Social and Environmental Sustainability of Municipal Solid Waste in the Context of the UN Sustainable Development Goals

IEA Bioenergy: Task 36

February 2025

Image Source: UN (2025) *Note: The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.*

Social and Environmental Sustainability of Municipal Solid Waste in the Context of the UN Sustainable Development Goals

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Preface

This report focuses on the UN Sustainable Development Goals (SDGs) as a means to evaluate aspects of environmental, social, and economic sustainability of approaches to manage municipal solid waste (MSW). The report considers the important impacts relating to MSW as identified in the IEA Bioenergy Task 36 regional workshop series. The purpose of this report, as all the work carried out by Task 36, is to inform countries on the environmental and social issues around MSW, including quantification of impacts and potential solutions in the waste/resource management sector that would facilitate their transition towards sustainability. Each SDG is considered for its relation to MSW, the problems posed by MSW related to the SDG and potential solutions in MSW management for each SDG.

IEA Bioenergy Task 36, working on the topic 'Material and Energy Valorisation of Waste in a Circular Economy', seeks to raise public awareness of sustainable energy generation from biomass residues and waste fractions including MSW as well as to increase technical information dissemination. As outlined in the 3-year work programme, Task 36 seeks to understand what role waste-to-energy and material recycling can have in a circular economy and identify technical and non-technical barriers and opportunities needed to achieve this vision.

See Task 36 | Material and Energy valorisation of waste in a Circular Economy for links to the work performed by IEA Bioenergy Task 36.

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Summary

Globally, significant volumes of municipal solid waste (MSW) are being generated, and are continuing to grow, while being disposed of in sub-optimal ways resulting in environmental, social and economic impacts. It is estimated that MSW generation by households will reach 3.8 billion tons by 2050 if urgent action is not taken, this is a 56% increase compared to 2020 (UNEP, 2024c). Development of sustainable MSW management strategies must be prioritised by all actors in the value chains, including municipalities and industries, to mitigate environmental impacts, leading to healthier ecosystems and reduced contributions to climate change. Developing scientifically based sustainability metrics is required to give a sound basis for decisions regarding future treatment of MSW. A proper decision framework integrating all the main aspects of sustainability (economy, environment and social) is an enabler to ensure that the developed MSW management strategies are not sub-optimised in favour of short-term solutions.

The Sustainable Development Goals (SDGs), adopted by the UN member states in 2015, are now widely used as a means of tracking progress towards the more sustainable use of natural and human resources for the betterment of global society, and have been applied widely to MSW (Elsheekh et al., 2021, Abubakar et al., 2022, Ram and Bracci, 2024). Consideration of the SDGs is essential for building sustainable and equitable societies, as they provide a framework for addressing key challenges, including waste management and its impact on environmental and social sustainability. This report focuses on the SDGs which address aspects of environmental, social, and economic sustainability, related to the important impacts relating to MSW as identified in the IEA Bioenergy Task 36 regional workshop series. This report does not consider the full 17 SDGs, rather it considers MSW from the perspective of the environmental, social and economic impacts indicated as very important by the stakeholders participating in the Task 36 regional workshop series (Murphy and Gusciute, 2024). The SDGs considered in this report are:

- SDG2 – Zero Hunger
- SDG6 - Clean water and sanitation
- SDG7 - Affordable and clean energy
- SDG9 - Industry, innovation and infrastructure
- SDG10 – Reduced inequalities
- SDG12 - Responsible production and consumption
- SDG13 - Climate action
- SDG14 – Life below water
- SDG15 – Life on land

Each SDG is considered for its relation to MSW, the problems posed by MSW related to the SDG and potential solutions in MSW management for each SDG.

Context and Background

Globally, significant volumes of municipal solid waste (MSW) are being generated, and are continuing to grow, while being disposed of in sub-optimal ways resulting in environmental, social and economic impacts. It is estimated that municipal solid waste generation by households will reach 3.8 billion tons by 2050 if urgent action is not taken, this is a 56% increase compared to 2020 (UNEP, 2024c). MSW consists of everyday waste from households and includes items such as food waste, product packaging, garden waste, bulky waste such as furniture, clothes, plastic, newspapers, etc. It includes waste from commerce and trade, office buildings, street sweepings but excludes waste from municipal sewage networks and treatment and waste from construction and demolition activities as well as industrial waste.

Development of sustainable MSW management strategies must be prioritised by all actors in the value chain, including municipalities and industries, to mitigate environmental impacts, leading to healthier ecosystems and reduced contributions to climate change. Developing scientifically based sustainability metrics is required to give a sound basis for decisions regarding future treatment of MSW. A proper decision framework integrating all the main aspects of sustainability (economy, environment and social) is an enabler to ensure that the developed MSW management strategies are not sub-optimised in favour of short-term solutions. IEA Bioenergy Task 36 held a regional workshop series (South Africa, Ireland and North America) considering regionally relevant waste management systems with the participation of stakeholders in development of a life cycle sustainability framework to consider the most relevant sustainability indicators (Murphy and Gusciute, 2024). The workshop series identified sustainability indicators to be considered in this report on waste and sustainability.

The three workshops showed that stakeholders consider a holistic approach which considers social, environmental and economic factors to be necessary in the decision-making process relating to new waste management infrastructure. Across all three workshops, stakeholders rated environmental and social impacts to be the most important factors when deciding on new waste management infrastructure, with economic impacts ranked third (Murphy and Gusciute, 2024). The environmental and social impacts which were deemed to be the most important across the three workshops are mapped onto relevant United Nations (UN) Sustainable Development Goals (SDGs) for the purpose of this report. Table 1 details relevant impacts and SDGs considered.

Table 1: Impacts Identified in the IEA Bioenergy Task 36 Regional Workshop Series and Relevent SDGs

Impacts	Relevant SDGs
Environmental Impacts	
Global warming potential	SDG7 - Affordable and clean energy; SDG12 - Responsible production and consumption; SDG13 - Climate action; SDG14 – Life below water; SDG15 – Life on land.
Human toxicity	SDG6 - Clean water and sanitation; SDG7 - Affordable and clean energy; SDG14 – Life below water; SDG 15 –

Impacts	Relevant SDGs
	Life on land.
Resource consumption	SDG2 – Zero Hunger; SDG7 - Affordable and clean energy; SDG9 - Industry, innovation and infrastructure; SDG10 - Reduced inequalities; SDG12 - Responsible production and consumption; SDG13 - Climate action; SDG14 - Life below water; SDG15 – Life on land.
Heavy metals	SDG6 - Clean water and sanitation; SDG7 - Affordable and clean energy; SDG14 – Life below water.
Land use	SDG14 - Life below water; SDG15 – Life on land.
Energy recovery	SDG7 - Affordable and clean energy; SDG14 – Life below water; SDG15 – Life on land.
Nutrient and resource recovery	SDG7 - Affordable and clean energy; SDG9 - Industry, innovation and infrastructure; SDG14 – Life below water; SDG15 – Life on land.
Social Impacts	
Human Rights: Free from discrimination	SDG10 – Reduced inequalities.
Human Rights: Equal opportunities	SDG2 – Zero Hunger; SDG10 Reduced inequalities.

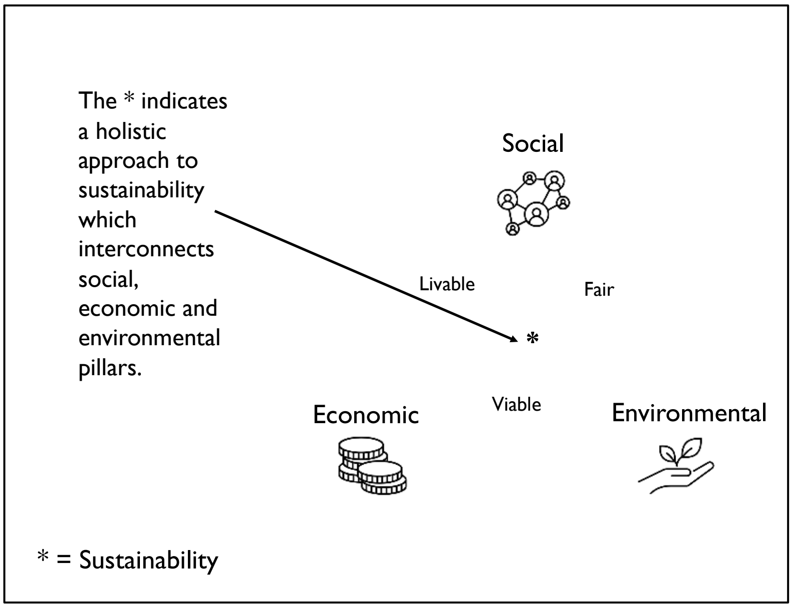
Impacts	Relevant SDGs
Human Rights: Free from child labour	SDG10 – Reduced inequalities.
Working Conditions: Occupational health and safety	SDG10 – Reduced inequalities.
Cultural Heritage: Community engagement	SDG2 - Zero Hunger; SDG6 - Clean water and sanitation; SDG10 – Reduced inequalities; SDG12 - Responsible production and consumption; SDG13 - Climate action; SDG14 - Life below water; SDG15 – Life on land.
Cultural Heritage: Safe and healthy living conditions	SDG2 - Zero Hunger; SDG6 - Clean water and sanitation; SDG10 – Reduced inequalities; SDG14 – Life below water; SDG15 – Life on land.
Cultural Heritage: Transparency on social/environmental issues	SDG2 - Zero Hunger; SDG10 – Reduced inequalities; SDG12 - Responsible production and consumption; SDG13 - Climate action; SDG14 - Life below water; SDG15 - Life on land.
Socio-economic Repercussions: Food security	SDG2 - Zero Hunger; SDG12 - Responsible production and consumption; SDG14 – Life below water; SDG15 – Life on land.
Socio-economic Repercussions: Transfer of technology and knowledge	SDG2 - Zero Hunger; SDG6 - Clean water and sanitation; SDG7 - Affordable and clean energy; SDG9 - Industry, innovation and infrastructure; SDG14 – Life below water; SDG15 – Life on land.
Socio-economic Repercussions: Total costs of waste management for the community	SDG2 - Zero Hunger; SDG6 - Clean water and sanitation; SDG7 - Affordable and clean energy; SDG10 – Reduced inequalities; SDG14 – Life below water; SDG15 - Life on land.
Governance: Free from corruption	SDG10 – Reduced inequalities.

Impacts	Relevant SDGs
Governance: Public commitments to sustainability	SDG2 – Zero Hunger; SDG6 - Clean water and sanitation; SDG7 - Affordable and clean energy; SDG10 - Reduced inequalities; SDG13 - Climate action; SDG14 - Life below water; SDG15 – Life on land.

Sustainability and SDGs

Sustainable development is most commonly defined as: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" as proposed by the Brundtland Commission of the United Nations in 1987 (WCED, 1987: 37). It focusses on the interdependent relationship between social, economic and environmental dimensions (see Figure 1). Sustainability is at the core of the three pillars.

Figure 1: The Three Pillars of Sustainability



In 2015, the UN Member States approved the 2030 Agenda for Sustainable Development; centred on the 17 SDG) which aim to provide 'a shared blueprint for peace and prosperity for people and the planet, now and into the future'[1]. The SDGs are now widely used as a means of tracking progress towards the more sustainable use of natural and human resources for the betterment of global society, and have been applied widely to MSW (Elsheekh et al., 2021, Abubakar et al., 2022, Ram and Bracci, 2024). Figure 2 illustrates the 17 SDGs which include: SDG1 - No Poverty, SDG2 - Zero Hunger, SDG3 Good Health and

[1] See https://sdgs.un.org/goals

Well-being, SDG4 - Quality Education, SDG5 - Gender Equality, SDG6 - Clean Water and Sanitation, SDG7 - Affordable and Clean Energy, SDG8 - Decent Work and Economic Growth, SDG9 - Industry, Innovation, and Infrastructure, SDG10 - Reduced Inequalities, SDG11 - Sustainable Cities and Communities, SDG12 - Responsible Consumption and Production, SDG13 Climate Action, SDG14 - Life Below Water, SDG15 - Life on Land, SDG16 - Peace, Justice and Strong Institutions, and SDG17 - Partnerships for the Goals.

Figure 2: UN SDGs

Source: UN (2025). Note: The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States.

The SDGs address aspects of environmental, social, and economic sustainability, some of which are related to the impacts relating to MSW identified in the IEA Bioenergy Task 36 regional workshop series (Murphy and Gusciute, 2024). This report does not consider the full 17 SDGs, rather it considers MSW from the perspective of the environmental, social and economic impacts indicated as very important by the stakeholders participating in the workshop series (also see Table 1):

- SDG2 – Zero Hunger
- SDG6 - Clean water and sanitation
- SDG7 - Affordable and clean energy
- SDG9 - Industry, innovation and infrastructure
- SDG10 – Reduced inequalities
- SDG12 - Responsible production and consumption
- SDG13 - Climate action
- SDG14 – Life below water
- SDG15 – Life on land

Since their inception in 2015, the world is not on track to achieve the goals by 2030[2] (Independent Group of Scientists appointed by the Secretary-General, 2023). In addition, the Covid-19 pandemic has further delayed progress in achieving the goals (Clemente-Suárez et al., 2022, Independent Group of Scientists appointed by the Secretary-General, 2023). Covid-19 has had a particularly significant impact on waste management and thus has impacted achievement of the relevant Goals (Martín-Blanco et al., 2022). Consideration of the SDGs is essential for building sustainable and equitable societies, as they provide a framework for addressing key challenges, including waste management and its impact on environmental and social sustainability.

SDG2: Zero Hunger

The overall objective of the Sustainable Development Goal 2 (SDG2) is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture[3].

The Impact of Food Waste on Hunger and Food Insecurity and nutrition

Food security can be '… defined as a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life' (Peng and Berry, 2019:1). Food waste is a significant contributor to global hunger and food insecurity. In 2022, an estimated 1.05 billion tonnes of food in the retail, food service and household sectors were wasted globally (UNEP, 2024a). Food waste not only exacerbates environmental issues (Crippa et al., 2021) but directly impacts on potential opportunities to address hunger and food insecurity.

Figure 3 illustrates the prevalence of moderate or severe food insecurity in the total population in 2023. On average, just under 30 per cent of people experience moderate or severe food insecurity globally (FAO, 2024). However this rate varies across regions; in Northern America and Europe just under 9 per cent of people experience moderate or severe food insecurity while this rate increases to 58 per cent in Africa (FAO, 2024). Gender differences can also be observed. Globally, women tend to experience higher rates of food insecurity on average. However, in Northern America, Europe, and Oceania, food insecurity is more prevalent among men (FAO, 2024).

Beyond food insecurity, access to nutritious diets remains a global challenge. The percentage of undernourished population has increased globally with 9 per cent of the global population experiencing undernourishment in 2023. The largest proportion of undernourishment is in Africa where over 20 per cent of the population experienced undernourishment in 2023. This is in stark contrast to North America and Europe where just under 2.5 per cent of the population was undernourished in the same period (see Figure 4). On the other end of the scale, global obesity is also on the rise (see Figure 5). In 2022 the global obesity rate was just under 16 per cent, an increase from just under 12 percent in 2010. All regions are experiencing an increase in obesity; with Latin America and the Caribbean having the highest rate of just under 30 per cent (FAO, 2024).

