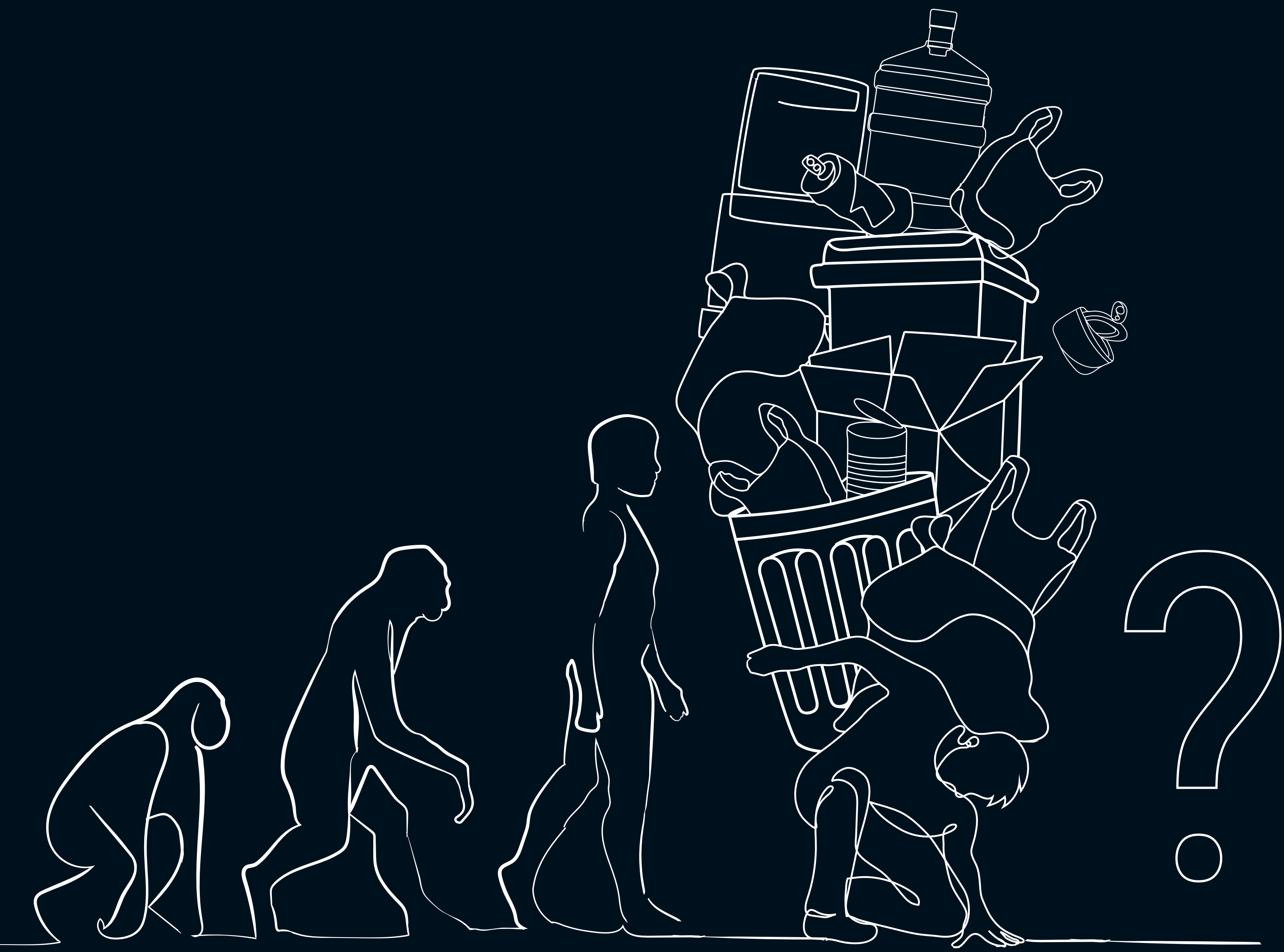
UN environment programme

Beyond an age of waste

Turning rubbish into a resource



ISWA

Global Waste Management Outlook 2024

ISBN: 978-92-807-4129-2
Job number: DTI/2619/NA
DOI: https://doi.org/10.59117/20.500.11822/44939

Suggested citation:
United Nations Environment Programme (2024). Global Waste Management Outlook 2024: Beyond an age of waste – Turning rubbish into a resource. Nairobi. https://wedocs.unep.org/20.500.11822/44939

URL: https://www.unep.org/resources/global-waste-management-outlook-2024

Co-produced with:

International Solid Waste Association

This publication was financially supported by the Governments of Japan and Sweden.

Acknowledgements

The United Nations Environment Programme (UNEP) and the International Solid Waste Association (ISWA) would like to thank the authors, reviewers and collaborators who have contributed to the report.

Lead author: Zoë Lenkiewicz
Project supervision and coordination: Daniel Ternald (UNEP), Carlos Silva Filho (ISWA), Aditi Ramola (ISWA)

Technical editor: John Smith
Contributing authors:
Fernando Bernardes, Achim Halpaap, Luca Louzada, Aditi Ramola, Carlos Silva Filho, Hugo Henrique Simone Souza, John Smith, Daniel Ternald, David Wilson
Editor's Note: In February 2024, one of the contributing authors listed here previously was removed upon their request.

Data analysis team: Hugo Henrique Simone Souza, Fernando Bernardes, Luca Louzada

Support and contributions:
Sheila Aggarwal-Khan, Jacqueline Alvarez, Keith Alverson, Björn Appelqvist, Sandra Averous-Monnery, Steffen Blume, Pierre Henri Boileau, Timothy Bouldry, Thanasis Bourtsalas, Marie Noel Brune Drisse, Francesca Calisesi, Ed Cook, Kenneth Davis, Nicolien Delange, Raphaelle Delmas, Premakumara Jagath Dickella Gamaralalage, Adriana Sanabria Gomez, Misato Dilley, Junko Fujioka, Jane Gilbert, Linda Godfrey , Chris Godlove, Marianne Grant, Kevin Helps, Andrea Hinwood, Shunichi Honda, Leonie Hoogland, Maria Hughes, Nicolas Humez, Shiho Jinno, Kartik Kapoor, Nele Kapp, Nagwa El Karawy, James Law, Melisa Lim, Ana Loureiro, Amani Maalouf, Monika MacDevette, Antonis Mavropoulos, Sandra Mazo-Nix, Saaiqa Merali, Llorenç Milà i Canals, Solange Montillaud-Joyel, Jane Muriithi, Susan Mutebi-Richards, Iyngararasan Mylvakanam, Mira Nagy, Takehiro Nakamura, Ligia Noronha, Tapiwa Nxele, Clementine O'Connor, Michiko Ota, Agamuthu Pariatamby, Johannes Paul, Pierre Quiblier, Arne Ragossnig, Réka Soós, Marco Ricci, Ieva Rucevska, Fernanda Romero, Laila Saada, Atilio Savino, Anne Scheinberg, Mary Fuad Tawfiq Shanti, Nalini Sharma, Otto Simonett, Aphrodite Smagadi, Christian Stiglitz, Steven Stone, Nao Takeuchi, Marc Tijhuis, Elisa Tonda, José Uribe, Costas Velis, Goran Vujić, Feng Wang, Andrew Whiteman, David Wilson, Moeka Yamaguchi, Sallie Yang, Yahan You

Copy editing: Amanda Lawrence Brown, Deanna Ramsay, John Smith

Production and launch support: UNEP Communication Division, ISWA Communications team

Design and layout:
Fluid – Strategic Communications
www.hellofluid.co.uk

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Abbreviations and acronyms

CCAC	Climate and Clean Air Coalition
CE	Circular economy
CH_4	Methane
CO_2	Carbon dioxide
EPR	Extended Producer Responsibility
EU	European Union
EUR	Euros
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GHG	Greenhouse gas
GNI	Gross national income
GWMO	Global Waste Management Outlook (2015)
HDI	Human Development Index
IETC	International Environmental Technology Centre
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
ISWA	International Solid Waste Association
kg	kilogram
LCA	Life cycle assessment
MSW	Municipal solid waste
Mt	Million tonnes (or megatonnes)
NDC	Nationally Determined Contribution
OECD	Organisation for Economic Co-operation and Development
POPs	Persistent Organic Pollutants
PPP	Purchasing power parity
SDGs	Sustainable Development Goals
SAICM	Strategic Approach to International Chemicals Management
SMEs	Small- and medium-sized enterprises
UK	United Kingdom
UN DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNITAR	United Nations Institute for Training and Research
UNODC	United Nations Office on Drugs and Crime
UPOPs	Unintentional Persistent Organic Pollutants
US$	United States dollars
WHO	World Health Organization
WMU	Waste management as usual
WtE	Waste-to-energy
WUC	Waste Under Control

Glossary

Sources of definitions relevant to municipal waste management include: International Organization for Standardization [ISO] (2013); United Nations Environment Programme [UNEP] (2021 a, b); UNEP (2023e); UNEP-Law and Environment Assistance Programme (n.d).

Additives: Plastic is usually made from polymer mixed with a complex blend of chemicals known as additives. These additives, which include flame retardants, plasticizers, pigments, fillers and stabilisers are used to improve the different properties of the plastic or to reduce its cost

CapEx (capital expenditure): Funds used by an organisation to acquire or upgrade assets such as property, buildings, technology, or equipment.

Circular economy: One of the current sustainable economic models, in which products and materials are designed in such a way that they can be reused, remanufactured, recycled or recovered and thus maintained in the economy for as long as possible, along with the resources of which they are made, and the generation of waste, especially hazardous waste, is avoided or minimized, and greenhouse gas emissions are prevented or reduced, can contribute significantly to sustainable consumption and production

Design for recycling: The process by which companies design their products and packaging to be recyclable (see **Recycling**).

Downstream activities: Involves end-of-life management – including segregation, collection, sorting, recycling and disposal. Recycling is a process that starts downstream and 'closes the loop' by connecting with upstream (i.e. starting a new life cycle for new plastic products with old materials). Similarly, repair/refurbish processes provide another way to close the loop by bringing products back into the midstream.

Dumpsites: Places where collected waste has been deposited in a central location and where the waste is not controlled through daily, intermediate or final cover, thus leaving the top layer free to escape into the natural environment through wind and surface water

Extended Producer Responsibility (EPR): An environmental policy approach in which a producer's responsibility for a product is extended to the waste stage of that product's life cycle. In practice, EPR involves producers taking responsibility for the management of products after they become waste, including: collection; pre-treatment, e.g. sorting, dismantling or depollution; (preparation for) reuse; recovery (including recycling and energy recovery) or final disposal. EPR systems can allow producers to exercise their responsibility by providing the financial resources required and/or by taking over the operational aspects of the process from municipalities. They assume the responsibility voluntarily or mandatorily; EPR systems can be implemented individually or collectively.

Externality: An economic term used to describe an indirect cost or benefit experienced by an unrelated third party, arising as an effect of another party's activity. For example, pollution caused from mismanaging waste is an externality.

Feedstock: Any bulk raw material that is the principal input for an industrial production process.

Incineration: Destruction and transformation of material to energy by combustion

Informal waste sector: Sector where workers and economic units are involved in solid waste collection, recovery and recycling activities which are – in law or in practice – not covered or insufficiently covered by formal arrangements.

Just transition: A framework to ensure that the benefits of the transition to a green economy are shared widely, for example through the protection of workers' rights and livelihoods.

Leakage: Materials that do not follow an intended pathway and 'escape' or are otherwise lost to the system. Litter is an example of system leakage

Legacy waste: Waste that has already been generated and is accumulating in dumpsites or the environment as existing pollution.

Mechanical recycling: Processing of waste into secondary raw material or products without significantly changing the chemical structure of the material.

Mismanaged waste: Collected waste that has been released or deposited in a place from where it can move into the natural environment (intentionally or otherwise). This includes dumpsites and unmanaged landfills. Uncollected waste is categorised as unmanaged

Municipal solid waste (MSW): Includes all residential and commercial waste but excludes industrial waste.

Glossary

Open burning: Waste that is combusted without emissions cleaning.

OpEx (operating expenses): Operating expenses incurred during the course of regular business, such as general and administrative costs, sales and marketing, or research and development.

Pathway: a course of action that combines system interventions across geographic archetypes to achieve a desired system outcome

Plastic pollution: Defined broadly as the negative effects and emissions resulting from the production and consumption of plastic materials and products across their entire life cycle. This definition includes plastic waste that is mismanaged (e.g. openly-burned and dumped in uncontrolled dumpsites) and leakage and accumulation of plastic objects and particles that can adversely affect humans and the living and non-living environment.

Recyclable: For something to be deemed recyclable, the system must be in place for it to be collected, sorted, reprocessed, and manufactured back into a new product or packaging—at scale and economically. Recyclable is used here as a short-hand for 'mechanically recyclable (see **Mechanical recycling**).

Recycling: Processing of waste materials for the original purpose or for other purposes, excluding energy recovery.

Reusable: Products and packaging, including plastic bags, that are conceived and designed to accomplish within their life cycle a minimum number of uses for the same purpose for which they were conceived. In terms of "minimum number of uses", the PR3 Reuse Standards (PR3 2024) suggest that reusable (containers) should be designed to withstand at least 10 reuse cycles.

Reuse: Use of a product more than once in its original form.

Safe disposal: Ensuring that any waste that reaches its end-of-life is disposed in a way that does not cause leakage of plastic waste or chemicals into the environment, does not pose hazardous risks to human health and, in the case of landfills, is contained securely for the long-term.

Sanitary landfill: An engineered facility for the disposal of solid waste on and in a controlled manner.

Scenarios: For the purpose of this report, three scenarios were developed to estimate the impacts of different municipal solid waste management approaches to 2050:

- **Waste Management as Usual** – waste generation and waste management practices continue as today, with waste generation projected to grow fastest in regions without adequate waste management capacity;
- **Waste Under Control** – a midway point, with some progress made towards preventing waste and improving its management;
- **Circular Economy** – waste generation decoupled from economic growth, with the global municipal solid waste recycling rate reaching 60 per cent and the remainder managed safely.

Single-use products: Often referred to as disposable plastics, are commonly used plastic items intended to be used only once before they are thrown away or recycled, e.g. grocery bags, food packaging, bottles, straws, containers, cups, cutlery etc.

Technology transfer: The transfer of technology and technical know-how from the owner to a new user, which may be an individual, a business or a municipality etc.

Upstream activities: Includes obtaining the raw materials from crude oil, natural gas or recycled and renewable feedstock (e.g. biomass) and polymerization. Plastic leakage into the environment (e.g. pellets and flakes) already happens at this stage.

Table of Contents

Beyond an Age of Waste - Global Waste Management Outlook 2024

Every year across the globe more than two billion tonnes of municipal solid waste is generated.

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01 Introduction

1.1. A wasteful world

Photo source: *dimazel / Adobe Stock*

Every year across the globe more than two billion tonnes of municipal solid waste (MSW) is generated. If packed into standard shipping containers and placed end-to-end, this waste would wrap around the Earth's equator 25 times, or further than traveling to the moon and back.

As well as municipal waste, human activity generates significant amounts of agricultural; construction and demolition; industrial and commercial; and healthcare waste. This waste is produced on farms and building sites and in factories and hospitals.

Municipal waste is generated wherever there are human settlements. It is influenced by each person in the world, with every purchasing decision, through daily practices and in the choices made about managing waste in the home. The way people buy, use and discard materials determines the amount of energy and raw materials used and how much waste is generated. Municipal waste is thus intrinsically linked to the triple planetary crisis of climate change, pollution and biodiversity loss.

The first *Global Waste Management Outlook* (GWMO), published in 2015, provided a pioneering scientific global assessment of the state of waste management. It was also a call to action to the international community to recognise waste and resource management as a significant contributor to sustainable development and climate change mitigation.

