

Waste Management in the GCC Countries: A Review of Current Practices, Challenges, and Future Directions

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Abstract

Waste Management has become an increasingly important environmental issue in the Gulf Cooperation Council (GCC) countries due to rapid urbanization, population growth, infrastructure development, and consumption-intensive lifestyles that result in high waste generation rates. This narrative review evaluates municipal solid waste (MSW) management across Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates (UAE), and examines waste generation and composition, current management practices, environmental impacts, policy and regulatory responses, and emerging sustainable solutions across the GCC region. The review synthesizes publicly available government reports, national strategies, statistical publications, international institutional reports, and peer-reviewed literature to provide a comparative overview of waste management conditions across the six GCC countries. The findings indicate that high waste generation rates, continued dependence on land-filling, limited source segregation, low and uneven recycling capacity, inadequate management of specific waste streams such as organic, plastic and e-waste, and fragmented policy implementation remain major challenges. Organic and construction-related wastes constitute important components of the regional waste stream, while inappropriate disposal practices may contribute to risks to soil, water, air quality, ecosystems, and human health. GCC countries are increasingly adopting waste-to-energy technologies, recycling initiatives, circular economy approaches, improved waste collection systems, and other technological solutions, although progress varies among countries. The review highlights the need for integrated solid waste management strategies that prioritize waste prevention and reduction, source separation, reuse, recycling, resource recovery, and sustainable treatment technologies, while considering extended producer responsibility. Strengthening governance, increasing

investment in green economy and infrastructure, promoting public awareness and participation, and enhancing regional cooperation are identified as key priorities for advancing sustainable waste management and supporting relevant Sustainable Development Goals.

Keywords

GCC Countries, Circular Economy, Integrated Solid Waste Management Approach, Sustainable Development, Waste Management Governance

1. Introduction

The Gulf Cooperation Council (GCC) member states—Saudi Arabia, the United Arab Emirates (UAE), Qatar, Kuwait, Oman, and Bahrain—are facing growing waste management challenges driven by rapid urbanization, population growth, and industrial development. Although these countries have implemented various strategies to manage waste generation and mitigate environmental impacts, significant challenges remain in promoting sustainable waste management practices, improving recycling rates, and raising public awareness (Kumari & Raghubanshi, 2023). This manuscript provides a detailed overview of waste management systems in the GCC countries, explores key trends and challenges, and offers insights into the future of waste management in the region. It also emphasizes the growing importance of adopting a circular economy and integrating modern technologies in waste management (Albreem et al., 2023).

The GCC countries, known for their substantial economic growth driven by oil revenues, are experiencing rapid urbanization and population expansion. These demographic and economic shifts have led to a significant increase in waste generation, which presents complex challenges for waste management systems (Kumari & Raghubanshi, 2023). Waste management in the region involves the collection, transportation, recycling, and disposal of waste, with a growing emphasis on environmental sustainability (Voukkali et al., 2024). Given the growing environmental, health, and economic implications of inadequate waste management, a comprehensive understanding of current practices and future directions is urgently needed in the GCC region. This review therefore seeks to critically examine trends in waste generation and current management practices across the member countries, assess the extent to which national policies align with global sustainable development goals (SDGs), and evaluate the technological innovations and circular economy strategies emerging in the region (Cudečka-Puriņa et al., 2022). Additionally, the paper aims to identify the key structural, cultural, and policy-related challenges hindering progress and to propose informed, strategic recommendations to guide future sustainable waste management efforts.

The article draws on government reports, peer-reviewed academic studies, and data from international organizations to provide an evidence-based overview. This paper outlines the waste management practices across GCC countries, evaluates

current challenges, and explores innovative solutions. High rates of waste generation constitute a major challenge for the Gulf Cooperation Council countries, which result from the basic drivers of population growth, urban development, and the increase in urban development activities at all levels, including economic, industrial, commercial, social, and technological levels (Raihan et al., 2022). Furthermore, unsustainable patterns of consumption and production, together with lifestyles rooted in a linear economic model characterized by resource extraction, production, consumption, and disposal, contribute significantly to the increasing generation of waste across the Gulf region (Abbas, 2019). The problem of increased waste generation is also considered one of the most prominent pressures on land resources when they are not managed in a correct and sustainable manner, as this causes potential pollution of water resources, soil, agricultural crops, and biodiversity, and its negative impact on air quality and thus human health and the quality of life on Earth (Kolawole & Iyiola, 2023).

2. Methodology

This review is based on an extensive qualitative synthesis of publicly available data, official government reports, and previously published academic and institutional sources relevant to waste management practices in the Gulf Cooperation Council (GCC) countries. The content was compiled through the integration of secondary data from documents such as national waste management strategies, sustainable development plans, environmental agency reports, and statistical publications, including the most recent GCC Statistical Center's 2023 waste report (GCC-STAT, 2023) and relevant reports from the United Nations Environment Programme (UNEP) (Citaristi, 2022).

The review covers six GCC countries, Saudi Arabia, the United Arab Emirates, Qatar, Kuwait, Oman, and Bahrain, and provides a comparative overview of municipal waste generation rates, treatment practices, recycling initiatives, disposal methods and environmental impacts. Where available, country-specific policies, regulatory frameworks, and technological advancements (such as waste-to-energy projects and circular economy initiatives) are included to illustrate national responses to rising waste volumes and sustainability commitments (Awino & Apitz, 2024). The primary aim of this methodology is to provide a coherent, evidence-based narrative review that consolidates fragmented regional information into a structured and accessible format. This approach does not include original fieldwork, interviews, or experimental data, and it refrains from including unverified projections or assumptions beyond what is directly cited in the reviewed materials. All data and interpretations reflect the conditions and documentation available up to the most recent reports cited, and no claims are made beyond the documented evidence.

2.1. Waste Statistics in the GCC Countries

According to GCC-STAT, the population of the Gulf States would reach about

83.6 million by 2050. According to the most recent report of GCC- STAT for 2024, the population of the GCC countries stood at approximately 61.5 million at the end of 2024, representing an increase of 8.5 million since 2019. This corresponds to an average annual growth rate of 2.8%, nearly three times the global average, underscoring the region's rapidly changing demographic landscape. This contributes to increasing levels of environmental pollution in the region, particularly in light of continued urban expansion and rapid urbanization, with the continuation of consumption patterns at the same pace. According to the latest data published by GCC-STAT, the total quantity of waste collected across the GCC countries reached approximately 262.7 million tonnes in 2023, representing a substantial 153.7% increase compared with the level reported in 2019. During the same period, the volume of waste undergoing treatment increased to approximately 192.0 million tonnes, corresponding to a 128.5% rise relative to 2019.

Despite the overall growth in waste generation, the per capita generation of household waste declined by 17.4%, reaching approximately 1.4 kg per person per day. The composition of collected waste was predominantly non-hazardous, accounting for 99.2% of the total. In contrast, approximately 95.8% of the hazardous waste generated was exported to other countries for treatment. The principal treatment approaches included recycling and the recovery of metals and metallic compounds from waste streams.

The daily per capita generation rate of waste in the GCC countries ranges from 1.1 and 2.0 kg, with an average of 1.5 kg/person per day, which is much higher than the global average of 0.74 kg/person per day, as well as the regional average for the Middle East and North Africa: 0.81 kg/capita/day (GCC-STAT, 2023; Kaza et al., 2018).

There are many factors affecting an efficient and sustainable waste management, including the lack of effective strategies and policies supporting sustainable waste management in the GCC countries. In addition, the limited natural resources and a geographical area wasting land uses, in addition to the lack of public awareness, and the adoption of irresponsible lifestyles that waste resources and encourage waste generation following the linear economy approach, all affect waste management (Kumari & Raghubanshi, 2023). The increase in the purchasing power of the individual resulting from the increase in the per capita share of wealth and GDP per capita plays a fundamental role in increasing consumption. Non-responsible consumption is considered a major reason for the increase in waste generation in the Gulf Cooperation Council countries (Memeti & Jurkowska-Gomulka, 2021). Moreover, the spread of consumption tourism and the adoption of the linear economy, with other factors, play a fundamental role in classifying the Gulf Cooperation Council countries as countries with the highest rates of waste generation per capita in the world. This leads to an increase in demand for waste dumps, which occupy vast areas of these countries despite their limited areas, posing a threat to the environment and health. Economy and society, if not managed in a correct and sustainable manner (Ostad-Ali-Askari, 2022).

2.2. Waste Management and the Sustainable Development Goals (SDGs)

Waste management plays a pivotal role in advancing the achievement of the seventeen Sustainable Development Goals (SDGs) of the 2030 Agenda. It is directly or indirectly interconnected with multiple dimensions of sustainable development, particularly through the implementation of an Integrated Solid Waste Management (ISWM) approach. This approach emphasizes the waste hierarchy, prioritizing waste prevention and source reduction, followed by reuse, recycling, recovery, and, as a last resort, environmentally sound disposal. Accordingly, effective waste management is essential for minimizing environmental impacts, conserving natural resources, and promoting more sustainable patterns of production and consumption.

