 1980s to early 1990s). Since 2000, MSW creation has decreased owing to shifts in the industrial framework and the Japanese economy. This is partially because of advancements in sorting, collection, recycling, and the growth of a sustainable material-cycle society. The Japanese government has tried to decrease the continuously increasing quantity of MSW by using incineration and recycling methods. Since 2000, the government has made efforts to decrease MSW disposal by setting specific goals for the quantity of waste that may be disposed of in the Basic Recycling Plan. Additionally, it has implemented efficient methods to incinerate and recycle waste. Due to these diligent efforts, the ultimate quantity of MSW has dropped significantly. Additionally, the government implemented many recycling laws during the 1990s, in addition to the Basic Recycling Act, to efficiently encourage the recycling of MSW. The initial Fundamental Recycling Strategy was established in 2003 with the purpose of delineating the concept of a sound material cycle society [38]. In September 2020, in Japan, the government released the "Guidelines for Measures against COVID-19 in Waste Treatment ", which provided explicit directions for the disposal of residential waste. No significant issues were noted in the handling and management of waste in Japan during the epidemic. The epidemic expedited the adoption of the 3Rs concept, digitalisation, and decentralisation [39].

3. Overview of Zero Waste Initiatives

Solid wastes have historically been seen as unavoidable and unwanted, resulting in significant expenses for their ultimate disposal. In earlier times, solid waste management was designed to support a linear economy that followed a certain sequence of stages: extracting raw materials, creating items, selling them, consuming them, and finally, disposing of them [10,11]. Transitioning from a production process centred around a linear economy to one centred around a circular economy is crucial [10–12]. The majority of contemporary societies have widely used built waste management systems to effectively recycle and reclaim resources from waste. Waste reduction has made great strides; however, the rate of development varies greatly from one city to another. The zero waste (ZW) concept, as defined by Curran and Williams [40], encompasses a set of methods designed to eradicate waste and challenge conventional thinking. Moreover, a novel way to evaluate the efficacy of waste disposal systems, called the 'zero waste index', is suggested by Zaman et al., who also provide an explanation of the "zero waste city" concept. Achieving a state known as ZW means completely eliminating waste and replacing it with transformation. In other words, ZW refers to the complete elimination of any superfluous or undesirable waste generated by a product during its entire life cycle [16].

The strategy of ZW is gaining increasing favour as the most effective approach. It promotes the recycling of goods as well as seeking to reorganise their design, manufacture, and distribution to avoid the generation of waste from the beginning [41]. Additionally, ZW is continuously evolving and being used in several areas, including waste disposal and treatment, mining, production, and the development of cities [42]. Among the primary objectives of the ZW concept is to replace virgin materials by recycling and reusing. The present patterns of excessive use exhaust deplete a vast quantity of natural resources on a daily basis. Therefore, the main goal in reaching ZW ought to be to replace resources with those obtained from waste that is generated on a daily basis [16]. Furthermore, implementing bans on problematic items like plastic bags and excessive packaging, while pushing solutions such as composting or recyclable takeout food packaging and reusable transportation packaging, are key strategies for attaining ZW objectives [43]. In ZW cities, the product flow is circular, implying that the exact same resources are utilised over and over till reaching the optimal level of usage. In circular cities, there is no wastage or underutilisation of resources. Consequently, items are reused, fixed, resold, or reassigned within the system as they reach the end of their lifespan. If reuse or maintenance is not feasible, the items are recycled or recovered from the stream of waste then utilised as resources, hence replacing the need for extracting raw materials. It is evident that the effectiveness of a city waste management systems is indicative of its overall success. The movement of materials in the city should follow a circular pattern, ensuring that resources are used with maximum efficiency. The effectiveness of waste management systems represents the effectiveness of a city that aims to achieve ZW. Therefore, it is crucial to provide a measuring instrument for cities that can effectively track and assess their progress in achieving ZW [16]. China is among the top three countries in the generation of MSW, with it is total MSW output comparable to that of the US and India combined. Therefore, a policy initiative for waste was announcement in December 2018 to establish ZW cities. The approach demonstrates the growing fascination with shifting from fossil fuels to renewable energy sources. The goal is to not just decrease China's carbon emissions, but also to minimise waste generation and optimise recycling. This involves using various forms of waste as secondary carbon resources, known as feedstock, for manufacturing purposes [18].

In Germany, the government has a piece of legislation named the German Closed Cycle Management Act, which aims to transform waste handling into resource management. Implementing closed cycle management nonetheless benefits ecosystems, additionally, yielding economic returns [17]. The objective of the Scottish Government is to transform Scotland into a society that produces no waste and operates on a circular economy model. This entails reducing people's reliance on raw materials and optimising the reuse, recycling, and recovery of resources, rather than seeing them regarded as waste [44,45]. To achieve ZW in Scotland, actions made are to enhance resource efficiency by implementing measures to discourage the use of one-time-use resources, implementing measures to mitigate and repurpose food waste and designing a beverage container deposit return program. The food waste reduction action plan was implemented in April 2019. It was designed in collaboration with ZW Scotland as a component of the strategy to decrease food waste. Scotland widely utilises anaerobic digestion (AD) facilities to maximise the utilisation of food waste and enhance resource efficiency. Moreover, the implementation of EPR for packaging started in 2025 [45]. The objective of the ZW Masterplan in Singapore is to achieve a 20% reduction in the daily per capita waste delivered to landfills by the year 2026. This goal would expedite the advancement towards achieving the goal of reducing it by 30% by the year 2030 [46].