Since then, despite some concerted efforts, little has changed. If anything, humanity has moved backwards - generating more waste, more pollution and more greenhouse gas (GHG) emissions. Billions of tonnes of municipal waste is still being generated every year, and billions of people still don't have their waste collected.

Uncontrolled waste knows no national borders. It is carried by waterways across and between countries, while emissions from the burning and open dumping of waste are deposited in terrestrial and aquatic ecosystems and in the atmosphere. Pollution from waste is associated with a range of adverse health and environmental effects, many of which will last for generations (Vinti *et al*. 2021; Siddiqua, Hahladakis and Al-Attiya 2022; World Health Organization [WHO] 2022).

In response to Resolution 2/7, adopted by the second session of the United Nations Environment Assembly and reiterated in Resolution 4/7, adopted by its fourth session (United Nations 2019a), the amount of energy and raw materials used update of the global waste management picture and an analysis of data related to MSW management globally. It assesses three potential scenarios of municipal waste generation and management and their impacts on society, the environment and the global economy. It also provides possible pathways to reducing waste and improving its management—following the waste hierarchy—with the goal that all waste materials are managed as a resource.

The Global Waste Management Outlook 2024 echoes the first GWMO's call to action to scale up efforts to prevent waste generation; to extend adequate safe and affordable MSW management to everyone worldwide; and to ensure that all unavoidable waste is managed safely.

1.2. Types of waste

The word "waste" means different things to different people. Different local conditions and data collection methods confuse attempts to arrive at clear definitions. Variously referred to as refuse, discards, trash or garbage, waste is essentially the unintended by-product of consumption and production.

Waste is hugely diverse and there are different ways of categorising it, for example by:

- Material, e.g. food waste or plastic waste;
- Product type, e.g. e-waste (electrical and electronic waste) or end-of-life vehicles, which contain multiple materials;
- Source, e.g. MSW, which contains multiple product types and materials.

This report focuses on MSW, which is the waste generated by householders; retailers and other small businesses; public service providers; and other similar sources. Managing MSW is generally a local service and is commonly the responsibility of local government. MSW is only a (comparatively small) part of the story, since enormous amounts of non-municipal waste are generated each year, for example:

- Construction and demolition waste
- Industrial waste
- Agricultural waste
- Healthcare waste

Data is severely lacking for these other waste streams. Quantities vary significantly according to whether a country's economy is primarily agricultural or industrial, and its level of urbanisation. Healthcare waste is usually only a fraction of municipal waste but may be more hazardous. These other types of waste may be mixed with MSW, particularly where formal waste management systems are not fully implemented (for example, demolition waste or healthcare waste may be disposed of in a municipal waste landfill or dumpsite).

Because MSW is generated by all residents, regular collection schemes need to reach everyone, everywhere. This requirement contrasts with the management of waste arising from industries, mining or hospitals, for example, which is often concentrated at specific sites.

MSW typically includes food waste; packaging; household items including broken furniture and electronic goods; clothes and shoes; and personal hygiene products. Its composition varies from place to place (and even at the neighbourhood level) and may be affected by the time of year, weather conditions and economic recessions or other major events and trends.

Photo source: Angelov / Adobe Stock

Some products or materials found in the MSW stream are of particular concern. This is owing to rapid increases in their amounts or difficulties in collection, treatment, and other aspects of waste management aimed at meeting standards for protecting health and the environment. Examples of these materials are:

- Hazardous chemical waste
- Electrical and electronic waste (e-waste)
- Textiles
- Plastics
- Food waste
- End-of-life vehicles and waste from mechanics' garages

The management of MSW poses unique challenges due to its sheer volume, continual growth, diverse composition, ubiquity in human settlements, variability and influence by cultural change, and the intricate web of social, economic and environmental impacts that arise from its management.

1.3. Why waste matters: People and planet

MSW management being delivered by municipal governments, formal and informal private actors, and civil society. Questions of global social and environmental justice also arise in discussions of municipal waste growth and its management, as illustrated by the many links with the Sustainable Development Goals (SDGs) (Table 1) (United Nations Environment Programme [UNEP] 2023). Delivered by municipal governments, formal and informal private actors, and civil society. Questions of global social and environmental justice now arise when discussing municipal waste growth and its management, as illustrated by the many links with the Sustainable Development Goals (SDGs) (Table 1) (United Nations Environment Programme [UNEP] 2023).

Table 1: Waste management and its links to the Sustainable Development Goals

SUSTAINABLE DEVELOPMENT GOALS

Goal 1. No poverty: Waste workers in informal economies who have no health or social protections are vulnerable to exploitation and are paid only the material value of the materials they collect. Inclusive municipal waste management policies are most effective for addressing both poverty and pollution.	**Goal 10. Reduced inequalities:** Intragenerational and intergenerational inequalities must be addressed through developing waste and resource management systems; attention is required from all stakeholders because the transition to a more circular economy will not occur by default.
Goal 2. Zero hunger: While global hunger is increasing, one-third of all the food grown in the world is wasted. Hunger can be reduced by preventing food waste and redistributing excess food. Converting unavoidable food waste into compost can replenish depleted agricultural soils.	**Goal 11. Sustainable cities and communities:** Solid waste management is a basic utility service without which air quality and living conditions become degraded, leading to poor health and social discontent. To make cities and communities inclusive, safe, resilient and sustainable, universal access to municipal waste management services is essential.
Goal 3. Good health and well-being: Communities without adequate municipal waste management services resort to dumping and open burning, both of which have significant negative health consequences, particularly for women and children.	**Goal 12. Responsible consumption and production:** Production and consumption patterns directly impact municipal waste generation. To reduce waste and prevent pollution, efforts are needed by companies, governments and citizens.
Goal 4. Quality education: Waste management courses in tertiary and higher education are uncommon, resulting in a lack of professional technical capacity and a shortage of workers with appropriate skills and knowledge.	**Goal 13. Climate action:** Poorly managed waste generates a wide range of emissions that contribute to climate change, most significantly methane from landfills and dumpsites, and black carbon and a range of other emissions from the widespread practice of the open burning of waste.
Goal 5. Gender equality: People's experience with waste and its management is gender-differentiated: e.g. household purchasing and domestic waste-generating activities, and levels of influence over community decision-making regarding waste collection services.	**Goal 14. Life below water:** Understanding why and how land-based waste reaches the sea, and introducing mitigation measures, is essential. Urgent action is particularly required in the case of Small Island Developing States, which face a complex set of waste management challenges.
Goal 6. Clean water and sanitation: Pollutants leaching from dumpsites can contaminate freshwater sources and associated food chains. Meanwhile, combining municipal solid waste and container-based sanitation services can achieve economies of scale that make both services more attractive to investors.	**Goal 15. Life on land:** The terrestrial environment continues to be the primary sink for waste, while rural communities face complex waste management challenges that if left unmanaged can significantly impact ecosystems and dependent livelihoods.
Goal 7. Affordable and clean energy: Unavoidable food waste can be used to make biogas, a clean-burning renewable fuel that could be used to tackle energy poverty, including in off-grid communities.	**Goal 16. Peace, justice and strong institutions:** The increasingly global nature of waste management calls for heightened international cooperation to build national capacity for the safe management of hazardous waste and to prevent its illegal trafficking.
Goal 8. Decent work and economic growth: The waste management and recycling sector is uniquely positioned to improve global resource efficiency, decouple economic growth from environmental degradation, and provide safe and decent work opportunities for all.	**Goal 17. Partnerships for the Sustainable Development Goals:** Current investments in waste management are insufficient. Far higher investments will be needed in the future to cope with increasing waste generation and the accumulation of legacy waste. The return on investment for waste management needs to be realised to catalyse increased finance.
Goal 9. Industry, innovation and infrastructure: Decentralised waste management systems can attract private sector investment, encouraging innovation, entrepreneurship, domestic technology development, greater resource efficiency and increased employment opportunities, and reduce financial risks for governments and municipalities.	

Source: United Nations Environment Programme 2023

Focusing specifically on the environmental impacts of municipal waste growth and management, its influence on the triple planetary crisis of climate change, biodiversity loss and pollution is clear (Table 2).

Table 2: Waste and the triple planetary crisis

Climate change	Biodiversity loss	Pollution
Transporting, processing and disposing of waste generates CO_2 and other greenhouse gases and airborne pollutants that contribute to climate change.	**Indiscriminate waste disposal practices can introduce hazardous chemicals into soil, water bodies and the air, causing long-term, potentially irreversible damage to local flora and fauna, negatively impacting biodiversity, harming entire ecosystems, and entering the human food chain.**	**Between 400,000 and 1 million people die every year as a result of diseases related to mismanaged waste that includes diarrhoea, malaria, heart disease and cancer (Williams *et al*. 2019).**
Methane is released from the decomposition of organic waste in landfills and dumpsites (UNEP and Climate and Clean Air Coalition [CCAC] 2021), with short-term effects on global warming (UNEP and Climate and Clean Air Coalition [CCAC] 2021).	The long-term pollution of land and aquatic ecosystems by waste has been recognised as one of the main drivers of biodiversity loss and puts the integrity of entire ecosystems at risk (Tovar-Sánchez *et al*. 2018; UNEP 2021a).	Waste disposed of on land can cause long-term pollution of freshwater sources by pathogens, heavy metals, endocrine-disrupting chemicals and other hazardous compounds (Kuchelar and Sudarsan 2022; Thives *et al*. 2022).
The open burning of waste releases black carbon (soot). When black carbon settles on the surface of sea ice it contributes to the acceleration of sea ice melting by absorbing rather than reflecting sunlight. Black carbon has a strong contribution to current global warming, second only to the greenhouse gas carbon dioxide (United States National Oceanic and Atmospheric Administration n.d.).	It is estimated that 90 per cent of all biodiversity loss is caused by land-use change and related consumption of resources (International Resource Panel 2019).	Open burning of waste releases Unintentional Persistent Organic Pollutants, "forever chemicals" that can be carried long distances in the air, persist in the environment, biomagnify and bioaccumulate in ecosystems, and have significant negative effects on human health and the environment (Stockholm Convention 2019; (WHO 2020; UNEP n.d.a).).

Working in waste management can carry severe health risks, especially under certain conditions such as in informal settings and at dumpsites, and when handling healthcare waste and dismantling e-waste (Zolnikov *et al*. 2021a; Sara, Bayazid and Quayyum 2022; WHO 2021). Health impacts are understood to be differentiated by gender and age, and more data is needed in this regard to better manage the risks and outcomes (Strategic Approach to International Chemicals Management [SAICM] 2017; UNEP International Environmental Technology Centre [UNEP-IETC] and GRID-Arendal 2019c).

Between communities and countries, varying quantities and compositions of municipal waste are generated, and different approaches to its management have been adopted. One universal truth stands, however: the best approach is to not generate the waste in the first place.

1.4. Actions to halt the waste crisis: Upstream and downstream

Municipal waste management priorities will depend on the status of waste generation and waste management in any given country.

- Countries can be classed as high, medium or low waste generators;
- They can further be classed as having high, medium or low waste management service provision (including regular waste collection, recycling and safe disposal capacity);
- These characteristics tend to be correlated with income levels, as discussed further in Section 2.1.

Both waste generation and its management have significant negative environmental impacts.

There is consequently an urgent need for both upstream measures to reduce resource use and waste generation, and downstream measures to reduce the environmental impacts of waste (Table 3). Different sectors play different roles in delivering these measures.

Photo source: *Javier / Adobe Stock*

Table 3: The waste hierarchy and the role of different parts of society in controlling the generation and management of municipal waste

		Governments	Producers	Retailers	Waste management sector	Consumers
UPSTREAM	Prevent	✓	✓	-	-	✓
	Reduce	✓	✓	✓	-	✓
	Reuse	✓	✓	✓	-	✓
DOWNSTREAM	Recycle	✓	✓	-	✓	✓
	Recover energy, heat and control emissions	✓	-	-	✓	✓
	Dispose	✓	-	-	✓	✓

Source: Authors' elaboration on the waste hierarchy (UNEP and International Solid Waste Association [ISWA] 2015, p. 31; Lansink 2018).

Access to waste collection services varies significantly within and between regions. In higher-income regions almost all municipal solid waste is collected, while less than 40 per cent of municipal solid waste is collected in lower-income countries.

Photo source: *Parilov / Adobe Stock*

02 Municipal solid waste generation, growth and management

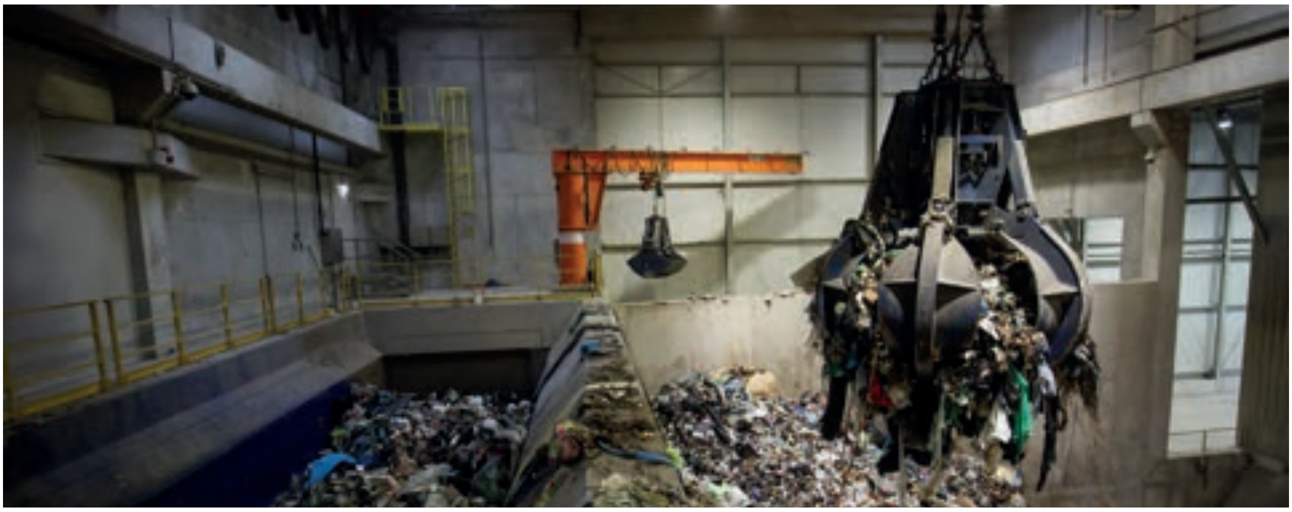
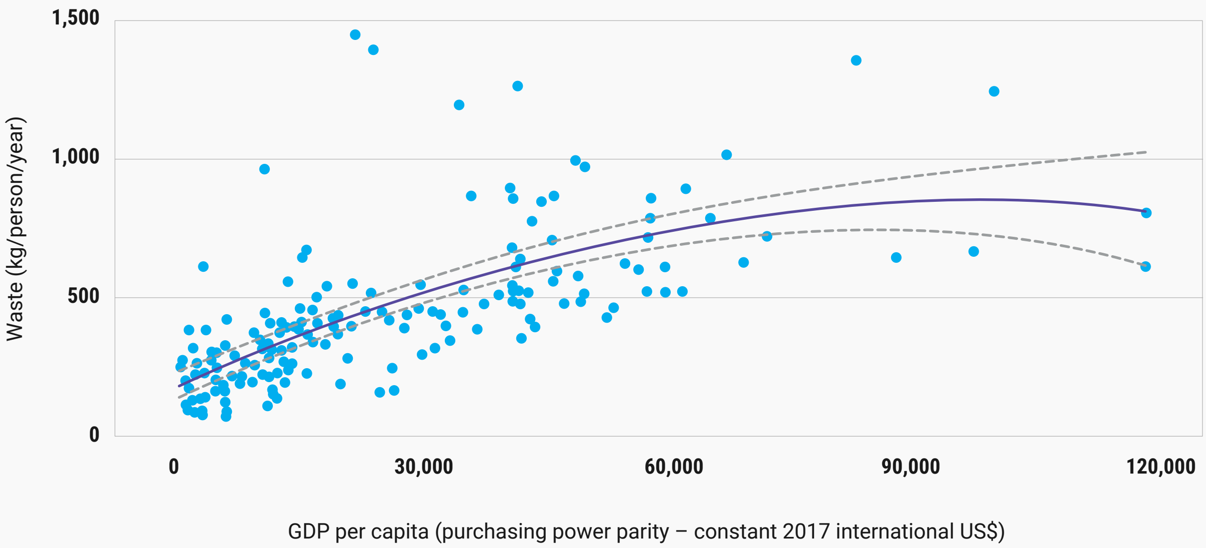


Photo source: zlikovec / Adobe Stock

2.1. Generation

Generally, as countries become wealthier, rates of industrialisation and urbanisation increase, housing and consumption patterns change, and a wider range of products becomes available on the market. This, in turn, drives an increase in the average amount of MSW generated per person, as illustrated in Figure 1.