Thus, integrated waste management can contribute to the achievement of SDGs 1 and 2 by preventing and reducing material wastage and facilitating the redistribution of usable goods and surplus food to vulnerable populations through food banks, charitable organizations, and other community-based initiatives. In the GCC countries, these practices have increasingly emerged as complementary mechanisms for addressing food insecurity and promoting more efficient resource utilization while simultaneously reducing waste generation. Moreover, the establishment of partnerships among governments, private-sector entities, civil society organizations, and local communities can support SDG 17 by strengthening collaborative frameworks for sustainable waste management. The growing adoption of such initiatives across the GCC countries reflects an increasing emphasis on resource redistribution, social inclusion, and multi-stakeholder collaboration as integral components of sustainable waste management. (Citaristi, 2022).

Sustainable waste management also contributes significantly to good health and well-being (SDG 3, Target 3.9). Avoiding pollutants through sustainable waste management means good health and well-being, which is also related to Goal 6 (Citaristi, 2022). The availability of healthy water will not be achieved with the current practices of filling waste in landfills that lack sanitary planning, thus increasing the risk of groundwater being exposed to contamination with hazardous substances and other pollutants that seep into groundwater through leaching resulting from all types of waste in landfills.

SDG 7, which focuses on access to affordable, reliable, sustainable, and modern energy, can be supported through investments in waste-to-energy projects that employ clean and advanced thermal conversion technologies, as well as biological processes for energy recovery. Similarly, investments in recycling infrastructure, waste-to-energy systems, and other waste-based industries can promote technological innovation, resource efficiency, and economic diversification in the GCC countries, thereby contributing to SDG 9 on industry, innovation, and infrastructure. The development and expansion of these emerging waste-management industries may also generate new employment opportunities and support inclusive economic development.

Furthermore, the adoption of integrated and sustainable waste management practices can contribute to SDG 11 by supporting cleaner, more resource-efficient, and resilient cities and communities. SDG 12, which focuses on responsible consumption and production, is particularly relevant to waste management, as it emphasizes the sustainable use of natural resources and the prevention and reduction of waste generation. Achieving these objectives requires a shift from end-of-pipe waste management toward waste prevention and source reduction, supported by more sustainable lifestyles, responsible consumption patterns, and informed purchasing decisions (Walker, 2021). Such a transition can reduce resource consumption and waste generation while strengthening the broader principles of a circular economy.

Responsible management of waste and chemicals is considered an imperative necessity to protect the environment and human health (Chankseliani & McCowan, 2021).

Waste management is also linked to SDG 13 of climate action (Chankseliani & McCowan, 2021). Sustainable waste management plays a critical role in preventing and reducing greenhouse gas emissions and, consequently, mitigating global warming. Among these emissions, methane (CH_4) is of particular concern because of its high global warming potential. Methane is generated predominantly in landfills through the anaerobic decomposition of biodegradable organic waste by microorganisms. Therefore, effective waste prevention, source separation, organic waste diversion, recycling, composting, and appropriate treatment of biodegradable waste can substantially reduce methane emissions from landfills and contribute to climate change mitigation.

Sustainable management of both hazardous and non-hazardous waste is also closely associated with SDGs 14 and 15, which address the conservation of marine and terrestrial ecosystems, respectively. Improper waste management can adversely affect these ecosystems through the release and accumulation of chemical pollutants, plastics, and other contaminants in terrestrial and aquatic environments. Of particular concern is the widespread occurrence of plastic debris and microplastics in marine ecosystems, where they can be ingested by aquatic organisms and subsequently transferred through food webs. This may facilitate the bioaccumulation and trophic transfer of contaminants, potentially increasing human exposure through the consumption of contaminated seafood. Consequently, effective waste prevention, collection, treatment, and environmentally sound disposal are essential for reducing pollution pressures on terrestrial and marine ecosystems and supporting the conservation objectives of SDGs 14 and 15.

The final SDG directly relevant to sustainable waste management is SDG 17, which focuses on strengthening partnerships to achieve the Sustainable Development Goals (Chankseliani & McCowan, 2021). Effective waste management requires coordinated action and collaboration among governments, private-sector organizations, academic and research institutions, civil society, and local communities. Such multi-stakeholder partnerships can facilitate the development of inte-

grated waste management systems, mobilize financial and technical resources, and strengthen institutional capacity, thereby contributing to the broader implementation of the SDGs.

Furthermore, a report on sustainable healthcare waste management and the Sustainable Development Goals highlighted that effective healthcare waste management, as an integral component of solid waste management, can contribute to progress across several SDGs (Rocheteau, 2023). In particular, improved management of healthcare waste can support five of the seventeen SDGs by reducing environmental and public health risks, promoting resource efficiency, and strengthening sustainable practices (Carlsen & Bruggemann, 2022). These include:

SDG 3—Good Health and Well-being: Promoting healthy lives and well-being for people of all ages through the safe management of healthcare waste and the reduction of associated health risks.

SDG 6—Clean Water and Sanitation: Protecting water resources from contamination and supporting sustainable water and sanitation management.

SDG 8—Decent Work and Economic Growth: Supporting inclusive economic development and safe, decent employment opportunities within waste management and resource-recovery activities.

SDG 12—Responsible Consumption and Production: Promoting sustainable consumption and production patterns through waste prevention, segregation, recycling, recovery, and environmentally sound treatment.

SDG 13—Climate Action: Reducing greenhouse gas emissions associated with waste generation, transportation, treatment, and disposal, thereby contributing to climate change mitigation.

2.3. Waste Management and Sustainable Development in the GCC Countries

High rates of waste generation represent a significant environmental and sustainability challenge for the GCC countries. These rates are driven by a combination of demographic and socioeconomic factors, particularly population growth and rapid urbanization, together with the expansion of urban development activities across economic, industrial, commercial, social, and technological sectors. The resulting growth in consumption, production, infrastructure, and economic activity has contributed to increased resource use and, consequently, higher volumes of waste generation throughout the region (Al-Saidi, 2021).

In pursuit of the Sustainable Development Goals (SDGs), the GCC countries have introduced a range of waste management initiatives designed to promote environmental sustainability, enhance resource recovery, reduce waste-related impacts, and support the transition towards more sustainable and circular waste management systems.

High rates of waste generation represent a significant challenge for the GCC countries and are driven by a combination of demographic, urban, economic, industrial, commercial, social, and technological factors (Al-Saidi, 2021). Rapid pop-

ulation growth and urbanization, together with increasing economic activity and rising household consumption, have contributed substantially to the continuous growth in waste generation across the region. In particular, increasing purchasing power and per capita wealth have encouraged higher levels of consumption, thereby contributing to greater waste generation. These trends are further reinforced by consumer-oriented lifestyles, tourism-related consumption, limited public awareness of sustainable consumption practices, and the continued prevalence of linear production and consumption patterns (Abubakar et al., 2022).

The high volume of waste generation places considerable pressure on land and other natural resources, particularly in countries characterized by limited land availability and fragile environmental conditions. Inadequate management and disposal of waste may result in the contamination of soil and water resources, impacts on agricultural systems and biodiversity, deterioration of air quality, and adverse consequences for human health and quality of life (Edo et al., 2024). Continued reliance on landfilling also requires substantial land resources and may increase the long-term environmental and socioeconomic burdens associated with waste disposal. These challenges highlight the need for integrated waste management strategies that prioritize waste prevention and reduction, sustainable consumption and production, resource recovery, recycling, and other circular-economy approaches.

The GCC countries are characterized by relatively high per capita municipal solid waste (MSW) generation rates compared with global and regional averages. According to GCC-STAT, daily per capita MSW generation across the GCC countries ranges from 1.1 to 2.0 kg, with an average of approximately 1.5 kg/capita/day, compared with a global average of 0.74 kg/capita/day and a Middle East and North Africa (MENA) regional average of 0.81 kg/capita/day (GCC-STAT, 2023; Kaza et al., 2018). In Saudi Arabia, the per capita MSW generation rate was approximately 1.6 kg/capita/day in 2023 (GCC-STAT, 2023). These relatively high generation rates, combined with population growth and continued urban expansion, place increasing pressure on existing waste management infrastructure and landfill capacity. Consequently, strengthening waste prevention, source segregation, recycling, and resource recovery is essential for reducing dependence on disposal-based systems and advancing sustainable MSW management across the GCC region.

