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Review

Review on Waste-to-Energy Approaches toward a Circular Economy in Developed and Developing Countries

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Abstract: International interest in using waste-to-energy (WtE) technology toward a circular economy (CE) is developing, spurred by environmental challenges such as inefficient solid waste dumping, pollution, and resource depletion. Incineration, pyrolysis, gasification, landfill, and anaerobic digestion are standard WtE technologies. Although these methods have been used for many decades, all countries try to implement the best plans based on their technologies and capacities. Therefore, an up-to-date comprehensive study is needed to evaluate the existing barriers to draw a logical roadmap for WtE to CE. Therefore, this review addresses the recent policies adopted by developed and developing countries for WtE technologies. Based on the findings, most countries seek the most cost-effective and environmentally sustainable pathways in WtE to CE; meanwhile, international collaboration and governmental support are needed to overcome the existing barriers and find a sustainable and economically viable plan for both developed and developing countries in the future.

Keywords: waste-to-energy; circular economy; solid waste management; developed and developing countries; policies and regulations

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1. Introduction

In recent decades, expanding populations, changing consumer preferences, and the introduction of new manufacturing methods have all contributed to significant growth in worldwide solid waste. More specifically, in a business-as-usual scenario, municipal solid waste (MSW) generation is predicted to rise from 2.01 billion tons in 2016 to 3.40 billion tons by 2050 [1]. However, according to the International Solid Waste Association (ISWA), more than 4 billion tons of MSW are generated worldwide annually. According to Iyamu et al., in 2020, only 19% of this MSW is recyclable or processed for mechanical and biological treatment, while the remaining 70% is disposed of in dumpsites and sanitary landfills. This tendency will continue as the demand for fossil fuels rises [1]. In response to resource depletion and the detrimental effects of using nonrenewable energy sources, which has contributed to climate change, the energy sector has shifted its focus from conventional fuels to renewable energy [2]. Waste management (WM), specifically solid waste management (SWM) and municipal solid waste management (MSWM), is a critical component of a circular economy (CE), which requires us to reduce waste and to maximize resource use by expanding and contracting material cycles and tracking waste input and output to create economic flow inventories [3].

Waste segregation is the initial step in WM, separating different waste materials at the source for proper disposal, recycling, and resource recovery. It has several advantages, such as reducing WM costs and negative environmental impacts, and resource conservation [4]. Different countries, especially developed ones, started a waste segregation system many years ago. They have advanced WM infrastructure, including well-established collection systems, recycling facilities, and WtE plants. These systems need highly technical facilities, while restricted regulation and increased public awareness are needed to implement a successful WM system. In addition, WM systems can help to reach a CE by reducing pollution impact, generating job opportunities, and increasing resource recovery [5,6].

CE processes impact the environment, energy, natural resources, hazardous waste, and land use. For instance, a CE plan can improve environmental quality by lowering air and water pollution, consuming fewer fossil fuels and other natural resources, and safely disposing of hazardous items. We can reduce nonrenewable resources in food production, boost the use of externally reused resources, and recycle more of our trash by using CE methods [7]. Reducing waste and using waste-to-energy (WtE) technologies has resulted in a CE in developed and developing countries [8]. Figure 1 displays potential sources of solid waste based on their type and origin in the environment [9].

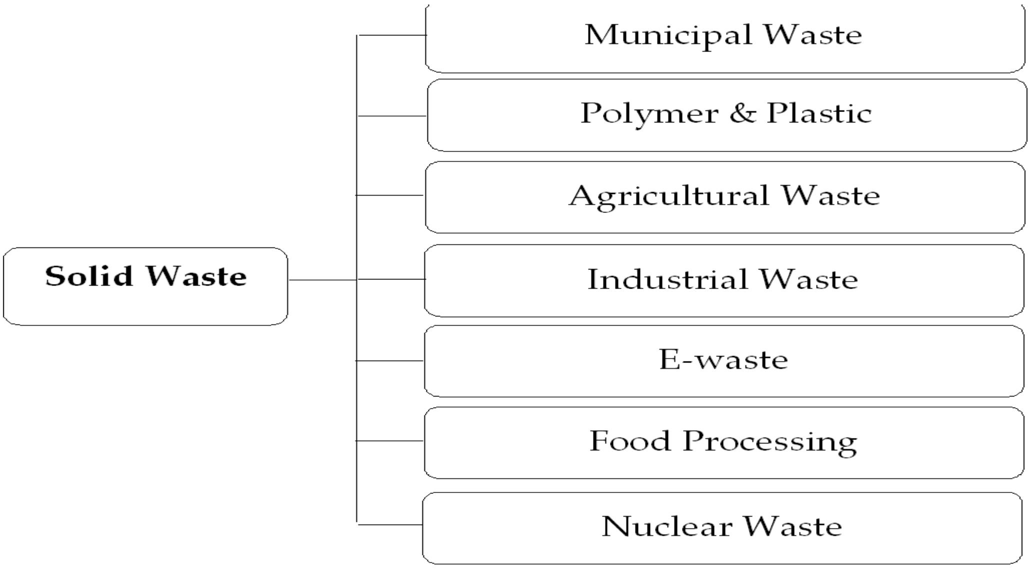

Figure 1. Different sources of solid waste.