Figure 1: Relationship between gross domestic product (GDP) and waste generation in most recent year available between 2010 and 2020



Note: Each dot represents a country, with GDP data for the corresponding year converted to international dollars using purchasing power parity rates. Data is in constant 2017 international US dollars), corresponding to the World Bank International Comparison Program 2023 (World Bank 2023c). The line of best fit is shown in purple.

In this report, linear regression models based on gross domestic product (GDP) are used to predict how MSW generation will change by the years 2030, 2040 and 2050. This assumes that MSW generation will follow trends in economic growth. Although there are significant relationships between waste generation and indicators such as the Human Development Index, share of urban population, gross national income and adult literacy rates, analysis shows that the best model fit is linear regression using only GDP per capita (Annex 2).

In the countries or regions with the highest total MSW generation, there is sometimes a relatively low rate of MSW generation per capita. For example, Figure 2 shows that comparable quantities are generated by North America and Central and South Asia, although there is a marked difference in the quantities generated per capita. In addition, the number of fast-growing middle-income countries, where waste management issues are especially prominent, is increasing.

Figure 2: Municipal solid waste (MSW) generation by region: Total MSW (million tonnes) and MSW per capita (kg/person/day)

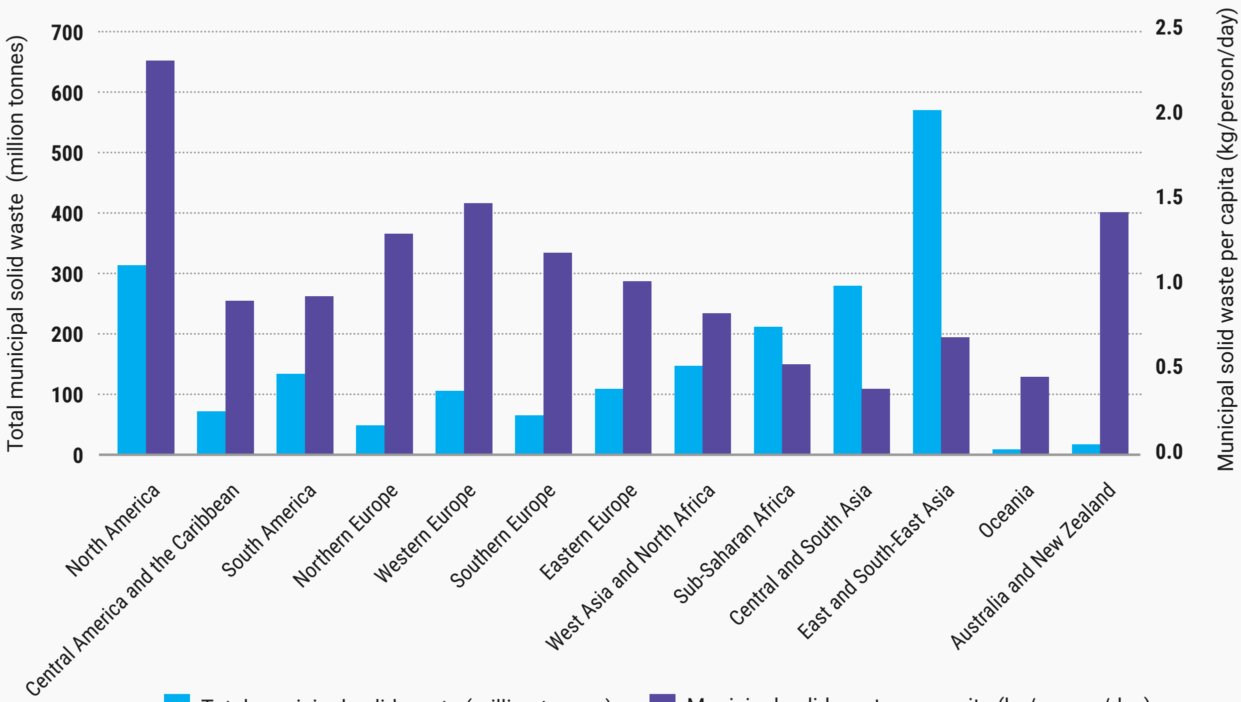


Photo source: *venusvi / Adobe Stock*

Box 1: Data availability, compilation and analysis

Across countries and regions there are significant challenges in terms of waste data and availability. One important issue is the lack of standardisation in measurement and reporting; another is the lack of well-developed monitoring systems in many countries, which means adequate estimates do not exist for simple indicators such as total collected waste and the share of collected waste deposited in controlled landfills.

> ***"Some countries have no official waste data whatsoever, or this data may be incomplete or inaccurate."***

Some countries have no official waste data whatsoever, or this data may be incomplete or inaccurate. The use of different methodologies can also make comparisons challenging. These issues are most pronounced in regions with the largest amounts of uncontrolled waste, underscoring the difficulties involved in providing accurate estimates and analyses of the impacts of uncontrolled waste globally, both now and in the future.

The data used for the analysis in this report is a compilation of existing municipal solid waste (MSW) data reported by countries, population data and projections, and socioeconomic data (see Annexes 1 and 2). As most data points are from before 2020, that is the year used as the baseline.

Countries have been grouped according to income levels, based on the United Nations Geoscheme (United Nations Statistics Division 1999). This enables statistical grouping for the purpose of the analysis.

While gross domestic product (GDP) has been used as the standard measure for this analysis, gross national income per capita in 2022 has been used to group countries according to the most recent World Bank classifications of countries as low income, lower middle-income, upper middle-income and high income (World Bank 2024a), which is standard international practice:

- Low income: < US$1,135 or less
- Lower middle-income: US$1,136–4,465
- Upper middle-income: US$4,436–13,845
- High income: > US$13,846 or more

This categorisation provides a useful framework for understanding countries' economic diversity and its relationship to waste management.

The *Global Waste Management Outlook 2024* adopts a similar approach to that of the World Bank's *What a Waste 2.0* (Kaza *et al*. 2018). Available data has been collected and linear regression analysis has been used to obtain estimates for missing data points and to forecast global waste generation to 2050 (Annex A2.1). Both reports focus on the management of municipal solid waste (MSW) globally. The key differences between them are that this report uses updated waste generation figures for most countries does not use logarithmic scales (to avoid visual distortions of the data), and includes weighted observations by population. Instead of establishing the relationship between GDP and waste generation in countries and determining a mean average, the analysis in this report uses a mean weighted by population (Solon, Haider and Wooldridge 2015). The estimates have been shown not to be affected significantly by the method used (linear or logarithmic GDP, weighting by population or not), while they provide a useful comparison with the What a Waste Global Database (World Bank 2024b).

The main regional reports and data sources used in preparing the Global Waste Management Outlook 2024 are listed in Annex 1. The methodology that has been used to determine waste generation and disposal is described in Annex 2. The use of life cycle analysis to estimate the benefits of recycling materials, the greenhouse gas emissions associated with different waste management practices and the externalities of MSW, for example, are described in Annex 3.

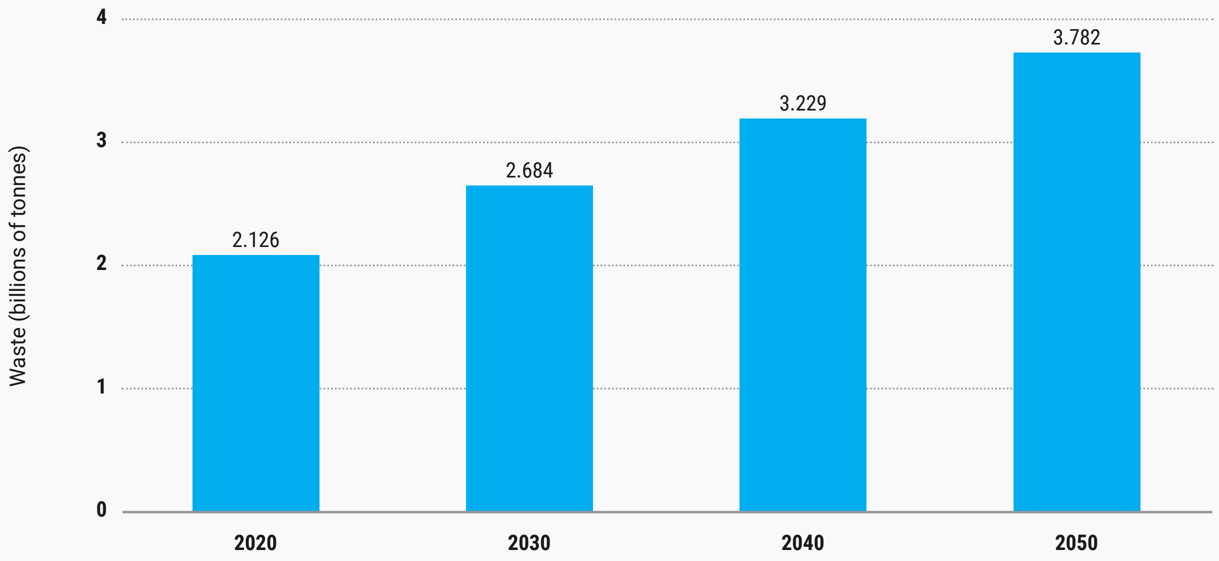
It is also important to note that data on waste management practices and impacts is rarely collected in a gender-disaggregated form. Since men and women influence and are impacted by waste generation and its management differently, it is vital that gender-differentiated data be collected in order to better understand and control waste, its management and its impacts.

The United Nations Human Settlements Programme (2023) carried out independent analysis of waste generation and management for its SDG 11 synthesis report. It estimated that 2.3 billion tonnes of municipal waste is generated globally, compared to the 2.1 billion tonnes estimated in this report. It also estimated a global average waste collection rate of 84 per cent (compared to 75 per cent in this report), and that 61 per cent of all municipal waste is "controlled" (compared to 62 per cent in this report). The discrepancies highlight the need for improved municipal waste data worldwide (discussed in section 5.1).

Discrepancies in waste data highlight the need for improved waste data standardisation in measurement and reporting worldwide.

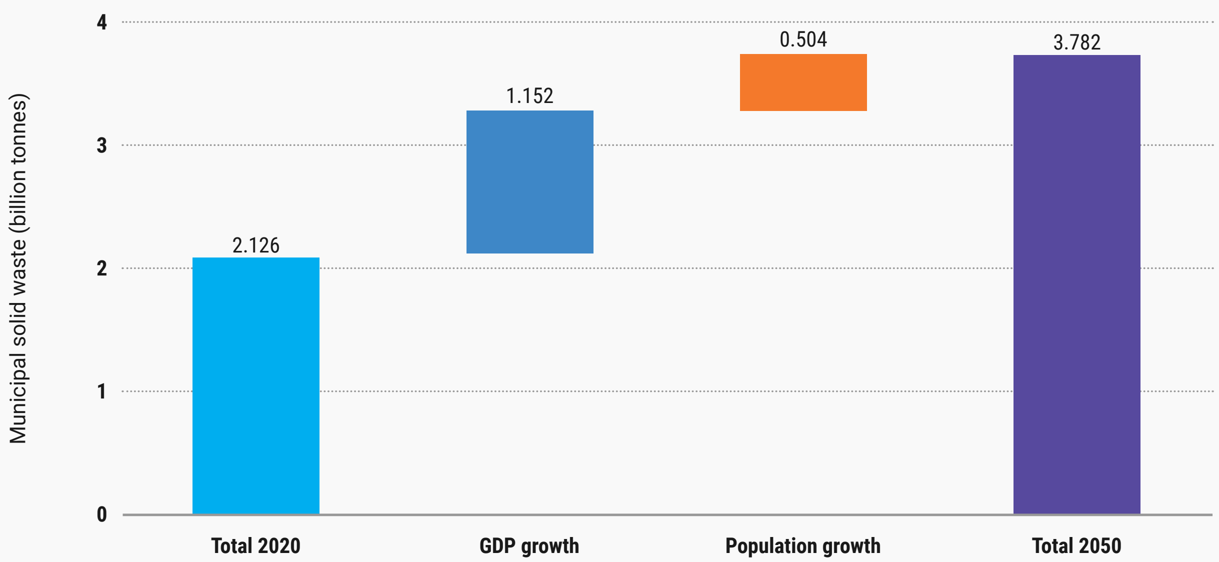
In 2020, global MSW generation is estimated to have been 2.1 billion tonnes per year. Owing to a combination of economic and population growth, it is projected to increase by 56 per cent to 3.8 billion tonnes by 2050 if urgent action is not taken (Figure 3).

Figure 3: Projections of global municipal solid waste generation per year in 2030, 2040 and 2050 if urgent action is not taken.



The contribution of GDP and population growth to the projected increase in MSW generation in 2050, if urgent action is not taken, is illustrated in Figure 4.

Figure 4: Contribution of gross domestic product growth and population growth to the projected increase in global municipal solid waste generation in 2050.



Globally until 2050, both GDP and population are expected to grow especially rapidly in Central and South Asia and Sub-Saharan Africa (PricewaterhouseCoopers 2017; United Nations Department of Economic and Social Affairs [UN DESA] 2022). It is estimated that more than half the projected increase in global population up to 2050 will be concentrated in eight countries: the Democratic Republic of the Congo, Egypt, Ethiopia, India, Nigeria, Pakistan, the Philippines and the United Republic of Tanzania (UN DESA 2022).

Figure 5 shows projected MSW generation rates and the quantities of controlled and uncontrolled waste in different regions for further discussion of the distinction see Section 2.3.1).

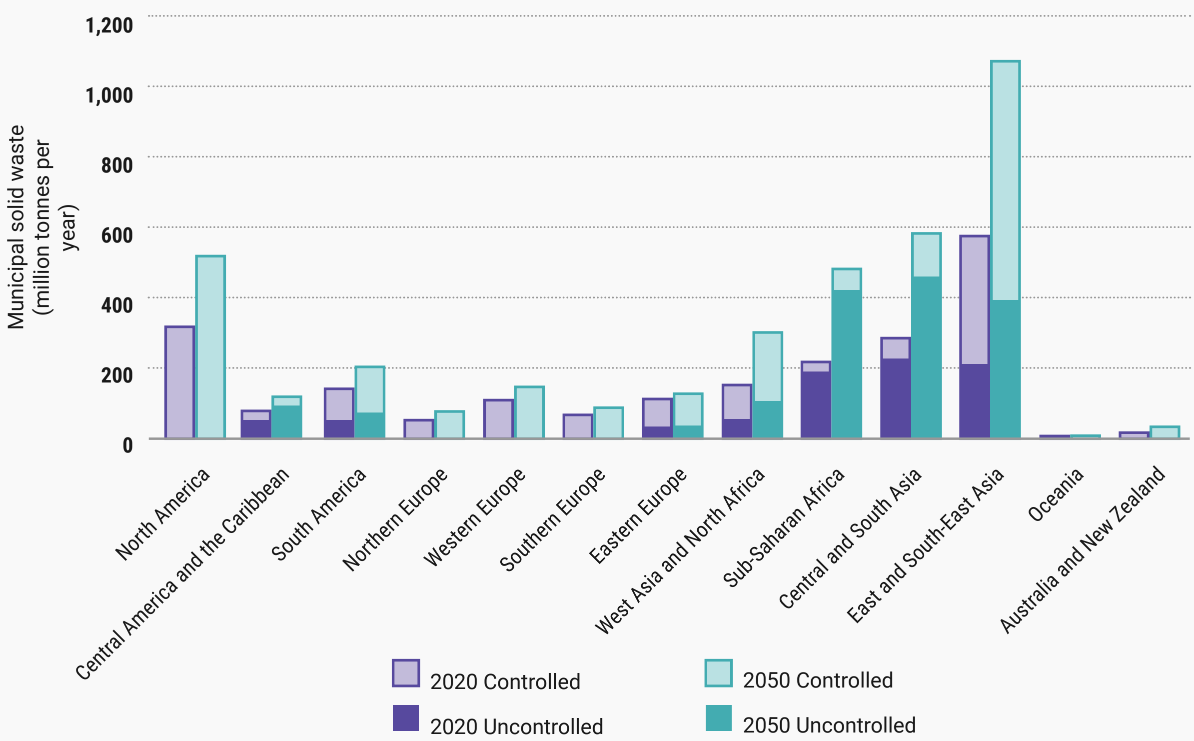
The chart shows that the largest growth in MSW generation is expected to take place in fast-growing economies, where waste generation is already outpacing the capacity to manage it.