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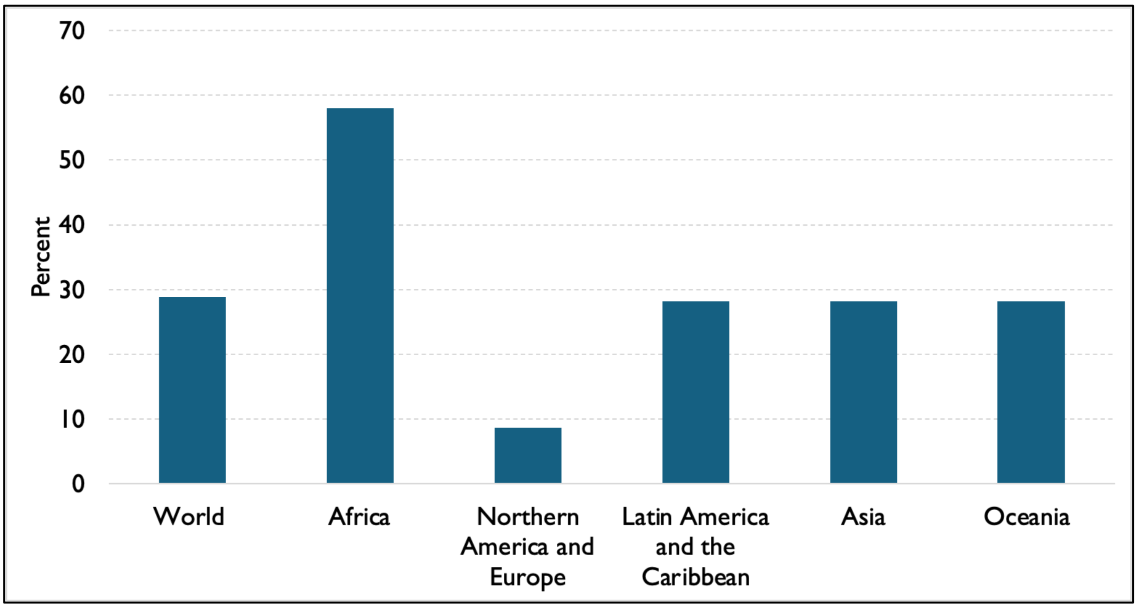
[2] See the UN report '*Global Sustainable Development Report 2023: Times of crisis, times of change: Science for accelerating transformations to sustainable development*' for further information on the current progress of the different Goals (Independent Group of Scientists appointed by the Secretary-General, 2023).

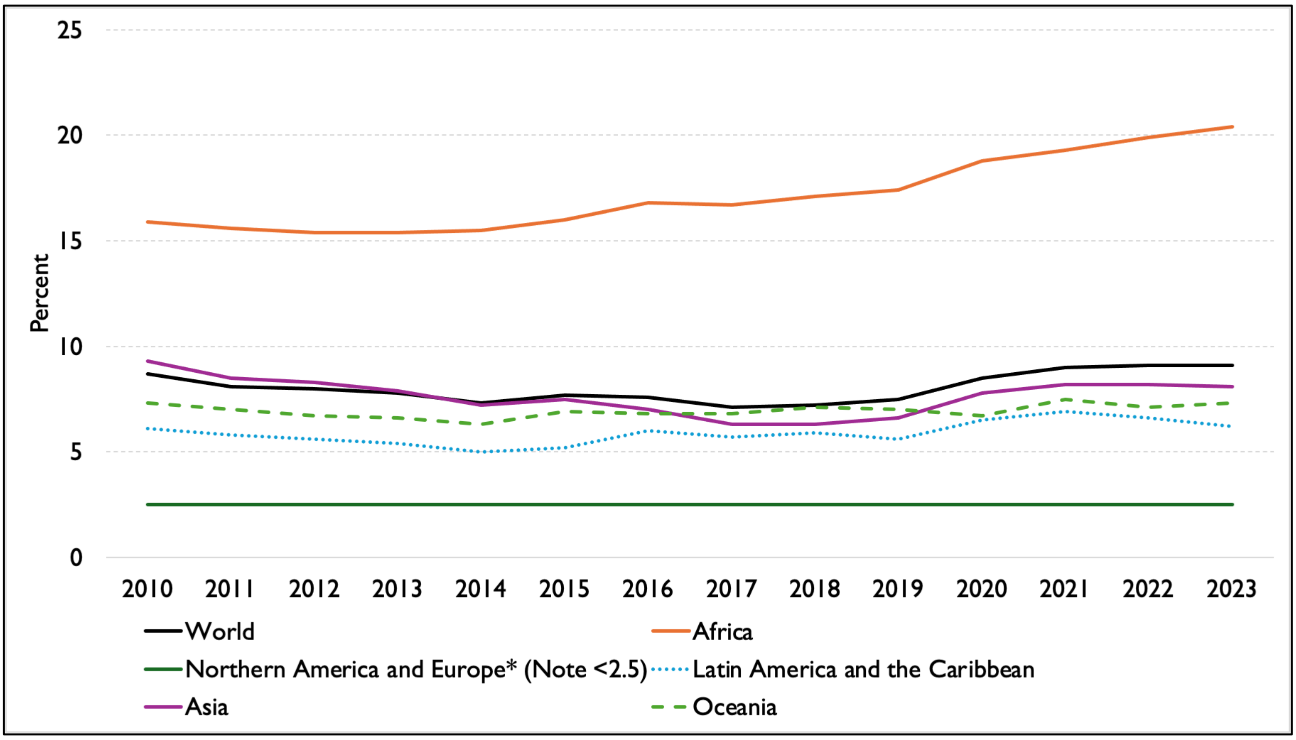
[3] See https://sdgs.un.org/goals/goal2

Figure 3: Prevalence of moderate or severe food insecurity in the total population (percent) in 2023 (annual value)



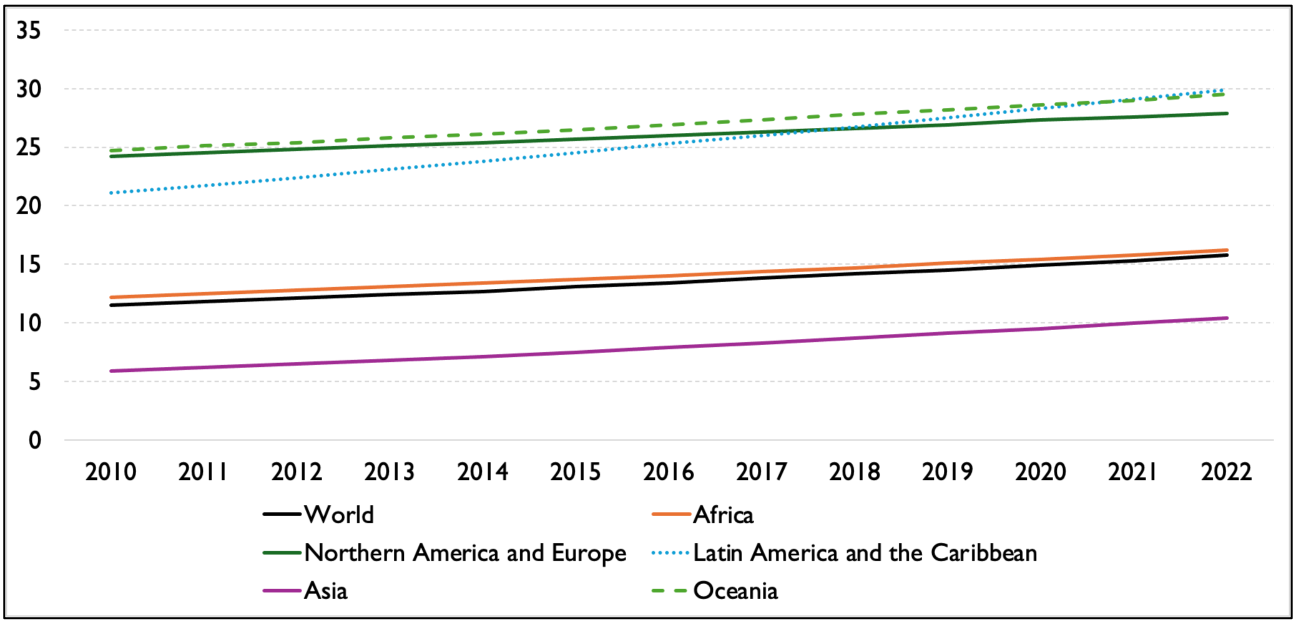
Source: FAO (2024)

Figure 4: Prevalence of undernourishment (percent) 2010-2023 (annual value)



Source: FAO (2024)

Figure 5: Prevalence of obesity in the adult population (18 years and older) (percent) 2010-2023 (annual value)



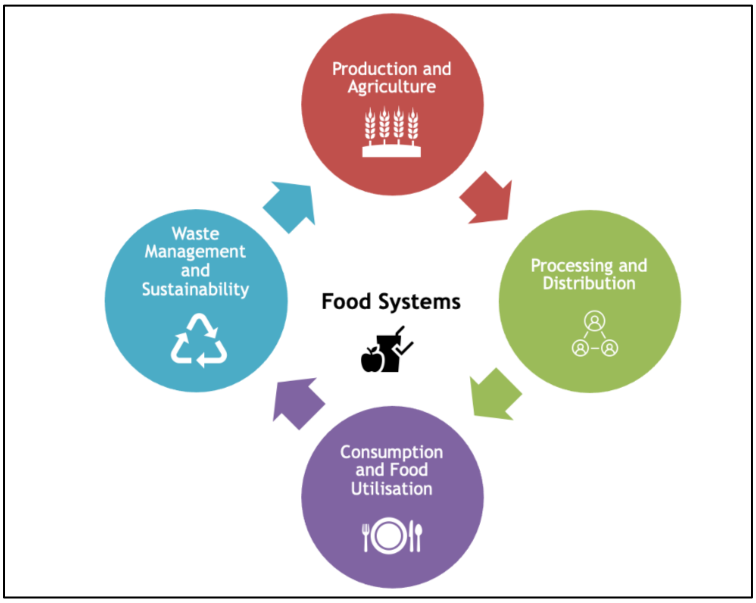
Source: FAO (2024)

In 2019, 17 per cent of the total food available to consumers was wasted (Murphy, 2024). In the United States, for example, food waste is one of the largest contributors to municipal solid waste which ends up in landfill (EPA, 2023a). This represents both a loss of vital resources and an opportunity cost to address food insecurity. Despite sufficient global food production to feed the population an estimated 30 per cent of all food produced globally is wasted (EPA, 2023a), leading to inefficient resource use and exacerbating food scarcity in many regions. The impact of food waste on hunger and food insecurity is multifaceted, and addressing it requires concerted efforts across all stages of the food supply chain. A reduction in food losses, particularly in developed regions would decrease the number of undernourished people in developing regions (Munesue et al., 2015). Greater interconnection among research, policy, governance and societal actions would also lead to solutions addressing food security (Onyeaka et al., 2024). A systematic global analysis of the link between suboptimal diets and non-communicable diseases (NCD) revealed their significant impact on NCD-related mortality and morbidity, emphasising the need for dietary improvements worldwide (Afshin et al., 2019). The intensification of production and consumption patterns, particularly regarding high calories and low nutrient foods, not only add to food waste but also have an impact on nutritious diets (Onyeaka et al., 2024). Overall greater integration of food security into sustainability agenda would ensure a more sustainable and nutritious food security for all (Peng and Berry, 2019).

Food Waste Reduction for Sustainable Food Systems

In order to address food waste and associated environmental, economic and social issues a transition to sustainable food systems is necessary; in particular sustainable agriculture (Velazquez et al., 2023). The minimisation of food waste along the different parts of the supply chain would reduce pressure on agricultural resources, reduced the environmental impact while ensuring that food distribution is more equitable and just (Cattaneo et al., 2021). Reducing food waste in the pursuit of SDG 2 has been associated with the interconnectedness between composting and sustainable agriculture (Velazquez et al., 2023). While pursuit of SDGs is generally linked to national agendas, encouraging stakeholders at all levels (individual, household, community, etc.) to engage in more sustainable food waste disposal such as composting is likely to achieve greater progress (Velazquez et al., 2023). The transition to a circular economy and sustainable agriculture would promote more efficient and responsible resource management and contribute to the broader achievement of the three pillars of sustainability (Allahyari and Poursaeed, 2019). Figure 6 illustrates the interconnected nature of the food systems. All four elements are key in ensuring fully functioning and sustainable global food production, distribution, consumption and waste management (Onyeaka et al., 2024).

Figure 6: Interconnected structure of global food systems



Source: Adapted from Onyeaka et al. (2024)

Potential solutions for MSW reduction and management to support SDG2

- Decreasing food waste would reduce food insecurity. This would require an interconnected approach across the entire food system to minimise food waste along the supply chain ensuring surplus food is redirected to vulnerable populations at risk of food insecurity and/or access to nutritious and fresh food (Onyeaka et al., 2024).
- Improving access to nutritious diets through sustainable food systems. For example, by promoting responsible food production and consumption and reducing reliance on ultra-processed foods access to nutritious food would be increased (García et al., 2023).
- Sustainable agriculture and resource efficiency to support circular economy practices in agriculture could be enhanced by composting food waste to improve soil fertility, using byproducts for animal feed, and reducing dependency on chemical fertilizers and unsustainable farming methods (Wang et al., 2021).
- Integration of food security and waste reduction into policy and governance could facilitate comprehensive national and international policies that align food security with waste reduction strategies, ensuring a more equitable, resilient, and sustainable food system (Onyeaka et al., 2024).

SDG6: Clean Water and Sanitation

Sustainable Development Goal 6 (SDG6) aims to ensure availability and sustainable management of water and sanitation for all [4].

Access to clean water and adequate sanitation

Access to clean water and adequate sanitation is fundamental for human health, environmental sustainability and economic prosperity. Despite significant progress, approximately 2 billion people worldwide still lack safely managed drinking water services, and 3.5 billion lack safely managed sanitation facilities (UN, 2023a). This global challenge highlights the urgent need for integrated approaches to address water, sanitation and waste management issues holistically. MSW management plays a crucial role in achieving SDG6, as improper handling of waste directly impacts water quality and sanitation infrastructure (Roy et al., 2023).

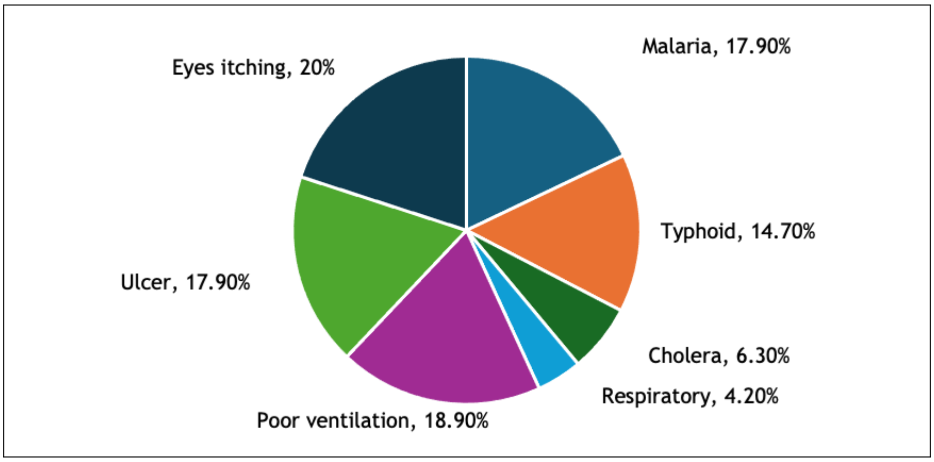
Improper handling and disposal of MSW can lead to contamination of water resources and hinder sanitation efforts, posing severe environmental and social challenges. When waste is improperly disposed of, it can generate leachate, a toxic liquid formed when rainwater percolates through waste materials, dissolving harmful substances. This leachate can contaminate surface water and groundwater, adversely affecting water quality (Eggen et al., 2010). Additionally, the accumulation of solid waste (especially plastic) can block waterways and drainage systems, leading to flooding and unsanitary conditions that promote the spread of diseases (Donuma et al., 2024). MSW often contains hazardous substances like heavy metals and persistent organic pollutants, which can leach into water bodies, posing risks to ecosystems and human health (Ochs et al., 2024).

Environmental and social impacts of MSW

The environmental impacts of MSW in relation to SDG6 are significant. Leachate from landfills contains high concentrations of harmful pollutants such as ammonia, nitrogen, iron and manganese that contaminate water bodies and harm aquatic ecosystems. For instance, a study in India revealed that landfill leachate had heavy metal concentrations exceeding safe limits, posing significant threats to nearby water sources (Ravikumar et al., 2020). Quantitative analyses of a case study in Ethiopia have shown that waste disposal sites emitted approximately 46 gigagrams of greenhouse gases annually in 2020, while the eutrophication potential of organic waste reached 59.4 grams of N-equivalent. Additionally, daily average leachate production amounted to 1,112 millimetres annually, indicating severe risks to human health and environmental integrity (Misganaw, 2023). The African Development Bank (2018) reported that over 100,000 aquatic species perish each year due to plastic-related issues, and an alarming 83% of subterranean potable water sources are contaminated by plastic remnants. Research on microplastic contamination in the environment around MSW treatment and disposal systems has found microplastics in different environmental media (soil, sediment, surface water, and groundwater) adjacent to MSW treatment and disposal systems, most of which were landfills/dumpsites (Sun et al., 2019)Further, improper disposal and burning of plastic waste release hazardous chemicals like ammonium, polyvinyl chloride, polychlorinated biphenyls, dioxins and furans into the environment (Donuma et al., 2024). These toxins contribute to excessive environmental contamination, aggravate respiratory ailments, cause eye irritation, and pose significant health risks to humans (see Figure 7).