Social and economic environment, weather conditions, recycling rates, collection frequencies, demographics, and other factors impact the composition and quality of MSW. According to a previous study, the MSW stream was divided into six categories based on physical characteristics. These categories include food and yard waste, paper and cardboard, plastic, metals and glass, inert, and miscellaneous [10]. Using WtE technology in MSWM can provide a long-term solution toward a CE by reducing the environmental implications of GHG emissions and increasing recycling or energy recovery rates if implemented wisely [11]. On the other hand, WtE is based on real-world scenarios, incorporating various components that need to be thoroughly studied through environmental impact assessments [2]. Figure 2 depicts the wide-ranging negative effects of municipal garbage on ecosystems and human health.

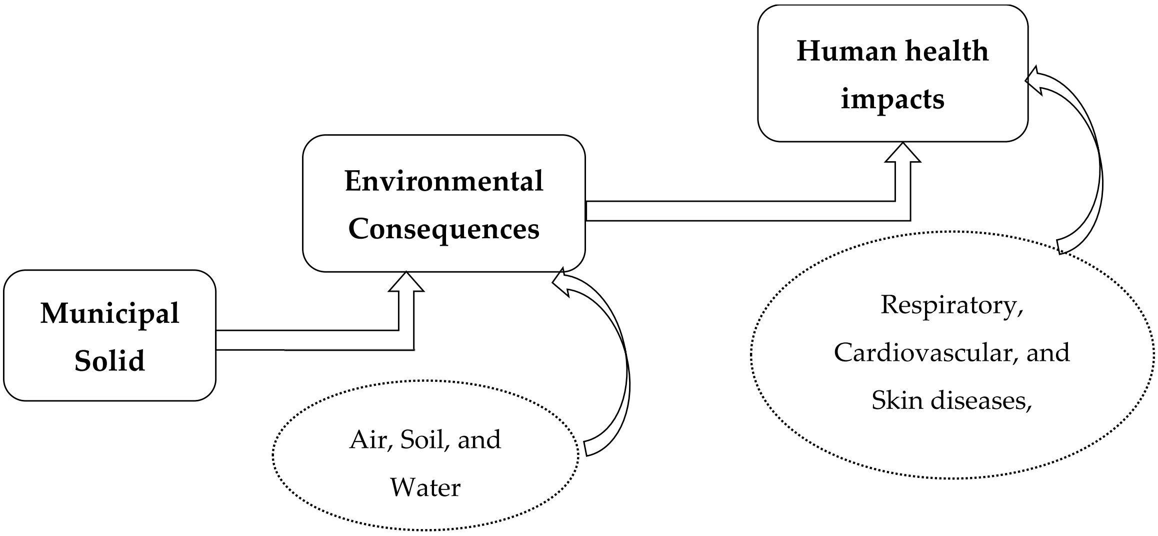

Figure 2. Environmental and health impacts of solid municipal waste.

The fate of poorly managed solid waste on the countries' economy, society, health, and environment has been increasing since the start of COVID-19. In addition, these effects are only projected to worsen due to a substantial shift in the form and volume of trash created in the future. As a result, extensive, long-term adaptation of relevant WtE technologies in developing countries necessitates additional research and a better understanding of WtE. [12]. Countries must enforce strict standards to prevent virus transmission through solid waste generated by self-isolated patients, households, and hospitals [13] because the pandemic has impacted waste disposal and collection. As previously noted, open dumping was a severe issue in underdeveloped countries during and after the COVID-19 pandemic [12].

Thus, this review focuses on the implementation of WtE toward a CE in developed and developing countries during the COVID and post-COVID periods. Although several review papers have been published in recent years (e.g., [14,15]), it is critical to review recent advances on WtE toward a CE to draw a roadmap for future studies.

The remainder of this study is organized as follows: Section 2 covers WtE technologies. Section 3 discusses CEs. Section 4 describes how WtE is implemented toward a CE in developed and developing countries. Section 5 includes CEs' suggestion and plan for using WtE. Section 6 concludes the investigation with a conclusion and future directions.

2. Waste-to-Energy Technologies

WtE technologies can recover useable heat, electricity (by forcing gas or steam via a turbine), or fuel from waste materials [16]. These technologies are the best chance to start using sustainable energy sources. The usage of fossil fuels, which emit GHGs that contribute to global warming and climate change [17], can be reduced using these cutting-edge technologies that create significant volumes of heat and energy from waste [18].

These technologies' economic and environmental benefits can also benefit society. As a result, more money must be invested in management activities and instruments, and the system's coverage area must expand in tandem with the population. Combustion, anaerobic digestion, and landfilling are the most effective treatment procedures and final disposal methods. However, due to the economic and environmental benefits, WM practices such as trash minimization, reuse, recycling, and composting are common in most countries [19]. Figure 3 illustrates the most used WtE technologies.