These findings underline the need for strategies to decouple economic growth from resource consumption and waste generation. They also point to the urgent need for greater waste management capacity, especially in countries already struggling to collect and manage waste where high growth in MSW is projected.

Photo source: dj_mono / Adobe Stock

It is estimated that more than half the projected increase in global population up to 2050 will be concentrated in eight countries.

Figure 5: Municipal solid waste generation and how much of this waste was uncontrolled in 2020, with projections for 2050 unless urgent action is taken.



2.2. Composition of waste

The previous section described how waste generation increases with economic development. Income levels also have an impact on waste composition. Figure 6 shows the composition of MSW, with the global average (far left) followed by regional compositions.

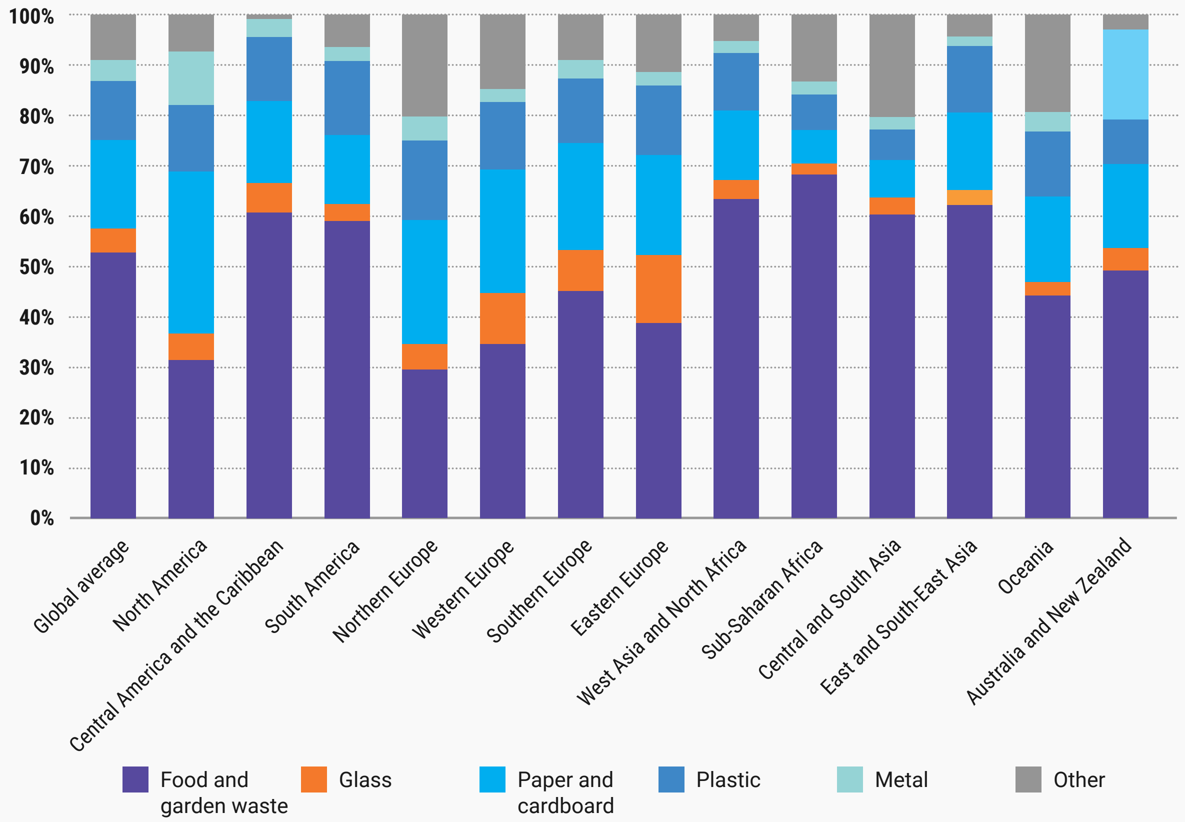
Low-income countries have proportionally larger rural populations, which means more people live close to locations where food is produced. In these countries, less packaging is used to transport food from rural to urban areas. Packaging therefore makes up a smaller proportion of MSW. This can be seen in the composition of MSW in Sub-Saharan Africa and South America. These regions have a higher relative proportion of food waste, not because they waste more food than other regions but because there is a smaller share of packaging waste in their MSW stream.

Higher income, more urbanised populations require more packaging to transport food safely from rural to urban areas (Chen 2018; Lozano Lazo, Bojanic Helbingen and Gasparatos 2022). Moreover, higher-income consumers tend to prioritise convenience, resulting in more single-use products and packaging from home deliveries and take-out food being found in the MSW stream (Ellison, Fan and Wilson 2022). These consumers also have more disposable income to spend on goods such as clothing and personal hygiene products ("Other" in Figure 6). The impact of their consumption patterns on MSW composition can be seen, for example, in MSW composition in North America and Northern and Western Europe.

Other factors affecting MSW composition include climate (more garden waste may be generated in areas with high rainfall), population density and cultural practices (He *et al*. 2022; Singhal *et al*. 2022).

Photo source: *Dave / Adobe Stock*

Figure 6: Global average and regional breakdown of municipal solid waste composition.
"Other" includes items such as textiles, wood, rubber, leather and household and personal hygiene products.



2.3. Current waste management methods

Notwithstanding the need for upstream measures to reduce waste and, ideally, decouple waste generation from economic growth (further discussed in Chapter 4), this section looks at how MSW is currently managed.

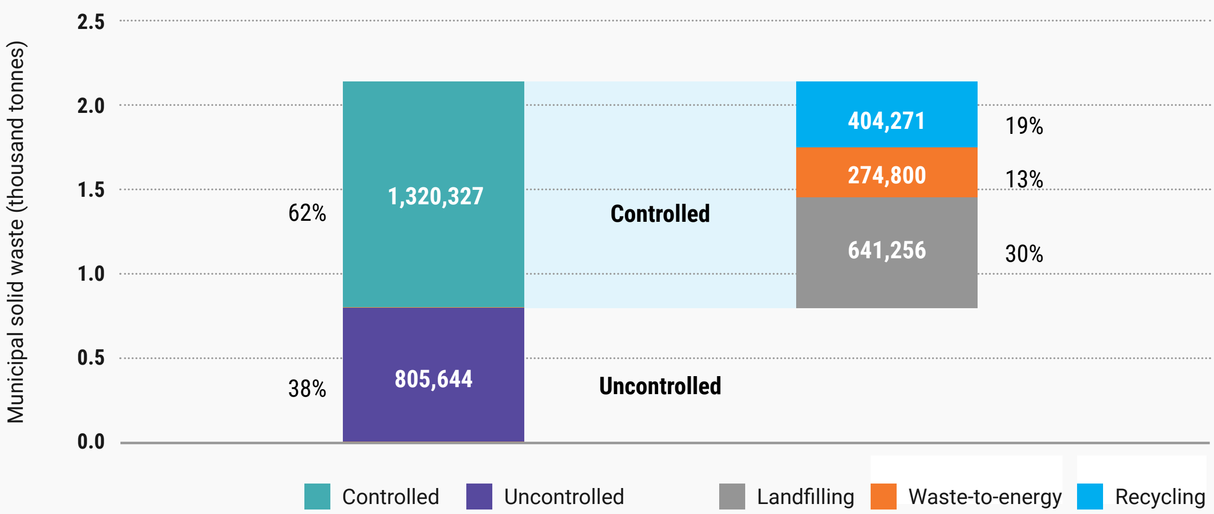
2.3.1. Controlled vs. uncontrolled

"Controlled waste" is:	"Uncontrolled waste" is either:
Collected, and then either recycled or disposed of in a controlled facility.	Not collected, and so by necessity dumped or burned in the open by the waste generator, or Collected and then dumped or burned at its final destination (Section 2.3.6).

According to the analysis undertaken for this report, 38 per cent of the MSW generated globally in 2020 was uncontrolled. Global destinations of MSW in 2020 are shown in Figure 7. There is a regional breakdown in Figure 8.

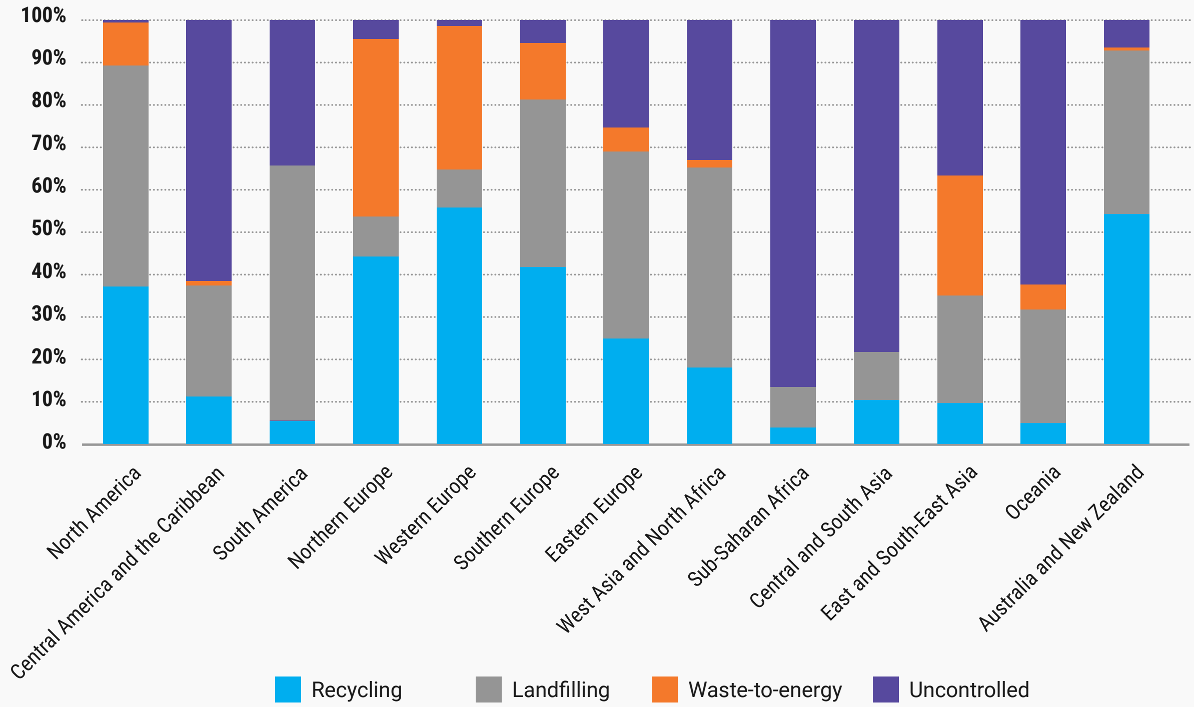
Photo source: *panaramka / Adobe Stock*

Figure 7: Global municipal solid waste destinations in 2020: Controlled (landfilling, waste-to-energy recycling) and uncontrolled.



The degree to which MSW is managed in a controlled manner varies significantly across regions. The lowest levels of MSW management are in Sub-Saharan Africa and Central and South Asia, whereas in North America and Western Europe almost all of this waste is managed in controlled destinations (Figure 8). Other differences include the fact that North America relies predominantly on sanitary landfill disposal (see Section 2.3.5), while in Western Europe recycling rates are higher and waste-to-energy is the dominant method of MSW disposal (Figure 8).

Figure 8: Regional distribution of municipal solid waste destinations (2020).



The global share of uncontrolled MSW disposal (dumping and open burning; see Section 2.3.6) is projected to increase slightly, from 38 per cent in 2020 to 41 per cent by 2050. However, when projected MSW growth (Section 2.1) is factored in, this proportional increase will mean an almost two-fold increase in uncontrolled MSW, from 806 million tonnes in 2020 to 1.6 billion tonnes in 2050, as shown in purple in Figure 9.

Figure 9: Projected global municipal solid waste destinations in 2030, 2040 and 2050 compared with 2020.

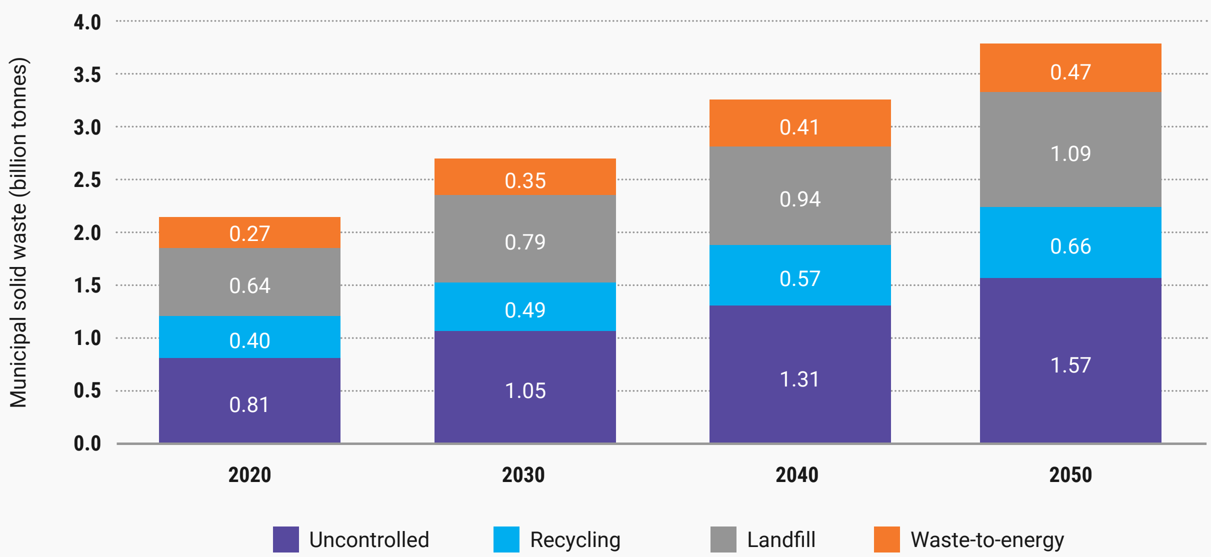


Photo source: *Alex Traveler / Adobe Stock*

Some
2.7 billion
people do not have their waste collected.