GCC countries have introduced a range of national strategies and initiatives to support the development of integrated and more resource-efficient waste management systems. Saudi Arabia and the United Arab Emirates, for example, have incorporated waste management and resource recovery into their national development strategies, including Saudi Vision 2030 and UAE Vision 2021, with targets related to waste reduction and diversion from landfills. At the municipal level, cities such as Dubai in the UAE and Riyadh in Saudi Arabia have introduced recycling bins and public awareness initiatives to promote source segregation and community participation. Kuwait's development plans also include measures to

increase recycling and enhance waste diversion from disposal. In Qatar, initiatives to reduce the use of single-use plastics have been introduced across institutions, shopping centers, and companies, including the promotion of reusable and biodegradable alternatives. In parallel, Oman, Qatar, Saudi Arabia, and the UAE have developed or invested in waste-to-energy (WTE) and integrated waste treatment facilities. Notable examples include Qatar's Integrated Domestic Solid Waste Management Centre (DSWMC) and the Warsan Waste Management Centre in Dubai, reflecting the growing role of treatment, energy recovery, and resource recovery within the region's evolving waste management systems (Alshawaf et al., 2025).

It is noteworthy that the Kingdom of Saudi Arabia and the United Arab Emirates account for a substantial proportion of the total municipal solid waste generated across the GCC countries, largely reflecting their rapid urbanization, expanding infrastructure, and development of new cities. These activities are also associated with significant quantities of construction and demolition waste. Across the GCC region, biodegradable organic waste represents a major component of municipal solid waste and is predominantly disposed of through landfilling (Goessler, 2022).

The continued reliance on landfilling presents significant environmental, economic, and social challenges, particularly in countries with limited land availability, such as Bahrain, Qatar, Kuwait and the United Arab Emirates. In some cases, landfill capacity has become severely constrained or existing facilities have reached or exceeded their intended operational lifespan, as reported in Bahrain. This situation underscores the need to develop and implement sustainable alternatives for the management and recovery of different waste streams. Such approaches are essential for reducing the environmental, economic, social, and public health impacts associated with continued dependence on landfilling and for supporting a transition toward more sustainable and resource-efficient waste management systems (Ibrahim et al., 2022).

According to the 2024 Waste Accounts published by the General Authority for Statistics (GASTAT), the total recorded waste generation in the KSA encompassing waste from various economic activities and households, reached 135.1 million tonnes in 2024, compared with 111.4 million tonnes in 2023, indicating a substantial year-on-year increase (GASTAT, 2024) while the waste generation rate was reported at approximately 1.6 kg per capita per day in 2023, according to GCC-STAT (2023).

This substantial increase in waste generation, coupled with continued dependence on conventional disposal practices, places additional pressure on existing waste management infrastructure and increases the potential for adverse environmental impacts, including soil and groundwater contamination. The environmental degradation associated with solid waste in Saudi Arabia was estimated by the Saudi National Center for Waste Management (MWAN) at approximately US\$1.3 billion in 2021.

According to Mahongnao and Kumar (2025), Saudi Arabia's waste manage-

ment sector is undergoing a strategic transition towards more sustainable waste treatment and resource recovery. However, current practices remain largely dependent on landfilling and open dumping, with limited waste treatment and recycling infrastructure. The reliance on informal waste pickers for waste segregation further constrains recycling efficiency and energy recovery, contributing to environmental pollution. Existing treatment infrastructure comprises composting, biomethanation, and recycling facilities, while incineration capacity remains limited or absent. In response to these challenges, Vision 2030 provides a policy framework for advancing integrated waste management. Furthermore, the National Center for Waste Management (MWAN), under Vision 2040, has established targets to divert 90% of waste from landfills by 2040, including 40% through recycling, 31% through composting, and 16% through incineration.

While the United Arab Emirates produces about 6.6 million tons of waste annually, at a rate of 1.8 kg per person per day. Waste management in the country is coordinated through local authorities (Ibrahim et al., 2022). Waste is also managed in the country through recycling and converting waste into energy and other resources, new technologies are used and waste sorting and collection systems are improved. The United Arab Emirates aims to reduce the harmful environmental impact per capita of cities, including by paying special attention to air quality, municipal waste management, and others. According to the official government platform of the United Arab Emirates (Goessler, 2022).

According to The United Arab Emirates' Government Platform (2026), The United Arab Emirates (UAE) has established an integrated regulatory framework to strengthen waste management and promote environmentally sustainable waste practices. Federal Law No. 12 of 2018 on Integrated Waste Management provides the overarching legislative framework for the sound management of waste, while Cabinet Resolution No. 39 of 2021 establishes its executive regulations. The framework aims to regulate waste management activities, standardize waste handling and disposal practices, and reduce environmental and public health risks (Sardara et al., 2024).

Waste management in the UAE is implemented through coordination among federal and local authorities, with increasing emphasis on waste reduction, source separation, recycling, resource recovery, and waste-to-energy technologies. These approaches are supported by improvements in waste collection and sorting systems and the development of treatment and recovery infrastructure. The UAE government has also linked integrated waste management to sustainable development goals (SDGs), particularly SDG 11 on sustainable cities and communities and SDG 12 on responsible consumption and production. The national approach includes reducing waste generation, increasing treatment and recycling, and promoting the conversion of waste into energy and other valuable resources.

Within this framework, the UAE has increasingly adopted resource-recovery approaches, including waste-to-energy projects, as part of efforts to reduce dependence on landfilling and improve the environmental performance of urban waste

management systems.

The average production of municipal waste in the Sultanate of Oman is 2.6 million tons annually, at a rate of 1.2 kg per person per day, with population of almost 3.9 million inhabitants (Zafar, 2025).

In the Sultanate of Oman, the waste management infrastructure comprises 11 engineered landfills, together with approximately 18 - 125 waste transfer stations and bulky waste delivery centers (Zafar, 2025). Solid waste is managed through a combination of licensed and unlicensed disposal sites, reflecting the existing waste disposal infrastructure across the country. Some landfill sites are located in or near residential areas and water collection or recharge zones associated with public and private water resources. The distribution and characteristics of these facilities highlight the importance of considering land use, environmental protection, and public health considerations in the planning and development of waste management infrastructure (Zafar, 2025).

The Sultanate of Oman has identified investment opportunities to support the transition towards a circular economy, including up to six initiatives related to waste-to-energy (WTE) and waste reprocessing. The combined investment value of these opportunities has been estimated at approximately OMR 580 million (Abushammala & Qazi, 2021).

Kuwait's population exceeded 4.5 million in 2026. It generates a considerable quantity of municipal solid waste (MSW), with reported per capita generation rates of approximately 1.7 kg/capita/day in 2025 (Alshawaf et al., 2025), compared with the global average of 0.74 kg/capita/day (UN Environment Programme, 2019; Zafar, 2022). These patterns reflect the influence of population growth, economic activity, and consumption levels on waste generation. Landfilling remains an important component of Kuwait's MSW management system, supported by a network of landfill and waste disposal facilities. Given Kuwait's relatively limited land area of approximately 17,820 km², the spatial requirements of waste disposal facilities are an important consideration in long-term waste management planning.

Kuwait's waste management sector is progressively developing towards more sustainable and integrated practices. Landfilling remains a major component of municipal solid waste (MSW) management, while recycling and composting are also practiced as complementary management options. A number of private-sector and non-profit organizations, including the Kuwait Recycling Company and Metal and Recycling Company, contribute to material recovery and the recycling of plastic, metals, and paper. The continued development of the sector provides opportunities to expand source segregation, recycling, composting, and other resource-recovery activities. Given Kuwait's limited land area and the growing importance of efficient resource use, enhancing public awareness, communication, and community participation can further support the implementation of integrated waste management practices. Developing a well-coordinated waste management system is an important component of Kuwait's broader sustainable de-

velopment objectives (Alshawaf et al., 2025).

Qatar is a geographically small country, with a land area of approximately 11,500 km². Over recent decades, the country has experienced substantial economic development, supported by its significant hydrocarbon resources, particularly natural gas, and has attained a high GDP per capita (Mariyam et al., 2022).

The Government of Qatar has identified waste management as one of the most pressing environmental issues in Qatar. Due to the growing population, the recent surge in construction in preparation for the 2022 FIFA World Cup, and the country's overall industrial growth, Qatar generates over 2.5 million tons of municipal solid waste annually, which equates to a per capita daily generation rate of approximately 2.5 kg (Keller, 2020; Zafar, 2022). Apart from the municipal solid waste generated in the country, the construction industry also contributes significantly to waste generation in Qatar. In 2012, it was estimated that commercial and industrial waste alone amounted to 1 million tons, and construction and demolition waste amounted to 20,000 tons per day. In October 2008, the General Secretariat for Development Planning in the State of Qatar issued a development plan titled Qatar National Vision 2030. Qatar National Vision 2030 is organized into four pillars: human development, social development, economic development, and environmental development. Qatar National Vision 2030 identifies the need for sustainable development in order to achieve a balance between the interests of the current generation and those of future generations, and emphasizes the need to take preventive measures to mitigate the effects of climate change (Keller, 2020).

In Qatar, recycling accounted for less than 15% of the waste stream, while more than 50% of generated waste was reported to be directed to landfills (Mariyam et al., 2022). These figures indicate the continued role of landfilling within the country's waste management system, alongside opportunities to further expand recycling and resource-recovery practices.