Twenty-seven cities, provinces, and countries globally joined in signing the Towards Zero Waste Declaration, including Stockholm, Boston, Auckland, Catalonia, Copenhagen, Dubai, London, Los Angeles, Milan, Montreal, Navarra, New York City, Newburyport, Paris, Philadelphia, Portland, Rotterdam, San Francisco, San Jose, Santa Monica, Sydney, Tel Aviv, Tokyo, Toronto, Vancouver, Wales, and Washington, D.C. Upon implementation, the pledges made by these 27 members will prevent the disposal of a minimum of 140 million tonnes of waste by 2030. Globally, waste production is growing more rapidly than any other environmental pollutant, and interventions in this domain could potentially diminish worldwide emissions by as much as 20%. This effort is crucial to restrict the global temperature increase to within 1.5 °C and prevent climate collapse. The Advancing Towards Zero Waste Declaration is founded on three audacious commitments: achieving a minimum 15% reduction in per person MSW production by 2030 relative to 2015; decreasing the volume of MSW sent to landfill and incineration by no less than 50% by 2030 compared to 2015; and elevating the diversion rate from landfill and incineration to a minimum of 70% by 2030 [47]. Another initiative launched in December 2018 is the Chinese government's strategy to establish ZW cities. This policy demonstrates a growing focus on transitioning from fossil fuels to sustainable energy sources, aimed at minimising China's carbon footprint, reducing waste generation, and optimising recycling, particularly through the use of various types of waste as secondary carbon feedstock for manufacturing [18]. Furthermore, the city with ZW is an exceptionally forward-thinking approach to addressing waste issues. Several cities worldwide, including Adelaide, San Francisco, and Stockholm, have announced their vision to achieving the ZW cities concept. These cities are actively striving to become the first ZW metropolises worldwide. San Francisco, a prominent city in the United States, has embraced the concept of ZW as a guiding principle for managing waste [16].

Furthermore, ZW SA is a governmental organisation in South Australia that was created by the ZW SA Act (2004) with the purpose of enhancing waste management systems and promoting a zero-waste approach in South Australia. Implementing a prohibition on shopping bags made of plastic has been a crucial measure taken in Adelaide to prevent the generation of waste [16]. Adelaide's Resource Recovery (Organics, Recycling and Waste) Strategy 2020–2028 is part of its aspiration to be the first city in Australia to attain "ZW to landfills". It establishes a redefinition of waste, enhances resource recovery, and develops a circular economy. This aligns with the government objective and is characterised by redirecting all waste from landfills where it is technologically, ecologically, and economically feasible. Adelaide has established objectives to achieve its ZW aims, commencing with the diversion of 75% of residential waste and 90% of waste from city events and activities from landfills in turn. Additionally, it aims to decrease waste creation by 5% per person and reduce the amount of food waste in residential waste containers by 50%. The city is prioritising comprehensive waste management education for all citizens, companies, and consumers. Adelaide is offering households and community members assistance by providing the services and tools needed to eradicate food waste and achieve ZW at home [48]. Moreover, the primary measures for reaching ZW targets in San Francisco include prohibiting problematic items, for example, plastic bags and excessive packaging, while advocating for solutions, for instance, recyclable or compostable take-out food containers and reusable transit packing [43]. In 2002, San Francisco established a target of diverting 75% of waste by 2010 and a long-term objective of achieving ZW. It surpassed its initial objective two years ahead of schedule, subsequently restoring over 80% of its waste and halving its disposal rate. The city implemented its Environment Code in 2003, based on the Precautionary Principle. The Mandatory Recycling and Composting Ordinance, enacted in 2009, mandates that all residents segregate recyclables, compostables, and waste. To achieve the ZW objective, San Francisco instituted a pioneering three-stream collection system for waste, featuring separate containers and a comprehensive array of size and frequency alternatives for commingled recyclables, compostables, and MSW. The city initiated the earliest and largest food waste composting program in the US by composting over two million tonnes of waste for agricultural producers. San Francisco has implemented several unique initiatives, including the Compostable or Recyclable Pre-Checkout Bag Act, food services and packaging waste reduction laws, legislation to reduce plastic litter and hazardous waste, and the Waste Separation Act. In its distinctive long-term waste policy, the city sets prices through a fee-based waste collection system. On the other hand, rate-making is complicated, time-consuming, and resource-intensive. The waste code limits competition for non-commercial waste but has successfully led to advancements in ZW initiatives. Privatisation by the Recology company eventually secured all necessary permissions. Recology builds infrastructure, collects, processes, and reports waste, while the city directs and supervises these activities [33].