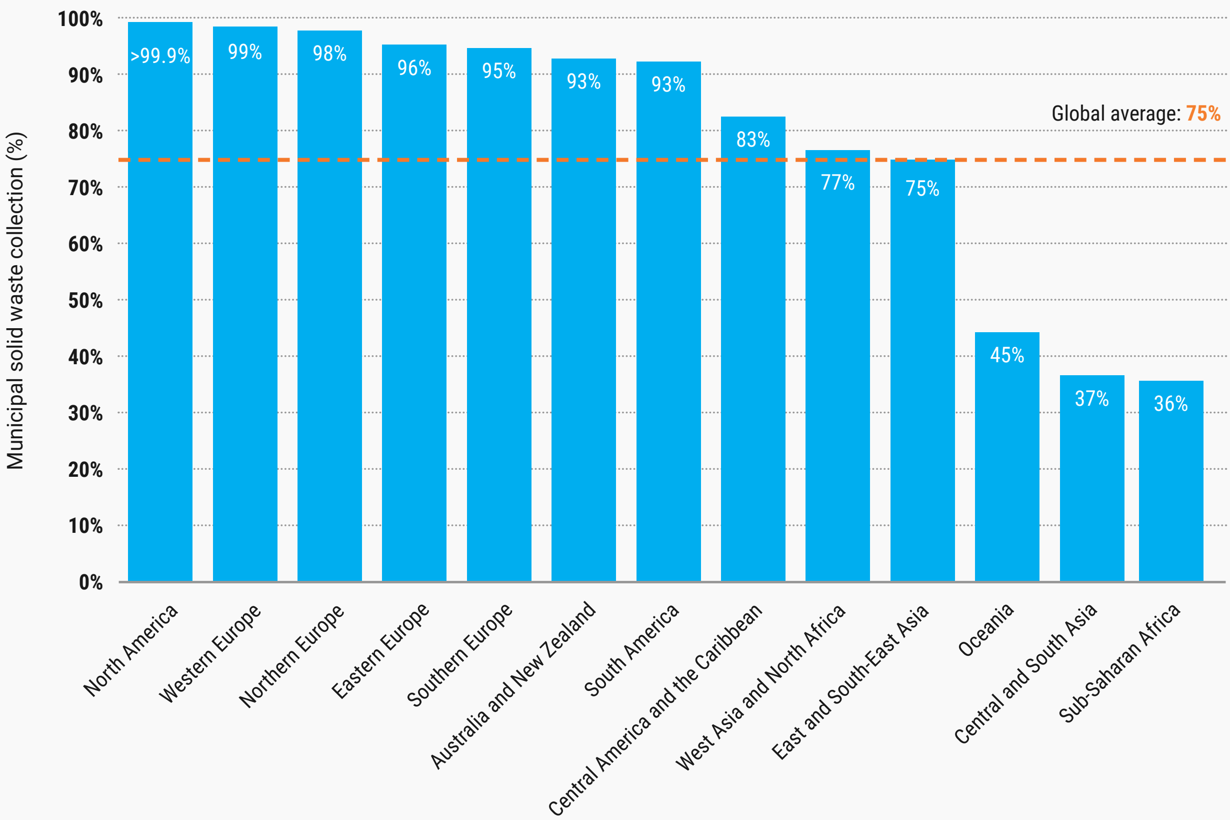
2.3.2. Waste collection

Access to waste collection services varies significantly within and between regions. In higher-income regions almost all MSW is collected, while less than 40 per cent of MSW is collected in lower-income countries (Figure 10). The regions with the lowest collection coverage (Oceania, Central and South Asia, Sub-Saharan Africa) also have the lowest urbanisation rates.

According to the analysis undertaken for this report:

- Some 2.7 billion people do not have their waste collected: 2 billion in rural areas and 700,000 in urban areas;
- This amounts to 540 million tonnes of MSW, or around 27 per cent of the global total, not being collected.

Figure 10: Municipal solid waste collection rates by region.



Note: Collection rates are calculated as the total amount of municipal solid waste (MSW) collected divided by the total amount of MSW generated. Regional averages (weighted by tonnes of MSW) are based on data from those countries for which data is available.

2.3.3. Reuse and recycling

Humans have been recycling agricultural waste since the Stone Age (Guttmann 2005) and the Romans were remelting metals and glass 2,000 years ago (Healy 1978; Freestone 2015). Despite this rich history, only 19 per cent of MSW is currently recycled (Figure 9), including metals; glass; paper and cardboard; some plastics; and biodegradable waste treated through composting and anaerobic digestion (to make biogas).

Reuse and recycling reduce demand for energy-intensive and environmentally damaging raw material extraction (Lizárraga-Mendiola, López-León and Vázquez-Rodríguez 2022), enable waste to be valued as a resource, and prevent pollution from waste leaking into the environment. Reuse features more highly on the waste hierarchy as it does not involve energy-intensive processes in the way that recycling can.

As illustrated in Figure 11, recycling rates vary significantly between countries and regions, with a small number of high-income countries reporting recycling rates of over 50 per cent while in Sub-Saharan Africa and South America the recycling rate is closer to 5 per cent.

Reported recycling rates do not account for materials that have been reused (or, for example, food waste fed to chickens or composted at home or in community composting facilities). Moreover, recycling rates do not account for materials that have been exported for recycling and then rejected (disposed of) due to contamination or mislabelling.

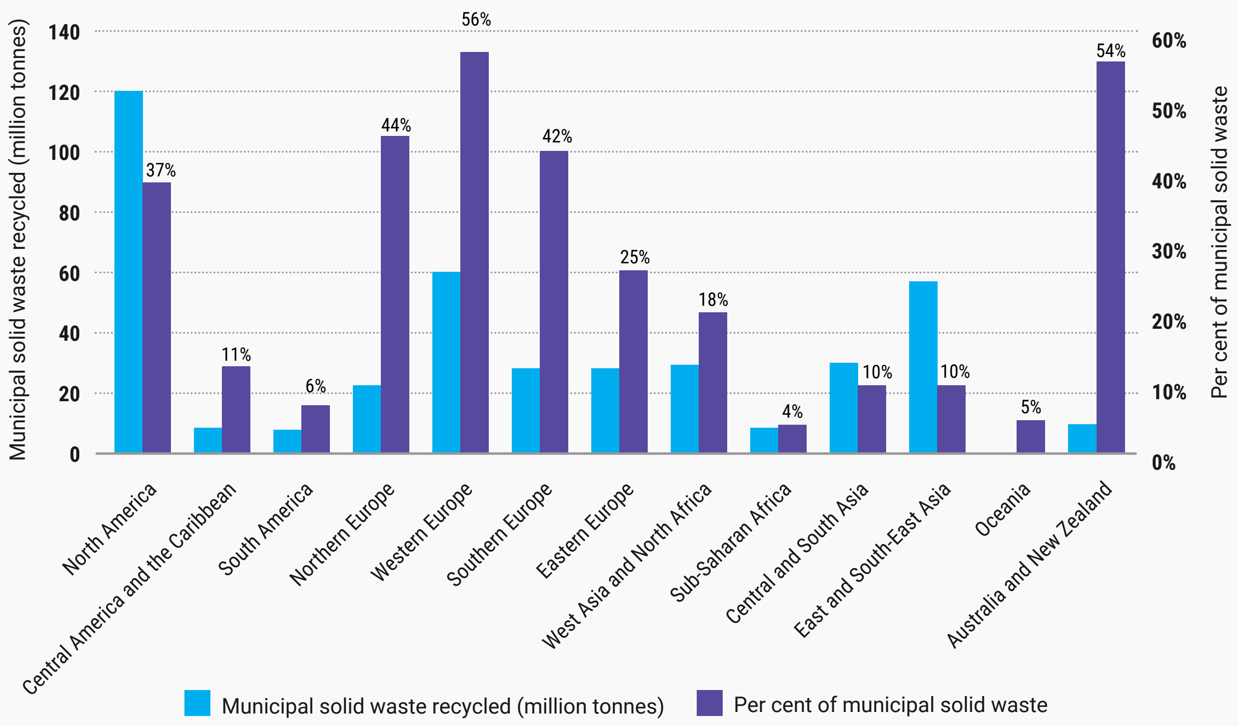
As shown in Figure 11, Northern and Southern Europe have among the world's highest recycling rates (44 and 42 per cent, respectively) although the total amount of waste recycled in East and South-East Asia is higher than that recycled in these European regions combined, in part because significant quantities of materials are shipped from Europe to Asia for recycling (presenting a risk of double-counting).

"Recycling" here refers to mechanical recycling. Chemical recycling is still in its early stage of development, and accurate assumptions about its impacts and contributions cannot yet be made (UNEP 2023e). However, it can be said that all waste processing technologies still require the waste to be collected in an appropriate way and transported to site, and that such processes require consistent feedstock and so may compete with waste reduction efforts.

It should be emphasised that recycling is not the ultimate goal of waste management: it is always better to reduce waste by preventing it in the first place, or reuse materials that would otherwise become waste, than to produce waste and then recycle it.

> ***"Recycling is not the ultimate goal of waste management: it is always better to reduce waste by preventing it in the first place."***

Figure 11: Municipal solid waste recycled (million tonnes) and recycling rates by region (2020).



2.3.4. Waste-to-energy

Thermal waste-to-energy, also known as incineration with energy recovery, is a waste treatment method used in a relatively small number of countries (Figure 12). Many governments are increasingly prioritising waste reduction, reuse and recycling as more cost-effective and more environmentally sound than the use of waste-to-energy technology (UNEP 2019a).

Waste-to-energy represents linear resource use since materials that are combusted can never be recovered and used again.

Although waste-to-energy technologies are widely used in some industrialised countries, questions persist concerning the adoption of these technologies. The issue of whether to adopt waste-to-energy is very controversial, with many people arguing that thermal treatment technologies reduce incentives to decrease waste generation and move towards a zero-waste and low-carbon society (UNEP 2018).

Thermal treatment technologies rely on the energy released from highly calorific waste (greater than 7 megajoules per kg)-namely plastics, cardboard, paper and textiles-to generate electricity. Since these are the materials most likely to be collected by informal waste collectors for recycling, destroying them using thermal treatment threatens already vulnerable livelihoods (UNEP 2019b). For that reason, waste picker associations in Latin America, Africa and Asia have protested against incineration, pointing out that it would be preferable to develop an integrated MSW management plan based on material flow analysis that integrates concepts such as the waste hierarchy, the circular economy and the creation of green jobs (IJgosse 2019).

Other challenges include the limitations of thermal combustion technologies with respect to processing wet food waste, which can dominate municipal waste streams (Mondal and Kitawaki 2023) (Figure 6); ineffective waste collection methods; lack of financial support; lack of policies related to energy recovery projects; absence of coordination between governmental bodies; lack of environmental regulation capacity; low energy efficiency (unless coupled with heat recovery into a district heating system or a similar arrangement); and the generation of hazardous waste by pollution abatement systems (Khan, Chowdhury and Techato 2022; Nguyen *et al*. 2023).

GHGs and other airborne pollutants emitted from combustion processes may also hinder countries' abilities to meet obligations related to their Nationally Determined Contributions (NDCs) and emission trading scheme allowances.

Figure 12: Municipal solid waste treated by waste-to-energy plants (million tonnes) and percentage of total municipal solid waste treated by waste-to-energy, across regions.

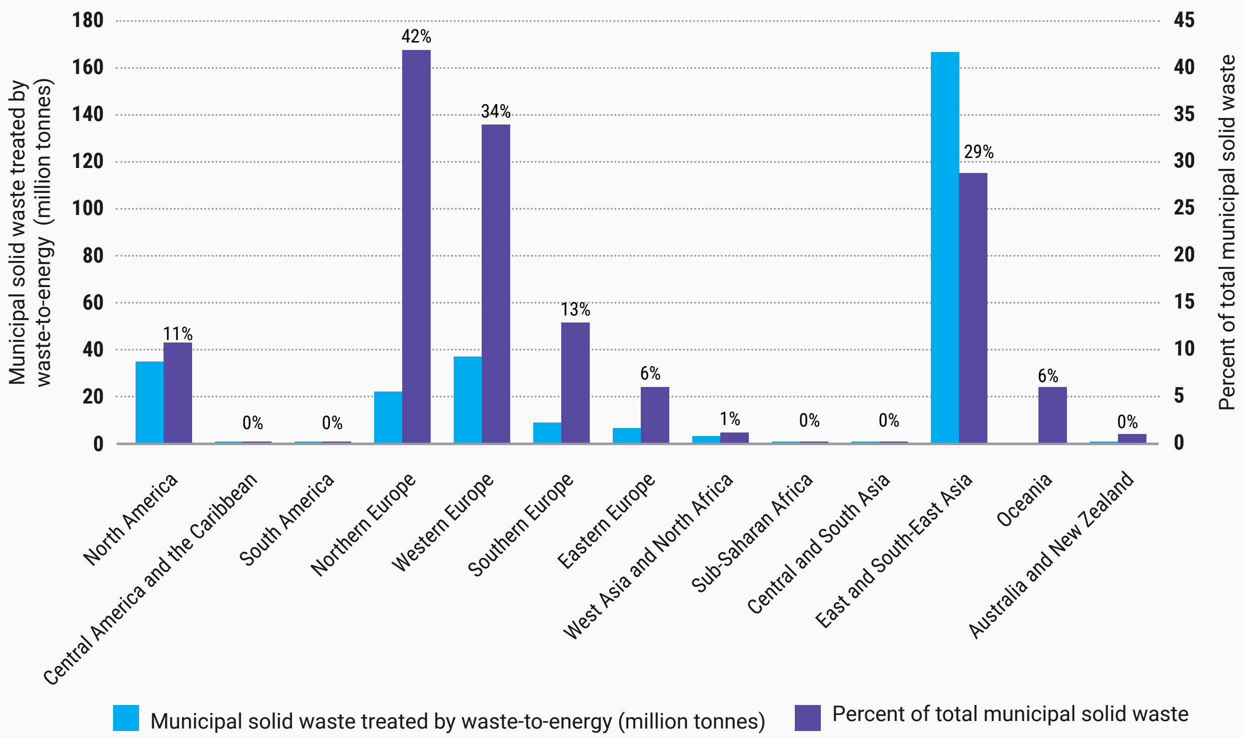


Photo source: *Timothy Bouldry*

Where waste-to-energy facilities are already in use, emissions from these facilities are coming under increasing scrutiny due to the need to reduce sources of anthropogenic atmospheric carbon, with the potential to retrofit carbon capture and storage technology adding to technological uncertainty and costs. In 2023, the European Union (EU) and the United Kingdom of Great Britain and Northern Ireland agreed to expand emissions trading schemes to include waste-to-energy, in recognition of the negative environmental impacts of GHG emissions from even the controlled combustion of waste. This decision represents the most significant regulatory intervention to the waste industry in a generation. It will fundamentally change the economics of the sector and will require further sorting of the municipal waste stream to extract more recyclable materials.

Helpful questions for policymakers to consider regarding thermal treatment technologies include:

- Is the technology the best available, and can it meet stringent emission and discharge limits, including for any hazardous waste residues?
- Can a guaranteed quantity of feedstock be supplied within the required window of calorific value and moisture content for the entire lifespan of the facility? If not, will contractual penalties be affordable?
- Is a suitable system in place to divert the majority of food waste from the feedstock?
- If recyclables such as plastic, paper and cardboard are to be used as feedstock, how will livelihoods within the recycling value chain and sustainability/zero waste/circular economy ambitions be impacted?
- Can the facility be operated by local people or will employment opportunities mainly be available to those from elsewhere?
- Do appropriate national regulations exist, and does the environmental regulator have sufficient capacity to monitor emissions and enforce these regulations?
- Will a hazardous waste landfill cell (a waste-holding unit within the landfill) be required for any of the outputs, and is this feasible?
- Can the technology be developed at an appropriate scale for the population it is designed to serve, and are transport networks suitable for a centralised facility?
- Will it be possible to utilize the heat and electricity generated in order to achieve minimum efficiency standards?
- Will airborne emissions meet air quality targets, climate change goals and countries' pledges in their NDCs?