Bahrain Vision 2030 identifies sustainability, competitiveness, and fairness as key principles aimed at ensuring a safe and secure standard of living for all Bahraini citizens. The vision also emphasizes the preservation of Bahrain's cultural heritage and natural environment, highlighting the importance of environmental protection and sustainable development. Among its priorities are investments in technologies that reduce carbon emissions, minimize pollution, and promote sustainable energy sources, alongside measures to support water sustainability and improve air quality (Abbas, 2019).

Bahrain faces considerable challenges in municipal solid waste (MSW) management, partly due to its high per capita waste generation, limited land availability, and growing population. Despite its relatively small geographical area, the country has been reported to have one of the highest MSW generation rates per capita among GCC countries. These conditions place increasing demands on policymakers, urban planners, and municipalities to develop effective and sustainable waste management systems (Zafar, 2026).

Similar to other rapidly developing countries, Bahrain is experiencing increas-

ing MSW volumes and pressure on existing landfill capacity. These challenges are accompanied by public concerns regarding waste management practices, potential environmental and health risks, and the long-term sustainability of current disposal systems (Abbas, 2019).

Population growth, industrial development, limited land resources, and the need for improved waste management coordination and public awareness further influence the development of the sector. In response, the Bahraini government has pursued initiatives to enhance waste management, including recycling programs and waste-to-energy projects, as part of broader efforts to improve resource recovery and environmental sustainability (Zafar, 2026; Abbas, 2019).

Bahrain recorded an MSW generation rate of 2.48 kg per capita per day in 2015, the highest among the GCC countries included in the reported dataset (Zafar, 2026). This figure highlights the importance of strengthening waste prevention, resource recovery, and sustainable waste management practices while considering the country's specific geographical and demographic conditions.

The rates of municipal waste generation in the Kingdom of Bahrain reached two million tons by 2020, with demolition and construction waste accounting for 50% of this waste, while this percentage decreased in 2021 to 1.5 million tons as the government of the Kingdom of Bahrain adopted policies to recycle construction waste and use it in road construction and other areas. The per capita share of municipal waste production amounted to 2 kg per day in 2018, while in 2021, the percentage decreased to about 1.1 kg per person per day (Fahmi Jamal & Abd El-Fattah, 2023).

Organic and biodegradable waste constitutes the largest proportion of household municipal waste in the Gulf Cooperation Council countries, reaching approximately 70% of this waste. We specifically mention food waste, which has witnessed unprecedented levels recently, according to the United Nations Environment Programme's Food Waste Index report for West Asia in 2021, as the Gulf Cooperation Council countries were classified as the highest food waste-producing countries in the world, and the Kingdom of Bahrain ranked first with an annual production rate of 132 kg per capita, while global averages do not exceed 50 to 70 kg per capita annually (Abbas, 2019).

The Askar landfill is a major waste disposal facility in Bahrain, receiving municipal solid waste (MSW), agricultural waste, and non-hazardous industrial waste. Covering an area of more than 700 acres, the site has faced increasing pressure on its disposal capacity, with over one million tonnes of waste reportedly deposited annually. Its proximity to residential areas has raised environmental concerns, particularly regarding potential effects on the surrounding environment. The continued accumulation of waste highlights the importance of effective landfill management and monitoring to protect air, soil, and groundwater quality and to support the development of more sustainable waste management practices (Zafar, 2026).

Furthermore, given the limited geographical area and the increasing demand

for land and land uses as a result of urban development (Fahmi Jamal & Abd El-Fattah, 2023; Abbas, 2019). Therefore, it has become urgently necessary to find sustainable alternatives for waste management in the Kingdom of Bahrain, transform it into a resource, and divert it from landfills.

2.4. Sustainable Waste Management Initiatives in the GCC Countries

Several GCC countries have begun to act to address waste management challenges by introducing sustainable solutions, backed by government initiatives and private sector involvement.

- Saudi Arabia's Vision 2030: Saudi Arabia's Vision 2030 aims to reduce waste sent to landfills and encourage recycling, with the goal of diverting 85% of waste from landfills by 2030. The Saudi government has allocated substantial investments in recycling infrastructure and waste-to-energy technologies.
- UAE: The UAE has adopted ambitious recycling targets, with Dubai targeting a zero-waste city by 2050. The government has implemented policies that encourage businesses and households to reduce, reuse, and recycle. Additionally, the Dubai Waste Management Centre facilitates the sorting and recycling of construction waste.
- Qatar has focused on integrating waste management into its national development plans.
- The Qatar Waste Management and Recycling Centre was established to handle recycling and minimize landfill dependence, promoting sustainability across both residential and industrial sectors.
- Bahrain has recently established the Waste Management Center (Estidama) to support the transition to a more sustainable waste management practices and implement the Waste management strategy.

2.5. Challenges to Effective Waste Management in the GCC Countries

According to a report published by the Emirates News Agency (WAM, 2025), based on GCC-STAT data, the total waste collected across GCC countries reached approximately 262.7 million tonnes in 2023, representing a 153.7% increase compared with 2019. During the same period, treated waste increased to 192.0 million tonnes, while household waste generation declined to 1.4 kg per capita per day, a reduction of 17.4%. Non-hazardous waste accounted for 99.2% of collected waste, whereas hazardous waste management involved substantial reliance on exports for treatment, particularly for metal recovery and recycling. In 2023, the GCC countries achieved a 30% rate of hazardous waste recycling and reuse, in line with Sustainable Development Goal 12.

Waste generation trends varied by sector. Household waste collected decreased from its 2020 peak of 35.5 million tonnes to approximately 30.8 million tonnes in 2023. Conversely, agricultural waste increased to 2.5 million tonnes, while munic-

ipal waste from other economic activities reached 14.3 million tonnes. Developments in hazardous and medical waste management included an increase in medical waste incineration facilities to 23 sites in 2023, with a combined design capacity of 207,500 tonnes. These trends reflect the expanding scope of waste management activities and the continuing development of treatment and resource recovery infrastructure across the region (WAM, 2025).

Furthermore, it was estimated that the GCC countries waste management market will reach approximately USD 68.3 billion in 2025 and is projected to grow to USD 97.4 billion by 2030, at a compound annual growth rate of 7.4%. These projections indicate expanding investment and economic activity in the sector, reinforcing the importance of integrated waste management systems, improved treatment capacity, and resource recovery to support sustainable development across the GCC countries (WAM, 2025).

Waste management practices across the Gulf Cooperation Council (GCC) countries have traditionally included landfill disposal, particularly for municipal solid waste (MSW). Alongside these practices, recycling and resource recovery initiatives have gradually expanded, although source separation and the development of integrated waste management systems vary across countries (Alhakbany et al., 2018).

According to GCC-STAT (2023), approximately 93.6 million tonnes of hazardous and non-hazardous waste were collected across the GCC countries in 2019. Non-hazardous waste accounted for 98.2% of the total, while hazardous waste represented 1.8%. The collected hazardous waste included industrial and medical waste, batteries, electronic waste, and other hazardous materials. Industrial waste constituted approximately 90% of hazardous waste, whereas construction waste represented around 61% of non-hazardous waste. The report further indicated that 77.5% of collected waste was treated, with non-hazardous waste accounting for 98.6% of the treated quantity. Among the reported management methods, landfill disposal remained significant, accounting for approximately 84% of non-hazardous waste, while recycling represented 16%, an increase of 1.9% compared with 2019. For hazardous waste, approximately 43% was recycled, 33% was disposed of in designated hazardous waste landfills, and 17% was stored, with the remainder treated through other methods, including incineration (GCC-STAT, 2023).

These figures highlight the importance of improving waste data collection, treatment coverage, and resource recovery across the region. Further clarification of waste treatment and disposal pathways, particularly for waste not included in the reported treatment categories, would support more comprehensive environmental assessments and informed policy development. Effective monitoring and appropriate waste management practices are important for minimizing potential impacts on soil, water, air quality, and public health (Varshney et al., 2022).

Electronic waste (e-waste) represents another emerging area of waste management in the GCC countries. Widmer (2023) reported that dedicated e-waste legislation and management frameworks differed across the member states, with fur-

ther opportunities to strengthen regulatory and operational coordination. Kuwait and Saudi Arabia were identified as major e-waste generators in the region, while Bahrain faces particular constraints associated with its limited disposal capacity. In Bahrain, electronic waste has been reported to enter municipal waste disposal streams, highlighting the potential benefits of improved source separation and dedicated collection systems. Across the GCC region, private-sector companies, non-governmental organizations, and other initiatives have contributed to e-waste recycling and the recovery of materials such as plastics, metals, and electronic components. These efforts provide a foundation for further development of coordinated collection, recycling, and environmentally sound treatment systems.