In September 2019, the city of Stockholm, Sweden, pledged to substantially reduce the waste it produces and disposes of in landfills and through incineration, advancing towards a ZW goal by endorsing C40's declaration on advancing towards zero waste [47]. This aims to minimise waste production, enhance the rate of recycling, and transition to a circular economy paradigm [49]. Stockholm has enacted an extensive waste disposal policy as a component of its overarching environmental objectives. The city aspires to achieve a fossil fuel free and environmentally friendly status by 2040. This ambitious objective involves managing waste as an essential element [50]. Additionally, to achieve ZW status, the Stockholm Royal Seaport is a large-scale urban development project that serves as an experiment for environmentally friendly concepts and sustainable solutions. It encompasses advanced waste management technologies and circular resource utilisation, converting an existing industrial site into a contemporary, environmentally sustainable area, including 12,000 new residences and 35,000 employment opportunities [51]. Stockholm has achieved notable advancements in WTE generation; specifically, the city has established a substantial biomass facility that supports its fossil fuel-free future. This facility aids in waste minimisation and the production of green energy. Additionally, it has established the first urban carbon sink with biochar. This novel method not only addresses organic waste management but also aids in carbon sequestration [52].

San Jose has a diversion rate of 74%, which is among the best in the country for waste management. In the 1980s, the city implemented a waste reduction policy, initiated curb side recycling, and expanded landfill capacity. During the 1990s, the collection of loose garden trimmings from the streets enhanced diversion, while the variable cost system incentivised households to increase recycling efforts. The city implemented a ZW policy framework in 2008. In 2013, San Jose inaugurated the earliest commercial scale dry fermentation AD and in-vessel composting plant in the USA. The innovative features of San Jose's waste management system include recycling reward payments, which are graded to reward recycling efforts that exceed a 40% diversion rate. A recycling reward program was established to mitigate contractors' expenses associated with managing difficult-to-sell items, such as textiles, and to guarantee that these products were effectively sold on the market. Additionally, under the recycling agreements, the recycling companies retain all cash generated from selling of recyclables. A further innovative feature for ZW is the pay-as-you-throw system, which implements fee mechanisms that decrease service costs when less waste is disposed of. Payment for waste disposal services parallels other utilities: more use results in higher costs. Consequently, during the first year of system deployment, recyclables surged by 149% and garden trimmings by 45%. However, a downside of the ZW city concept is that the implementation of ZW innovations necessitates the management of separate agreements and complicated incentive payments, which requires additional people for the oversight and auditing of these systems [53].

4. National Policies and Legislation

In the context of Waste Management, "strategy" refers to a collection of programs aimed at minimising the ecological effects of various processes. These initiatives involve decreasing the use of energy, managing and treating waste, minimising water usage, decreasing the overall environmental footprint, and promoting a shift in social attitudes and behaviours. Additionally, the strategy involves engaging in operations associated with prevention, reduction, reuse, refurbishment, and remanufacturing, while also assessing the effects on society [54]. Several countries and provincial governments have tackled the management of waste using diverse policies and financial approaches [55]. The success and failure of such policy tools depend on a variety of factors, ranging from societal aspects to implementation strategies [56]. Plenty of nations have implemented policies and plans to enhance the management of MSW via measures such as waste reduction, recycling, energy recovery, and landfill management [57–59].

Approximately 4.75 million tonnes of MSW are produced annually in New South Wales (NSW), Australia. Of this, about 42.53% is sent to landfills, about 51.79% is recycled, and about 5.77% of the organic waste is processed using AD. In NSW, preventing waste is of the utmost importance, followed closely by recovering resources. Waste-to-energy (WTE) and recycling are two distinct methods of recovering resources; nevertheless, recycling is more preferred for material recovery than WTE. Therefore, if recycling is not feasible, WTE technologies may be used [60]. In Sao Paulo, Brazil, about 97.8% of the MSW produced is being managed via the official MSW disposal system and most of the MSW in Sao Paulo consists of mixed MSW originating from homes. Aside from the official MSW management system, recyclable goods are also collected by individual pickers and picker organisations via unofficial channels. The city's officially collected MSW is dumped of through two sanitary landfills equipped with gas capture and leachate collecting systems. Furthermore, Sao Paulo has two automatic sorting facilities dedicated to the segregation of recyclable materials, including plastic, paper, cardboard, metal, and glass [4]. A total 79.4% of MSW in Moscow, Russia, is gathered as mix waste, while the remaining 20.6% is disposed of in a co-mingled container designated for recyclable materials. Nevertheless, there is significant variation in the quality of effective waste separation by the people [61]. Germany has implemented a comprehensive waste management system that encompasses waste reduction, composting, recycling, and dumping in landfills [17,57]. Furthermore, in Germany and South Africa, manufacturers and users of packaging materials are obligated to adhere to the standards of EPR, which entails the industry taking responsibility for the recycling and recovery of packaging waste [31,56].

The prevailing type of MSW management in the Kingdom of Saudi Arabia (KSA), Riyadh is an open unsanitary landfill. This approach involves waste compression and everyday soil coverings, but lacks a bottom liner and leachate and landfill gases collection [62]. Plenty of the county landfills are approaching their maximum capacity and will reach it within a short period of time [63]. Additionally, regarding the collection of waste in the kingdom, waste is gathered from waste bins and sent to landfills, which often occurs twice daily [64]. Currently, the only technique for recycling used by unauthorised individuals is the recycling of metal and cardboard, which constitutes around 10–15% of the overall waste generation [65]. Among of the aims of KSA 2030 VISION, as stated by SAGO [66], is to achieve a 50% reduction in food waste by the year 2030. Nottingham is at the forefront of WTE and waste reduction efforts in England, UK. The East Croft Energy waste facility was constructed in the beginning of the 1970s and underwent an update in 1998 to implement the cogeneration of combined heat and power (CHP) using waste as a fuel source. The electricity and heat that have been restored are provided to the national grid and used for heating city centre buildings via a district heating system. Refuse derived fuel (RDF) is generated from a material recovery facility (MRF) in order to enhance the recovery of energy. Nottingham implemented a kerbside collection service (KCS) in 2002, which included sorting recyclable products such as paper, cardboard, cans, mixed plastics, mixed glass, and garden debris at the source; prior reservation is necessary for the pickup of large items. The city has one civic amenity (CA) site, which is also referred to as a household waste recycling centre. Additionally, there are several bring sites, also called small recycling centres, spread all over the city for the purpose of collecting recyclable materials. Furthermore, Nottingham City Council has set high goals for managing MSW by 2025 and 2030, as presented in Figure 2 [67].