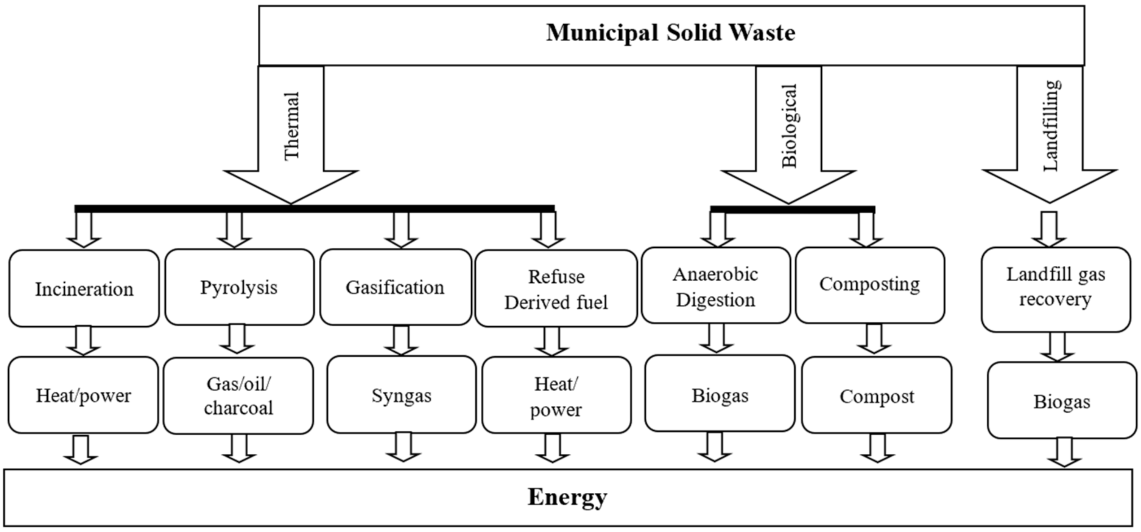

Figure 3. WtE technologies to convert solid waste into energy.

2.1. Incineration

Incineration is the most widely used waste treatment technology since it can reduce waste mass and volume by 70% and 90%, respectively, while providing heat and power [10]. Organic municipal solid waste (OFMSW) can be burned to recover thermal and electrical energy. It cannot, however, recycle waste nutrients such as nitrogen and phosphorus. Phosphorus is typically not recycled from ash, although nitrogen may be discharged into the environment during incineration via nitrogen oxides [20]. According to Baean et al., energy recovery from waste incineration is critical to an environmentally sustainable WM approach [21].

2.2. Pyrolysis and Gasification

Pyrolysis, a specialized thermal treatment procedure, involves disintegrating MSW at temperatures ranging from 300 to 1000 °C in an oxygen-free atmosphere. Byproducts of this process include syngas, bio-oil, and char [22]. Product quality and yield are affected by the waste feedstock composition and particle size of the pyrolysis byproducts, the pyrolysis temperature and heating rate, and the time the byproducts remain in the reactor [11]. Higher reaction temperatures promote volatile cracking, dehydration, decarboxylation reactions, and secondary biochar degradation, which reduces bio-oil and biochar yields [23,24]. Gasification involves cooking MSW in a controlled atmosphere with oxygen, steam, and air at temperatures ranging from 500 to 900 °C [25].

Forest biomass, agricultural waste, plastics, and tires are just a few kinds of trash that can be gasified or pyrolyzed to recover energy [10]. These strategies can reduce pollutants, greenhouse gas emissions, and energy waste more effectively than incinerators [26–30]. Pyrolysis, gasification, and incineration are all thermal treatment technologies that can significantly reduce waste volume and recover energy. If the first drying process is not performed correctly, it wastes a lot of energy [25]. Higher conversion efficiency, the zero-waste concept, shorter resistance times, improved economic performance, and compatibility with a diverse range of feedstocks (wet and dry) have all contributed to an interest in using thermochemical conversion processes in recent decades [31].

2.3. Landfilling

Despite being the simplest disposal strategy in the MSW management hierarchy, landfilling MSW is the least favored option for long-term sustainability. Due to a scarcity of suitable land in some areas, sanitary landfilling in densely populated areas can be challenging [32]. As a result, waste minimization is continually sought as a preventative strategy, with waste valorization rather than landfilling as a follow-up. However, landfilling may become more appealing when combined with biogas extraction and adequate leachate treatment procedures [31]. Landfills are ecological reactors because waste undergoes physical, chemical, and biological transformations [33]. During the decomposition of such solid waste in a landfill, a wide range of other materials will be generated, including several organic alcohols, simple sugars acids, and aldehydes (containing dissolved, non-dissolved, and suspended materials). Therefore, the generations of leachates from these wastes are caused by precipitation percolating and waste deposits [34].

Shih et al. compared incineration with heat recovery-based electricity production and landfilling with biogas recovery for electricity production, and found that the landfill was the best option due to energy usage and resource recovery [35].

Unsanitary landfills have much bigger environmental impacts than sanitary landfills [36]. Note that landfilling has a substantially greater net impact than incineration (372% higher), and gasification/pyrolysis (166% higher) is vital. Landfilling lowered greenhouse gas emissions less than incineration or the combination of gasification and pyrolysis [37].