Overall, the GCC countries have opportunities to build on existing waste management infrastructure and recycling initiatives through improved source separation, reliable waste statistics, dedicated e-waste management frameworks, and expanded recovery technologies. Such measures can support a gradual transition toward more integrated and resource-efficient waste management systems, while reflecting the differing environmental, economic, and institutional circumstances of each member state.

E-waste management practices and infrastructure vary across the GCC countries. Oman and Qatar have acknowledged the importance of strengthening e-waste management, including the development of appropriate regulations and treatment facilities. In the UAE, dedicated e-waste classification and sorting activities have been reported at certain waste management centers, alongside efforts to develop regulatory frameworks and recycling infrastructure. These developments reflect growing regional recognition of the need for specialized e-waste collection, treatment, and resource recovery systems (Iattoni et al., 2021). Given the potential presence of hazardous constituents, including heavy metals and certain chemical substances, e-waste requires appropriate handling and environmentally sound treatment.

Landfill disposal remains an important component of waste management across the GCC countries, making landfill design, operation, and environmental monitoring important considerations for sustainable waste management. Depending on their design and management, disposal sites may present risks associated with leachate generation and landfill gas emissions. Leachate can contain dissolved chemicals, heavy metals, and microorganisms, while the decomposition of organic waste under anaerobic conditions generates landfill gas, primarily comprising methane and carbon dioxide (Micales & Skog, 1997). Methane is a potent greenhouse gas, and its capture can provide opportunities for energy recovery while reducing emissions. Accordingly, landfill gas collection, leachate management, and groundwater monitoring are important measures for improving environmental performance and supporting resource recovery (Gupta et al., 2022).

The potential interaction between landfill operations and groundwater resources is particularly relevant in arid regions, where water resources are limited. Leachate migration and inadequate wastewater management may affect groundwater and

surface water quality, depending on local hydrogeological conditions and landfill management practices (Young & Parker, 1983).

An example from Oman is the Barka area, where the relationship between landfill activities, wastewater disposal, and groundwater quality has been investigated. Baawain and Al-Futaisi (2014) assessed groundwater quality using inorganic, organic, and microbiological indicators in samples collected from supply wells. Their findings identified variations in total dissolved solids and several chemical constituents, including chloride, sodium, magnesium, and sulphate, indicating differences in groundwater chemistry and the potential influence of surrounding pollution sources. The study also reported concerns relating to metal concentrations, biochemical oxygen demand, chemical oxygen demand, and total coliform counts. The findings highlighted the importance of appropriate wastewater management and continued groundwater quality monitoring in the vicinity of landfill facilities.

Overall, these studies emphasize the value of integrating engineered landfill management, leachate treatment, landfill gas recovery, and systematic environmental monitoring into regional waste management strategies. Strengthening these measures, alongside waste prevention, source separation, and recycling, can contribute to the protection of water resources, improved environmental performance, and the gradual development of more sustainable waste management systems across the GCC countries.

Environmental pressures associated with waste and wastewater management have been reported in several GCC countries. In Kuwait, recurring fish mortality events have raised concerns regarding the condition of marine ecosystems, while in Bahrain, the Tubli Bay area has experienced environmental pressures associated with wastewater and sludge management. Tubli Bay is an ecologically important coastal area that historically supported mangrove vegetation, biodiversity, and migratory birds. Al-Matouq and Bushaibah (2024) highlighted the importance of improving wastewater treatment and sludge management to reduce potential pressures on coastal ecosystems and associated water quality. These observations also illustrate the interconnected environmental, social, and economic dimensions of sustainable waste and wastewater management in densely populated and land-constrained areas.

Plastic waste represents another important component of the GCC countries waste stream, accounting for approximately 30% of household waste according to the cited literature. Plastic entering marine environments can fragment into smaller particles, including microplastics, which may persist in aquatic ecosystems and enter food webs. This has increased scientific interest in the environmental fate and potential human exposure associated with marine plastic pollution (Stöfen-O'Brien et al., 2022). Consequently, improving plastic waste collection, source separation, recycling, and material recovery can provide environmental benefits while also supporting resource efficiency.

The transition toward sustainable waste management is increasingly aligned

with the broader objectives of the Sustainable Development Goals, particularly SDG 12 on responsible consumption and production. Recycling, waste-to-energy, waste prevention, and resource recovery initiatives have consequently received increasing attention across the GCC countries. Examples include waste-to-energy and recycling projects developed or planned in countries such as the UAE and Qatar. These developments indicate a gradual shift from predominantly disposal-based approaches toward systems that place greater emphasis on resource recovery and the efficient use of materials.

The circular economy provides a framework for further advancing this transition. Rather than following a linear model of resource extraction, use, and disposal, circular approaches emphasize waste prevention and the continued use of materials through reuse, sharing, repair, refurbishment, remanufacturing, and recycling. Such approaches can reduce demand for virgin resources, waste generation, pollution, and associated carbon emissions while creating opportunities for economic diversification and resource efficiency (Tascione et al., 2021). For the GCC countries, circular-economy principles may therefore complement existing recycling and waste-to-energy initiatives and support longer-term environmental and economic objectives.

In Saudi Arabia, the National Center for Waste Management (MWAN) has highlighted the economic and environmental significance of improving waste management. According to information reported by the Center, environmental degradation associated with solid waste in the Kingdom was estimated at approximately USD 1.3 billion in 2021. The Center has also reported annual waste generation of approximately 53 million tonnes, emphasizing the scale of the resource-management challenge and the potential value of increasing recovery and recycling.

Saudi Arabia has established targets to expand recycling and strengthen the national waste management system. These targets include increasing the recycling of different waste streams and generating environmental and socioeconomic benefits through improved resource recovery. The reported objectives for 2035 include reducing approximately 13 million tonnes of CO₂ emissions, attracting USD 1.6 billion in foreign direct investment, creating approximately 23,000 jobs, and contributing an estimated USD 9.9 billion to national GDP. These targets illustrate the potential for sustainable waste management to contribute simultaneously to environmental protection, resource efficiency, and economic development.

Overall, the GCC region is progressively developing waste management approaches that combine improved collection and treatment infrastructure with recycling, waste-to-energy, resource recovery, and circular-economy principles. Future progress would benefit from greater emphasis on waste prevention and reduction at source, sustainable consumption and production, improved source separation, accurate and comparable waste data, and environmentally sound treatment of residual waste. Such measures can strengthen the environmental performance of the waste sector while supporting the region's broader sustainability and resource-efficiency objectives.

2.6. Perspectives

- Several complementary pathways can support the continued development of sustainable waste management systems across the GCC countries. These include strengthening community awareness of sustainable consumption patterns, supporting the growth of the regional waste management market, and integrating circular economy strategies with national waste management plans.
- Investment in sustainable waste management infrastructure and appropriate treatment technologies represents an important opportunity for the region. Technologies such as anaerobic digestion and advanced waste-to-energy systems can contribute to energy recovery and resource efficiency when appropriately designed and managed (Küfeoğlu, 2024). Similarly, composting can facilitate the recovery of organic waste and its conversion into useful soil amendments for agricultural applications, both locally and potentially for wider markets.
- Strengthening institutional coordination through integrated legislative and regulatory frameworks may further support the development of the waste management sector. Greater coordination among relevant authorities, together with effective source-separation systems, can improve the quality of recovered materials and enhance the efficiency of recycling, composting, and other treatment technologies (Ansar et al., 2025).
- Sustainable lifestyles, informed consumer behaviour, responsible purchasing, and capacity building are also important components of waste prevention and resource efficiency. In parallel, the adoption of sustainable and green supply-chain practices across different industries can contribute to more sustainable production and consumption patterns and support the objectives of Sustainable Development Goal 12.
- Waste generation in the GCC countries is influenced by demographic, economic, and developmental factors. A 2020 GCC Secretariat report estimated annual MSW generation at approximately 50 million tonnes, with projections indicating substantial growth by 2030 (Hameed et al., 2022). Key factors contributing to waste generation include:
 - **Urbanization and population growth:** Continued urban development and population growth increase the demand for goods, services, housing, and infrastructure, consequently influencing waste generation.
 - **Consumption patterns:** Increasing household purchasing power and consumption levels, particularly in rapidly developing economies, contribute to higher quantities of packaging and consumer waste.
 - **Industrial and construction activities:** Large-scale infrastructure and urban development projects generate substantial quantities of construction and demolition (C&D) waste.
 - **Food waste:** Food waste represents an important component of the regional waste stream, with considerable quantities generated across households, commercial activities, and the food-service sector (GCC-STAT, 2023).
- The waste stream in the GCC countries generally includes substantial propor-

tions of organic materials, paper, plastics, and C&D waste. In particular, the prevalence of plastic materials highlights the potential for expanding source separation, recycling, material recovery, and circular-economy applications. Collectively, these approaches can contribute to waste prevention, improved resource efficiency, and the gradual transition toward more sustainable and circular waste management systems in the GCC region.