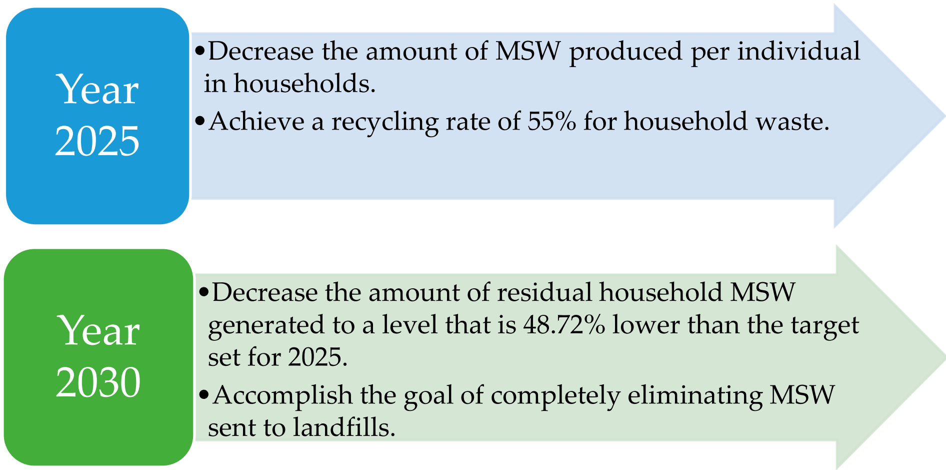


Figure 2. Goals for managing MSW by 2025 and 2030 by Nottingham City Council.

The Japan International Cooperation Agency reports that the predominant method of plastic waste disposal in Japan is incineration. Just 22% of the plastic waste collected undergoes mechanical or material recycling. The government in Japan, in 2019, implemented the Plastic Resource Circulation Strategy, which is centred on the principles of reducing, reusing, and recycling plastic waste, as well as incorporating renewable resources. The objective of this strategy is to shift towards a circular economy by effectively managing plastic waste. The Strategy outlines three specific goals: implementing fines to discourage the use of one-time-use plastic; implementing waste classification during collection and optimising resource utilisation; and advocating for the use of sustainable materials, such as paper and bioplastic, as well as exploring alternate options to plastic [68]. The central authority in China is responsible for the administration of MSW, which includes tasks such as collecting, transferring, and treatment. Municipalities and/or scavengers collect MSW, either via official or informal means. The residential cohort independently transports waste to designated collection stations, whilst the recyclables are gathered by waste collectors via door-to-door collection schemes. Private waste handlers gather the MSW produced by the industry. Recyclable substances undergo separation and are marketed as raw materials to industries. Subsequently, waste collectors carry the waste to transfer sites. Ultimately, the waste is either deposited in a landfill or incinerated [35]. The waste management in China heavily depends on sanitary landfilling and waste incineration. However, the shift from waste dumps towards waste management was facilitated by the government's many laws and supplementary initiatives. There are three guiding concepts that the policies and programmes are based on: beginning by minimising waste, then, sorting it, and then, putting it to use via energy recovery [18,34].

The waste management hierarchy begins with the primary goal of waste prevention, which is the highest priority in the waste hierarchy, and it is the topmost priority of Swedish waste legislation. Various techniques are used for waste management, including material recycling, biological treatment, energy recovery, and landfill disposal. According to the Swedish Environmental Code, each municipality has the duty to guarantee that MSW is transported and recycled or handled of in the most optimal manner. Furthermore, the EPR program has been implemented, whereby manufacturers bear the responsibility of collecting and disposing of items that have reached the end of their life cycle. Consequently, it is essential to have appropriate mechanisms for collecting and treating recyclable materials. Starting on 1 January 2024, municipalities will have the duty of collecting packaging waste, while manufacturers will retain the responsibility of recycling it. Households are tasked with the responsibility of segregating and disposing of waste at designated collection stations. Additionally, the Swedish government has decided to implement a system for collecting and recycling textile wastes starting from first of January 2025. The responsibility for collecting this waste will still lie with the municipalities [69].