2.4. Anaerobic Digestion or Bio Methanation

Anaerobic digestion (AD) is one of the most efficient and environmentally beneficial waste treatment technologies. In this technology, microorganisms degrade biodegradable materials without oxygen to produce biogas [2]. AD is one of the most powerful renewable energy sources since digestion produces methane [38]. AD is responsible for energy recovery into biogas and nutrient recovery from digestate, which can be used for soil amendment [39]. This technology could improve the efficiency of existing WtE systems, such as incineration, by diverting OFMSW with a high moisture content and low calorific values from burning [40]. Hybrid technologies have recently been developed, combining AD with other WtE processes, such as gasification [41]. AD can convert organic waste, such as food scraps, into biogas. In contrast, gasification may convert less digestible organic waste, such as wood scraps and crop residues, into syngas, proving the efficiency of a WtE system. This strategy would be more sustainable and efficient for cities, preventing much organic waste from being disposed of in landfills [38].

2.5. Composting

When solid organic waste is composted, enzymes produced by microorganisms and other microscopic animals, such as worms and insects, break it down into carbon dioxide and water. This procedure produces compost (or hummus) that is used in agriculture [42]. Composting was determined to have the lowest acidification potential among anaerobic digestion, incineration, and landfills, with biogas recovery [35] and the second-lowest eutrophication potential after landfills, including energy recovery. In terms of global warming potential and ozone depletion, reducing greenhouse gas emissions has the opposite effect on the environment. Multiple studies revealed the same pattern when assessing the impacts of home composting followed by landfill disposal on global warming potential and environmental pollution levels [43].

3. Circular Economy

Preston [44] defines a CE as a sustainable paradigm that prioritizes environmental preservation, resource conservation, and economic growth promotion. To be sustainable, an economic system should imitate natural ecosystems regarding material and energy fluxes [45]. A CE can control industrial waste by reusing and upcycling it into new, more eco-friendly commodities using effective and inexpensive ways [46]. Supply chains are strengthened, resource price volatility is decreased, consumer connections are improved, and new job opportunities are created, benefiting businesses and society [47,48]. For instance, a recycling company tries to maximize profits by lowering the money it spends on purchasing and processing recyclable rubbish compared to the amount it receives from selling newly made commodities [49]. A CE's three tenets are maximizing resources, decreasing behaviors that lead to environmental degradation, and enlarging the economic loop [50]. As a result, a CE strives to improve the stability and harmony of the economy, the environment, and society by encouraging the adoption of closed-loop production patterns within an economic system. It is achieved by focusing on municipal and industrial waste [51].

4. Implementing WtE toward CE in Different Countries

Governments around the world have adopted top-down and bottom-up measures to speed the arrival of a CE. There is now a universal consensus in many countries that a CE is required. As a result of the importance of CE development in reforming the industrial structure and economic growth, nurturing ecological civilization, and supporting long-term progress, many governments have accepted it as a policy. In the early 1990s, industrialized countries began to regard CE adoption as a tool to achieve long-term development strategies [51–53]. Bottom-up methods for environmental and waste management are at the heart of CE policy in the European Union (EU), Japan, and the United States. Simultaneously, China has called for a top-down national policy [51]. Ogumakinde analyzed the evolution of CEs in predecessor countries like Germany, China, and Japan. The researchers determined that these countries utilized a top-down approach for CE implementation. Policy and legislative frameworks that permit a CE and cooperation and support from all relevant stakeholders, particularly consumers, are critical to its successful implementation [54]. The bio-economy, mineral extraction and mining, urban WM and recycling, and urban WM and recycling are the five businesses most responsible for contributing to CEs in developing countries in Africa, the Pacific Islands, and Southeast Asia [55].

Although determining the level of CE development takes time and work, CE is critical for economic progress. As a result, researchers and politicians have moved their attention to CE programs, such as concept analysis and selection. This section outlines the WtE movement toward a CE, which has recently been implemented in several developed and developing countries worldwide.

4.1. Developing Countries

4.1.1. China

In China, top-down planning resulted in a CE, implying a hierarchical authority system extending from the central government to the citizenry [51]. China has prioritized CE development by situating its roots and current efforts at multiple levels [56]. Research has been undertaken to explore the potential implications of changes in solid waste legislation on CEs [57,58], and the steps that need to be taken to encourage long-term CE development in China have been highlighted [59]. Non-parametric approaches have also been widely employed to investigate MSW collection service performance [60]. Moreover, China has invested in a sustainable WM system as its population and urbanization have grown over the last four decades. To reduce negative environmental and public health implications, efforts are being made to integrate the recycling process digitally. Policymakers must plan the correct system only if the CE models' environmental friendliness and economic feasibility are considered [61].

4.1.2. India

India is also aiming to transition its economy to a CE-based one. Because it relied on natural resources, India's GDP has been demonstrated to be proportional to its population. They follow Singapore's efficient strategies, integrating sustainability principles with corporate models and legal frameworks to produce direct economic gain.

Thus, effective governance with strong legislative frameworks provided the impetus for a CE-compliant economy in India [62]. Furthermore, the Ministry of Environment, Forestry, and Climate Change suggested rules in 2015 under the heading "Management and Transboundary Movement," and indicators for recycling and waste energy recovery were developed. They presented the following rules: (1) identify locations for long-term storage, treatment; (2) disposal of hazardous wastes from a variety of sources; (3) waste co-processing should be prioritized for energy recovery over disposal; (4) the implementation of environmentally friendly Standard Operating Procedures for WM; and (5) hazardous waste imports from other countries should be permitted for recycling, recovery, and reuse [63]. These measures include WM training and capacity building for the informal sector, consumer procurement of items based on environmental impact, and reconceptualization of the eco-labeling scheme to be more compatible with CE objectives. Therefore, this movement is expected to positively impact the flow of circularity in the WM and energy sectors [64].