3. Waste Management Practices, Systems and Market

Waste management systems across the GCC countries are evolving in response to increasing waste generation, urban development, and the growing emphasis on environmental sustainability. Historically, waste management has largely focused on collection, transportation, and final disposal, while the adoption of waste prevention, source segregation, recycling, and resource recovery has progressed at different rates across countries and waste streams. More recently, circular economy principles have gained greater attention within national environmental and development agendas, encouraging a gradual shift from predominantly disposal-oriented approaches toward integrated waste management, resource efficiency, material recovery, and sustainable treatment technologies. This transition is supported by the development of national strategies, regulatory frameworks, infrastructure, and investments aimed at improving waste prevention, recycling, recovery, and the efficient use of resources under the specific environmental and socioeconomic conditions of the GCC region (Hemidat et al., 2022).

The GCC countries waste management market has experienced substantial growth in recent years, reflecting increasing demand for waste collection, treatment, recycling, and resource-recovery services across the region. According to *Fortune Business Insights* (2026), the GCC countries waste management market was valued at approximately USD 70.97 billion in 2025 and is projected to increase from USD 75.59 billion in 2026 to USD 109.74 billion by 2034, representing a compound annual growth rate (CAGR) of 4.77%. The report identifies Saudi Arabia as the largest national market within the GCC countries, accounting for 35.37% of the market in 2024, with continued growth anticipated in response to expanding waste management infrastructure, regulatory developments, and investments in sustainable waste treatment and resource recovery.

3.1. Waste Collection and Transportation

Waste collection across the GCC region is generally provided through public-sector services, private contractors, or a combination of both. Collection systems are relatively well established in major urban areas, with collected waste subsequently directed to landfills, treatment facilities, or waste-to-energy facilities, depending on the waste stream and available infrastructure.

Saudi Arabia: The Kingdom is progressively developing its waste management systems, with major urban centers such as Riyadh and Jeddah implementing organized waste collection and disposal services as part of broader efforts to improve

resource recovery and environmental performance.

United Arab Emirates: The UAE has incorporated digital technologies into waste collection in some urban areas. In Dubai, for example, smart collection systems incorporating sensors and identification technologies have been introduced to monitor waste levels and support more efficient collection and operational planning.

Despite the substantial and growing volume of material flows, recycling activities remain limited relative to the overall scale of material generation at the GCC region level (GCC-STAT, 2023; Islam, 2026; Zafar, 2025).

3.2. GCC Countries Circular Economy Benchmarking

A recent study conducted by Aljaradin and Azzuni (2025) indicated substantial variation in circular-economy development and waste-management performance across the GCC countries. In 2022, the UAE recorded a recycling rate of 94.5% for treated non-hazardous waste, while recycling rates reported for several other GCC countries were considerably lower, highlighting differences in waste-treatment infrastructure and resource-recovery practices (Aljaradin & Azzuni, 2025). Qatar has established a target to reduce greenhouse-gas emissions by 25% by 2030, while Saudi Arabia has set a target of diverting 82% of waste from landfills as part of its longer-term waste-management strategy. Bahrain, Kuwait, and Oman have likewise introduced national and sector-specific initiatives supporting waste recovery, recycling, and circular-economy development. Across the region, the transition toward a circular economy is supported by several interconnected factors, including integrated policy and regulatory frameworks, technological innovation, appropriate financing mechanisms, stakeholder participation, and regional cooperation. Economic assessments have estimated that comprehensive circular-economy adoption could generate substantial economic value across the GCC region, including potential savings of approximately USD 138 billion by 2030 and the creation of up to 77,000 jobs in Saudi Arabia. These estimates should be interpreted as potential outcomes rather than achieved benefits and are dependent on the extent and effectiveness of future circular-economy implementation (Aljaradin & Azzuni, 2025).

According to GCC-STAT (2023) and Islam (2026), recycling across the GCC region remains relatively limited compared with the scale of waste generation and international circular-economy objectives. Nevertheless, all GCC countries have introduced policies, programs, or initiatives aimed at increasing recycling and improving resource recovery. In the UAE, for example, Dubai has pursued waste-diversion initiatives, including the expansion of recycling infrastructure, the provision of recycling bins in public areas, public awareness programs, and incentives encouraging businesses to adopt more sustainable practices. Qatar has also established targets under its National Waste Management Strategy to reduce waste generation, increase recycling, and promote resource recovery. Despite these ongoing efforts, recycling performance varies considerably across the GCC region, reflect-

ing differences in waste composition, infrastructure, collection and segregation systems, and reporting methodologies. Some studies have reported relatively low recycling rates for particular waste streams or countries, indicating that further development of source segregation, recycling infrastructure, and resource-recovery systems remains important for advancing circular-economy practices in the region (GCC-STAT, 2023; Islam, 2026; Zafar, 2022).

3.3. Waste-to-Energy (WTE) Projects

Waste-to-energy (WTE) technologies represent an important option for reducing the environmental impacts associated with waste disposal while supporting resource recovery and energy generation in the GCC countries.

As part of efforts to reduce reliance on landfilling and increase resource recovery, several GCC countries have begun investing in waste-to-energy (WTE) facilities that convert non-recyclable waste into energy. The UAE has developed major WTE infrastructure, including the facility in Dubai, which was designed to process approximately 1.9 million tonnes of waste annually. Saudi Arabia and Qatar have also been developing and planning WTE projects as part of broader waste-management and sustainability strategies. These initiatives reflect the growing interest across the GCC region in integrating energy recovery into waste-management systems while supporting resource efficiency and reducing the environmental impacts associated with waste disposal.

According to Alghafis et al. (2025), Saudi Arabia has identified the development of approximately 3 GW of WTE capacity by 2030 as part of its broader sustainability initiatives. However, the wider adoption of WTE across the GCC region may be influenced by factors such as regulatory requirements, financing needs, technological considerations, and public acceptance. Advancing sustainable waste management in the GCC countries will therefore require supportive policy frameworks, collaboration among relevant stakeholders, appropriate investment in WTE and other resource-recovery technologies, and continued public awareness and education. These measures can contribute to improving waste-resource efficiency and supporting the region's broader environmental and sustainability objectives.

WTE plants are being developed in some GCC countries, e.g., UAE and Qatar, which not only help reduce the volume of waste but also generate electricity. For example, Dubai's Al Qusais WTE Plant is capable of processing up to 1000 tons of waste per day and converting it into energy.

3.4. Effective Waste Management Limitations in the GCC Countries

(1) Cultural and Behavioral Factors

Public awareness, consumption patterns, and household waste-management practices can influence the effectiveness of waste-management systems across the GCC countries. Source segregation at the household level remains at different stages of development among GCC countries, highlighting the importance of continued public awareness, environmental education, and community engagement. Strength-

ening these efforts can encourage waste prevention, source separation, recycling, and more sustainable consumption practices.

(2) Infrastructure Limitations

Although GCC countries have made significant investments in waste-management infrastructure, the capacity and technological development of facilities vary across countries and waste streams. Further development of waste-sorting and material-recovery facilities, recycling plants, composting facilities, and other treatment technologies can support greater resource recovery and reduce reliance on final disposal. Improving collection systems and strengthening monitoring and enforcement mechanisms can also contribute to more effective and integrated waste management (Mani, 2026).

(3) Landfill Capacity

Landfilling continues to play an important role in managing residual waste across the GCC region. However, continued urban growth and increasing waste generation can place additional pressure on available landfill capacity. Environmental considerations, including methane emissions and the potential risks associated with soil and groundwater contamination, further highlight the importance of developing waste-prevention, recycling, resource-recovery, and alternative treatment options to reduce the volume of waste requiring final disposal.

(4) Economic and Institutional Factors

The development of sustainable waste-management systems requires adequate and sustained financial resources, effective institutional coordination, and supportive policy frameworks. Differences in investment priorities, financing mechanisms, regulatory capacity, and coordination among governmental and other relevant stakeholders can influence the implementation of waste-management strategies across the GCC region. Strengthening institutional cooperation, financing mechanisms, regulatory frameworks, and long-term planning can therefore support the effective implementation of national waste-management policies and circular-economy initiatives.

(5) Waste Management Infrastructure and Practice Limitations

Waste-management infrastructure and practices across the GCC region have developed considerably; however, differences in infrastructure capacity, technological development, and waste-treatment options remain among the factors influencing the transition toward more sustainable waste management. The extent of source segregation, recycling, resource recovery, and alternative treatment varies among countries and waste streams, while final disposal continues to represent an important component of waste management.

(6) Landfill Use and Environmental Considerations

Landfilling remains an important pathway for managing residual waste in several GCC countries. Historical estimates have indicated high levels of landfill dependence in countries such as Saudi Arabia and Kuwait. Such reliance can increase pressure on existing disposal capacity, particularly in the context of continued urban development and waste generation. In addition, landfill management

requires consideration of potential environmental impacts, including methane emissions and risks to soil and groundwater. These factors highlight the need to strengthen waste prevention, source segregation, recycling, resource recovery, and alternative treatment capacity to reduce the volume of waste requiring final disposal.