[4] See https://sdgs.un.org/goals/goal6

Figure 7: Common ailments reported by respondents in Borno State, Nigeria, due to the burning of plastic and resulting air pollution



Source: Adapted from Donuma et al. (2024).

The social impacts of improper MSW management are severe. Contaminated water sources increase the risk of waterborne diseases such as cholera, typhoid and dysentery, contributing to approximately 505,000 diarrheal deaths each year (WHO, 2023a). Polluted water adversely affects communities dependent on fishing and agriculture, leading to economic losses and food insecurity as fish populations decline, while poor waste management disproportionately impacts low-income and marginalised communities by intensifying existing inequalities and increasing their exposure to harmful waste pollution due to inadequate waste disposal services (Ochs et al., 2024, UN, 2024a).

In conclusion, proper management of MSW is essential for achieving SDG6. The environmental and social impacts of improper MSW disposal on water quality and sanitation are substantial and far-reaching. Addressing these challenges requires an intricate approach involving technological solutions, policy interventions, and community participation. By improving waste management practices, investing in innovative technologies, and fostering collaboration among stakeholders, we can mitigate the negative impacts of MSW on water resources and sanitation, contributing to the broader goals of sustainable development.

Potential Solutions for effective management of MSW to support SDG6

- Addressing these challenges requires implementing solutions for MSW to achieve SDG6 through improved waste management practices and technological innovations. Constructing engineered sanitary landfills with liners and leachate collection systems prevents groundwater contamination by isolating waste from the environment (EPA, 2013). Technological innovations like advanced leachate treatment methods such as membrane filtration, granular sludge processes, and advanced oxidation processes effectively remove contaminants before discharge, protecting water quality (EEA, 2024). Utilising MSW as a resource through waste-to-energy facilities reduces landfill volumes and environmental impacts by converting waste into electricity or heat, contributing to renewable energy goals (Roy et al., 2023)
- Policy and regulatory frameworks are crucial for promoting sustainable MSW management and are related to achieving many of the SDGs considered in this report. Enforcing strict waste disposal regulations and penalties for non-compliance encourages proper practices, while financial incentives for recycling and waste reduction motivate environmentally friendly behaviours. Community engagement and education are crucial; educating the public on proper waste disposal and its impact on water and sanitation promotes responsible behaviour (Dri et al., 2018). Involving communities, non-governmental organisations (NGOs) and the private sector in waste management planning and implementation enhances shared responsibility and sustainable solutions.

SDG7: Affordable and Clean Energy

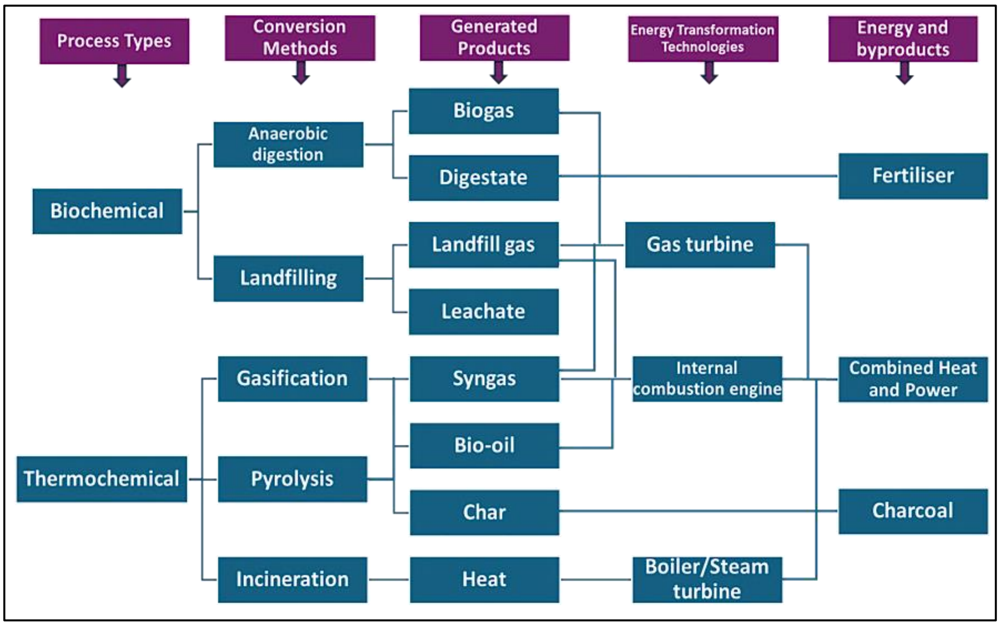
Sustainable Development Goal 7 (SDG7) centres on the global ambition to achieve universal access to affordable, reliable, sustainable, and modern energy by the year 2030[5].

Energy is a fundamental driver of economic growth, social development and environmental sustainability. Globally, 675 million people remain without access to electricity, while 2.3 billion still depend on traditional fuels like biomass, coal, and kerosene for cooking and heating, leading to significant health and environmental impacts (IEA, 2023). Progress in renewable energy adoption has been slow, with its share in total final energy consumption inching up from 16% in 2010 to just 19.2% by 2021 (WHO, 2023b). At this rate, the world is set to miss its 2030 target for sustainable energy, underscoring an urgent need for accelerated action and innovation. MSW, comprising everyday items discarded by households and commercial establishments, presents a unique opportunity to contribute to SDG7. As urbanisation and population growth increase, MSW generation is expected to rise from 2.1 billion tonnes in 2023 to 3.8 billion tonnes by 2050 (UNEP, 2024c, Kaza et al., 2018). Properly managed, MSW can become a valuable resource for clean energy generation, addressing both waste management and sustainability goals.

MSW and Waste-to-Energy technologies

MSW can be converted into energy using Waste-to-Energy (WtE) technologies, which align with SDG7's objectives by increasing renewable energy use and improving energy efficiency (Khan and Kabir, 2020). The potential WtE technologies, along with their respective energy products, are illustrated in Figure 8. WtE reduces dependence on fossil fuels, lower greenhouse gas emissions, and promote a circular economy by recovering energy and valuable resources (Alao et al., 2022).

Figure 8: Overview of Municipal Solid Waste (MSW) Conversion Processes and Products



Source: Adapted from Alao et al. (2022)

[5] See https://sdgs.un.org/goals/goal7

For instance, each metric ton of waste used in WtE can substitute a quarter ton of coal or a barrel of oil, reducing U.S. greenhouse gas emissions by approximately 26 million tons of CO_2 annually (Psomopoulos et al., 2009). Thermal WtE plants can further avoid up to 1,010 kg of CO_2 per ton of waste diverted from landfills without methane capture. Among WtE technologies, anaerobic digestion (AD) has been identified as an environmentally friendly option (Alao et al., 2020), alongside gasification and pyrolysis (Khan and Kabir, 2020). AD not only produces biogas but also generates by-products like digestate, a high-value fertiliser rich in nitrogen and phosphorus, supporting sustainable agriculture. However, the digestate quality must be assessed regarding local regulations as it may contain heavy metals, pathogens, and microplastics (Sobhi et al., 2024)

Beyond environmental benefits, WtE technologies contribute socially by improving energy access and reducing energy poverty, particularly in underserved regions. WtE plants can supply electricity and/or heat to urban and rural grids, enhancing energy availability and security by utilising locally available waste resources (Khawaja et al., 2024). Economic benefits include job creation in the development, construction, and operation of WtE facilities, providing employment opportunities across various sectors (Khan and Kabir, 2020).

In conclusion, MSW offers immense potential to advance SDG7 by generating renewable energy, reducing greenhouse gas emissions, and improving waste management. Waste-to-Energy technologies present a holistic solution, delivering environmental benefits such as reduced landfill reliance and fossil fuel use, while creating social and economic advantages like job creation and enhanced energy access. Achieving these outcomes requires ongoing investment in modern technologies, robust policy frameworks, and active community engagement. By transforming waste into energy, societies can address pressing waste challenges while contributing to a cleaner, more sustainable energy future.

Potential Solutions for effective management of MSW to support SDG7

- Investment in advanced WtE technologies is essential to maximise MSW's potential. Modern incineration plants equipped with emissions control systems, such as the Amager Bakke facility in Denmark, are able to handle large volumes of mixed waste and produce flue gas that can exceed stringent requirements for emissions of a range of potential pollutants. This facility combines waste incineration with energy production, supplying electricity and district heating to thousands of households, processing large volumes of waste efficiently while minimising environmental impacts (Amager Bakke Centre, 2024).
  Hybrid WtE systems offer even greater potential by combining technologies to optimise both economic and environmental outcomes. For instance, a financial analysis by Mabalane et al. (2021) found that integrating anaerobic digestion (AD) and gasification is more cost-effective than operating these technologies independently. Similarly, Alao et al. (2020) reported that combining AD, landfill gas recovery, and pyrolysis in Lagos, Nigeria, could achieve an impressive 91.16% reduction in greenhouse gas emissions, demonstrating the environmental advantages of hybrid approaches for management of MSW. These modern and hybrid WtE systems represent promising avenues for future investment.
- Policy and regulatory frameworks play a critical role in supporting WtE adoption to treat non-recyclable MSW. In Sweden, the landfill bans, on sorted combustible waste introduced in 2002 and on organic waste introduced in 2005, and the landfill ban introduced in Norway in 2009, were catalysts for the diversion of MSW from landfills to WtE (Kjær, 2013, Milios, 2013). Financial incentives such as feed-in tariffs, tax credits, and subsidies encourage renewable energy investments by guaranteeing favourable returns. Germany's Renewable Energy Sources Act (EEG) provides feed-in tariffs for biogas electricity generation, with rates of €0.143 per kWh for plants up to 500 kW capacity and €0.1252 per kWh for plants up to 20 MW, with annual reductions of 0.5% to reflect technological advancements[6]. Ireland's landfill levy, introduced in 2002 and set at €85 per tonne as of 2023, has reduced landfill usage dramatically, decreasing municipal waste sent to landfills from over 80% in 2001 to just 16% in 2021 (EPA, 2023b). These measures promote

[6] See https://clean-energy-islands.ec.europa.eu/countries/germany/legal/res-electricity/feed-tariff#14697

waste diversion to recycling and WtE facilities, fostering sustainable waste management and renewable energy development.

SDG9: Industry, Innovation and Infrastructure

Sustainable Development Goal 9 (SDG9) Industry, Innovation, and Infrastructure focuses on building resilient infrastructure, promoting industrialisation, which is sustainable and inclusive, as well as fostering innovation[7].

MSW management and SDG9 are related in serval ways including sustainable waste management infrastructure development, innovation in waste management technologies, and the promotion of resource efficiency. Current MSW management techniques are still heavily reliant on landfills and open, illegal, dumps globally and cause significant environmental impacts. This particularly arises from the release of greenhouse gas (GHG) emissions from landfills to the atmosphere and the discharge of concentrated leachate (rich in nitrogen (N), phosphorus (P), potassium (K), etc.), pollutants, and pathogens into soil and water bodies (Turrén-Cruz and López Zavala, 2021). The innovative management of waste and use of more sustainable management approaches can result in significant benefits for society; minimising the adverse effects of climate change, and can improve social and economic sustainability (Ram and Bracci, 2024).

Efficient MSW management requires innovations in infrastructure for; Waste collection and transportation, Recycling and composting facilities, and Waste-to-energy plants and advanced landfill systems. An analysis of trends in industrial knowledge and innovation in MSW by Ye et al. (2023) found that the top 10 highly cited patents in the post-SDG declaration period emphasised the role of conversion, conservation, and recycling with a focus on fermentation, waste treatment, and energy generation through waste. The patent citation analysis showed that there was an overall trend from linear operations and management to a more circular approach. The major patent areas of interest to MSW are; firstly, P43 which addresses the mechanical attributes that can help clean or separate waste disposal, secondly Q73 which includes the combustion apparatus and processes for lighting and heating, third, Q35 which includes patents that address refuse collection, conveyors, and sorting facilitation, and finally D15 and P41 which address the biological treatment of industrial waste/sewage and sorting/separating solid waste mechanically, respectively (Ye et al., 2023).

Waste collection-related issues have shifted towards tools and techniques that can help in the process of conversion, conservation, and energy generation from waste and refuse collection, thus showing that stakeholders are considering more sustainable approaches for MSW management including integrated approaches (Kundariya et al., 2021).

The UN Clean Development Mechanism (CDM) has driven innovation in municipal waste management across the globe. The carbon credits mechanism has motivated municipalities to pursue energy recovery projects, the carbon credits for which make the projects more viable financially. CDM projects in waste management and energy have included; landfill gas recovery with electricity generation, anaerobic digestion, gasification, and mechanical/thermal treatment (Potdar et al., 2016).

Innovative solutions in waste management technologies

Waste collection and transportation

Advanced sorting technologies have been applied in waste collection systems which can increase the type and number of materials that can be separated, improve quality, and optimise the process in terms of efficiency, time, and costs. Examples of such advanced sorting technologies is a smart sorting system in

[7] See See https://sdgs.un.org/goals/goal9

Sweden (SiteZero plant owned by Svenk Plaståtervinning) for sorting post-consumer plastic packing into 12 grades (Edo et al., 2024).

The system consists of NIR/VIS, laser, GAIN (deep learning camera system) and electromagnetic sensors, in addition to screening drums, ballistic separators, exhaust air technology, compaction systems, an intelligent bunker management system, fully automatic baling presses and digital process monitoring. This integrated approach ensures both high recovery rates of targeted plastics and quality of the sorted fractions.

Waste-to-energy

Waste-to-energy (WtE) is a well-established waste management approach typically based on combustion. Incineration is the most commonly used WtE technology, with over 1,700 thermal WtE plants in operation worldwide (UNEP, 2019). In incineration, MSW is directly burnt in an excess supply of oxygen in a furnace with temperature in the range of 800°C–1000 °C and minimum residence time, after last addition of air/oxidiser, of 2 s leading to the production of a hot flue gas and (bottom and fly) ash (Alao et al., 2022). As the circular economy develops, WtE priorities will shift from the traditional areas of waste, heat, and power, and intersect more with the manufacturing, construction, and transport sectors, with the overall aim to keep molecules in use for longer (Johansson et al., 2023, Roberts et al., 2022). When modern incineration plants are equipped with advanced separation and resource recovery stages they can contribute to increased recycling (Roberts et al., 2022), , with high quality material such as metals being recovered and lower quality material being combusted. Further innovation is focusing on recovering as much value from waste as possible. An example is the use of ash generated in the process. Bottom ash can be used as an aggregate for backfilling in road construction application and in concrete making subject to compliance with environmental regulations (Blasenbauer et al., 2020, Alao et al., 2022). Further valorisation technology approaches are being developed to treat fly ashes using various combinations of washing, acid treatment, and salts and metals recovery (Becidan, 2018, Roberts et al., 2022).

Organic waste valorisation

Organic waste can be transformed into biogas or compost for agriculture, creating industrial symbiosis where waste from one process becomes input for another. Anaerobic digestion (AD) is a process in which microorganisms cause the decomposition of the organic component of the waste in the absence of oxygen to produce methane-rich gas called biogas and a digestate co-product (Alao et al., 2022). AD is a commonly used approach to recover energy from single and mixed streams of organic waste which has been demonstrated for many decades as an industrially robust technology (Hoffman, 2022). Biomethanation is a biogas upgrading technology that can be co-located with any biogas source, such as AD. The biomethanation process uses a single-celled biocatalyst to convert CO2 and hydrogen into high-purity methane which when properly conditioned, is compatible with existing transmission, distribution, and geologic storage infrastructure. A key benefit of this approach is that the process does not require any changes to existing organic waste handling processes.

Efficient management of municipal solid waste directly supports the goals of SDG 9 by enabling sustainable industrial processes, fostering innovation in waste treatment technologies, and building sustainable infrastructure, all of which contribute to a circular economy and reduced environmental impact.

SDG10: Reduced Inequalities

Sustainable Development Goal 10 (SDG10) [8] focusses on reducing inequality within and among countries. Municipal solid waste management is a key service that intersects with wider social, economic, and environmental inequalities.