4.1.3. Vietnam

Vietnam has much potential for a CE because most of its waste can be recycled [65]. It has made the 3R method a fundamental aspect of its WM policy due to its emphasis on environmental responsibility [66]. The National 3R Strategy established the following objectives ending in 2020: to reduce trash production; to have a 95% solid waste collection rate; to reach a 60% recycling and reuse rate; and to have a 40% solid waste disposal rate [67]. The government's efforts to implement the 3R plan can be broadly classified. These goals include (1) establishing a governing framework to launch a CE in Vietnam; (2) promoting the 3R project, with a focus on Hanoi, Ho Chi Minh City, and Danang; (3) developing environmentally friendly techniques for hazardous waste and 3R within metropolises and industrial zones; (4) establishing and developing a governing framework to launch a CE in Vietnam [68]; and (5) motivating and supporting the creation of models for source-based WM. Unfortunately, there have been significant hurdles to progress: (1) the 3R programs are currently only being tested in pilot projects in Hanoi, Ho Chi Minh City, and Danang [69]; (2) the outcomes of these activities could be better due to gaps in plan execution and time and financial restrictions. While CE law exists, it could be more tightly implemented to make many 3R activities more applicable to local populations [70].

4.1.4. Brazil

Most municipalities in Brazil dump solid waste in unregulated dumps. Brazil dumps 29.4 million tons of MSW in open dumps, uncontrolled landfills, highway medians, valley bottoms, and bodies of water [71]. MSW is frequently disposed of in sanitary landfills. Private companies operate most of these landfills. For instance, in Sao Paulo, 12 out of the 29 WTE energy facilities use landfill gas [72]. The Brazilian solid waste regulation (PNRS) was proven effective in 2018. These regulations include (a) localized WM for PNRS success given Brazil's vastness and cultural and socioeconomic variety; (b) the mayor must select city secretaries based on professional ability rather than political affiliation; (c) MSW managers must attend national training; (d) sanitary landfills should be established nationwide and supervised by new regulations, resulting in waste reduction. Change in demand management culture takes time. The PNRS waste production law must be amended. Several factors can improve PNRS including the government addressing the issue of rising urban garbage and recycling while environmentally friendly landfills are not operated [73]. As a result, Sao Paulo's sustainable MSW management necessitates a steady landfill reduction. Also, AD of source-separated organic waste and mechanical–biological treatment of MSW can help Sao Paulo lessen its environmental impact [43].

A second Brazilian SWM study investigated the COVID-19 period. Despite Brazil's MSWM issue, municipalities with deficient management systems have been significantly impacted by the epidemic's large increase in residential garbage. To implement the recommendations, governments must plan ahead of time, invest in education, and provide options for disposing of potentially infected household garbage [74]. Hence, integrated MSW management costs are high, but a small recycling market and restrictions are the main issues [75]. De Oliveira Leite et al. investigated the energy, economic, and environmental consequences of Minas Gerais' MSW treatment systems. MSW processing produces useful byproducts, while composting produces less than AD. It should be noted that AD produces 0.16 MWh/t, incineration produces 0.57 MWh/t, and landfill gas produces 0.13 MWh/t of electricity. Meanwhile, most emissions are generated by incineration, gasification, AD, and recycling [76].

In Xangri-lá, Brazil, a numerical analysis of the effects and benefits of various management approaches on WM optimization was carried out. Given the findings, Xangri-lá should increase recycling rates gradually. Following recycling, the city must use more complex processes, such as AD and gasification [77].

4.1.5. African Countries

Ref. [78] recently investigated the use of CE principles in Africa's transition from fossil fuels to renewable energy. Forecasts between 2030 and 2050 indicate that the continent's five major economies, Algeria, Nigeria, Egypt, Morocco, and South Africa, will continue to grow. Although fossil fuels will continue to dominate global economies and industries, the transition should be conducted in a way that does not limit economic development potential. South Africa is refocusing its efforts on trash management. The former emphasis on rubbish disposal has turned to garbage reduction in the first place. South Africa and the rest of the world are about to enter the fifth global phase of "The Future is a Circular Economy" to make CEs popular in developing countries [79]. Landfills account for an estimated 90% of all rubbish generated in South Africa, making them the dominating technical solution. It is driven by various reasons, including (until recently) an abundance of space in South Africa, low landfill entrance fees, and cities' and garbage providers' refusal to pursue alternative solutions. Some municipalities have raised their entrance prices to between EUR 25 and EUR 40 per ton because of severe landfill airspace shortages.

Adopting innovative waste treatment technology is particularly expensive due to the low entry costs. Effective measures for transitioning to a CE, increasing environmental education, introducing participatory environmental initiatives, and enhancing the three core sustainability competencies should be considered [80]. This was based on a recent survey of rural institutions in South Africa, which discovered that 41% needed economic incentives to participate in recycling systems. The potential of a CE for industrial-scale SWM in Nigeria, a developing country, has been investigated. Based on the findings, many segments of the Nigerian economy appear to be engaged in illegal rubbish recycling. WM solutions are qualitative due to their ineffectiveness and require a solid foundation based on science, business, or economics, which is currently lacking. To ensure beneficial outcomes, it is now necessary to incorporate the CE principle into the development and implementation of such policies and practices [81].