Alternative thermal treatment approaches include co-combustion of low-value plastics in cement kilns (Prakash and Palkar 2023). The suitability of this treatment depends upon the availability of cement kilns at an appropriate distance from urban areas. Research and development are also taking place on pyrolysis of plastic waste into diesel, offsetting the need for virgin fossil fuels (Janarthanan and Sivandi 2022). However, there are concerns about the safety standards in cottage industry scale pyrolysis, as well as about carbon and other emissions released from the combustion of mixed plastics (and associated additives), which could negatively impact local air quality and public health and contribute to global climate change.

Photo source: *Timothy Bouldry*

Where waste-to-energy facilities are already in use, emissions from these facilities are coming under increasing scrutiny due to the need to reduce sources of anthropogenic atmospheric carbon.

2.3.5. Sanitary landfill

A sanitary landfill is an engineered facility for the disposal of solid waste on land in a controlled manner. Certain key features distinguish sanitary landfills from uncontrolled landfills or dumpsites:

- Site selection-typically downstream from human settlements and with non-porous underlying geology;
- Geomembranes or appropriate barriers to prevent leaching into the environment as well as technology to enable collection of liquid leachate and a leachate management system;
- Landfill gas recovery with flaring or energy recovery;
- Placing of waste in cells, with compaction and daily cover using inert materials;
- Fencing, weighbridges and security measures.

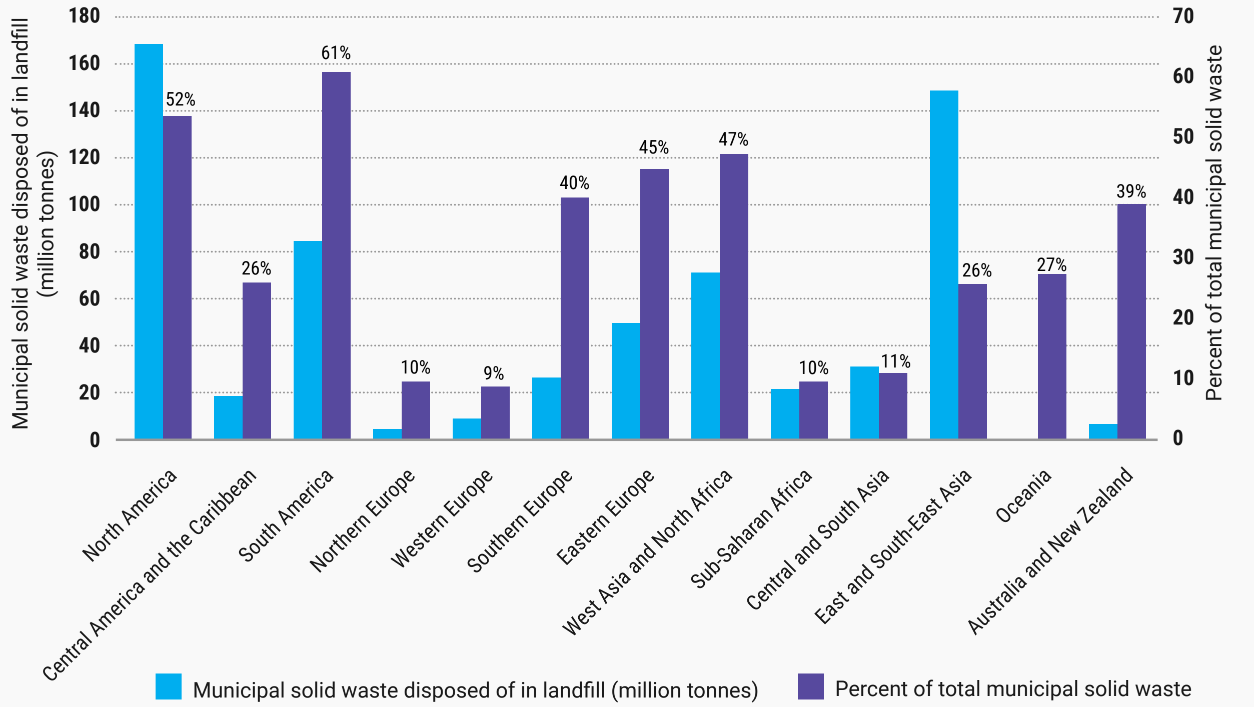
The gradual decomposition of biodegradable waste in landfills generates landfill gas (also called biogas), which is rich in methane. Methane, a GHG with a warming potential more than 80 times greater than that of CO_2 over a 20-year time frame, is responsible for half a degree Celsius of global warming to date (Climate and Clean Air Coalition 2022). To reduce methane emissions from landfills, many countries have prioritised the diversion of biodegradable waste into recycling (in the case of paper and cardboard), or composting or anaerobic digestion (in the case of garden and food waste).

Increased waste reduction and recycling efforts will reduce the amount of waste disposed of in landfills. Nevertheless, landfills are likely to remain an important part of waste infrastructure since they can hold residual waste from which no further materials and/or energy can be recovered (including bottom ash from waste-to-energy facilities) (Vaverková 2019; Organisation for Economic Co-operation and Development [OECD] 2021).

Photo source: *ronedya / Adobe Stock*

Where waste management infrastructure is nascent, the construction and use of landfills can be an important step towards more sustainable solid waste management (Kaza *et al*. 2018). The semi-aerobic landfill (Fukuoka method), a waste treatment technology midway between a dumpsite and a sanitary landfill, offers an affordable option and can be retrofitted to existing dumpsites, thereby “upgrading” them (UNEP 2019b; United Nations Human Settlements Programme [UN-Habitat] 2020; NUA Campus 2023). Evidence from Mozambique suggests that upgrading from a dumpsite to a semi-aerobic landfill can reduce landfill gas emissions by 40 per cent (Muchangos and Tokai 2020).

Figure 13: Municipal solid waste (MSW) landfilling rates and per cent of total MSW sent to landfill, by region (2020).



2.3.6. Dumping and open burning of waste

Photo source: *Timothy Bouldry*

While humans have been dumping and burning waste since prehistoric times, both population and waste growth along with the increasing complexity of materials mean that today uncontrolled waste disposal practices are increasingly problematic.

Figure 14 shows current dependence on dumping and open burning of MSW across the world.

Globally, the widespread practices of open dumping and burning of waste pose a significant challenge for human and planetary health. It has been estimated that between 400,000 and 1 million people in the Global South die each year from diseases related to mismanaged waste that include diarrhoea, malaria, heart disease and cancer (Williams *et al*. 2019).

Dumped waste attracts vermin and blocks drains, leading to local flooding and the fostering of breeding grounds for disease-mosquitoes, and ultimately contributing to marine plastic pollution (Faiza *et al*. 2019; Schmidt *et al*. 2022; Sharma, Brahmbhatt and Panchal 2022; Micella *et al*. 2024).

Open burning is a way to prevent waste from accumulating in the environment, in backyards and at dumpsites, as well as a means of removing plastic casing from metals in informal recycling (Velis and Cook 2021). Since high temperatures destroy pathogens, the burning of waste may be a recommended practice for hospitals and medical centres lacking a waste management service (WHO 2019). However, waste burning generates a wide range of airborne pollutants including Unintentional Persistent Organic Pollutants and other chemicals of concern for public health (Pathak *et al*. 2023). Pollutants from mismanaged waste can bioaccumulate in the food chain and in mothers' breast milk, with potential multigenerational consequences (Guo *et al*. 2019; López Sanguos *et al*. 2023). Black carbon emitted from open burning has adverse impacts on human health and the environment. It is a powerful atmospheric warming agent that increases the melting rate of polar ice (Arctic Council Secretariat 2021).

Figure 14: Regional breakdown of uncontrolled disposal of municipal solid waste (MSW) in million tonnes and per cent of total MSW.

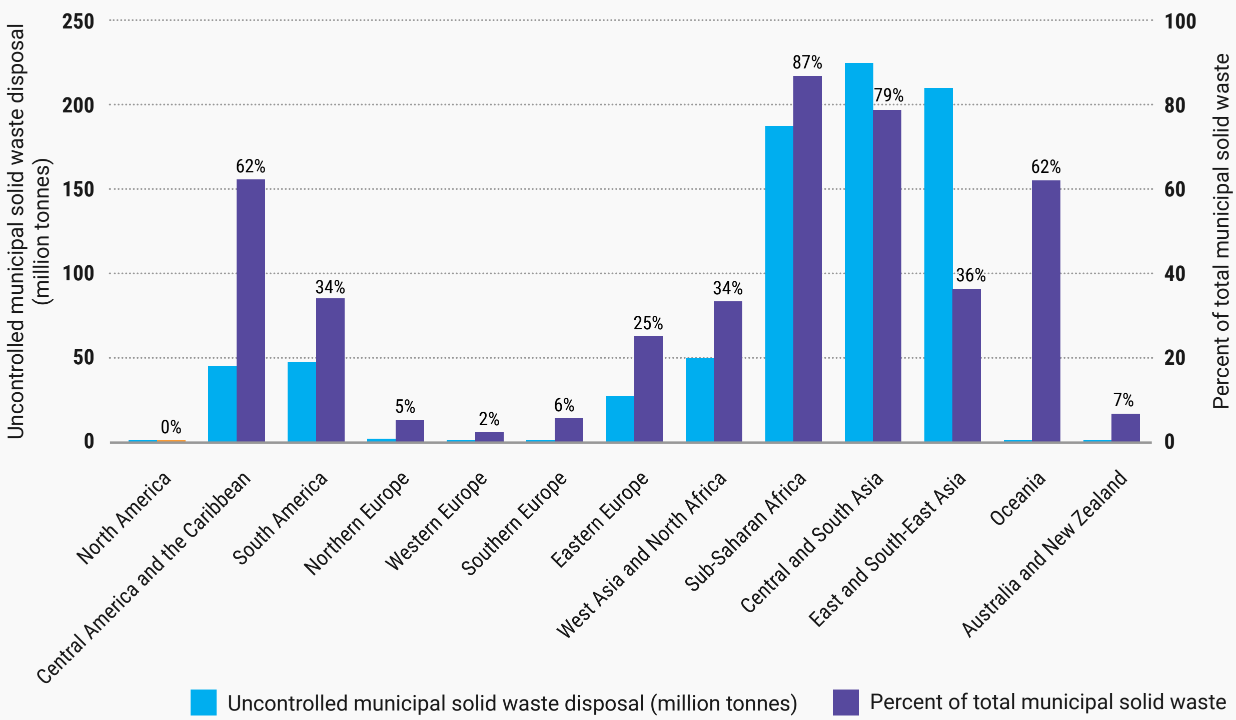


Photo source: *Timothy Bouldry*

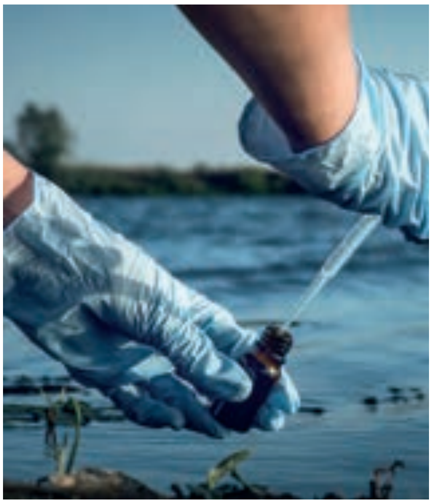


Photo source: *Natali / Adobe Stock*

Photo source: *Timothy Bouldry*

Dumpsites are prone to fires, which can smoulder continuously beneath the surface for months and can be very difficult and dangerous to extinguish.

The term “dumping of waste” can refer to indiscriminate disposal (littering) and also to the accumulation of waste at uncontrolled dumpsites, many of which have existed for decades and have reached immense proportions. Uncontrolled dumpsites, which until the middle of the last century were the dominant disposal choice globally, pose ongoing risks to water quality, public health and the climate (Cristóbal *et al*. 2022; Alao 2023; Alao *et al*. 2023;

A significant proportion of dumpsites are on or near coastlines, where they may leak persistent, bioaccumulative and toxic chemicals such as polychlorinated bisphenols, as well as plastics and other types of waste, into coastal and marine environments. The risks associated with these dumpsites are exacerbated by climate change (higher temperatures, sea level rise and greater magnitude and frequency of storms) (Brand and Spencer 2019; Nicholls *et al*. 2021).

Dumpsites are prone to fires, which can smoulder continuously beneath the surface for months and can be very difficult and dangerous to extinguish. Emissions from burning dumpsites are challenging to measure or estimate with accuracy, as waste composition and the combustion temperature affect the nature, character and magnitude of the pollutants emitted. Due to the difficulties of assessing emissions from dumpsite fires, it is likely that the global warming impact of these human-made disasters is under-estimated. Studies have shown, however, that dumpsite fires expose millions of people to dangerous levels of pollutant emissions (Bihałowicz, Rogula-Kozłowska and Krasuski 2021; Dabrowska, Rykala and Nourani 2023).

Dumpsites also present a risk of landslides, with multiple fatal occurrences every year, making their remediation an eventual necessity. Remediating dumpsites or older landfills is a complex and expensive undertaking in any part of the world (Ospanbayeva and Wang 2020; Yin *et al*. 2020).

2.4. The current costs of waste

Unsustainable consumption and production patterns result in increasing quantities of waste to manage, which in turn increase the direct costs to society. The analysis carried out for this report (see Annex 2) found that in 2020 MSW management globally cost US$252.3 billion (Figure 15).

Why does MSW management cost so much? The most expensive step in the waste management chain is usually collection, with crew wages; vehicle fuel and maintenance; insurance; and other indirect costs to be covered (Kaza *et al*. 2018).

Recycling requires sorting and processing infrastructure, together with funds for ongoing operational costs. Waste disposal facilities such as engineered landfills and waste-to-energy plants require significant up-front investments in infrastructure. They also have high operational and maintenance costs. Even the open dumping of waste has direct costs, with fires needing to be extinguished and land value being lost.

These direct costs do not include the externalities of MSW and its (mis)management, which are intrinsically linked to the triple planetary crisis of climate change, biodiversity loss and pollution, as well as to human health and environmental and social justice, as discussed in Chapter 1.