Unequal Access to Municipal Solid Waste Services

The level of controlled[9] municipal solid waste management varies greatly by region, with Sub-Saharan Africa and Central and South Asia having the lowest rates, while North America and Western Europe have the highest (UNEP, 2024c). However, even in North America and Europe differences can be observed in how municipal solid waste is managed. For example in North America, municipal solid waste is collected and then disposed of in a landfill while in Western Europe majority of municipal solid waste is either recycled or incinerated (Ackerman and Levin, 2023). It is also worthwhile to note that while waste recycling in the European Union (EU) has increased overall due to the EU binding recycling targets; the rate varies between countries. For example in 2022, Germany recycled 69 per cent of its municipal waste, whereas Romania recycled only 12 per cent (EPA, 2024b).

In addition, access to waste collection services vary within and between regions. The global average of municipal solid waste collection is approximately 75 per cent; in higher income regions almost all of municipal solid waste is collected in higher income regions while less than 40 per cent is collected in lower income regions (UNEP, 2024c). In addition it is estimated that approximately 2 billion people in rural areas and 700 million people in urban areas do not have access to municipal solid waste collection (UNEP, 2024c).

The level of uncontrolled[10] municipal solid waste is estimated to be approximately 38 per cent in 2020, however as global waste is predicted to increase overall, the share of uncontrolled municipal solid waste will also increase (see Figure 9). The uncontrolled MSW is estimated to increase from 0.81 billion tonnes in 2020 to 1.57 billion tones by 2050 (UNEP, 2024c).

Fraudulent activities, the high cost of responsible waste management, and inconsistent regulations across nations creates significant opportunities for corruption in the global waste trade. An example is the Think Pink case in Sweden is an example[11]. It is estimated that environmental crime which includes waste trafficking is the fourth most lucrative illegal business in the world (UNEP, 2024c). Effective enforcement of waste management regulations is crucial, particularly in preventing corrupt practices which can lead to significant negative environmental and social impacts.

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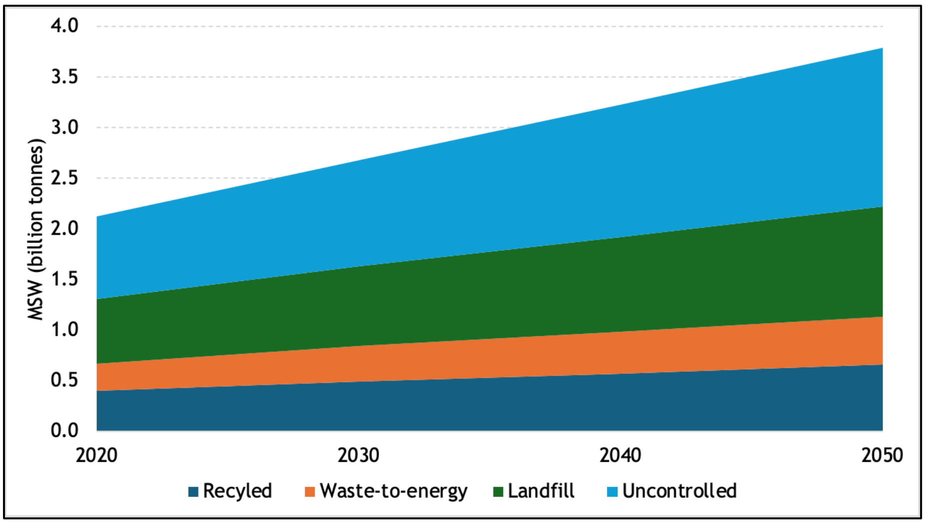
[8] See https://sdgs.un.org/goals/goal10

[9] 'Controlled waste' refers to waste which is collected, and then either recycled or disposed of in a controlled environment. See UNEP (2024).

[10] 'Uncontrolled waste' is either not collected and by necessity dumped or burned in the open, or collected and then dumped or burned. See UNEP (2024).

[11] https://www.ecowatch.com/sweden-environmental-crime-toxic-waste-think-pink.html, https://swedenherald.com/article/the-think-pink-scandal-in-five-points

Figure 9: Projected Global Municipal Solid Waste (MSW), 2020-2050

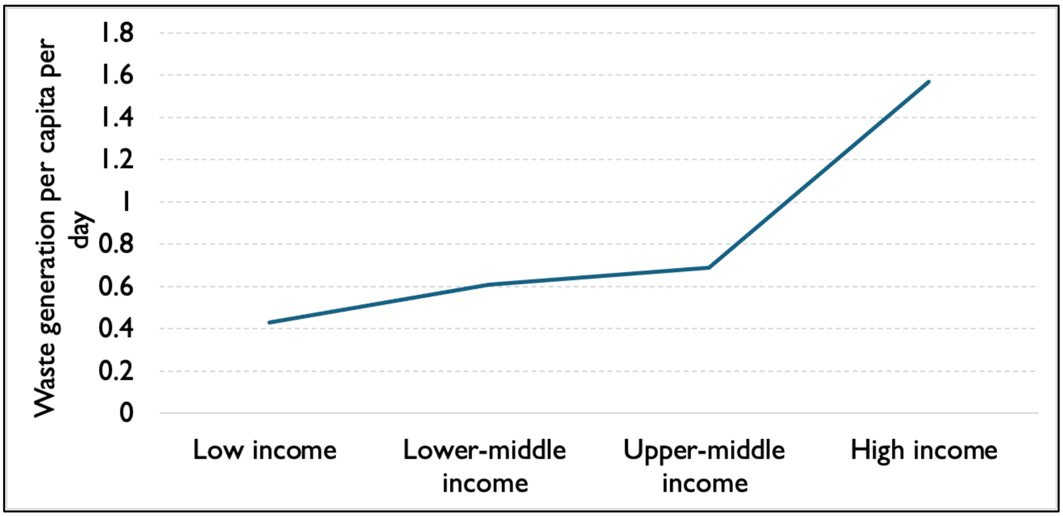


Source: UNEP (2024c).

Economic Disparities in Municipal Solid Waste Generation and Management

As countries grow wealthier, industrialisation and urbanisation increase and as a result consumption patterns evolve; all resulting in increased municipal solid waste generated per person (UNEP, 2024c). Generally, the higher the economic growth and consumption, the greater the amount of waste generated (Vieira and Matheus, 2018). Higher income countries make up 16 per cent of the world's population but generate 34 percent of global waste. In contrast, low-income countries, which represent 9 percent of the global population, contribute only about 5 percent of the world's waste (Kaza et al., 2018). Figure 10 shows the daily per capita waste generation across countries with different income levels. Low income countries produce approximately 0.43 kilos of waste per capita per day in contrast to high income countries which generate 1.57 kilos of waste per capita per day (Kaza et al., 2018).

Figure 10: Waste generation per capita per day by country income group



Source: Kaza et al. (2018)

In the predicted estimations of waste generation by 2050; it is expected that low income countries will triple their waste generation as they undergo significant economic and population growth (Kaza et al., 2018). As the largest share of MSW generation is expected to occur in rapidly growing economies, strategies aimed at decoupling economic growth from resource consumption and waste generation will be crucial (UNEP, 2024c).

Environmental Inequality and Social Inclusion in Municipal Solid Waste Systems

Environmental inequality focusses on the intersection between environmental quality and wider social hierarchies; emphasising the relationship between social inequality and distribution of environmental burdens (Pellow, 2000). Bullard (1990) carried out the first study on environmental injustice/racism on the disproportionate location of landfills in predominantly black communities in the United States. Since Bullard's work, numerous studies have shown evidence of disproportionate siting of hazardous waste treatment, storage and disposal facilities in ethnic and racial minority communities, communities of colour and communities with lower socio-economic status (Martuzzi et al., 2010, Mohai and Saha, 2015, Cannon, 2020, Dunajeva and Kostka, 2022, Cannon, 2024). A recent study by Cannon (2024) showed that the siting of non-hazardous and hazardous waste landfills are linked to communities of colour, female-headed households, and disaster-affected areas in the US. In Europe, members of the Roma community often face environmental racism due to marginalisation to highly polluted areas near landfills (Heidegger and Wiese, 2020), their living spaces are used as dumping sites and waste is often not removed (Dunajeva and Kostka, 2022). In addition to the disproportionate siting of landfills in marginalised communities, residents living near these facilities face significant health risks due to contaminated groundwater and harmful emissions (Siddiqua et al., 2022). Poor waste management leads to an increase in both communicable and non-communicable diseases, along with long-term health disparities (Vinti et al., 2021, Fuller et al., 2022).

In the global North, the circular economy (CE) is often viewed as a novel approach to waste management. However, the concept of circular resource flows has been a fundamental aspect of waste pickers' work worldwide for generations. Operating individually or in cooperatives, waste pickers recover, sort, and return discarded materials into the economy, effectively reducing waste. Despite their significant role, their contributions to the circular economy often go unrecognised, and many of the essential services they provide remain unpaid (Gutberlet and Carenzo, 2020). In addition, waste pickers face barriers such as social stigma, economic instability, legal liminality and lack employment rights (Rosaldo, 2024). In informal economies, waste pickers experience heightened health risks, occupational hazards, and adverse health outcomes (Zolnikov et al., 2021). A study in Brazil found that women make up the majority of the waste picker population and experience higher rates of chronic and respiratory diseases (Marques et al., 2021). Child labour can also be an issue in informal waste management systems. Sara et al. (2022) carried out a scoping review on child waste workers in South Asia, highlighting the numerous occupational hazards they face. Despite their significant involvement in waste management, child waste workers are often overlooked by mainstream child protection and support systems, leaving them more vulnerable to workplace harassment and injuries.

Potential Solutions for effective management of MSW to support SDG10

Global inequalities in MSW management and generation are evident across regions, with lower-income countries and marginalised communities facing limited waste collection services, disproportionate exposure to landfills, and higher health risks. Addressing these disparities requires targeted policies and inclusive waste management strategies, for example:

- Increase waste collection in underserved areas by investing in infrastructure, funding, and equitable service distribution to ensure universal access.

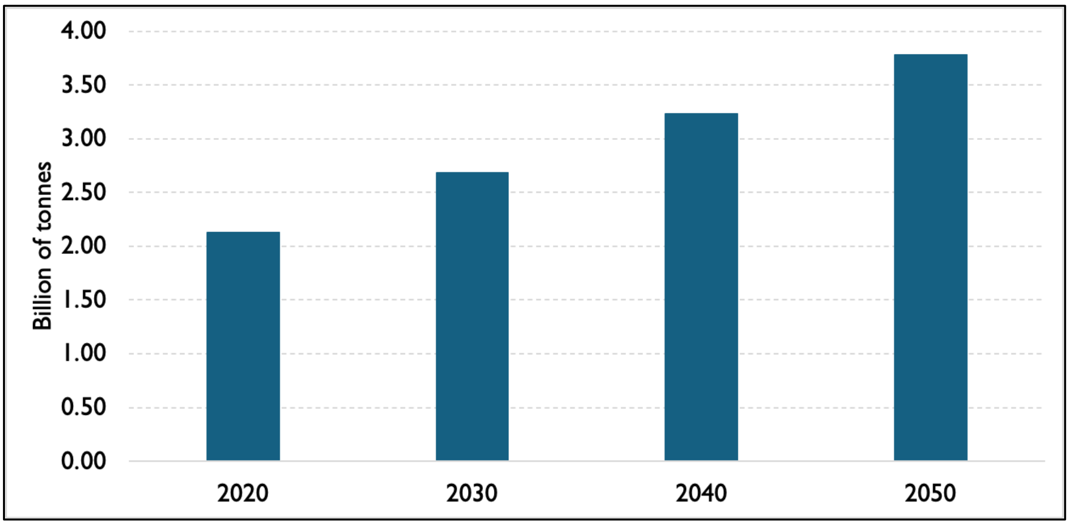
- Implementing policies that prevent the disproportionate siting of landfills in marginalised communities and integrating informal waste pickers into formal systems.
- Mitigate health risks from landfill pollution through stricter regulations, improved monitoring, and healthcare access for impacted populations, including waste pickers.
- Policymakers should develop targeted programs to support child waste pickers by providing essential protective gear, healthcare, education, and adequate nutrition to reduce health risks and improve their well-being. Additionally, authorities should explore alternative income-generating opportunities to help children transition away from hazardous waste work (Sara et al., 2022).
- Encourage waste prevention, recycling, and resource efficiency to decouple economic growth from waste generation, with targeted interventions in regions with low recycling rates.

SDG12: Responsible Production and Consumption

The issue of MSW is strongly linked to the Sustainable Development Goal 12 (SDG12) - responsible production and consumption as it focusses on ensuring sustainable consumption and production patterns[12]. MSW generation and disposal pose a significant burden on human health, land use and environmental sustainability.

Figure 11 shows the quantity of MSW generated on a global scale in 2020 and relative projections for the following decades due to population increase and/or wealth increase leading to further consumption: unless appropriate measures are taken to mitigate waste generation, the current waste management crisis will not cease. Figure 12 highlights a clear divergence between collected and properly managed waste by group of regions, highlighting the differences in MSW infrastructure between regions.

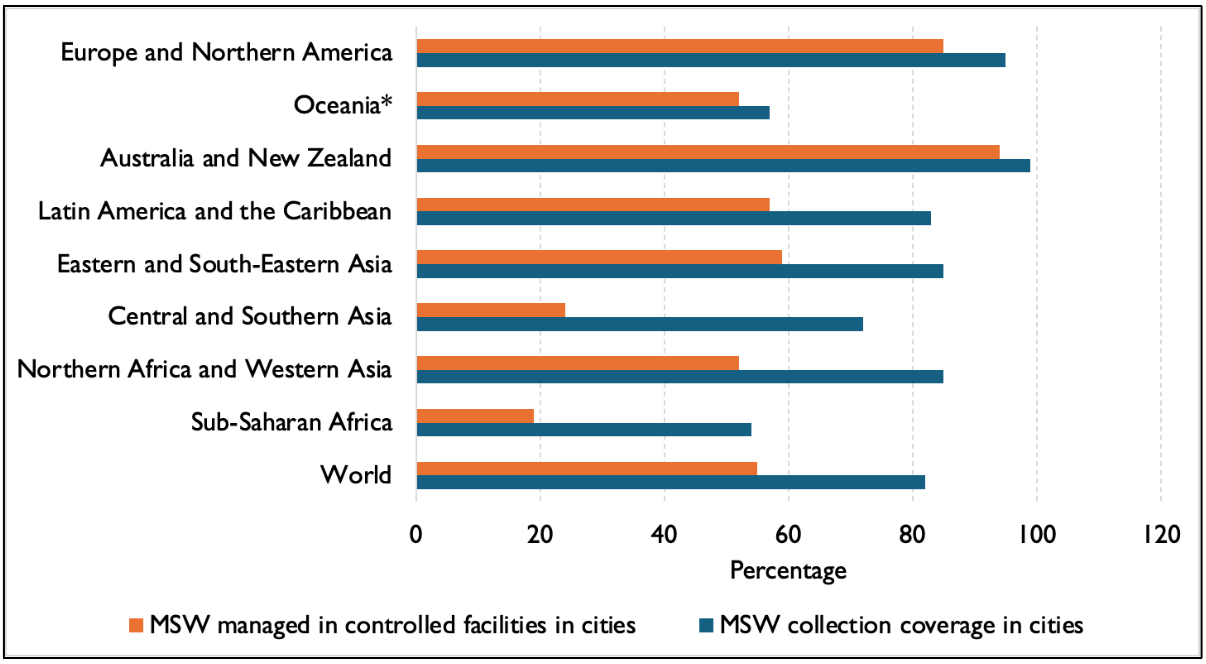
Figure 11: Generation of global municipal waste



Source: UNEP (2024b) *Note:* 2020 figure refers to actual amount of waste generated. 2030-2050 figures refer to estimated amounts of waste which are expected to be generated globally.

[12] See https://sdgs.un.org/goals/goal12

Figure 12: MSW collection coverage and MSW managed in controlled facilities in 2021



Source: UN (2024b) *Note:* *Excluding Australia and New Zealand. MSW collection coverage: amount collected as a proportion of total MSW generated.

A positive correlation exists between gross domestic product (GDP) and generation of waste (UNEP, 2024b): economic development drives a growing demand for natural and energy resources; which if not well managed, they may eventually end up as waste (OECD, 2020). High levels of waste generation often stem from overconsumption, and inefficient production and consumption patterns. A significant share of MSW relates to food waste, which continue to grow despite the rising world-wide hunger. Most food waste stems from domestic activities (60%): values of 79 kg of household food waste per capita were registered globally in 2022, with only limited variation (7 kg per capita) between low- and high-income countries (UN, 2024b). The generation of MSW is a reflection of the overall efficiency of resource use within a community. Products are currently designed, used, and disposed of in a linear manner resulting in growing quantities of MSW. Another challenge to be addressed concerns the consequences of the digital transformation that is currently shaping our society, hence the increasing availability, ownership and subsequent disposal of electric appliances and electronic devices. Compared to 2010, the amount of e-waste generated globally in 2022 almost doubled (from 34.16 to 61.91 million kg), while the collection rate diminished (from 23.3% to 22.3%) (Baldé et al., 2024).