Africa, as the world's second most populated continent, exhibits the most rapid growth rate in world population. Many African nations continue to be afflicted by poverty, inadequate hygienic conditions, and limited resources, including inefficient waste treatment systems [70]. As in several African nations, landfilling continued to be the primary approach for managing of MSW in Algeria. However, none of the landfill in the country are used for energy generation. Presently, Algeria has a total of 221 landfills, out of which 112 have facilities with technology and 109 are under monitoring. The technologically advanced landfills are equipped with isolating equipment and are specifically designed to manage waste, while the regulated ones lack such technology. Regrettably, neither of these dumps is utilised for energy generation, which signifies a noteworthy, squandered chance. In order to tackle the problem of waste, Algeria has established a separate administrative body called the "Directorate for Environmental Protection". A map illustrating the geographical distribution of waste produced in 2020 is generated to obtain a deeper comprehension of how residential and comparable waste is distributed throughout different provinces [71]. The frequent practice of disposing waste without discrimination along main roads at temporary dumping sites is a common occurrence in Nigerian towns. MSW is often scattered around the country, including along roadways, drainage lines, and open fields. Moreover, the issue of waste disposal persists and has led to the pollution of rivers in the country, particularly in Port Harcourt, the country's oil metropolis. This pollution has had a detrimental impact on the local population, causing significant issues. In fact, Port Harcourt, once a popular destination for tourists, is now recognised to be among of the 15 polluted towns worldwide. Nigeria, as well as many lower and middle-income nations, produces a very small amount of waste. However, it struggles to efficiently handle it owing to inadequate environmental management procedures. The collection of MSW is mostly carried out by the government, sometimes in collaboration with private businesses; approximately 47% of MSW is manually collected by authorities from designated waste receptacles and transported to open landfills. As a result, 53% of the waste produced ends up in illicit dumpsites and open spaces [72]. A summary of the global national waste policies and legislation are shown in Table 2.

Table 2. Summary of worldwide national policies and legislation.

Country (National/Local)	Policies and Legislation				Environmental Strategies	Since Year	Ref.
	Waste Separation	Landfill	WET	Recycle			
Australia [Local (New South Wales)]	×	√	×	×	All MSW is dumped in landfills.	2021	[60]
Brazil [Local (Sao Paulo)]	√	√	×	√	Within the city, there are two MRFs. Merely a small fraction of MSW undergoes treatment at these facilities, while the overwhelming bulk of MSW is dumped in landfills.	2018	[4]
Russia [Local (Moscow)]	√	√	√	√	Implementing a green and circular economy.	2021	[61,73]
Germany [National]	√	√	√	√	Implementing an EPR programme.	2021	[17,57]
South Africa [National]	×	√	√	√	Planning to implement an EPR programme.	2017	[31]
Saudi Arabia [National]	×	√	×	×	Nowadays, open unsanitary landfills. Government set plans to implement green strategies.	2022	[9,62,66,74]
United Kingdom [Local (Nottingham)]	√	√	√	√	Aiming to increase recycling rate and zero households MSW sent to landfills by 2030. [35]	2020	[67]
Japan [National]	√	√	√	√	Implementation of the 3Rs concept and aiming to increase plastic recycling to reach 60% in 2030.	2022	[38,68]
China [National]	√	√	√	√	ZW city policies were put into place by the government in 2018 and the 3Rs concept was implemented.	2022	[18,34,35]
Sweden [National]	√	√	√	√	Implementation of waste hierarchy, EPR programme, and circular economy.	2023	[70]
Singapore [National]	√	√	√	√	Implementation of the 3Rs concept and ZW masterplan.	2023	[46,75]
Algeria [National]	×	√	×	×	Mainly depends on landfills; half of these facilities have technology and others are under monitoring.	2024	[71]
Nigeria [National]	×	√	×	×	Dumping the MSW in open landfill and open spaces.	2018	[72]

5. Strategic Approaches to Waste Minimisation

MSW management can be approached in several ways, depending on the specific demands and GDP of the country. Public knowledge and the implementation of waste avoidance tactics are more prevalent in economically advanced countries, whereas underdeveloped countries rely on low-tech solutions due to a greater focus on immediate rewards or survival [57]. European countries have significantly reduced the amount of waste being disposed of in landfills, opting instead to recycle and repurpose resources for energy production [57]. The Waste Framework Directive, implemented by the EU, establishes a hierarchy for waste management processes. These stages include waste prevention, preparation for reuse, recycling, alternative forms of recovery, and finally, disposal [76]. Furthermore, the EU has set a target to recycle a least 65% of MSW and limit the amount sent to landfills to no more than 10% by the year 2030 [59]. Becoming a resource-efficient area represents one of the primary goals of the "Vision Stockholm 2030" project. In terms of regulations and laws pertaining to waste management systems, Stockholm is highly regarded. A major waste management policy is the prohibition of landfilling organic and combustible waste [16]. The word "fulplast" was introduced in Sweden to designate non-recyclable plastic as part of the "Stop non-recyclable plastic" (Stoppa fulplasten) program. The campaign's objective is to reduce the amount of plastic waste and encourage businesses to use recyclable polymers in their products [70].