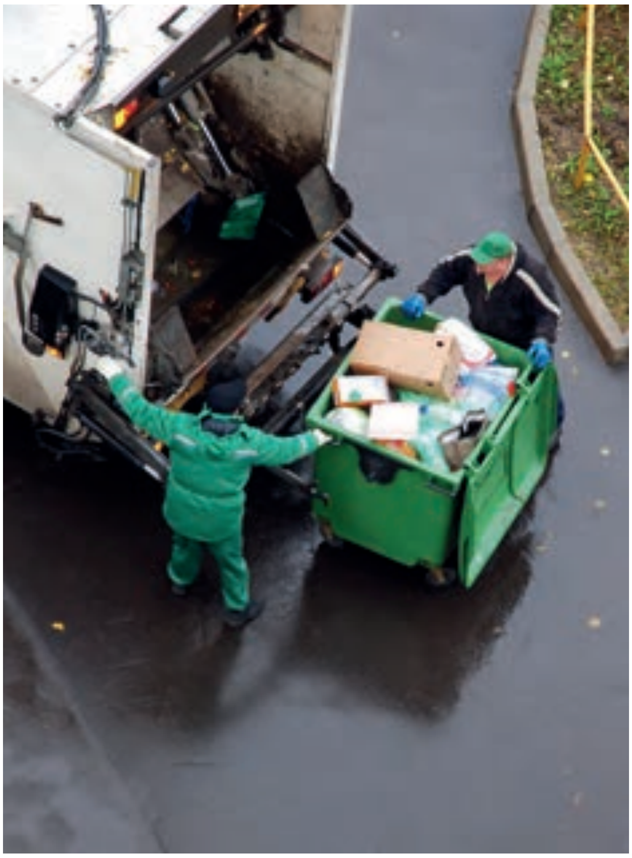
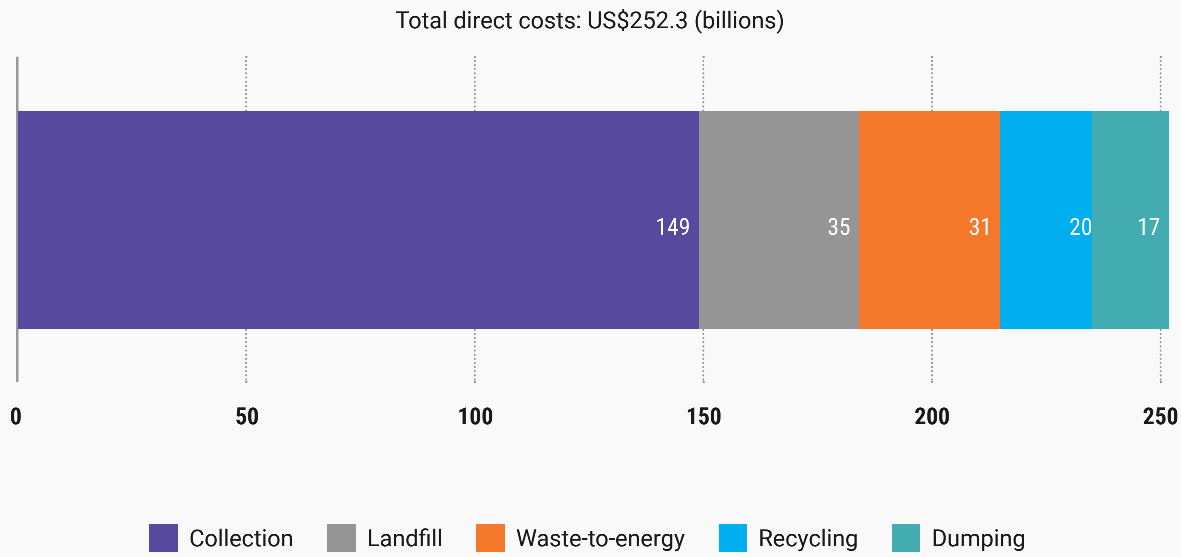


Photo source: *Enso / Adobe Stock*

Figure 15: Estimated direct costs of municipal solid waste management globally in 2020.



Note: These costs take into account the regional averages of costs for each step in the waste management chain, estimated by the World Bank (Kaza et al. 2018) and updated to 2020 with consideration given to inflation and currency changes (US$ 2020).

Worldwide, the externalities of MSW and its mismanagement are experienced most severely by communities that are already disproportionately affected by poor environmental quality, particularly waste workers and citizens in lower-income countries and Small Island Developing States (Faiza *et al*. 2019; UNEP 2019b; Zolnikov *et al*. 2021b; McClelland *et al*. 2022; Sara, Bayazid and Quayyum 2022; Schmidt *et al*. 2022; Sharma, Brahmbhatt and Panchal 2022).

The reasons for this vary. They include:

- Limited capacity and technical capability to deal with fast-growing waste streams;
- Prohibitive costs of upgrading infrastructure;
- Inability to hold polluters to account, either through enforcing environmental regulations or through market mechanisms such as Extended Producer Responsibility (EPR);
- Illegal waste trafficking to countries with weaker (or poorly enforced) environmental regulations and already inadequate waste management systems;
- Limited influence or control over product design, including material choice and design for longevity, reuse or recycling.

Furthermore, within countries, differences due to gender and socioeconomic status can result in unequal access to waste management services as well as unequal exposure to pollution from waste and associated health outcomes (United Nations Development Programme [UNDP] 2020; Gupta 2022; Rajapaksha and Karanurathna 2022).

The burden of inadequate waste management practices can be difficult to quantify, yet it is substantial. On the other hand, reducing waste and recycling unavoidable wastes results in positive externalities, including reduced demand for raw material extraction; reduction of waste's environmental and social impacts; less need for waste disposal capacity; reduced GHG emissions; and healthier populations (Cudjoe *et al*. 2021; Conlon 2024; Li *et al*. 2024; Maus and Werner 2024; Worrell 2024).

External costs, in terms of the negative impacts of waste disposal and positive gains from recycling (for the climate, ecosystems and human health), were calculated for this report using the methodology and parameters described in the *Environmental Prices Handbook* (CE Delft 2018, Table 2).

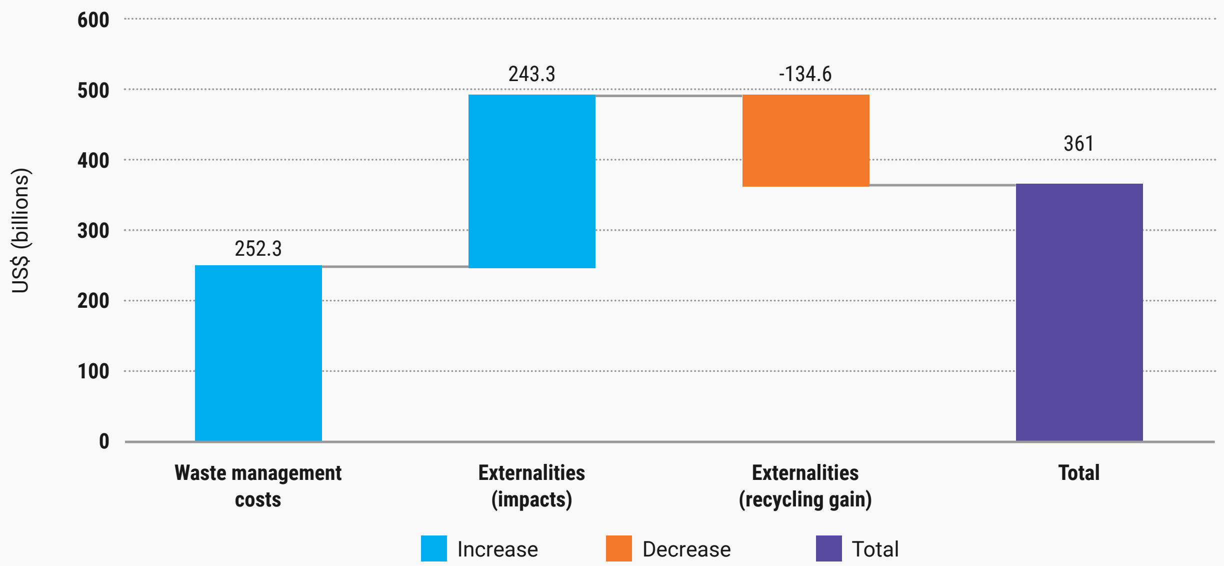
Environmental prices are indices that calculate marginal social value (i.e. the satisfaction society experiences associated with a specific good, plus or minus overall environmental and social costs or benefits) of preventing emissions (or other activities such as land-use change). They are expressed in terms of monetary cost per unit of damage. In this sense, environmental prices are often the same as externalities or external costs. Figure 16 shows the significant "hidden" costs of MSW and its (mis)management, as well as gains from recycling.

> ***"Data suggests that in 2020 the total global costs to society of waste and its (mis)management amounted to US$361 billion."***

While national contexts vary and there is no one-size-fits-all solution that can be used to move towards zero waste and a circular economy, it is clear that the hidden costs of waste are unaffordable for current and future generations.

Recognising the full cost of these externalities provides governments and other decision-making bodies with the evidence needed in order to prioritise waste reduction and waste management for a sustainable future.

Figure 16: Direct costs, externalities and total overall costs of municipal solid waste and its management (2020) (US$ 2020).



Improving waste management worldwide will require significant investments, by far the most affordable solution is to drastically reduce waste and value secondary materials as a resource.

Photo source: *aryfahmed / Adobe Stock*

03 Predicting future waste generation

Photo source: *schusterbauer.com / Adobe Stock*

3.1. Using scenarios to estimate the impacts of different municipal solid waste management approaches to 2050

To assess the potential impacts of MSW management to 2050, three scenarios were developed.

01 Waste Management as Usual

Waste generation and waste management practices continue as today, with waste generation projected to grow fastest in regions without adequate waste management capacity.

02 Waste Under Control

A midway point, with some progress made towards preventing waste and improving its management.

03 Circular Economy

Waste generation decoupled from economic growth, with the global MSW recycling rate reaching 60 per cent and the remainder managed safely.

The principal characteristics of each scenario are presented in Boxes 2–4. Key assumptions are shown in Table 4.

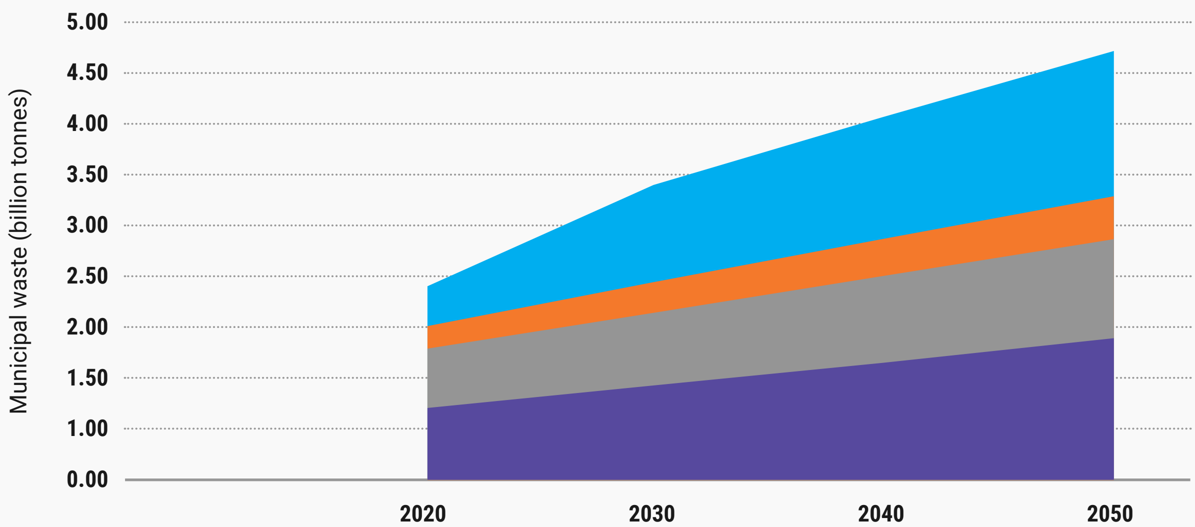
Box 2: Scenario 1 – Waste Management as Usual

Summary: The world continues current consumption and production patterns.

Photo source: vchalup / Adobe Stock

Waste generation	Collection, recycling and disposal
Waste generation continues to increase with economic growth.	Investments in infrastructure remain limited; collection, recycling and disposal practices remain unchanged.

Figure 17: **Waste Management as Usual (Scenario 1) projections.**



	2020	2030	2040	2050
Recycled	0.40	1.05	1.31	1.57
Waste-to-energy	0.27	0.35	0.41	0.47
Landfilled	0.64	0.79	0.94	1.09
Uncontrolled	0.81	1.05	1.31	1.57

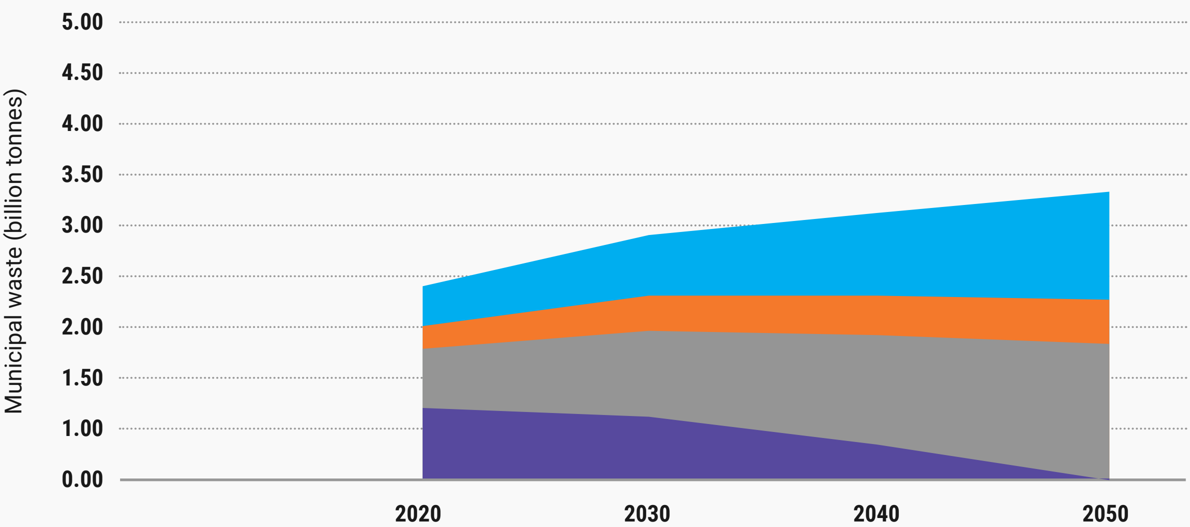
Box 3: Scenario 2 – Waste Under Control

Summary: Waste generation stabilises due to waste prevention measures, while waste management improves.

Photo source: *nordroden / Adobe Stock*

Waste generation	Collection, recycling and disposal
Government policies and producer actions make progress towards designing out waste; waste generation is decoupled from economic growth by 2030.	Investments in waste prevention and management increase; collection coverage increases to 100 per cent by 2050; recycling increases proportionally with other treatment methods; uncontrolled disposal ends by 2050.

Figure 18: **Waste Under Control (Scenario 2) projections.**



	2020	2030	2040	2050
Recycled	0.40	0.66	0.89	1.16
Waste-to-energy	0.27	0.39	0.44	0.47
Landfilled	0.64	0.94	1.19	1.51
Uncontrolled	0.81	0.70	0.40	0.00

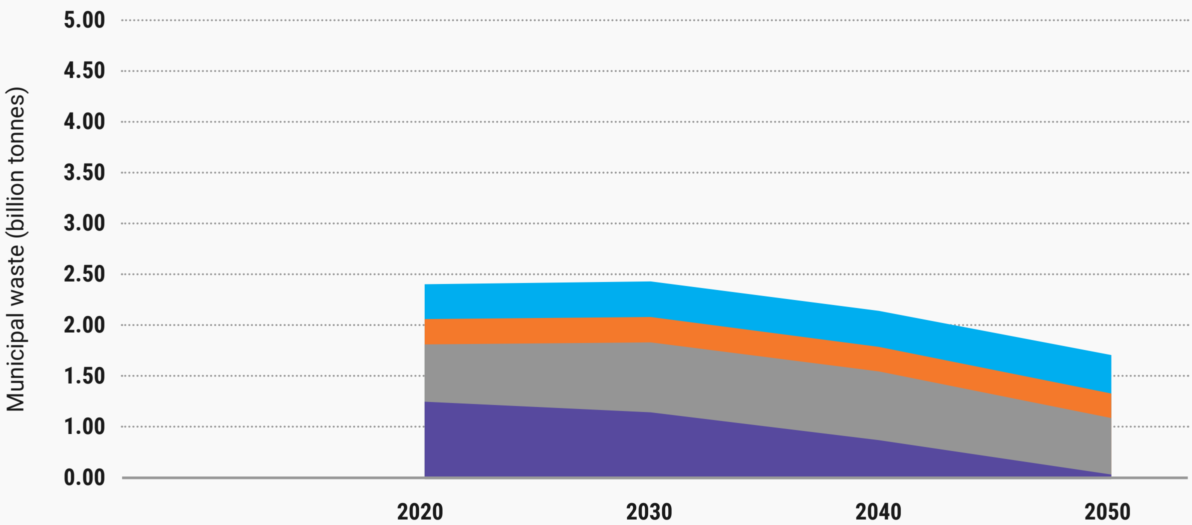
Box 4: Scenario 3 – Circular Economy

Summary: A sustainable economic model in which products and materials are designed in such a way that they can be reused, remanufactured, recycled or recovered and thus remain in the economy as long as possible together with the resources from which they are made; generation of waste, especially hazardous waste, is avoided or minimised while greenhouse gas emissions are prevented or reduced, contributing significantly to sustainable consumption and production, as called for in United Nations Environment Assembly Resolution UNEP/EA.4/Res.1 (United Nations 2019b).