Potential Solutions for effective management of MSW to support SDG12

- Area of interventions and policies must be further developed and implemented to face the above challenges. Society as a whole (governments, companies, citizens) is asked to take action with everyday choices and decisions that directly impact waste generation and management. Achieving SDG 12 requires actors across the whole value chain, including businesses, consumers, policymakers and municipalities, to work together to raise awareness about the importance of reducing MSW, and to implement policies that encourage sustainable consumption and production. Policies applied in this area often focus on increasing waste segregation, and introducing extended producer responsibility, or financial incentives for recycling. SDG 12 calls for a shift toward a circular economy, where materials are reused and recycled, reducing the need for virgin resources and minimizing waste generation.

- Proper data collection, standardisation and reporting are important in order to identify and quantify losses along the production chain. Countries should invest in digitalisation to strengthen the comprehension and transparency of the waste value chain, thereby delivering tailored campaigns to foster public awareness (UNEP, 2024b).
- MSW can mainly undergo four paths: recovery of materials by category, recovery of energy by combustion, bioconversion, landfilling of the non-recoverable portion. The treatment of MSW plays a pivotal role for appropriate management: recycling, incineration, composting, pyrolysis and gasification are potential processes for waste conversion into energy or valorisation as renewed materials (Al-Jaf and Aziz, 2024).
- Shifting from a linear to a circular economy model can prevent excessive waste generation and extend the life cycle of resources and materials, while reducing the need for virgin resources, thus achieving the crucial goal of waste reduction (UNEP, 2024b). In this context, waste-to-energy, and the 3Rs approach (reduce, reuse, recycle) are relevant pathways to pursue for better waste handling (Kumar et al., 2023), focusing on policies and practices fundamentally aimed at revising the design of materials, as well as production and consumption patterns of businesses and citizens (Arenibafo, 2023). E-waste must be properly managed to limit the release of hazardous substances and enhance the recovery of valuable materials. Furthermore, effective collection systems should be established to boost collection rates, especially in higher-income countries where access to and use/disposal of electrical and electronic equipment are prevalent (Baldé et al., 2024).

Efficient and sustainable management of MSW which focuses on waste reduction, resource efficiency, and recycling can directly contribute to more sustainable production and consumption patterns.

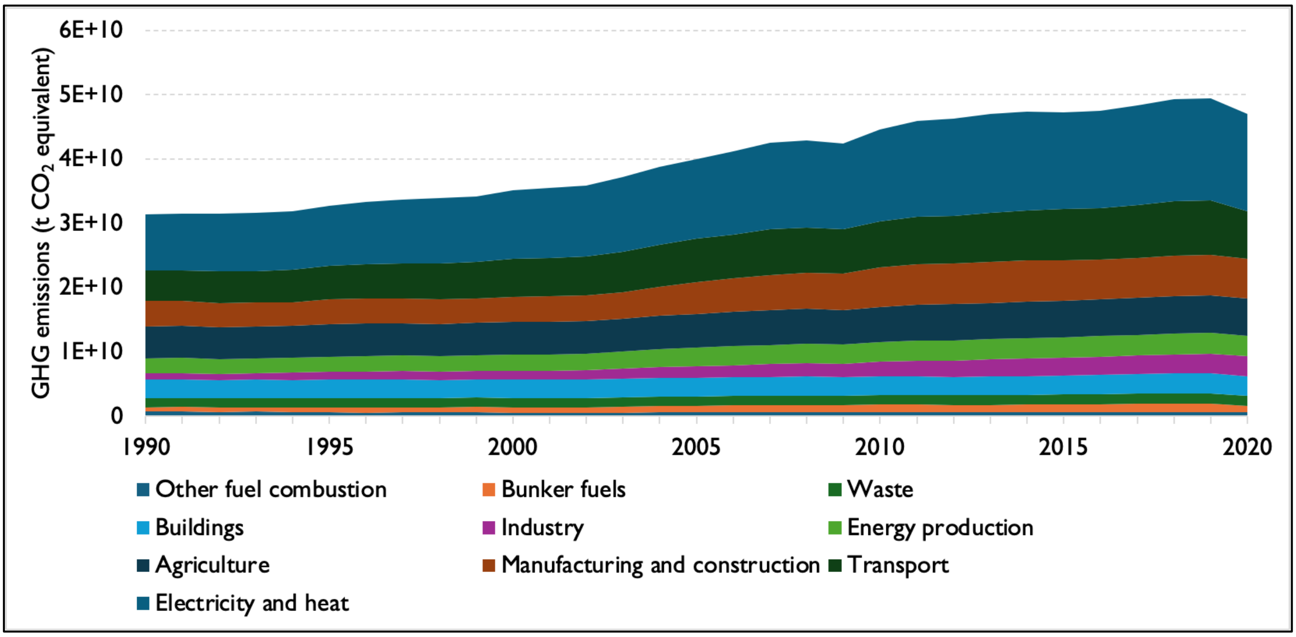
SDG13: Climate Action

Climate change and relative endeavours to address its detrimental impacts are the focal point of the Sustainable Development Goal 13 (SDG13) – Climate action[13]. SDG13 is related to MSW as waste management practices, especially those involving the disposal and treatment of waste, have a direct impact on GHG emissions. The Intergovernmental Panel on Climate Change (IPCC) mandates all relevant sectors to quickly undertake concrete measures to mitigate GHG emissions (UN, 2023b). The amount of GHGs generated globally increased from 1990 to 2021 (see Figure 13). Flows of greenhouse gases such as methane (CH_4) and carbon dioxide (CO_2) stem from a number of sectors with the waste sector accounting for 3.3% of global GHG emissions in 2019 (Climate Watch, 2024). Projections for 2050 predict that the MSW generation will rise to 3.5 billion tons (UNEP, 2024b). The proper management of MSW is therefore of utmost relevance to mitigate its contribution to the global threat of climate change[14].

The GHG emissions from MSW management can vary significantly depending on the methods employed, ranging from waste prevention to disposal, and the existing waste management strategy which is being replaced. Many regions are still reliant on landfilling of waste, including in open landfills, and on open burning of waste. Such improper waste management practices can contribute significantly to GHG emissions (e.g., methane from organic waste decomposition in landfills) with the resulting climate change directly affecting terrestrial ecosystems, accelerating biodiversity loss and desertification (Ali et al., 2014).

[13] See https://sdgs.un.org/goals/goal13
[14] See https://www.epa.gov/system/files/documents/2021-11/swm-guide-flyer-general-2020-08-07.pdf

Figure 13: Global GHG emissions by sector (1990-2020)



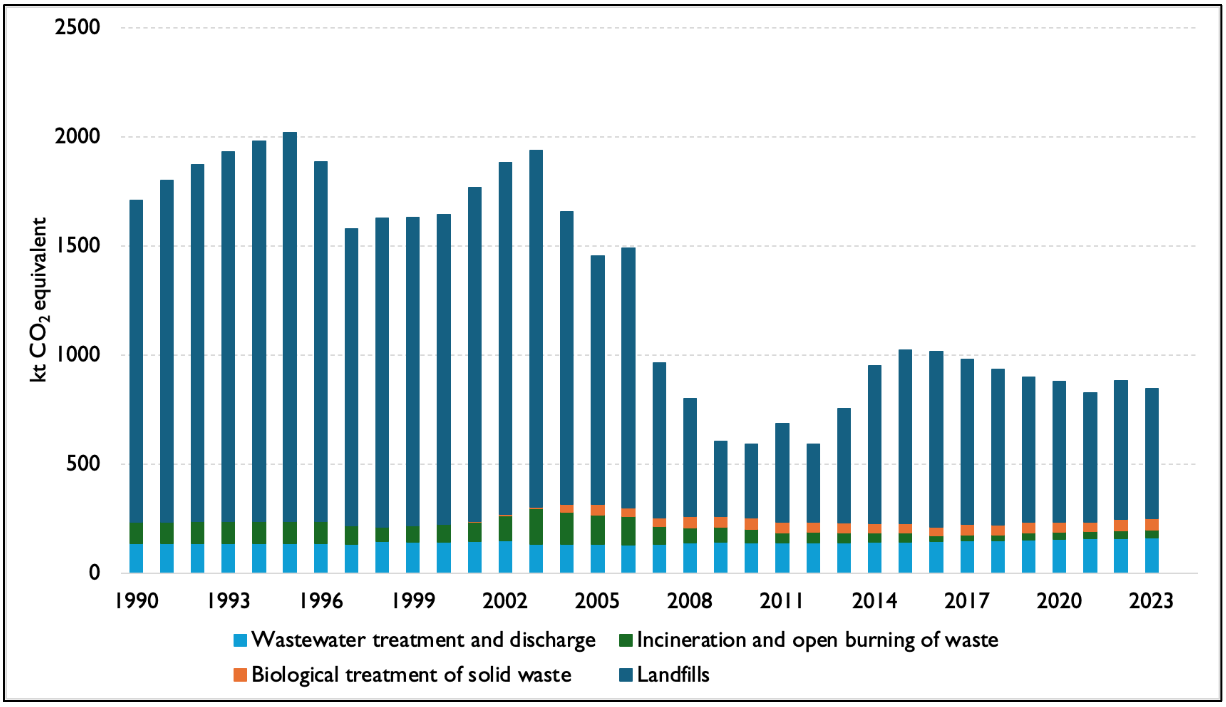
Source: Ritchie et al. (2020)

Potential Solutions for effective management of MSW to support SDG13

- Understanding the actual impact of current MSW management technologies is an important starting point to foster tailored actions to lower emissions from landfills and incineration plants. Different techniques can be implemented to investigate and estimate the generation of GHGs, e.g. time series procedures, Machine Learning approach (Magazzino et al., 2020), life cycle assessment methodologies (Ceraso and Cesaro, 2024). This would allow specific areas of intervention to be identified (including carbon capture, utilisation and storage and biomass co-firing, carbon capture and sequestration) and potentially optimised.
- Carbon from MSW disposed in the most common way, through landfill, can be sequestered on site, emitted as CO_2 following waste decomposition or by collection and subsequent combustion of CH_4, emitted as CO_2 from oxidation of CH_4, or escape as uncaptured CH_4. The latter has been identified as the major contributor to climate change impact in the waste sector (Lee et al., 2017). Disposal of waste in sanitary landfills remains the prevalent method while allowing both biogenic carbon sequestration and the protection of soil and groundwater from unwanted contamination (Salvador and Doong, 2024). However, emphasis should be given to the application of more sustainable practices that could lower the environmental impact of waste management.
- Reducing waste along the production chain can result in minimised resource extraction, moderating the need for raw materials, and energy demand from manufacturing and transport can be reduced, thus resulting in decreased GHG emissions from production and waste processing. Taking the case of food waste, a minimisation strategy showed the best environmental performance, reducing GHG emissions, eutrophication and acidification potential impacts when compared to treatment of landfilling, composting, anaerobic digestion and incineration (Bernstad Saraiva Schott and Andersson, 2015, Oldfield et al., 2016), compared to both incineration and anaerobic digestion (Bernstad Saraiva Schott and Andersson, 2015).
- The biogenic fraction of MSW (e.g., food waste, paper) can serve as a biomass feedstock for anaerobic digestion (AD) with the resulting biogas replacing fossil fuels for the generation of

energy. Further, by partially substituting common AD feedstocks, energy crops and agricultural residues, adverse effects concerning land use and deforestation would be lessened, and competition with crops destined for food production avoided. Figure 14 displays a snapshot of the GHGs emitted from waste management in Ireland for the period 1990-2023, broken down by subcategories. As evidenced by the data, landfill disposal was the main hotspot. The year 2023 experienced a 4% reduction overall, and a 6% decrease was registered for the subcategory landfills (EPA, 2024a). This positive trend is the result of successful actions and regulations such as waste planning at regional level, improved waste segregation and handling, recycling rates, and diversion from landfill disposal (Government of Ireland, 2024).

Figure 14: GHG emissions from the waste sector in Ireland (1990-2023)



Source: EPA (2025)

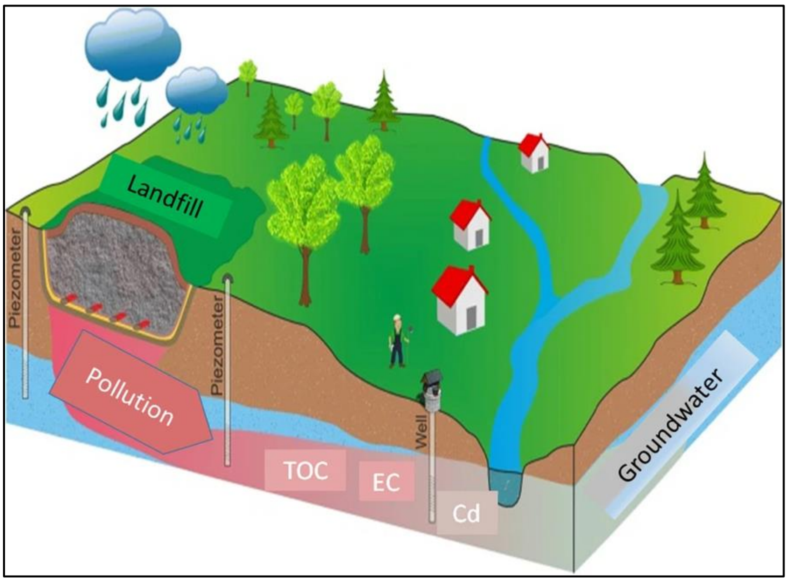
SDG14: Life Below Water

Sustainable Development Goal 14 (SDG14) Life Below Water aims to conserve and sustainably use the oceans, seas and marine resources for sustainable development[15]. MSW management and SDG14 are related as inefficient MSW management practices can have detrimental effects on marine ecosystems and the sustainability of marine life. The use of landfills for disposal of MSW is still one of the most common approaches employed across the global, irrespective of the countries developmental status and uncontrolled “landfills” (known as open dumpsites) are widely used in many developing countries (Siddiqua et al., 2022). Landfilling of MSW is associated with underground water pollution due to the leaching of organic, inorganic, and other substances of concern contained in the pollution from landfill runoff (Siddiqua et al., 2022). Figure 15 shows how landfill operations can lead to contamination of underground water sources through the landfill leachate; one, through flaws in the liner of the landfill,

[15] See https://sdgs.un.org/goals/goal14

and second, from rainfall dissolving inorganic and organic elements of the landfilled waste. In turn, this releases toxic chemicals that leak to the underground water systems (Siddiqua et al., 2022).Landfill leachate and runoff can have high metal contents, can be toxic if consumed by humans, and if the leachate reaches a water body such as lake or river systems it may have adverse effects on aquatic life (Zhang et al., 2016).

Figure 15: Route of underground water pollution from landfills due to leaching



Source: Siddiqua et al. (2022).

Global solid waste is composed of persistent (plastics, glass, metal, other waste) and naturally degradable components (food, green, wood, paper and cardboard, rubber/leather, other waste). The persistent materials require specific collection and processing to prevent avoid such waste becoming long-term pollutants (Coe et al., 2019). The processing of plastic waste is particularly problematic as improper disposal of MSW contributes to the breakdown of plastic waste into microplastics, which are ingested by marine organisms, disrupting food chains, and potentially affecting human health (Kopatz et al., 2023, Iñiguez et al., 2017). An unintended consequence of plastic use driven by human activities, and improper municipal solid waste collection, is the accumulation of waste plastics in the marine environment (Murshed et al., 2022). Plastic waste in the ocean will either stay afloat or sink to the seabed, depending on the size and density of the particles. Plastics in the ocean environment will degrade over time into small pieces called microplastics which can move up through the food chain as humans consume sea life that have been eating these microplastics. It is estimated that there are currently approximately 150 million tonnes of plastics in the oceans, and with the forecast increase it is estimated there will be 1 tonne of plastic for every 3 tonnes of fish by 2025, and by 2050, there will more plastic in the oceans than fish (by weight) (Dąbrowska et al., 2021).