Germany is striving to achieve a circular economy that preserves resources and reduces environmental consequences by maximising the effective use of raw materials, improving recycling rates, and eliminating any remaining waste that cannot be recovered. Thus, in recent decades, Germany has emerged as a global exemplar of circular economy and best practices MSW management [56]. The use of environmental levies, such as taxes for disposal of waste and the deposit refund system (DRS), to influence the individual behaviour is commonplace [77]. Waste producers may be enticed and motivated to minimise their waste generation through recycling as a result of the incentives provided by disposal fees [56]. According to Huang et al. [78], an effective waste disposal tax would require polluters to fully compensate for the harm they cause to the ecosystem. [17] In the US, initiatives aimed at reducing, reusing, and recycling MSW are classified as types of diversion. This is because they redirect waste that would otherwise be sent to landfills and incinerators. This practice helps preserve landfill capacity and mitigate the environmental consequences of waste disposal, and it has the potential to lower overall waste management expenses, particularly when diverting waste is more cost-effective than disposing of it. The disposal methods consist of incineration, both with and without energy recovery, as well as landfilling. Incineration is a process that decreases the amount of waste by transforming it into gas and ash. The ash must be discarded in approved landfills, or treated as hazardous waste, while gases produced are regulated for emissions under the Clean Air Act. Landfilling involves burying MSW in trenches that are lined, compacted, and covered daily using soil. Additionally, leachate is treated and landfill gas is collected during this process [3]. Leachate is generated when precipitation permeates through waste deposited in a landfill. Once this fluid contacts the dumped waste, it leaches chemicals or components from the waste. Consequently, in the USA, the specification for composite liners includes a flexible membrane covering several feet of compacted soil in the landfill. Leachate capture and elimination devices are positioned above the liner to extract, process, and remove it [79].

To tackle waste problems in China, the government has implemented a range of policies and measures to transition from waste dumping to effective waste management. The policies and initiatives are centred on three main principles: reducing waste, waste separation, and waste utilising through energy recovery [18]. By initiating a program for the sorting of waste, this initiative sought to provide a model for waste separation. The strategy included enhancing citizen awareness of waste categorisation, augmenting investment in MSW treatment plants, and optimising the structure for collection, transportation, and waste treatment [80]. Additionally, by implementing many advantageous measures to promote energy recovery from waste in the WTE business. These involve prioritised commercial bank loans, reduced interest rates, guaranteed subsidised pricing for power procurement, carbon funding, and no or low taxation on income [81].

Singapore's adopted MSW management strategy prioritises two main objectives: waste reduction and recycling, also known as the 3Rs (reduce, reuse, and recycle). Incinerator facilities are the most effective technological option in Singapore, where land is limited. They effectively reduce the size of MSW, helping to save landfill space. The 3Rs, which are reduce, reuse, and recycle, are essential in avoiding the creation of waste and offer several advantages. The objective is to transform Singapore's transformation into a ZW country by decreasing waste production and effectively repurposing and recycling all resources to extend their usefulness [75]. Additionally, the Japanese government has designated October as the month to promote the 3Rs initiative, with the aim of increasing awareness and collaboration among consumers and businesses in implementing these initiatives [38]. The KSA 2030 Vision seeks to achieve a 50% reduction in food waste by the year 2030 [66]. Furthermore, the Kingdom future waste management goals include increasing recycling rates to 23% and using 11% of waste for electricity generation [74]. The waste management strategy in Riyadh aligns with the "Riyadh Without Containers" campaign by providing containers for residential units to sort waste at the point of origin. These containers are then collected at a designated time, leading to the elimination of existing street containers [9].

The implementation of ZW requires companies and communities to adhere to specific standards, including the complete eradication of or significant decrease in waste production and the suppression of incineration and disposal in sanitary landfills. Ensuring the proper handling of hazardous wastes requires strategic planning from both political and commercial stakeholders; along with fostering creativity and investments in redesigning goods to prevent toxicity and promote genuinely environmentally friendly goods. Additionally, the imposition of high taxes on the treatment of MSW in local landfills would incentivise the redirection of this waste to more distant landfills [82].

6. Case Studies of Successful Waste Reduction Programs

Several countries have implemented policy and strategy reforms to improve the management of MSW. As a result, there are several nations have made significant progress and have been successful in managing the waste. Sweden is among the top performers worldwide in terms of waste management. The country has implemented a waste management policy based on the circular economy, where waste is considered a valuable resource. This approach ensures that waste is either recycled or used to produce electricity. Sweden's waste management system is highly effective, with over 99% of MSW being recycled or used for electricity generation [83]. Furthermore, Avfall Sverige states that Sweden's waste management objective is to achieve a minimum 25% reduction in the combined quantity of food and residual waste per capita (relative to 2015) by 2025. In Sweden, the adoption of the waste hierarchy resulted in a 4% reduction in household waste in 2023, as compared to the previous year. Significantly, the quantity of food and leftover waste fell by 2% [70].

The intricate nature of the MSW disposal in Germany has led to the formulation of groundbreaking legislation as the nation embraced a sustainable production and consumption model to address its MSW issue [56]. To efficiently mitigate environmental contamination caused by waste, specialists suggested implementing a prohibition on the disposal of untreated MSW in landfills, and instead, encouraging the adoption of specific treatment and recycling rates. Consequently, the number of dump sites in Germany significantly declined, dropping from 65 thousand in 1970 to 1100 in 2015. Similarly, the process of extracting energy from waste via WTE facilities flourished [18]. It is now illegal to dispose of untreated business and residential waste in landfills in Germany. Approximately 14% of the raw materials utilised by German industry are derived from recycled waste. This practice effectively reduces the need for excavation and, in turn, minimises the associated impact of the environment. Modern closed cycle management plays a significant role, accounting for about 20%, in helping Germany meet its Kyoto targets for reducing emissions that contribute to climate change. The management of waste sector in Germany has grown significantly and is now a prominent and influential industry. It employs almost 200,000 people across around 3000 enterprises, generating a yearly profit of approximately

EUR 40 billion. About 15,000 installations enhance environmental sustainability via recovery and recycling techniques. The recycling rates for different types of waste are over 60% for MSW, 60% for commercial waste, and a remarkable 90% for building and demolition debris [17].