(7) Recycling and Waste-Sorting Limitations

Although recycling and waste-sorting initiatives have expanded across the GCC countries, their implementation remains variable among countries and waste streams. Limitations include differences in collection and source-separation systems, sorting and material-recovery infrastructure, market demand for recovered materials, and levels of public participation. In the UAE, for example, waste-diversion and recycling initiatives have been developed through national and local programs, while Qatar has introduced initiatives targeting improved management and recovery of construction and demolition waste (Zafar, 2025; Mariyam et al., 2022). Further strengthening of source segregation, collection systems, sorting facilities, recycling capacity, and public engagement could help address these limitations and increase the recovery of materials from the waste stream.

4. Future Directions in Waste Management

(1) Technological Innovations

The continued adoption of advanced technologies is expected to support the development of more efficient and sustainable waste-management systems across the GCC countries. Emerging solutions, including artificial intelligence (AI)-assisted waste sorting, automated recycling and material-recovery systems, digital monitoring, and blockchain-based waste tracking, may improve operational efficiency, enhance material recovery, and strengthen the monitoring of waste flows. The applicability of these technologies will depend on local infrastructure, technical capacity, economic feasibility, and regulatory conditions.

(2) Circular Economy Adoption

The transition toward circular-economy approaches is receiving increasing attention across the GCC countries, with greater emphasis on waste prevention, reuse, recycling, resource recovery, and efficient use of materials. Saudi Arabia's Circular Carbon Economy framework represents one example of national efforts to promote resource efficiency and reduce greenhouse-gas emissions as part of broader sustainability objectives (Saudi Vision 2030, 2021). Continued integration of circular-economy principles into waste-management policies can support the development of more resource-efficient and resilient systems across the region.

(3) Public-Private Partnerships (PPPs)

Greater participation of the private sector may contribute to the development and modernization of waste-management infrastructure in the GCC countries. Public-private partnerships (PPPs) can provide mechanisms for mobilizing investment, introducing technological expertise, and supporting the development and operation of recycling, treatment, resource-recovery, and waste-to-energy facilities.

Effective PPPs require clear regulatory frameworks, appropriate financial mechanisms, transparent responsibilities, and long-term institutional coordination.

(4) Domestic Waste Generation and Management

Domestic waste generation in the GCC countries has increased over recent decades in association with population growth, urbanization, economic development, and changing consumption patterns. The magnitude and composition of household waste vary among countries and are influenced by demographic, socioeconomic, and consumption characteristics. Continued urban development and increasing waste generation highlight the importance of strengthening waste-prevention measures, collection systems, source segregation, recycling, and resource-recovery capacity.

Household waste in the GCC countries generally contains substantial proportions of organic materials, together with plastics, paper, and other recyclable materials. However, the extent of source segregation, recycling, and recovery varies among countries and waste streams. Further development of separate collection, sorting, recycling, composting, and other treatment infrastructure could increase the recovery of valuable materials and reduce the quantity of residual waste requiring final disposal. In countries where landfill capacity is subject to increasing pressure from urban development and waste generation, improving waste prevention and diversion from final disposal can also contribute to more sustainable long-term waste-management systems.

As an example of managing Composting and Biodegradable Waste: Oman and Bahrain have developed small-scale composting facilities that turn organic waste into valuable compost, reducing landfill dependency and providing environmentally friendly soil for agriculture.

5. Waste Management Technologies in the GCC Countries

The increasing emphasis on sustainable waste management across the GCC countries has encouraged the adoption and development of technologies aimed at improving waste treatment, resource recovery, and reducing reliance on final disposal. These technologies include waste-to-energy (WTE), recycling and material-recovery systems, advanced waste-sorting and separation processes, composting, anaerobic digestion, and other treatment technologies. Their application varies among GCC countries according to waste characteristics, infrastructure, technical capacity, investment requirements, regulatory frameworks, and local environmental conditions (Al-Saidi, 2021). The following sections examine the main waste-management technologies implemented or proposed across the GCC region.

5.1. Waste-to-Energy (WTE) Technologies

Waste-to-energy (WTE) technologies have emerged as a leading solution for managing waste in the GCC countries. These technologies convert waste materials into usable energy, typically electricity or heat, through processes like: incineration, pyrolysis, and gasification (Abbas, 2019; Porshnov, 2022).

(1) Incineration and Combined Heat and Power (CHP) Systems

Incineration is one of the most widely used WTE technologies in the GCC region, with plants designed to burn waste at high temperatures, reducing its volume and generating energy. The UAE, particularly Dubai, has made significant strides in this area with the construction of the Dubai Waste-to-Energy Plant, the world's largest single-site WTE facility. This plant processes 1.9 million tons of municipal waste annually, generating 200 MW of electricity, enough to power 135,000 homes.

- **Technology Benefits:** Incineration significantly reduces the amount of waste that ends up in landfills, helps lower greenhouse gas emissions, and provides an alternative energy source. The UAE's WTE plant, for example, is designed to reduce carbon emissions by offsetting the need for fossil fuel-based power generation.
- **Challenges:** While incineration helps in reducing waste volume, it can have high capital and operational costs and raises concerns about air pollution from emissions.

(2) Gasification and Pyrolysis

Gasification and pyrolysis are alternative thermal treatment methods that convert organic waste into synthetic gas or bio-oil, which can then be used to produce energy. Saudi Arabia and Oman are exploring gasification as part of their renewable energy strategies. Saudi Aramco, in collaboration with local partners, is investigating the potential of waste gasification to produce syngas for power generation.

- **Technology Benefits:** These technologies can process a wider range of waste, including hazardous and non-recyclable materials. They also produce cleaner emissions compared to traditional incineration.
- **Challenges:** High energy consumption for these processes and the complexity of scaling these systems in the region's hot desert climate are some of the barriers to widespread adoption.

5.2. Recycling Technologies

Recycling plays a pivotal role in sustainable waste management by recovering valuable materials from waste and reducing the need for virgin resources. Several advanced recycling technologies are being implemented in the GCC countries to enhance recycling efficiency (Awogbemi et al., 2022).

(1) Mechanical Biological Treatment (MBT)

Mechanical biological treatment (MBT) is a waste management technology that combines mechanical sorting and biological processes like composting to treat waste. The UAE and Qatar are increasingly adopting MBT systems to handle municipal waste more efficiently. For example, the Qatar National Waste Management Strategy emphasizes the expansion of MBT plants to treat organic waste and improve recyclability (Abbas, 2019). **Technology Benefits:** MBT systems help segregate recyclable materials and produce compost from organic waste. They also reduce the volume of waste sent to landfills and help extend landfill lifespan.

- **Challenges:** While MBT technologies improve recycling rates, they require high investment costs and the development of suitable waste sorting infrastructure.

(2) Automated Sorting Systems

The GCC countries are increasingly adopting automated waste sorting technologies that use artificial intelligence (AI), robotics, and machine learning to sort recyclable materials from mixed waste streams. In Dubai, the Dubai Carbon Centre of Excellence has introduced advanced automated sorting systems that utilize AI and optical sorting to separate recyclables like paper, plastics, metals, and glass.

- **Technology Benefits:** These systems improve sorting accuracy, reduce labor costs, and increase recycling rates. They can also process large volumes of mixed waste efficiently.
- **Challenges:** High upfront costs for implementing these systems and the need for continuous maintenance are key challenges. Also, public awareness about waste segregation is crucial for the success of automated systems.

(3) Organic Waste Treatment Technologies

Organic waste, which comprises a significant portion of municipal waste, presents an opportunity for resource recovery through composting and anaerobic digestion (Babu et al., 2021).

(4) Anaerobic Digestion

Anaerobic digestion (AD) is a biological process that breaks down organic waste in the absence of oxygen, producing biogas that can be used for power generation (Induchoodan et al., 2022). The UAE and Saudi Arabia have started to incorporate AD technology in managing organic waste, particularly food waste from commercial and industrial sources.

- **Technology Benefits:** AD technology reduces the volume of organic waste, generates renewable energy in the form of biogas, and produces nutrient-rich digestate that can be used as fertilizer.
- **Challenges:** High initial investment and the need for specialized infrastructure for food waste collection and processing are key barriers to widespread implementation.

(5) Composting

Composting is the process of decomposing organic waste into humus, which can be used as a natural fertilizer. The UAE, Qatar, and Oman have started to promote large-scale composting projects to manage organic waste and create valuable products for the agricultural sector.

- **Technology Benefits:** Composting is low-cost and can be applied to a wide range of organic waste materials. It is particularly useful in the GCC countries' agricultural and landscaping industries.
- **Challenges:** The scale of composting operations in the region is still limited, and there is a need for more infrastructure to collect and process organic waste efficiently.