Plastics constitute over 12% of all MSW globally and leakage occurs at all phases of the production-disposal life cycle due to inadequate management (Coe et al., 2019). The primary sources of macroplastic losses are from poorly managed MSW (i.e. open dumping and inadequate landfilling) (Ryberg et al., 2018). It is estimated 275 million tonnes of plastic waste are generated each year, with approximately 4.8–12.7 million tonnes of mismanaged plastic waste entering the ocean. Further is it estimated that only 20 countries are responsible for 83% of the plastic waste entering the world's oceans (Jambeck et al., 2015). Indonesia is an example of a country with limited MSW management services which is contributing to plastic pollution in the marine; it is the second largest country after China, with about 3.22 million tonnes tons of plastic waste mismanaged per year (Tibbetts, 2015). MSW management services only serve 47.35% of total population in Indonesia, with only 24.9% of the total MSW landfilled. Further, ±99% of landfills in Indonesia are operated as open dumping sites (Lestari and Trihadiningrum, 2019). This highlights the scale of the challenge to more efficiently manage plastic waste with appropriate MSW management approaches.

If no action is taken, the global generation of plastics will continue to grow, and 12,000 Mt of plastic waste will be in discarded landfills or in the natural environment by 2050 (Geyer et al., 2017). Further, if current management practices persist, there will be a significant addition of waste plastic to the ocean.

The indicators set out in the SDGs – such as municipal solid waste collections (SDG 11.6.1), food loss and waste indices (SDG 12.3.1), national recycling rate (SDG 12.5.1), or marine plastic density (SDG 14.1.1) – have the potential to show us if things are improving. However, data is limited, as demonstrated in Figure 2 for SDG indicator 12.5.1.

Potential Solutions for effective management of MSW to support SDG14

Effective MSW management is crucial to achieve SDG 14, which has set and indicator of marine plastic density (SDG 14.1.1). MSW management can be improved in several ways;

- *Waste Generation:* Minimising plastic and other waste. This can be assisted by better regulation, e.g. the Single-Use Plastics Directive[16] which was introduced in the EU in 2021. The directive prohibits placing 10 types of single-use plastic products (i.e., cotton buds, cutlery, plates, straws, stirrers, balloon sticks, food containers, and polystyrene cups); they will be replaced with alternative products (Dąbrowska et al., 2021).
- *Improving Waste Collection and Recycling:* Ensuring waste is collected and processed properly prevents leakage into waterways. Alternatives to landfilling should be pursued. The integration of sorting plants with MSW management systems (such as WtE) which sort recyclable waste fractions like plastic packaging from non-recyclable streams leading to material recovery and reduction of fossil CO2 emissions (Edo et al., 2024)Waste plastic fractions have value and are suitable for recycling, mainly by chemical or energy recovery, which especially attractive for polyolefin waste (Iñiguez et al., 2017). An example of an alternative for is waste plastic treatment by pyrolysis to generate liquid, gaseous and solid products.
- *Strengthening Regulations:* Implementing policies to prevent illegal dumping in oceans or near water bodies. Examples include extended producer responsibility (EPR) schemes which shift financial responsibility for end-of-life disposal to product manufacturers, thereby providing an incentive for improved product design, reuse, and recycling (Tibbetts, 2015).

Effective MSW management is crucial for achieving SDG 14 by reducing the environmental pressures on marine ecosystems, ensuring sustainable use of ocean resources, and protecting aquatic biodiversity.

SDG15: Life on Land

Sustainable Development Goal 15 aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss"[17]. Municipal Solid Waste is related to SDG due to the shared focus on environmental health, ecosystem preservation, and sustainable resource use. Effective waste management strategies can support SDG15 by reducing pollution, improving environmental health and conserving

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[16] Official Journal of the European Union. *Directive (EU) 2019/904 of the European Parliament and of the Council of 5 June 2019 on the Reduction of the Impact of Certain Plastic Products on the Environment*; Publications Office of the European Union: Luxembourg, 2019; pp. 1–19.

[17] See https://sdgs.un.org/goals/goal15

resources (Ram and Bracci, 2024).

MSW management in both developed and developing countries poses a threat to environmental integrity and human health (Lebelo and Mochane, 2021). As already mentioned in relation to SDG14, open dumping MSW management practices are widely used in many developing and emerging countries (Siddiqua et al., 2022), with open dumping and burning occurring widely. Such improper waste management practices can cause serious health and environmental impacts due to the emission of GHGs, toxic leachates and volatile organic compounds, which contribute to pollution of air, soil and water (Choudhary et al., 2024). Poorly managed MSW contributes significantly to GHG emissions (e.g., methane from organic waste decomposition in landfills) with the resulting climate change directly affecting terrestrial ecosystems, accelerating biodiversity loss and desertification. Many landfills and dumping sites in developing countries lack leachate collection and treatment systems, which can result in significant emission of landfill leachate, the quantity and quality of which are influenced by factors such as the composition of the waste, the biochemical processes occurring in the degradation of the waste, the moisture content, and local parameters (Ali et al., 2014, Rezapour et al., 2018). The leachate generated by open burning and dumping of solid waste is hazardous to soil microbes and causes chemical and biological contamination in soil. The chemical interactions between the soil mineral particles and the leachate, which is comprised of high levels of dissolved organic, inorganic salt ions, microorganisms, and heavy metals may substantially impact on soil behaviour over time, resulting in deterioration of the soil environment, disruption of ecological balances and biodiversity loss (Mor and Ravindra, 2023). Further, landfills often encroach upon natural habitats, destroying ecosystems and endangering species.

As already outlined in relation to SDG7, MSW can be converted into energy using Waste-to-Energy (WtE) technologies. This benefits SDG15 by providing renewable energy (from the biogenic portion of MSW), reducing the size of MSW provided renewable energy, avoiding the emission of GHGs and improving the urban environment (Cui et al., 2024, Istrate et al., 2020). Refuse derived fuel (RDF) is another commonly used method of using MSW as an energy source and is used in sectors such as the cement industry. The use of wastes as a fuel sources and in energy generation avoids secondary pollution which occurs in the case of uncontrolled disposal, including soil contamination by heavy metals and pathogens (Shehata et al., 2022). However there are negative environmental impacts associated with development of WtE infrastructure, due to the land requirement for the construction of the WtE plant with resulting impacts on the ecosystem and environment (Cui et al., 2024). Further, thermal processing of waste can have negative impacts due to the possible generation of emissions of contaminants in flue gas; the presence of hazardous substances in the ash, and pollution of water used in particular technological points of the incineration equipment (Tabasová et al., 2012). Human health impacts can arise due to the emission of dioxins, furans, heavy metals and polycyclic aromatic hydrocarbons (Istrate et al., 2020). However, such emissions can be controlled. For example, maximum emission limits are set in the EU by the Industrial Emissions Directive[18] which WtE plants must meet (Malinauskaite et al., 2017, Neuwahl et al., 2019). This can be enabled by using appropriate air pollution control systems for.

Potential Solutions for effective management of MSW to support SDG15

- Waste Reduction: Minimising waste generation aligns with reducing pressure on ecosystems by reducing the volumes of MSW to be treated. Public awareness campaigns, education and engagement are important in fostering behavioural changes and encouraging responsible waste practices that can reduce environmental harm and protect ecosystems (Choudhary et al., 2024).
- Recycling and Circular Economy: Sustainable waste management practices such as reuse recovery and recycling can promote the reuse of resources, reducing the demand for raw materials and

[18] See European Council DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (Recast)
Eur Parliam Counc Eur Union (2010), p. L334

mitigating deforestation and ecosystem degradation. Recycling MSW as a resource reduces the amount of land needed to dispose of MSW in landfills and reduces demand for natural resources and avoids overexploitation and destruction of ecosystems (Cui et al., 2024). Circular economy practices such as composting can be employed to enhance soil health and reduce the need for chemical fertilisers, promoting sustainable land use (Choudhary et al., 2024).

- Proper Waste Disposal and Treatment: Governments, municipalities, and businesses can contribute to implementation of sustainable MSW management strategies, and appropriate infrastructure to prevents land degradation and contamination of ecosystems by safely managing toxic and hazardous wastes. For example, municipalities should ensure that proper landfill design is followed. Further, policy interventions and technological innovations play crucial roles in enhancing waste management systems (see SDG9), ensuring effective resource recovery while and minimising environmental and health risks (Choudhary et al., 2024).

Concluding remarks

Significant volumes of municipal solid waste are generated globally and are improperly handled, resulting in significant environmental, economic and social impacts. Efforts are being made to move to more sustainable use of natural and human resources for the betterment of global society, with the Sustainable Development Goals adopted to track progress. This report has highlighted the detrimental effect of sub-optimal MSW management approaches on environmental and social sustainability through the lens of the SDGs.

Food waste is a significant contributor to global hunger and food insecurity (SDG2). In 2022, an estimated 1.05 billion tonnes of food in the retail, food service and household sectors were wasted globally (UNEP, 2024a), directly impacting on potential opportunities to address hunger and food insecurity. Despite sufficient global food production to feed the population an estimated 30 per cent of all food produced globally is wasted (EPA, 2023a), leading to inefficient resource use and exacerbating food scarcity in many regions. This relates also to SDG12, high levels of MSW generation often stem from overconsumption, and inefficient production and consumption patterns. Products are currently designed, used, and disposed of in a linear manner resulting in growing quantities of MSW. The use of landfills for disposal of MSW is still one of the most common approaches employed across the global, irrespective of the countries developmental status and uncontrolled "landfills" (known as open dumpsites) are widely used in many developing countries (Siddiqua et al., 2022). Improper handling and disposal of MSW can lead to contamination of water resources and hinder sanitation efforts (SDG6), posing severe environmental and social challenges. When waste is improperly disposed of, it can generate leachate, a toxic liquid formed when rainwater percolates through waste materials, dissolving harmful substances. This leachate can contaminate surface water and groundwater, adversely affecting water quality (SDG14) and soil quality (SDG15) (Eggen et al., 2010). Further, waste management systems have a direct impact on GHG emissions (SDG13), accounting for approx. 3% of global GHG emissions. improper waste management practices can contribute significantly to GHG emissions (e.g., methane from organic waste decomposition in landfills) with the resulting climate change directly affecting terrestrial ecosystems, accelerating biodiversity loss and desertification (Ali et al., 2014).

Municipal solid waste management is a key service that intersects with wider social, economic, and environmental inequalities (SDG10). The level of controlled municipal solid waste management varies greatly by region, with Sub-Saharan Africa and Central and South Asia having the lowest rates, while North America and Western Europe have the highest (UNEP, 2024c). There are further economic disparities in municipal solid waste generation and management; higher income countries make up 16 per cent of the world's population but generate 34 percent of global waste, while low-income countries, which represent 9 percent of the global population, contribute only about 5 percent of the world's waste (Kaza et al., 2018). In addition to the disproportionate siting of landfills in marginalised communities, residents living near these facilities face significant health risks due to contaminated groundwater and harmful emissions (Siddiqua et al., 2022). Poor waste management leads to an increase in both communicable and non-communicable diseases, along with long-term health disparities (Vinti et al., 2021, Fuller et al., 2022). In informal economies, waste pickers experience heightened health risks and adverse health outcomes (Zolnikov et al., 2021).

Despite the environmental and social impacts generated by MSW management systems, technical solutions exist. MSW can be converted into energy using WtE technologies, which align with SDG7's objectives by increasing renewable energy use and improving energy efficiency (Khan and Kabir, 2020). WtE reduces dependence on fossil fuels, lower greenhouse gas emissions, and promote a circular economy by recovering energy and valuable resources (Alao et al., 2022). The innovative management of waste (SDG9) and use of more sustainable management approaches can result in significant benefits for society; minimising the adverse effects of climate change, and can improve social and economic sustainability (Ram and Bracci, 2024). Stakeholders are considering more sustainable approaches for MSW management including integrated approaches (Kundariya, Mohanty et al. 2021), with innovations occurring in waste collection and transportation, waste-to-energy technologies and organic waste valorisation.

Governments and municipalities have an important role in implementing sustainable MSW management to achieve the SDGs. Minimising waste generation aligns with reducing hunger (SDG2), GHG emissions (SDG13) and pressure on ecosystems (SDG14 and 15) by reducing the volumes of MSW to be treated (SDG6 and SDG7) and by retaining products in the economy for longer. Sustainable waste management practices such as reuse recovery and recycling can promote the reuse of resources, reducing the demand for raw materials (SDG12) and mitigating deforestation and ecosystem degradation (SDG15) (Cui et al., 2024). Circular economy practices such as composting can be employed to enhance soil health and reduce the need for chemical fertilisers, promoting sustainable land use (Choudhary et al., 2024). Public awareness campaigns, education and engagement are important in fostering behavioural changes and encouraging responsible waste practices that can reduce environmental harm and protect ecosystems (Choudhary et al., 2024). Governments, municipalities, and businesses can contribute to implementation of sustainable MSW management strategies, and appropriate infrastructure to prevents land degradation and contamination of ecosystems by safely managing toxic and hazardous wastes. For example, municipalities should ensure that proper landfill design is followed to minimise pollution and risks to workers and marginalised communities (SDG10). Further, policy interventions and technological innovations play crucial roles in enhancing waste management systems (SDG9), ensuring effective resource recovery while and minimising environmental and health risks.

It is important that technical and governance solutions are implemented to mitigate the impact of MSW management on the SDGs.

References

ABUBAKAR, I. R., MANIRUZZAMAN, K. M., DANO, U. L., ALSHIHRI, F. S., ALSHAMMARI, M. S., AHMED, S. M. S., AL-GEHLANI, W. A. G. & ALRAWAF, T. I. 2022. Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. *Int J Environ Res Public Health,* 19.

ACKERMAN, J. & LEVIN, D. B. 2023. Rethinking plastic recycling: A comparison between North America and Europe. *Journal of Environmental Management,* 340, 117859.

AFRICAN DEVELOPMENT BANK GROUP (AFDB). 2018. *Climate Change and Green Growth Department : 100,000 Marine Animals Killed by Plastic Pollution Every Year* [Online]. Available: https://www.vanguardngr.com/2018/06/afdb-says-100000-marine-animals-killed-plastic-pollution-every-year/ [Accessed 10/12/2024].

AFSHIN, A., SUR, P. J., FAY, K. A., CORNABY, L., FERRARA, G., SALAMA, J. S., MULLANY, E. C., ABATE, K. H., ABBAFATI, C., ABEBE, Z., AFARIDEH, M., AGGARWAL, A., AGRAWAL, S., AKINYEMIJU, T., ALAHDAB, F., BACHA, U., BACHMAN, V. F., BADALI, H., BADAWI, A., BENSENOR, I. M., BERNABE, E., BIADGILIGN, S. K. K., BIRYUKOV, S. H., CAHILL, L. E., CARRERO, J. J., CERCY, K. M., DANDONA, L., DANDONA, R., DANG, A. K., DEGEFA, M. G., EL SAYED ZAKI, M., ESTEGHAMATI, A., ESTEGHAMATI, S., FANZO, J., FARINHA, C. S. E. S., FARVID, M. S., FARZADFAR, F., FEIGIN, V. L., FERNANDES, J. C., FLOR, L. S., FOIGT, N. A., FOROUZANFAR, M. H., GANJI, M., GELEIJNSE, J. M., GILLUM, R. F., GOULART, A. C., GROSSO, G., GUESSOUS, I., HAMIDI, S., HANKEY, G. J., HARIKRISHNAN, S., HASSEN, H. Y., HAY, S. I., HOANG, C. L., HORINO, M., IKEDA, N., ISLAMI, F., JACKSON, M. D., JAMES, S. L., JOHANSSON, L., JONAS, J. B., KASAEIAN, A., KHADER, Y. S., KHALIL, I. A., KHANG, Y.-H., KIMOKOTI, R. W., KOKUBO, Y., KUMAR, G. A., LALLUKKA, T., LOPEZ, A. D., LORKOWSKI, S., LOTUFO, P. A., LOZANO, R., MALEKZADEH, R., MÄRZ, W., MEIER, T., MELAKU, Y. A., MENDOZA, W., MENSINK, G. B. M., MICHA, R., MILLER, T. R., MIRAREFIN, M., MOHAN, V., MOKDAD, A. H., MOZAFFARIAN, D., NAGEL, G., NAGHAVI, M., NGUYEN, C. T., NIXON, M. R., ONG, K. L., PEREIRA, D. M., POUSTCHI, H., QORBANI, M., RAI, R. K., RAZO-GARCÍA, C., REHM, C. D., RIVERA, J. A., RODRÍGUEZ-RAMÍREZ, S., ROSHANDEL, G., ROTH, G. A., et al. 2019. Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet,* 393, 1958-1972.