4.2. Developed Countries

4.2.1. Singapore

Singapore unveiled its CE strategy in 2019 to reduce consumption through increasing reuse and recycling and using the 10R strategy to achieve zero waste (reduce landfill usage by 30%) by 2030 [82]. Ref. [83] proposed new responsibilities for properly collecting and disposing of food and electronic waste (E-waste). Increasing producer responsibility for E-waste by 2021, demanding adequate food waste disposal by 2024, and increasing producer responsibility for plastics by 2025 are on the agenda for new obligations for properly collecting and managing food and E-waste [84]. Waste transferred to landfills and incinerators will decrease considerably if the proposed procedures are followed [85].

Moreover, Singapore may achieve its 70% recycling objective in 50 years [86]. Infrastructure improvements in transportation and manufacturing have benefited the country's efforts to reduce waste and carbon emissions [82]. Singapore's zero-waste program is a conglomeration of government regulations, laws, and initiatives. Singapore's CE policies comprise the Sustainable Singapore Blueprint and the Resource Sustainable Bill. Therefore, government support for CE-related research activities will increase the country's sustainability [87].

4.2.2. Japan

Japan, due to a lack of native material resources, began the adoption of a CE in the year 1870 and implemented the Recycling legislation in 1991 [51]. The Japanese government has tried to boost circularity through effective consumer–manufacturer engagement. The 1996 "resource-efficient law" underlined the necessity of lowering reliance on oil and high energy use to address the energy crisis and enhance energy efficiency. Businesses, industrial parks, and the surrounding neighborhood were considered [88]. In the new era, Japan increased its recycling rate by 20% while decreasing the number of incinerators by the same percentage. Furthermore, designing with circularity will aid in developing WtE and heat-recovery technologies. As a result, the government is focusing on three main goals: (1) reducing the number of incinerators, (2) increasing recycling rates, and (3) lowering total costs [89].

4.2.3. Sweden

Sweden is at the forefront of WM plan implementation, and the country's environmental law that has been in effect since the 1960s is called the "Nature Conservancy Act of 1964." The "Products Hazardous to Health and the Environment" Act was passed by Congress in 1973. Furthermore, Sweden began working to reduce waste's environmental impact in 1980. In a 1992 statute, "eco cycles" referred to the sustainable reuse, recycling, and safe disposal of natural resources. By 1997, sustainable "end-of-life" product management attempted to reduce the quantity of rubbish transported to landfills. In Sweden, the 2030 Agenda and the gradual transition to a more sustainable economy were critical [46]. The Swedish steel industry has recently been pressured to modernize and shift to a CE-based production model. One of the key goals is identifying the barriers and opportunities within supply chains to support the transition to a CE in Sweden [90].

4.2.4. Denmark

The disposal of MSW and combustible waste in landfills was prohibited in Denmark. The statistics show that waste generation increased by 61% in 1997 [91]. Denmark is one of the high-income countries that creates MSWM based on environmental laws, regulations, lifestyle, technical developments, and the 3R system [92]. Denmark outperformed Sweden and Finland in the EU-27 treatment sector, ranking second in Europe only behind Germany's recycling program. In contrast to Sweden, the WM program prioritizes the volume of recyclables and compostables [91]. According to the statistics, between 2010 and 2016, Denmark's 36 home waste recycling centers (HWRCs) showed increased recyclable rates and decreased burned garbage percentages [93]. Magannino et al. explored how factors such as income, urbanization, and per capita MSW output influence the contribution of Denmark's waste sector to greenhouse gas emissions. They discovered that higher levels of wealth, which necessarily lead to increasing rubbish output, are associated with reduced waste sector emissions. As a result, when disposable income increases, alternative WM methods such as recycling, composting, and incineration may replace traditional landfills, improving environmental quality. These policies substantially shifted from a linear to a CE economy in Denmark [94].

Denmark affirmed that WM enterprises should be able to play various roles in a sustainable CE transition across all three pillars of sustainability. It necessitates a network of stakeholders, including individuals, non-governmental organizations, and the business sector, with strong linkages [95]. A recent study investigated the drivers driving waste system reform on the Danish island of Bornholm using the Integrated Sustainable WM paradigm. The findings showed that additional work is needed to influence customers' consumption habits, attitudes, and opinions toward product reuse [96].

4.2.5. Germany

The 1996 German "kreislaufwirtschaft" rule exemplifies European closed-loop recycling legislation. The regulation emphasizes the importance of designing products to minimize waste and ensure its recovery and reuse. In 2012, EU guidelines were revised to protect the environment, climate, and resources. CEs entered the competition with a proposal to make Europe more resourceful; this plan, dubbed the CE Package at the time, is today known as "Closing the Loop: An Action Plan for the Circular Economy". Later in the plan, a proposal to alter waste and landfill regulations was included. Therefore, the CE policies were modeled after worldwide solid waste policies [97,98].