5.3. Challenges

- **High Capital Costs:** Many sustainable waste management technologies require significant investment, which can be a barrier for GCC countries to scale these solutions effectively (Khan et al., 2024).
- **Public Awareness:** A lack of awareness about the importance of waste segregation and recycling remains a major challenge in the GCC countries. Public education campaigns are essential to support the successful implementation of these technologies.
- **Climate and Environmental Conditions:** Extreme temperatures and harsh environmental conditions in the GCC region can affect the performance of certain technologies, particularly in waste collection, sorting, and biological processes (Moossa et al., 2022).
- **Regulatory and Policy Issues:** Clear, consistent policies and regulations are crucial to incentivize the adoption of sustainable waste management technologies.

5.4. Opportunities

- **Integration with Renewable Energy:** As GCC countries work to diversify their energy sources, integrating WTE technologies with renewable energy production can help meet sustainability goals.
- **Public-Private Partnerships (PPPs):** PPPs are essential for mobilizing the resources needed for large-scale waste management infrastructure. Many GCC countries are already exploring PPP models to finance and operate WTE plants and recycling facilities (Vassileva, 2022).
- **Technological Advancements:** The GCC countries' focus on technological innovation provides an opportunity to introduce cutting-edge waste management technologies, such as blockchain for waste tracking and AI for waste sorting.

5.5. Emerging Technologies and Sustainable Solutions

Sustainable waste management technologies in the GCC countries are evolving, with waste-to-energy, advanced recycling systems, and organic waste treatment technologies playing a pivotal role in reducing environmental impacts. Despite challenges such as high costs, public awareness, and climate conditions, the region is making significant strides toward adopting these technologies. With the right policies, investments, and partnerships, the GCC countries have the potential to become a leader in sustainable waste management in the Middle East (Alghafis et al., 2025).

5.6. Waste Composition

Across the GCC countries, household waste is typically composed of:

- Organic waste (food scraps, yard waste): 40% - 50%.
- Plastics: 15% - 25%.
- Paper and cardboard: 15% - 20%.
- Metals: 5% - 10%.

- Others (glass, textiles, etc.): 10% - 20%.

The predominance of organic waste in the region reflects dietary habits, while plastic waste is a direct result of high consumption and packaging use, and both are relevant to the income level.

5.7. Environmental and Health Impacts of Poor Waste Management

Inadequate waste management practices can contribute to a range of environmental and public health concerns across the GCC countries. The environmental implications are influenced by waste composition, disposal methods, landfill management practices, and local environmental conditions. Key concerns include:

Air pollution: The decomposition of organic waste under anaerobic conditions in landfills can generate methane, a potent greenhouse gas. In addition, uncontrolled waste burning may release particulate matter and other air pollutants.

Water contamination: Landfill leachate, if not adequately collected and treated, may migrate into surrounding soil and water resources and potentially affect groundwater quality.

Public health risks: Inadequate waste collection, storage, and disposal can create conditions that support the proliferation of pests and may increase exposure to environmental contaminants. Open burning of waste can also contribute to respiratory exposure to particulate matter and other combustion-related pollutants.

These potential environmental and health impacts highlight the importance of improving waste collection, controlled disposal, landfill management, source segregation, recycling, and resource-recovery practices across the GCC countries. Consideration of local climatic and environmental conditions is also important when designing and operating waste-management systems to minimize emissions, leachate generation, and other potential environmental impacts.

6. Conclusion

Waste management in the GCC countries is undergoing a gradual transition from predominantly disposal-oriented systems toward more integrated approaches that emphasize waste prevention and reduction, source separation, recycling, material and energy recovery, engineered treatment, and circular-economy principles. This transition is reflected in national waste-management strategies, regulatory developments, infrastructure investments, and the increasing adoption of recycling, resource-recovery, and waste-to-energy initiatives. However, the pace and extent of progress vary among countries and across waste streams, reflecting differences in waste composition, population growth, infrastructure capacity, institutional arrangements, regulatory frameworks, investment mechanisms, and data availability. Consequently, regional progress should be assessed using clearly defined indicators that distinguish between policy targets, planned infrastructure, operational capacity, and documented waste-management outcomes.

Landfilling is expected to remain an important component of waste management

in the GCC countries in the near term, particularly for residual waste that cannot be prevented, reused, recycled, or otherwise recovered. Nevertheless, a sustainable long-term approach should progressively reduce the quantity of waste requiring final disposal while improving the environmental performance of remaining disposal facilities. This requires greater emphasis on the waste-management hierarchy, beginning with prevention and reduction, followed by reuse, recycling and material recovery, appropriate treatment and energy recovery, and environmentally sound final disposal for unavoidable residuals.

Strategic Priorities for Sustainable Waste Management in the GCC Countries

Several strategic priorities emerge from this review. First, waste prevention and reduction should receive greater attention as the foundation of sustainable waste management. Policies and programs should promote sustainable consumption and production, resource efficiency, waste-conscious lifestyles, product durability, reuse, and the reduction of unnecessary material consumption. Addressing waste generation at its source can reduce pressure on collection, treatment, recycling, and disposal systems while supporting more efficient use of natural resources.

Second, reliable and comparable waste data should be established as a regional priority. Accurate, consistent, and transparent data are fundamental for assessing waste-generation trends, comparing national performance, designing infrastructure, evaluating environmental impacts, and supporting evidence-based policymaking. Future assessments should clearly distinguish between municipal solid waste and other waste categories, including construction and demolition waste, industrial waste, hazardous waste, e-waste, and wastewater sludge, while also reporting the relevant geographical coverage, population basis, units, and year of measurement. Harmonized data definitions and reporting methodologies across the GCC countries would substantially strengthen regional benchmarking and reduce uncertainty in waste-management planning.

Third, source separation and recycling systems should be progressively strengthened. Expanding separate collection, sorting, material-recovery facilities, recycling infrastructure, and markets for recovered materials can increase the recovery of valuable resources and reduce the quantity of residual waste requiring disposal. Public participation is an important component of this transition; therefore, infrastructure development should be accompanied by sustained environmental education, community engagement, and practical incentives that encourage appropriate waste-separation and recycling practices.

Fourth, resource recovery and waste-to-energy (WTE) technologies should be developed according to local conditions and waste characteristics. WTE can provide an option for appropriate non-recyclable residual waste while reducing the volume requiring final disposal and recovering energy. However, its application should complement rather than displace waste prevention, reuse, and recycling, and should be evaluated according to technical feasibility, environmental performance, economic viability, emissions control, waste composition, and the availability of alternative recovery pathways.

Fifth, regulatory and institutional frameworks should be further strengthened. Effective implementation requires clear responsibilities among national and local authorities, appropriate monitoring and enforcement mechanisms, long-term planning, and coordination among government, industry, municipalities, and other stakeholders. Extended producer responsibility (EPR) and other policy instruments can support greater producer involvement in product and packaging design, collection, recycling, and end-of-life management. Public-private partnerships may also contribute to mobilizing investment and technical expertise where appropriate, provided that responsibilities, performance requirements, and environmental safeguards are clearly defined.

Sixth, regional cooperation within the GCC countries should be enhanced. The countries face several common challenges, including rapid urbanization, changing consumption patterns, increasing material flows, limited availability of land in some areas, and the need to develop economically viable recycling and recovery markets. Regional cooperation in data harmonization, technology assessment, research, capacity building, standards development, knowledge exchange, and investment can help address these shared challenges and facilitate the transfer of solutions that are technically and economically appropriate to GCC countries' conditions.

Seventh, research, innovation, and institutional capacity should be strengthened. Sustainable waste management requires continued research into waste characterization, prevention strategies, recycling technologies, organic-waste treatment, resource recovery, WTE, environmental impacts, life-cycle assessment, and circular business models. Capacity building through technical training, professional development, institutional strengthening, and collaboration between universities, research institutions, government agencies, and industry is essential for translating research findings into practical waste-management solutions. Emerging digital technologies, including advanced monitoring, data analytics, automated sorting, and artificial intelligence, may further support system efficiency where their technical and economic feasibility has been demonstrated.

Overall, the future of waste management in the GCC countries should be guided by a shift from managing waste primarily as a disposal problem toward managing materials as valuable resources within a circular-economy framework. This transformation will require coordinated action across the entire waste-management hierarchy, supported by reliable data, effective institutions, appropriate technologies, sustainable financing, private-sector participation, public engagement, and regional cooperation. Progress should be evaluated not only by the expansion of waste-treatment infrastructure or the achievement of diversion targets, but also by measurable reductions in waste generation, increased prevention and reuse, improved recycling and material recovery, reduced environmental impacts, and the environmentally sound management of unavoidable residual waste. By integrating these strategic priorities, the GCC countries can progressively improve resource efficiency, reduce environmental pressures, strengthen the resilience of waste-management systems, and support the region's broader sustainability and circular-economy objectives.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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