AL-JAF, H. A. K. & AZIZ, S. Q. 2024. Simulation Model to Evaluate the Scenarios of Municipal Solid Waste Management. *Transactions of the Indian National Academy of Engineering*.

ALAO, M. A., AYODELE, T. R., OGUNJUYIGBE, A. S. O. & POPOOLA, O. M. 2020. Multi-criteria decision based waste to energy technology selection using entropy-weighted TOPSIS technique: The case study of Lagos, Nigeria. *Energy,* 201, 117675.

ALAO, M. A., POPOOLA, O. M. & AYODELE, T. R. 2022. Waste – to – energy nexus: An overview of technologies and implementation for sustainable development. *Cleaner Energy Systems,* 3, 100034.

ALI, S. M., PERVAIZ, A., AFZAL, B., HAMID, N. & YASMIN, A. 2014. Open dumping of municipal solid waste and its hazardous impacts on soil and vegetation diversity at waste dumping sites of Islamabad city. *Journal of King Saud University - Science,* 26, 59-65.

ALLAHYARI, M. S. & POURSAEED, A. 2019. Sustainable Agriculture: Implication for SDG2 (Zero Hunger). *In:* LEAL FILHO, W., AZUL, A. M., BRANDLI, L., ÖZUYAR, P. G. & WALL, T. (eds.) *Zero Hunger*. Cham: Springer International Publishing.

AMAGER BAKKE CENTRE. 2024. *From Waste to Energy – The technology Inside Amager Bakke* [Online]. Available: https://a-r-c.dk/amager-bakke/from-waste-to-energy/ [Accessed 05/12/2024].

ARENIBAFO, F. E. 2023. The 3Rs(Reduce, Reuse, Recycle) of Waste Management – An effective and Sustainable Approach for Managing Municipal Solid Waste in Developing Countries. *Proceedings of the International Conference of Contemporary Affairs in Architecture and Urbanism-ICCAUA,* 6, 383–398.

BALDÉ, C. P., KUEHR, R., YAMAMOTO, T., MCDONALD, R., D'ANGELO, E., ALTHAF, S., BEL, G., DEUBZER, O., FERNANDEZ-CUBILLO, E., FORTI, V., GRAY, V., HERAT, S., HONDA, S., IATTONI, G., KHETRIWAL, D., LUDA DI CORTEMIGLIA, S. V., LOBUNTSOVA, Y., NNOROM, I., PRALAT, N. & WAGNER, M. 2024. *Global E-waste Monitor 2024,* Geneva/Bonn, International Telecommunication Union (ITU) and United Nations Institute for Training and Research (UNITAR).

BECIDAN, M. 2018. Fly ash treatment technologies: Report SINTEF, https://www.noah.no/wp-content/uploads/2018/06/SINTEF-Report-2018-Fly-ash-treatment-technologies-FINAL.pdf.

BERNSTAD SARAIVA SCHOTT, A. & ANDERSSON, T. 2015. Food waste minimization from a life-cycle perspective. *Journal of Environmental Management,* 147**,** 219-226.
BLASENBAUER, D., HUBER, F., LEDERER, J., QUINA, M. J., BLANC-BISCARAT, D., BOGUSH, A., BONTEMPI, E., BLONDEAU, J., CHIMENOS, J. M., DAHLBO, H., FAGERQVIST, J., GIRO-PALOMA, J., HJELMAR, O., HYKS, J., KEANEY, J., LUPSEA-TOADER, M., O'CAOLLAI, C. J., ORUPÕLD, K., PAJĄK, T., SIMON, F.-G., SVECOVA, L., ŠYC, M., ULVANG, R., VAAJASAARI, K., VAN CANEGHEM, J., VAN ZOMEREN, A., VASAREVIČIUS, S., WÉGNER, K. & FELLNER, J. 2020. Legal situation and current practice of waste incineration bottom ash utilisation in Europe. *Waste Management,* 102**,** 868-883.
BULLARD, R. 1990. *Dumping on dixie: race, class and environmental quality,* Boulder, COWestview Press.
CANNON, C. E. B. 2020. Examining rural environmental injustice: An analysis of ruralness, class, race, and gender on presence of landfills across the United States. *Journal of Rural and Community Development,* 15**,** 89-114.
CANNON, C. E. B. 2024. Advancing sustainable transitions: A spatial analysis of socio-environmental dynamics of landfills across the United States. *Elementa: Science of the Anthropocene,* 12.
CATTANEO, A., FEDERIGHI, G. & VAZ, S. 2021. The environmental impact of reducing food loss and waste: A critical assessment. *Food Policy,* 98**,** 101890.
CERASO, A. & CESARO, A. 2024. Life Cycle Sustainability Assessment of municipal solid waste management systems: a review. *Journal of Environmental Management,* 368**,** 122143.
CHOUDHARY, M., SINGH, D., PARIHAR, M., CHOUDHARY, K. B., NOGIA, M., SAMAL, S. K. & MISHRA, R. 2024. Chapter 3 - Impact of municipal solid waste on the environment, soil, and human health. *In:* MEENA, V. S., RAKSHIT, A., MEENA, M. D., BASLAM, M., FATTAH, I. M. R., LAM, S. S. & KABA, J. S. (eds.) *Waste Management for Sustainable and Restored Agricultural Soil.* Academic Press.
CLEMENTE-SUÁREZ, V. J., RODRIGUEZ-BESTEIRO, S., CABELLO-ERAS, J. J., BUSTAMANTE-SANCHEZ, A., NAVARRO-JIMÉNEZ, E., DONOSO-GONZALEZ, M., BELTRÁN-VELASCO, A. I. & TORNERO-AGUILERA, J. F. 2022. Sustainable Development Goals in the COVID-19 Pandemic: A Narrative Review. *Sustainability,* 14**,** 7726.
CLIMATE WATCH. 2024. *Historical GHG Emissions* [Online]. Available: https://www.climatewatchdata.org/ghg-emissions?breakBy=sector&chartType=percentage&end_year=2019&source=Climate%20Watch&start_year=1990 [Accessed 03/01/2025].
COE, J. M., ANTONELIS, G. B. & MOY, K. 2019. Taking control of persistent solid waste pollution. *Marine Pollution Bulletin,* 139**,** 105-110.
CRIPPA, M., SOLAZZO, E., GUIZZARDI, D., MONFORTI-FERRARIO, F., TUBIELLO, F. N. & LEIP, A. 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. *Nature Food,* 2**,** 198-209.
CUI, W., SU, H., LIU, X., JI, N. & WEI, Y. 2024. Resource utilization potential of municipal solid waste affects the sustainable development goals progress in China. *Resources, Conservation and Recycling,* 205**,** 107562.
DĄBROWSKA, J., SOBOTA, M., ŚWIĄDER, M., BOROWSKI, P., MORYL, A., STODOLAK, R., KUCHARCZAK, E., ZIĘBA, Z. & KAZAK, J. K. 2021. Marine Waste—Sources, Fate, Risks, Challenges and Research Needs. *International Journal of Environmental Research and Public Health,* 18**,** 433.
DONUMA, K. U., MA, L., BU, C., GEORGE, L.-Y., GASHAU, M. & SULEIMAN, A. O. 2024. Environmental and human health risks of indiscriminate disposal of plastic waste and sachet water bags in Maiduguri, Borno State Nigeria. *Waste Management Bulletin,* 2**,** 130-139.
DRI, M., CANFORA, P., ANTONOPOULOS, I. & GAUDILLAT, P. 2018. *Best Environmental Management Practice for the Waste Management Sector,* EUR 29136 EN, Publications Office of the European Union, Luxembourg, doi:10.2760/50247, JRC111059.
DUNAJEVA, J. & KOSTKA, J. 2022. Racialized politics of garbage: waste management in urban Roma settlements in Eastern Europe. *Ethnic and Racial Studies,* 45**,** 90-112.
EDO, M., GRANSTRÖM, L., SPELHAUG, C. & POTTER, C. 2024. Advanced sorting technologies in the waste sector: Case studies compilation. *In:* BECIDAN, M. (ed.). IEA Bioenergy: Task 36, https://www.ieabioenergy.com/wp-content/uploads/2024/07/IEA-Bioenergy_-Advanced-sorting-technologies-in-the-waste-sector.pdf.
EEA. 2024. *Leachate pollution from landfills* [Online]. Available: European Environment Agency, https://www.eea.europa.eu/en/european-zero-pollution-dashboards/indicators/emission-from-waste-management-facilities?activeTab=658e2886-cfbf-4c2f-a603-061e1627a515 [Accessed 10/01/2025].
EGGEN, T., MOEDER, M. & ARUKWE, A. 2010. Municipal landfill leachates: A significant source for new and emerging pollutants. *Science of The Total Environment,* 408**,** 5147-5157.

ELSHEEKH, K. M., KAMEL, R. R., ELSHERIF, D. M. & SHALABY, A. M. 2021. Achieving sustainable development goals from the perspective of solid waste management plans. *Journal of Engineering and Applied Science,* 68**,** 9.

EPA. 2013. *Lanfill Manuals- Lanfill site design* [Online]. Available: Environmental Protection Agency, https://www.epa.ie/publications/compliance--enforcement/waste/EPA_landfill_site_design_guide.pdf [Accessed 11/01/2025].

EPA 2023a. *2019 Wasted Food Report. Estimates of generation and management of wasted food in the United States in 2019,* United States Environmental Protection Agency, https://www.epa.gov/system/files/documents/2024-04/2019-wasted-food-report_508_opt_ec_4.23correction.pdf.

EPA. 2023b. *Municipal waste statistics for Ireland* [Online]. Available: Environmental Protection Agency, https://www.epa.ie/our-services/monitoring--assessment/waste/national-waste-statistics/municipal/ [Accessed 10/01/2025].

EPA. 2024a. *Greenhouse gas emissions (GHG), Waste* [Online]. Available: https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/waste/ [Accessed 04/01/2025].

EPA. 2024b. *Waste recycling in Europe* [Online]. European Environmental Agency Available: European Environmental Agency; https://www.eea.europa.eu/en/analysis/indicators/waste-recycling-in-europe [Accessed 03/01/2025].

EPA. 2025. *Waste* [Online]. Available: https://www.epa.ie/our-services/monitoring--assessment/climate-change/ghg/waste/ [Accessed 13/01/2025].

FAO. 2024. *FAOSTAT: Suite of Food Security Indicators* [Online]. https://www.fao.org/faostat/en/#data/FS. [Accessed 16/10/2024].

FULLER, R., LANDRIGAN, P. J., BALAKRISHNAN, K., BATHAN, G., BOSE-O'REILLY, S., BRAUER, M., CARAVANOS, J., CHILES, T., COHEN, A., CORRA, L., CROPPER, M., FERRARO, G., HANNA, J., HANRAHAN, D., HU, H., HUNTER, D., JANATA, G., KUPKA, R., LANPHEAR, B., LICHTVELD, M., MARTIN, K., MUSTAPHA, A., SANCHEZ-TRIANA, E., SANDILYA, K., SCHAEFLI, L., SHAW, J., SEDDON, J., SUK, W., TÉLLEZ-ROJO, M. M. & YAN, C. 2022. Pollution and health: a progress update. *The Lancet Planetary Health,* 6**,** e535-e547.

GARCÍA, S., PASTOR, R., MONSERRAT-MESQUIDA, M., ÁLVAREZ-ÁLVAREZ, L., RUBÍN-GARCÍA, M., MARTÍNEZ-GONZÁLEZ, M. Á., SALAS-SALVADÓ, J., CORELLA, D., FITÓ, M., MARTÍNEZ, J. A., TOJAL-SIERRA, L., WÄRNBERG, J., VIOQUE, J., ROMAGUERA, D., LÓPEZ-MIRANDA, J., ESTRUCH, R., TINAHONES, F. J., SANTOS-LOZANO, J. M., SERRA-MAJEM, L., CANO-IBAÑEZ, N., PINTÓ, X., DELGADO-RODRÍGUEZ, M., MATÍA-MARTÍN, P., VIDAL, J., VÁZQUEZ, C., DAIMIEL, L., ROS, E., BUIL-COSIALES, P., MARTÍNEZ-RODRÍGUEZ, M. Á., COLTELL, O., CASTAÑER, O., GARCIA-RIOS, A., BARCELÓ, C., GÓMEZ-GRACIA, E., ZULET, M. Á., KONIECZNA, J., CASAS, R., MASSÓ-GUIJARRO, P., GOICOLEA-GÜEMEZ, L., BERNAL-LÓPEZ, M. R., BES-RASTROLLO, M., SHYAM, S., GONZÁLEZ, J. I., ZOMEÑO, M. D., PEÑA-ORIHUELA, P. J., GONZÁLEZ-PALACIOS, S., TOLEDO, E., KHOURY, N., PEREZ, K. A., MARTÍN-SÁNCHEZ, V., TUR, J. A. & BOUZAS, C. 2023. Ultra-processed foods consumption as a promoting factor of greenhouse gas emissions, water, energy, and land use: A longitudinal assessment. *Science of The Total Environment,* 891**,** 164417.

GEYER, R., JAMBECK, J. R. & LAW, K. L. 2017. Production, use, and fate of all plastics ever made. *Science Advances,* 3**,** e1700782.

GOVERNMENT OF IRELAND. 2024. *Climate Action Plan 2024* [Online]. Available: https://www.gov.ie/pdf/?file=https://assets.gov.ie/284675/70922dc5-1480-4c2e-830e-295afd0b5356.pdf#page=null [Accessed 05/11/2024].

GUTBERLET, J. & CARENZO, S. 2020. Waste Pickers at the Heart of the Circular Economy: A Perspective of Inclusive Recycling from the Global South. *Worldwide Waste,* 3 (1).

HEIDEGGER, P. & WIESE, K. 2020. *Pushed to the Wastelands: Environmental Racism Against Roma Communities in Central and Eastern Europe.,* Brussels, European Environmental Bureau, https://eeb.org/library/pushed-to-the-wastelands-environmental-racism-against-roma-communities-in-central-and-eastern-europe/.

HOFFMAN, B. 2022. Valorisation of biowaste in the United States: Distributed biogas upgrading to Renewable Natural

Gas (RNG) using biomethanation. *In:* HARRISON, K., ROBERTS, D., EDO, M. & JOHANSSON, I. (eds.). IEA Bioenergy: Task 36, https://www.ieabioenergy.com/wp-content/uploads/2022/09/Task-36-biomethanation_final-version.pdf.