Azevedo et al. recently reported on a German city as a standard, attesting to Brazilian UHSWM inefficiencies (particularly in its governance elements). They provided practical ideas based on the three pillars of Germany's solid WM system: clear rules, regular public campaigns, and charge methodology. Conceivable methods included more financing, better technology, and regular public campaigns to educate the local population on critical environmental issues. According to a study, the industry sector and consumers should accept financial assistance to strengthen the recycling chain. It is especially relevant given that the public sector struggles to pay for UHSWM systems [99]. Table 1 presents the recently used WtE models used to achieve CEs in several developed and developing countries around the world.

Table 1. Worldwide practices in WtE sectors toward a CE.

Waste Type	Location	Country Development	Findings	Ref.
MSW	New Zealand	Developed	To reach a CE, there are several challenges in New Zealand, such as a low-to-moderate understanding of the community, higher costs, policy uncertainty, technology readiness levels, and limited commercial success.	[100]
MW	Poland	Developed	Increase CE awareness among the Polish community by attaining 55% recycling by 2025 and implementing CE successfully with national and international funds.	[101]
Biomass	Madagascar	Developing	Madagascar's energy supply is 80% biomass; gasification and torrefaction would help Madagascar's energy "crisis" by utilizing wastes and moving toward a CE.	[102]
Food waste	Costa Rica	Developing	CE is applicable for different activities which can be shifted from one scenario to another, such as landfilling to the valorization of FW to improve WM.	[103]
MSW	Norway	Developed	CE creates an opportunity for WtE to strengthen and expand its role in growing new value chains, such as the valorization of new waste streams and secondary raw material production, which can be used to fund the building of the required infrastructure.	[104]
SW	Singapore		Singapore can reach 70% recycling by 2050 and reduce 30% landfill usage by 2030; the Singapore zero waste initiative includes government legislation, tactics, and incentives; The Sustainable Singapore Blueprint and Resource Sustainable Bill governs the CE in Singapore.	[105]
SW	France	Developed	Reducing anthropogenic resource usage by 30% by 2030, 50% less non-hazardous trash dumping by 2050, 100% plastic recycling by 2050; plastic recycling reduces GHG; CE development creates 300,000 jobs.	[105]
MSW	Demark	Developed	GHG affects MSW generation, income, and urban population; Denmark regularly switches to a CE; waste policy efforts should focus on changing people's behavior and firms' decisions.	[94]

Table 1. *Cont.*

Waste Type	Location	Country Development	Findings	Ref.
CW	China	Developing	Currently, the CE level is 58%, which should be 100%; to improve the adoption of the CE in the building sector, serious steps should be considered by all the stakeholders.	[106]
IW	India	Developing	The initiatives by the government will create employment opportunities in the local community resulting in IW reduction without exerting any additional expenditure.	[107]
MSW	Indonesia	Developing	Strict environmental legislation and nationwide recycling program enforcement are needed; use economic mechanisms, legal enforcement, and resource recovery to support integrated SWM and speed up its long-term transition towards a CE nationwide.	[108]
C&DW	Malaysia	Developing	There is a need for an integrated framework to guide the construction actors for effective and sustainable WM toward CE implementation to create a sustainable future.	[109]
SW	Pakistan	Developing	The government should be more responsible for formulating new policies following the CE approach; this can be accomplished by adopting new smart waste technologies in sustainable WM practices.	[110]
SW	Bangladesh	Developing	Eight CE challenges—lack of technical innovation, financial support from authorities, strong legislation, a reverse logistics facility, a communication framework, CE awareness, social community pressure, and long-term strategic goals—formed the framework.	[111]
MSW	Russian Federation	Developed	Digitalization improves garbage storage and recycling and can assist trash recycling businesses in converting to a CE.	[112]
WtE	Sri Lanka	Developing	WtE projects could financially and economically assist CEs; WtE plants have far lower marginal generation costs than thermal power plants.	[113]
PW	South Korea	Developed	The 9R model helps Korean firms and policymakers examine and improve their circularity; also, nations require the continuous efforts of consumers, governments, and companies to achieve an upright CE.	[114]
MW	Lithuania	Developed	Learning, vision sharing, reflexive governance, regulation, and network negotiation create a local administration for a CE framework.	[115]
MSW	Australia	Developed	Waste trading pinch analysis improves resource sharing and facility usage for a sustainable and mutually beneficial CE transition; social behavior analysis helps forecast waste creation during transitions and improves trash trading designs.	[116]

AD: anaerobic digestion. AHP: analytic hierarchy process. ANN: artificial neural network. BC-GC: Breitung–Candelon Spectral Granger Causality. CP: composting. CW: construction waste. C&DW: construction and demolition waste. EC: environmental commitment. ETPB: extended theory of the Planned Behavior Model. GEI: green economic incentives. LCT: life cycle thinking. L&I: landfill and incineration. LP: linear programming. MCDM: Multi-Criteria Decision-Making. MW: municipal waste. MSW: municipal solid waste. PBM: Planned Behavior Model. PW: packing waste. SW: solid waste. WM: waste management. IW: industrial waste.

While numerous countries are attempting to implement CE methods for WtE conversion, success will take time. Furthermore, further information about the practicality of current waste-to-energy systems and their relationship to a CE is required. As a result, feasibility studies for currently available WtE technologies should be conducted to ensure CE implementation.