The objective of the Singapore Green Plan is to increase the recycling rate for all types of waste to 70% by 2030 while simultaneously reducing the need for further incineration facilities [84]. In Singapore, the 3Rs (reduce, reuse, and recycle) concept is utilised. Recyclables are separated and recovered at the point where waste is created, in order to save resources. The rest waste is collected and burned in incineration facilities. Using incineration, landfill space may be saved by up to 90% of waste. The heat produced is used to create steam, which powers turbine generators that supply up to 3% of the island's electrical demands. Subsequently, the ash resulting from incineration and other types of waste that cannot be incinerated is transferred to the landfill for ultimate disposal [75]. South Korea is notable for its emphasis on food waste recycling via public legislation, resulting in a recycling food waste rate of 95% [85]. Furthermore, South Korea has implemented effective laws for MSW, such as a pay-as-you-throw system, resulting in a significant reduction in the amount of waste generated. [86]. There is legislation that prioritises the recovery of waste above its disposal in Portugal [57]. The Japanese government has implemented a waste management system that integrates waste reduction, recycling, and reutilisation [87]. Japan is placed second in the Plastics Management Index (PMI), a measure used to compare nations' performances in managing plastic waste from different perspectives. This ranking places Japan right behind Germany out of a total of 25 countries. Furthermore, Japan ranks as one of the leading nations globally in terms of PET bottle management, with an impressive recycling rate of 85.8% [68]. In addition, the Gulf Cooperation Council (GCC) has achieved substantial advancements in this field. For instance, the United Arab Emirates (UAE) has a highly advanced approach to managing MSW. The UAE has allocated funding to recycling and WTE initiatives in order to achieve a 75% reduction in landfill disposal [88].

7. Challenges and Barriers to Zero Waste

In recent years, ZW has been gaining considerable momentum as governments worldwide aim to adopt more sustainable waste management practices. The concept, which can be comprehensively described as the elimination of waste production and the maximisation of resource recovery, offers a persuasive picture for a future in which nothing is wasted. Nevertheless, the journey towards achieving ZW is fraught with difficulties, challenges, and barriers [82]. Additionally, the practical realisation of ZW may be unattainable in reality [89]. The challenges in implementing ZW include perceptions of exorbitant expenses, initial costs, and limited funding resources, coupled with the intricacy of its execution and the insufficient expertise among the specialists engaged. Additionally, controlling waste in industry is challenging because recycling will only occur if it yields a direct economic benefit [82]. Furthermore, the financial payback provided by recycling frequently proves inadequate to offset the expenses, resulting in reduced participation. Absent strong legislative frameworks that provide incentives for waste avoidance and resource recovery, the shift to ZW continues to be difficult [90]. In addition to the direct monetary expenses, there are also implicit 'hidden' costs, including the time and human resources that enterprises must allocate to implement environmental enhancements [91]. Indeed, the actual achievement of ZW may be unattainable in real life. Firstly, products are subject to the constraints of thermodynamics, which govern that completely closed cycles are unattainable. If energy supplies are finite, losses are inevitable. Furthermore, a fully integrated recycling society would inherently imply that every product we consume incorporates recycled materials [92].

Another challenge is defining the involvement of the stakeholders in order to establish a truly sustainable network of suppliers and a circular economy to reach ZW. Additionally, there is a demand for allocating resources towards the advancing research endeavours aimed at enhancing waste management technology, along with its widespread distribution.

Technical limitations provide a significant obstacle to the widespread implementation of ZW initiatives in many areas, nations, and market sectors. The finite number of times that any recyclable product may be recycled is a challenge, and fully recycling materials demands a thorough understanding of the product life cycle. It is essential to emphasise that altering the consuming habits and behaviour of consumers provides significant challenges for addressing environmental issues [82]. A further challenge with utilising waste as a raw material for new procedures is that waste composition tend to be very heterogeneous, including mixed materials, pollutants, and different quality levels. This inconsistency hinders the conversion of waste into good quality raw materials for new goods. Contamination is a significant challenge in the recovery of plastics, electronics, etc., since it may include the presence of deleterious elements such as heavy metals or dangerous compounds. An additional technical obstacle is that MRFs encounter various operational difficulties including the identification of recyclable materials, the separation of materials, the assurance of purity to prevent contamination that may diminish the value of recovered materials, and the establishment or transportation to markets capable of purchasing recovered materials. Barriers often escalate when items are more complex or resilient in design and manufacturing, use various materials, especially, hazardous materials, or comprise components that are closely integrated [93]. Substantial challenges exist regarding the recovery of even the most frequently recycled materials, including food packaging and cardboard. Such objects are classified as non-durable goods [94]. Numerous problems hinder the efficient recycling of plastic food packaging, including inadequate collection ratios. The absence of standardisation in permitted recycling products results in poor diversion rates, since municipalities have varying criteria for plastic recycling, with many municipalities excluding food packaging made from lower grade plastics [93]. The diminished quality post-recycling constrains the material's capacity to effectively navigate the circular economy [95].