IEA 2023. *A Vision for Clean Cooking Access for All: World Energy Outlook Special Report*, The International Energy Agency (IEA) and the African Development Bank Group,

https://www.iea.org/reports/a-vision-for-clean-cooking-access-for-all.
INDEPENDENT GROUP OF SCIENTISTS APPOINTED BY THE SECRETARY-GENERAL 2023. *Global Sustainable Development Report 2023: Times of crisis, times of change: Science for accelerating transformations to sustainable development,* New York, United Nations
IÑIGUEZ, M. E., CONESA, J. A. & FULLANA, A. 2017. Pollutant content in marine debris and characterization by thermal decomposition. *Marine Pollution Bulletin,* 117, 359-365.
ISTRATE, I.-R., IRIBARREN, D., GÁLVEZ-MARTOS, J.-L. & DUFOUR, J. 2020. Review of life-cycle environmental consequences of waste-to-energy solutions on the municipal solid waste management system. *Resources, Conservation and Recycling,* 157, 104778.
JAMBECK, J. R., GEYER, R., WILCOX, C., SIEGLER, T. R., PERRYMAN, M., ANDRADY, A., NARAYAN, R. & LAW, K. L. 2015. Plastic waste inputs from land into the ocean. *Science,* 347, 768-771.
JOHANSSON, I., EDO GIMÉNEZ, M., ROBERTS, D., HOFFMAN, B., BECIDAN, M., CICERI, G., MURPHY, F., TROIS, C., CURRAN, T. P. & STAPF, D. 2023. Material and energy valorization of waste as part of a circular model. *IEA Bioenergy*.
KAZA, S., YAO, L., BHADA-TATA, P. & VAN WOERDEN, F. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development Series.* , Washington, DC, World Bank.
KHAN, I. & KABIR, Z. 2020. Waste-to-energy generation technologies and the developing economies: A multi-criteria analysis for sustainability assessment. *Renewable Energy,* 150, 320-333.
KHAWAJA, M. K., ALKAYYALI, K., ALMANASREH, M. & ALKHALIDI, A. 2024. Waste-to-energy barriers and solutions for developing countries with limited water and energy resources. *Science of The Total Environment,* 926, 172096.
KJÆR, B. 2013. Municipal waste management in Norway European Environmnet Agency, https://www.eea.europa.eu/publications/managing-municipal-solid-waste/norway-municipal-waste-management.
KOPATZ, V., WEN, K., KOVÁCS, T., KEIMOWITZ, A. S., PICHLER, V., WIDDER, J., VETHAAK, A. D., HOLLÓCZKI, O. & KENNER, L. 2023. Micro- and Nanoplastics Breach the Blood-Brain Barrier (BBB): Biomolecular Corona's Role Revealed. *Nanomaterials (Basel),* 13.
KUMAR, A., SINGH, E., MISHRA, R., LO, S. L. & KUMAR, S. 2023. Global trends in municipal solid waste treatment technologies through the lens of sustainable energy development opportunity. *Energy,* 275, 127471.
KUNDARIYA, N., MOHANTY, S. S., VARJANI, S., HAO NGO, H., W. C. WONG, J., TAHERZADEH, M. J., CHANG, J.-S., YONG NG, H., KIM, S.-H. & BUI, X.-T. 2021. A review on integrated approaches for municipal solid waste for environmental and economical relevance: Monitoring tools, technologies, and strategic innovations. *Bioresource Technology,* 342, 125982.
LEBELO, K. & MOCHANE, M. J. 2021. Chapter 8 - The environmental impact of municipal solid waste and the application of biosurfactants in the bioremediation of polluted environments. *In:* INAMUDDIN & ADETUNJI, C. O. (eds.) *Green Sustainable Process for Chemical and Environmental Engineering and Science*. Elsevier.
LEE, U., HAN, J. & WANG, M. 2017. Evaluation of landfill gas emissions from municipal solid waste landfills for the life-cycle analysis of waste-to-energy pathways. *Journal of Cleaner Production,* 166, 335-342.
LESTARI, P. & TRIHADININGRUM, Y. 2019. The impact of improper solid waste management to plastic pollution in Indonesian coast and marine environment. *Marine Pollution Bulletin,* 149, 110505.
MABALANE, P. N., OBOIRIEN, B. O., SADIKU, E. R. & MASUKUME, M. 2021. A Techno-economic Analysis of Anaerobic Digestion and Gasification Hybrid System: Energy Recovery from Municipal Solid Waste in South Africa. *Waste and Biomass Valorization,* 12, 1167-1184.
MAGAZZINO, C., MELE, M. & SCHNEIDER, N. 2020. The relationship between municipal solid waste and greenhouse gas emissions: Evidence from Switzerland. *Waste Management,* 113, 508-520.
MALINAUSKAITE, J., JOUHARA, H., CZAJCZYŃSKA, D., STANCHEV, P., KATSOU, E., ROSTKOWSKI, P., THORNE, R. J., COLÓN, J., PONSÁ, S., AL-MANSOUR, F., ANGUILANO, L., KRZYŻYŃSKA, R., LÓPEZ, I. C., A.VLASOPOULOS & SPENCER, N. 2017. Municipal solid waste management and waste-to-energy in the context of a circular economy and energy recycling in Europe. *Energy,* 141, 2013-2044.
MARQUES, C. P., ZOLNIKOV, T. R., NORONHA, J. M. D., ANGULO-TUESTA, A., BASHASHI, M. & CRUVINEL, V. R. N. 2021. Social vulnerabilities of female waste pickers in Brasília, Brazil. *Archives of Environmental & Occupational Health,* 76, 173-180.
MARTÍN-BLANCO, C., ZAMORANO, M., LIZÁRRAGA, C. & MOLINA-MORENO, V. 2022. The Impact of COVID-19 on the Sustainable Development Goals: Achievements and Expectations. *Int J Environ Res Public Health,* 19.

MARTUZZI, M., MITIS, F. & FORASTIERE, F. 2010. Inequalities, inequities, environmental justice in waste management and health. *European Journal of Public Health,* 20**,** 21-26.
MILIOS, L. 2013. Municipal waste management in Sweden. European Environmnet Agency, https://www.eea.europa.eu/publications/managing-municipal-solid-waste/sweden-municipal-waste-management.
MISGANAW, A. 2023. Assessment of potential environmental impacts and sustainable management of municipal solid waste using the DPSIRO framework: a case study of Bahir Dar, Ethiopia. *Environmental Monitoring and Assessment,* 195**,** 297.
MOHAI, P. & SAHA, R. 2015. Which came first, people or pollution? A review of theory and evidence from longitudinal environmental justice studies. *Environmental Research Letters,* 10**,** 125011.
MOR, S. & RAVINDRA, K. 2023. Municipal solid waste landfills in lower- and middle-income countries: Environmental impacts, challenges and sustainable management practices. *Process Safety and Environmental Protection,* 174**,** 510-530.
MUNESUE, Y., MASUI, T. & FUSHIMA, T. 2015. The effects of reducing food losses and food waste on global food insecurity, natural resources, and greenhouse gas emissions. *Environmental Economics and Policy Studies,* 17**,** 43-77.
MURPHY, F. 2024. *Food Loss and Waste: Quantification, Impacts and Potential for Sustainable Management*, IEA Bioenergy: Task 36. https://www.ieabioenergy.com/wp-content/uploads/2024/10/Task36_-Food-Waste-Report-Final.pdf.
MURPHY, F. & GUSCIUTE, E. 2024. Energy from waste: Regional Sustainability Workshop Series. *In:* EDO, M. & TROIS, C. (eds.) *IEA Bioenergy Task 36 Workshop Report* IEA Bioenergy, https://task36.ieabioenergy.com/wp-content/uploads/sites/34/2024/03/Task-36-Regional-Sustainability-Workshop-Series-Report.pdf.
MURSHED, M. F., KAMAL, N. H. M., FAGBENRO, O. K., WANG, L. K. & WANG, M.-H. S. 2022. Solid Waste and Marine Litter Management. *In:* WANG, L. K., WANG, M.-H. S. & HUNG, Y.-T. (eds.) *Solid Waste Engineering and Management: Volume 2.* Cham: Springer International Publishing.
NEUWAHL, F., CUSANO, G., GÓMEZ BENAVIDES, J., HOLBROOK, S. & ROUDIER, S. 2019. *Best Available Techniques (BAT) Reference Document for Waste Incineration. EUR 29971 EN,* doi:10.2760/761437.
OCHS, C., GARRISON, K., SAXENA, P., ROMME, K. & SARKAR, A. 2024. Contamination of aquatic ecosystems by persistent organic pollutants (POPs) originating from landfills in Canada and the United States: A rapid scoping review. *Science of The Total Environment,* 924**,** 171490.
OECD 2020. *Environment at a Glance 2020. in Environment at a Glance*, doi: 10.1787/4ea7d35f-en.
OLDFIELD, T. L., WHITE, E. & HOLDEN, N. M. 2016. An environmental analysis of options for utilising wasted food and food residue. *J Environ Manage,* 183**,** 826-835.
ONYEAKA, H., DUAN, K., MIRI, T., PANG, G., SHIU, E., POKHILENKO, I., ÖGTEM-YOUNG, Ö., JABBOUR, L., MILES, K., KHAN, A., FOYER, C. H., FREW, E., FU, L. & OSIFOWORA, B. 2024. Achieving fairness in the food system. *Food and Energy Security,* 13**,** e572.
PELLOW, D. N. 2000. Environmental Inequality Formation:Toward a Theory of Environmental Injustice. *American Behavioral Scientist,* 43**,** 581-601.
PENG, W. & BERRY, E. M. 2019. The Concept of Food Security. *In:* FERRANTI, P., BERRY, E. M. & ANDERSON, J. R. (eds.) *Encyclopedia of Food Security and Sustainability.* Oxford: Elsevier.
POTDAR, A., SINGH, A., UNNIKRISHNAN, S., NAIK, N., NAIK, M., NIMKAR, I. & PATIL, V. 2016. Innovation in Solid Waste Management through Clean Development Mechanism in Developing Countries. *Procedia Environmental Sciences,* 35**,** 193-200.
PSOMOPOULOS, C. S., BOURKA, A. & THEMELIS, N. J. 2009. Waste-to-energy: A review of the status and benefits in USA. *Waste Management,* 29**,** 1718-1724.
RAM, M. & BRACCI, E. 2024. Waste Management, Waste Indicators and the Relationship with Sustainable Development Goals (SDGs): A Systematic Literature Review. *Sustainability,* 16**,** 8486.
RAVIKUMAR, P., SHRIDHAR, D. M. & PRAKASH, K. L. 2020. Assessment of Leachate Contaminated Groundwater Quality near Mandur Solid Waste Dumping Site, Bangalore. *Current World Environment* 15.
REZAPOUR, S., SAMADI, A., KALAVROUZIOTIS, I. K. & GHAEMIAN, N. 2018. Impact of the uncontrolled leakage of leachate from a municipal solid waste landfill on soil in a cultivated-calcareous environment. *Waste Management,* 82**,** 51-61.
RITCHIE, H., ROSADO, P. & ROSER, M. 2020. *Energy Production and Consumption* [Online]. Published online at OurWorldInData.org. Available: https://ourworldindata.org/energy-production-consumption [Accessed 06/01/2025].
ROBERTS, D., EDO, M., JOHANSSON, I., HOFFMAN, B., BECIDAN, M., CICERI, G., MURPHY, F., TROIS, C. &

CURRAN, T. P. 2022. *Material and Energy Valorisation of Waste in a Circular Economy,* IEA Bioenergy Task 36, https://task36.ieabioenergy.com/wp-content/uploads/sites/34/2022/04/Final-Report.pdf.
ROSALDO, M. 2024. Top-Down and Bottom-Up Formalization: Waste Pickers' Struggles for Labor Rights in São Paulo and Bogotá. *ILR Review,* 77, 32-61.
ROY, S., RAUTELA, R. & KUMAR, S. 2023. Towards a sustainable future: Nexus between the sustainable development goals and waste management in the built environment. *Journal of Cleaner Production,* 415, 137865.
RYBERG, M., LAURENT, A. L. & HAUSCHILD, M. Z. 2018. Mapping of global plastic value chain and plastic losses to the environment: with a particular focus on marine environment. France.
SALVADOR, R. W. & DOONG, R.-A. 2024. Simultaneous achievement of energy recovery and carbon sequestration through municipal solid waste management: A review. *Chemosphere,* 361, 142478.
SARA, H. H., BAYAZID, A. R. & QUAYYUM, Z. 2022. Occupational Health Sufferings of Child Waste Workers in South Asia: A Scoping Review. *International Journal of Environmental Research and Public Health,* 19, 8628.
SHEHATA, N., OBAIDEEN, K., SAYED, E. T., ABDELKAREEM, M. A., MAHMOUD, M. S., EL-SALAMONY, A.-H. R., MAHMOUD, H. M. & OLABI, A. G. 2022. Role of refuse-derived fuel in circular economy and sustainable development goals. *Process Safety and Environmental Protection,* 163, 558-573.
SIDDIQUA, A., HAHLADAKIS, J. N. & AL-ATTIYA, W. A. K. A. 2022. An overview of the environmental pollution and health effects associated with waste landfilling and open dumping. *Environmental Science and Pollution Research,* 29, 58514-58536.
SOBHI, M., ELSAMAHY, T., ZAKARIA, E., GABALLAH, M. S., ZHU, F., HU, X., ZHOU, C., GUO, J., HUO, S. & DONG, R. 2024. Characteristics, limitations and global regulations in the use of biogas digestate as fertilizer: A comprehensive overview. *Science of The Total Environment,* 957, 177855.
SUN, J., DAI, X., WANG, Q., VAN LOOSDRECHT, M. C. M. & NI, B.-J. 2019. Microplastics in wastewater treatment plants: Detection, occurrence and removal. *Water Research,* 152, 21-37.
TABASOVÁ, A., KROPÁČ, J., KERMES, V., NEMET, A. & STEHLÍK, P. 2012. Waste-to-energy technologies: Impact on environment. *Energy,* 44, 146-155.
TIBBETTS, J. H. 2015. Managing Marine Plastic Pollution: Policy Initiatives to Address Wayward Waste. *Environmental Health Perspectives,* 123, A90-A93.
TURRÉN-CRUZ, T. & LÓPEZ ZAVALA, M. Á. 2021. Framework Proposal for Achieving Smart and Sustainable Societies (S3). *Sustainability,* 13, 13034.
UN. 2023a. *Sustainable Development Goals Report 2023* [Online]. United Nations, https://unstats.un.org/sdgs/report/2023/The-Sustainable-Development-Goals-Report-2023.pdf. . [Accessed 18/12/2024].
UN 2023b. *The Sustainable Development Goals Report: Special Edition* United Nations, https://unstats.un.org/sdgs/report/2023/The-Sustainable-Development-Goals-Report-2023.pdf.
UN. 2024a. *Goal-6: Clean water and sanitation* [Online]. Available: United Nations, https://wedocs.unep.org/bitstream/handle/20.500.11822/25761/SDG6_Brief.pdf?sequence=1&isAllowed=y [Accessed 06/01/2025].
UN 2024b. *The Sustainable Development Goals Report 2024: Special Edition* United Nations, https://unstats.un.org/sdgs/report/2024/.
UN. 2025. *Sustainable Development Goals* [Online]. Available: https://www.un.org/sustainabledevelopment/ [Accessed 12/02/2025].
UNEP 2019. *Waste-to-Energy: Considerations for Informed Decision-Making*, United Nations Environment Programme, https://www.unep.org/ietc/resources/publication/waste-energy-considerations-informed-decision-making.
UNEP 2024a. *Food Waste Index Report 2024. Think Eat Save: Tracking Progress to Halve Global Food Waste,* Nairobi, United Nations Environmnet Programme, https://wedocs.unep.org/20.500.11822/45230.
UNEP 2024b. *Global Waste Management Outlook: Beyond an age of waste – Turning rubbish into a resource,* Nairobi, United Nations Environment Programme, doi: https://wedocs.unep.org/20.500.11822/44939. .
UNEP 2024c. *Global Waste Management Outlook 2024: Beyond an age of waste – Turning rubbish into a resource,* United Nations Environment Programme Nairobi; https://wedocs.unep.org/20.500.11822/44939.
VELAZQUEZ, L., MUNGUIA, N., ALVAREZ-ALVAREZ, D., CUAMEA-CRUZ, G., ANAYA-EREDIAS, C. & MARTINEZ-CASTAÑEDA, F. 2023. Residential waste segregation: The interconnection with SDG 2 zero hunger. *Environmental Challenges,* 10, 100675.

VIEIRA, V. H. A. M. & MATHEUS, D. R. 2018. The impact of socioeconomic factors on municipal solid waste generation in São Paulo, Brazil. *Waste Management and Research,* 36, 79-85.
VINTI, G., BAUZA, V., CLASEN, T., MEDLICOTT, K., TUDOR, T., ZURBRÜGG, C. & VACCARI, M. 2021. Municipal Solid Waste Management and Adverse Health Outcomes: A Systematic Review. *Int J Environ Res Public Health,* 18.
WANG, Y., YUAN, Z. & TANG, Y. 2021. Enhancing food security and environmental sustainability: A critical review of food loss and waste management. *Resources, Environment and Sustainability,* 4, 100023.
WCED 1987. Report of the World Commission on Environment and Development: Our Common Future. United Nations World Commission on Environment and Development.
WHO. 2023a. *Drinking water-key facts* [Online]. Available: World Health Organisation, https://www.who.int/news-room/fact-sheets/detail/drinking-water. [Accessed 05/11/2024].
WHO. 2023b. *Tracking SDG 7 – The progress report 2023* [Online]. Available: World Health Organization, https://cdn.who.int/media/docs/default-source/air-pollution-documents/air-quality-and-health/sdg7-report2023-full-report_web.pdf?sfvrsn=669e8626_3&download=true [Accessed 04/01/2025].
YE, Q., UMER, Q., ZHOU, R., ASMI, A. & ASMI, F. 2023. How publications and patents are contributing to the development of municipal solid waste management: Viewing the UN Sustainable Development Goals as ground zero. *Journal of Environmental Management,* 325, 116496.
ZHANG, B., LI, G., CHENG, P., YEH, T.-C. J. & HONG, M. 2016. Landfill Risk Assessment on Groundwater Based on Vulnerability and Pollution Index. *Water Resources Management,* 30, 1465-1480.
ZOLNIKOV, T. R., FURIO, F., CRUVINEL, V. & RICHARDS, J. 2021. A systematic review on informal waste picking: Occupational hazards and health outcomes. *Waste Management,* 126, 291-308.

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