5. Recommendation and Roadmap for the CE Using WtE

Drawing an innovative roadmap is crucial for the transition of all nations to a CE in the near future. Several studies have been conducted in WM and CEs in different countries. For instance, Ref. [117] investigated the influence of inefficient WM systems during COVID-19 on the UN Sustainable Development Goals. Nonetheless, the UN SDGs might be met swiftly with CE-based SWM. As a result, to find the best model for their economies and ecosystems, countries must experiment with the 10R approaches. Based on the available literature, it was determined that a technology that simultaneously checks boxes from multiple perspectives needs to be developed and improved [15].

Because CEs re at the top of the EU agenda, all EU Member States (including EEA nations) should develop a more intelligent waste treatment system incorporating the CE concept into their waste policy. The Commission classified various WtE processes based on their position in the waste hierarchy. It also stated that WtE might contribute to the transition to a CE, but only if the waste hierarchy is followed. To fully realize the potential of the WtE industry, increased collaboration between local WM authorities and ministries in charge of various policies such as WM, energy, and the environment is required [118]. A transition to a circular economy in Africa could aid in achieving the UN Sustainable Development Goals; however, the concept is still in its infancy on the continent [119].

Furthermore, in a comprehensive data-driven literature review of MSWM in a CE, incineration, life cycle assessment, plastic waste, solid waste sorting, and sustainability were the top five indications for future investigation [120]. Hence, there is an urgent need to identify a structure that can serve as the foundation for a real-time guideline to direct future research and as a resource to assist WM policymakers and practitioners in facilitating the CE transition (the goal is to reduce waste generation) [121]. Therefore, the European Union (EU) must try to build an SWM system qualitatively, focusing on philosophy, methodology, indicators, targets, and policies based on legislation and enforcement. To do this, the European Union's efforts to create a more effective and efficient system included the following: first, from a strategic standpoint, the EU approach has conveyed vertical integration of WM; second, increased investment in the sector in facilities and training; third, a focus on the business rather than just the collection service; fourth, greater geographical aggregation; and fifth, improved service and business across the EU [122]. Despite the availability of numerous energy recovery technologies and processes, best practices and sustainable SWM implementation are still required in developing countries. Political, financial, and regulatory barriers in underdeveloped countries, such as a lack of money and inconsistent laws and procedures, are also relevant issues for discussion [14]. Therefore, the recommended policies for developed and developing countries are presented in Figure 4.

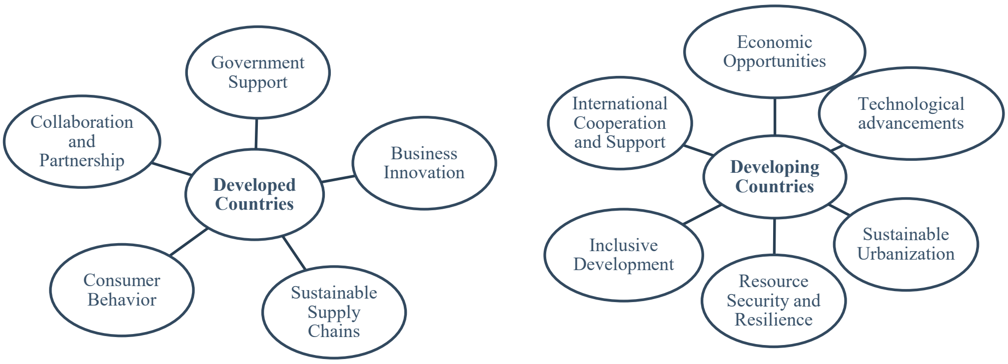

Figure 4. Suggested policies for developed and developing countries to reach a CE.

6. Conclusions and Future Directions

In this review, we discussed the most common WtE technologies, including incineration, landfills, anaerobic digestion, and composting, that have been investigated and successfully implemented in various developed and developing countries in recent years. In addition, the existing challenges and barriers and important policies for reaching a CE by different nations worldwide have been summarized. The significant findings of this review are listed below.

The limitations of well-known MSW collection and treatment methods must be set out, and it must be clear how these obstacles can be overcome by utilizing WtE procedures. The majority of WtE technologies have substantial limits in terms of waste utilization. Waste collection, processing, and transportation all contribute to the overall cost. Reducing waste and improving the well-being of the informal economy through post-COVID measures should concentrate on capacity-building, direct benefit transfer, and welfare programs.

The main challenges developed countries face are changing consumer behavior, innovation in business practices, creating economic opportunities through international collaboration, transitioning towards a CE by government support, and logical usage of renewable materials in the production cycle. Meanwhile, in developing countries, the challenges are different due to a lack of funds and technologies, which can be listed as the need for circularity programs for public awareness, inclusive investment by government agencies, changing traditional linear models to innovative technologies, increasing resource security to have a resilient economy, and technology transfer and knowledge sharing from developed countries.

In summary, WtE technologies play a significant role in supporting CE policies. Countries must implement different policies for WtE approaches toward a CE, including investing in less waste generation rather than waste treatment, proper waste collection and recovery systems, effective material recovery and reuse in the waste cycle, environmental and economic considerations of existing technologies, public awareness on the benefits of circularity, and national and international collaboration of nations to save the planet as much as possible for future generations. By adopting a holistic approach to waste management, societies can move closer to achieving the goals of a CE.

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