The expense is an additional limitation to using plastic food packaging as raw material, since elevated levels of contamination have contributed to rising total prices. Contamination, encompassing non-recyclable items and food waste, leads to elevated labour expenses for collection, sorting, and disposal [93]. The variety of plastic food packaging presents challenges for the recycling industry, which must develop new methods for sorting and processing these items, and for customers, who consider it challenging to adapt to evolving package types and recycling requirements [96]. A significant obstacle is the absence of uniform norms and standards for the use of waste-derived resources. Companies employing waste as a raw resource encounter rigorous regulatory oversight, especially in businesses where health and safety are critical. The lack of standardisation for recycled items results in ambiguities over product quality, thereby dissuading producers from using waste resources. Managing numerous materials presents significant challenges, particularly with complicated consumer products, including huge and intricate items, for example, electronics and cars [93]. Complex products, such as smartphones, include distinct qualities that may hinder recycling; there are practical limitations regarding what can be efficiently recovered, recycled, and reused [97]. Among the hardest items to recycle from tires are textiles, owing to contaminated and poor value; they may also pose a risk in recycling processes as dust and fibres accumulate on equipment [98].

The impression of consumers is vital to the marketability of items derived from waste. Recycled items may be seen as inferior in quality or less appealing than those manufactured from raw resources. This may restrict customer appetite for such items, even in markets that are generally predisposed to endorse sustainable methods [99]. Moreover, various societal trends, such as increased income and buying power among the populace, as well as family sizes, contribute to decreased public engagement in waste reduction efforts. Therefore, it is essential to foster continuous and effective communication and education. Additionally, it requires time for people and society to acclimatise to new strategies [82]. Moreover, applying fees on waste generation to minimise the waste can be challenging; the applying of financial tools to a few waste streams, such as waste created in public spaces, is challenging due to the inability to accurately determine appropriate charges [56]. The combination of a dense population, limited resources, and inadequate infrastructure, as seen in countries like in India, presents a significant challenge for managing MSW [100]. Additionally, a ZW challenge is seen in the MSW system's efforts to promote reduced consumption, more diversion, and the adoption of practices such as repair, reuse, and environmentally friendly shopping [16].

8. Future Directions and Recommendations

Governments may use various legal initiatives to encourage waste management practices that will reduce GHG emissions. Approaches that are either practical or universally applicable in many cities include promoting community awareness. Additionally, consumers may be motivated to reduce waste and increase recycling by implementing a tax on products, which would be an additional charge added to the product cost and directly linked to the expenses of the waste management system. Furthermore, advertising the products made from recycled components and utilising waste as a fertiliser can also be effective strategies [6]. It is imperative to allocate resources towards improving environmental management practices and implementing a circular economy. This is because the linear economic approach is inadequate in the long run as it accelerates resources depletion and prevents the reuse of recyclable materials in subsequent phases of production. Hence, it is essential to revamp the life cycles of products in order to alleviate their environmental consequences. This necessitates the development of goods design that strongly prioritises the reduction of waste creation and the merging of waste that cannot be prevented into new manufacturing processes [82]. In order to guarantee the effective management of waste, most municipalities' facilities depend on a comprehensive system that is both environmentally friendly and widely supported by the community. However, adequate finance, infrastructures, and technologies are crucial elements of an effective waste management system [101].

9. Conclusions

The current review paper emphasises the urgent need to transcend traditional waste management methods and progress towards a ZW initiative future. It highlights the importance of shifting from a linear economy, which is primarily relies on dumping MSW in landfills, to a circular economy that views waste as a valuable resource to be recycled and repurposed. Through an examination of successful ZW programs in countries such as Germany, Sweden, and Japan, this paper demonstrates the efficacy of policies and technologies in minimising waste generation, conserving resources, and mitigating environmental impacts. The aforementioned countries have implemented extensive frameworks that prioritise recycling, energy recovery, and EPR, offering clear examples for other countries to follow. Despite the advancements of these programs, the paper also highlighting the persistent obstacles in achieving worldwide ZW objectives. Financial limitations, technological challenges, and low public participation continue to be significant barriers for contemporary waste management systems in developing countries, leading to an over reliance on landfills and presenting substantial environmental and health risks. Additionally, the cultural perspectives on waste, especially in countries with limited awareness of sustainability, pose challenges in achieving widespread transformation.

In order to tackle these difficulties, the study points out the need for governments to promote change through legislation, financial incentives, and public education. The implementation of policies that incentivise recycling, impose taxes on wasteful activities, and foster producer accountability may effectively induce the necessary behaviour changes in among both consumers and businesses. Moreover, it is crucial to allocate additional investment towards technical advancements, particularly in WTE and sophisticated recycling methods, to successfully achieve ZW objectives and optimise the recovery of resources. To summarise, the transition to ZW is necessary and achievable through the implementation of appropriate policies, fostering innovation, and encouraging public participation. However complicated the process might seem, the examples of prominent nations demonstrate that substantial advancements can be achieved when a well-defined goal is supported by strong processes and active societal participation. The global implementation of ZW policies would not only contribute to the conservation of natural resources but also substantially mitigate environmental deterioration, thereby ensuring a more sustainable future for next generations.

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