Photo source: *ChayTee / Adobe Stock*

Waste generation	Collection, recycling and disposal
Government policies and producer actions lead to widespread adoption of eco-design and reuse, further designing waste out of consumption and production; waste generation falls to 2020 levels by 2050.	Collection coverage at 100 per cent; MSW recycling rates increase to 60 per cent by 2050; uncontrolled disposal of this waste ends by 2050.

Figure 19: **Circular Economy (Scenario 3) projections.**



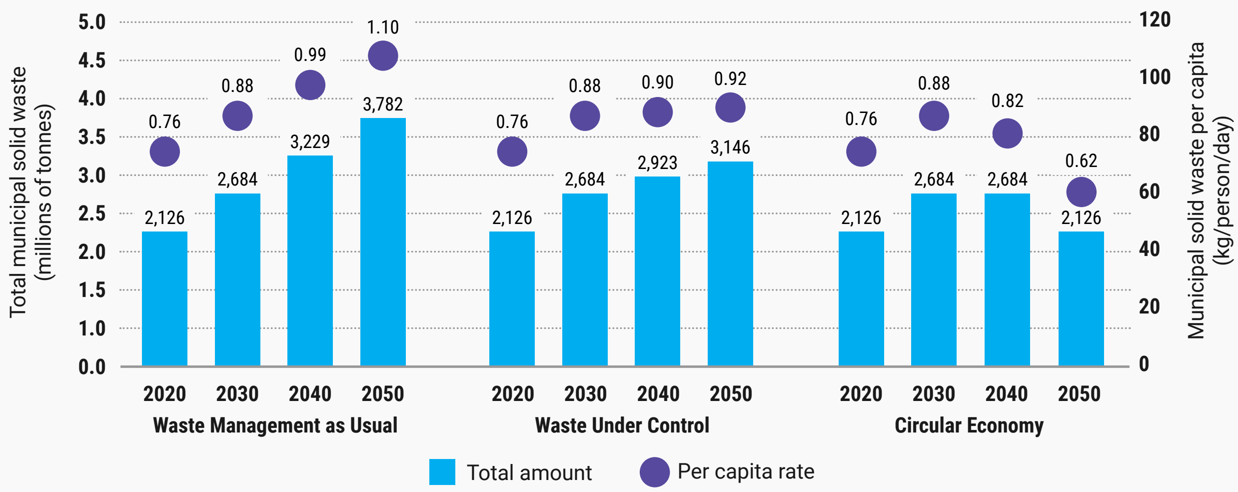
	2020	2030	2040	2050
Recycled	0.40	0.40	0.40	0.40
Waste-to-energy	0.27	0.27	0.27	0.27
Landfilled	0.64	0.78	0.76	0.63
Uncontrolled	0.81	0.70	0.37	0.00

Table 4: Key assumptions for the three scenarios.

Assumption	Rationale
Waste generation is decoupled from economic growth by 2030	Apart from degrowth (deliberately reducing consumption and production and therefore gross domestic product) (*Hickel et al. 2022*), decoupling waste generation from economic growth is the only way to stabilise or reduce waste generation. The 2030 start year is based on the United Nations Sustainable Development Goal (SDG) 12, target 12.5 ("By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse"). Evidence on whether decoupling is achievable globally is unclear, but successful decoupling is possible at the local level (Kaza, Shrikanth and Chaudhary 2021).
Collection coverage increases to 100 per cent by 2050 and uncontrolled disposal ends by 2050	Commonly cited objectives based on SDG 11, target 11.6.1 ("Proportion of municipal solid waste collected and managed in controlled facilities out of total municipal waste generated, by cities"), which is referred to, for example, in the *Africa Waste Management Outlook* (UNEP 2018), are to achieve 100 per cent collection and 0 per cent uncontrolled disposal by 2030. However, the data compiled for this report, as well as in other publications such as SDG progress reports, suggest that this objective is far from being achieved. In this report it has been considered achievable by 2050.
Waste generation decreases to 2020 levels by 2050	The third scenario (Circular Economy) will require a reduction in waste generation. Although 2020 has been used as the baseline year for the analysis in this report, it should by no means be seen as an "ideal" to be maintained, as resource consumption and waste generation levels in 2020 were already unsustainable.
Municipal recycling rates increase to 60 per cent by 2050	The assumption of a 60 per cent global recycling rate by 2050 is based on the target set for Member States of the European Union (EU), under the EU Waste Framework Directive of achieving 60 per cent recycling by 2030 (European Commission 2009).

Based on these three scenarios, Figure 20 illustrates projected global MSW generation from the baseline year of 2020 through to the years 2030, 2040 and 2050.

Figure 20: Comparative analysis of the three scenarios for global municipal solid waste generation.



To achieve the Circular Economy scenario (bringing waste generation back to 2020 levels), regions such as North America, Australia and New Zealand, and most of Europe will need to dramatically reduce resource-intensive consumption and waste generation (Figure 2). In other regions where increasing economic growth, urbanisation and industrialisation are anticipated, maintaining current waste generation levels will also require significant waste prevention measures.

The Waste Management as Usual scenario (Figure 17) assumes that uncontrolled waste disposal will continue to grow with waste arisings, whereas the Waste Under Control and Circular Economy scenarios assume that uncontrolled disposal will end by 2050.

To achieve Waste Under Control (Figure 18), upstream and downstream measures will be required in order to prevent waste generation; products and materials will need to be used more efficiently and longer; and global recycling capacity will need to double from 660 to 1,200 million tonnes (Mt). The greatest increases in recycling capacity will be needed in Sub-Saharan Africa and South America (eight and five times the current capacity, respectively), with corresponding investments in waste management infrastructure (see methodology in Annex 2).

The Circular Economy scenario (Figure 19) will require economic growth to be entirely decoupled from resource use, with government policies and producer actions fully aligned. Investments in recycling will need to be even more significant, with a three-fold increase in global capacity to recycle MSW, from around 400 million tonnes in 2020 to more than 1.2 billion tonnes in 2050.

3.2. Using scenarios to understand the potential environmental impacts of waste reduction and management

For this report, modelling was done to understand the potential impacts of the three scenarios on GHG emissions, ecosystem quality and human health (Annex 3). Since such projections rely strongly on model selection, assumptions and the accuracy of the raw data (which are notoriously poor for waste), it is prudent to consider the outputs from a relative perspective, rather than absolute numbers.

For these reasons, the figures below have been presented in percentual changes compared to the base year of 2020.

From Figure 21, Figure 22 and Figure 23 the message is clear:

- The Waste Management as Usual scenario consistently presents as an increasing negative impact on the climate, ecosystem quality and human health.
- The Waste Under Control scenario reduces negative impacts on the climate and, to a lesser extent, human health from the 2020 baseline (though the impacts are still significant), but is only able to stabilise the impacts on ecosystem health to 2020 levels.
- The Circular Economy scenario has a net-positive effect on GHG emissions and human health, and reduces significantly the negative impact on ecosystem quality (though still it does not bring this down to zero by 2050).

Photo source: Igor / Adobe Stock

Figure 21: Estimated negative impact on greenhouse gas emissions from waste relative to 2020.

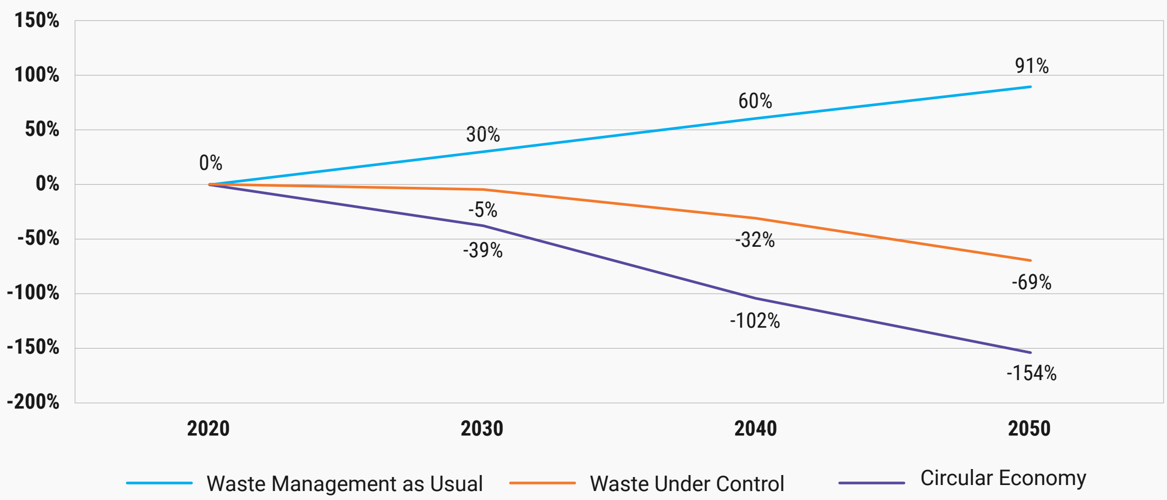


Figure 22: **Estimated negative impact on potential loss of species from waste relative to 2020.**

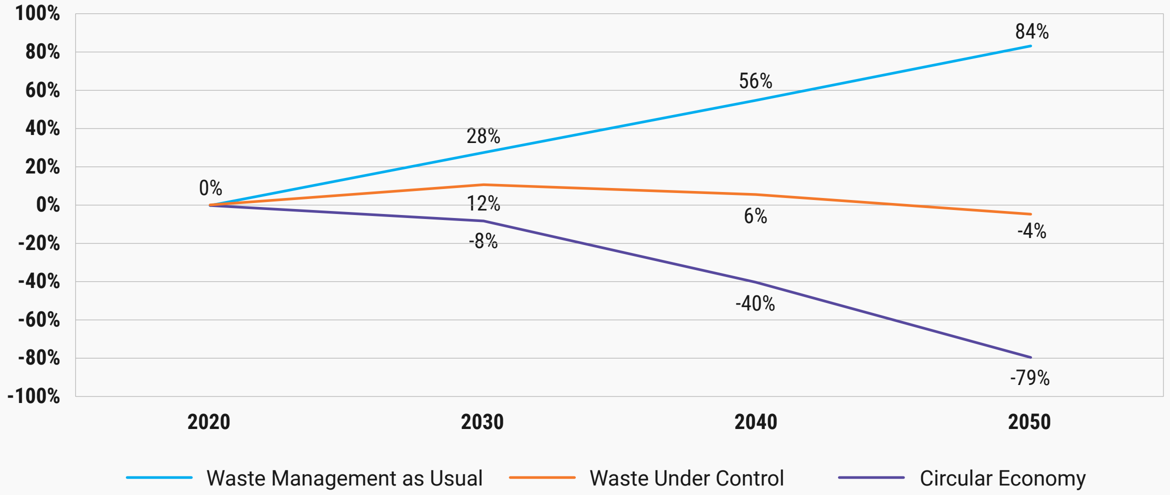
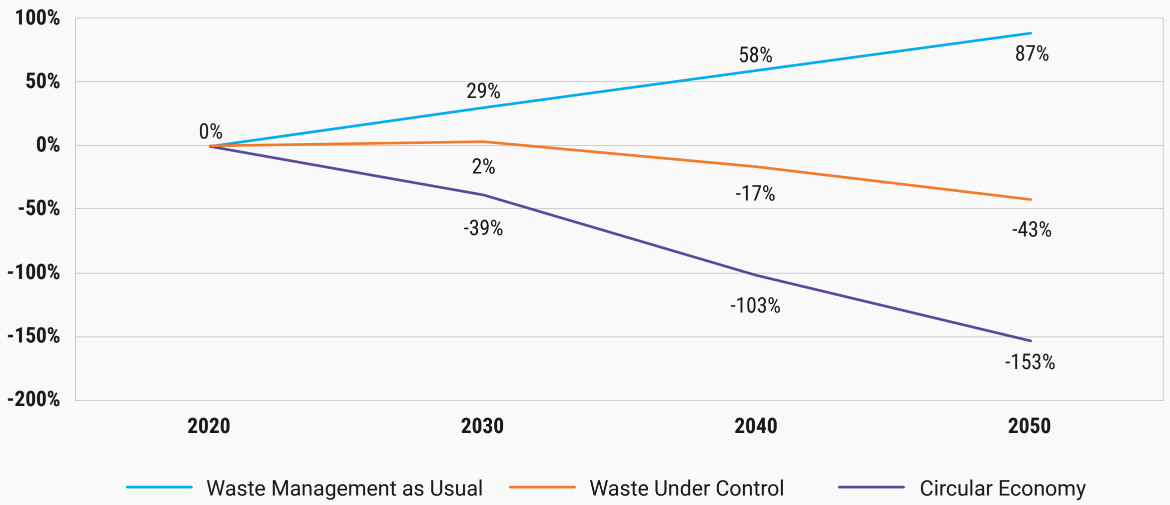


Photo source: *Stéphane Bidouze / Adobe Stock*

Figure 23: **Estimated negative impact on human health from waste relative to 2020.**

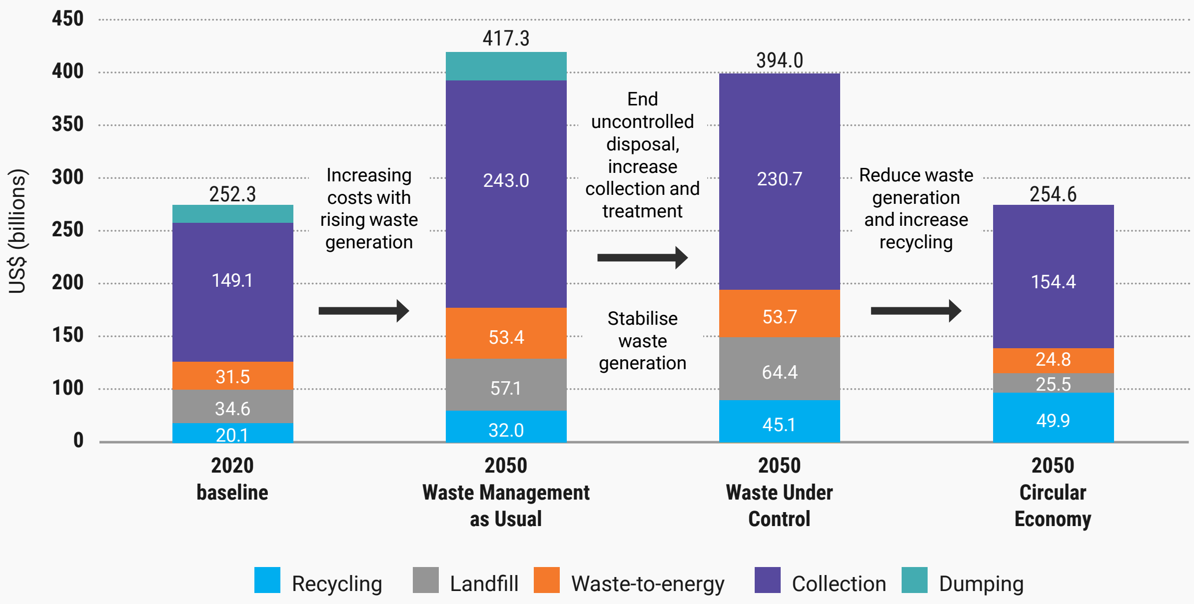


3.3. The future costs of waste

What are the cost implications of transitioning to better waste management systems? Figure 24 shows the direct costs of global MSW management from 2020 to 2050 under each of the three scenarios.

Waste generation and treatment methods have been projected for each region, year and scenario. *What a Waste 2.0* (Kaza *et al*. 2018) provides average costs for each of these methods, including the costs of collecting, recycling and processing (using waste-to-energy technology or landfilling) each tonne of waste in countries in different income groups. These costs have been combined with weighted averages for the countries in each region in order to calculate regional and global cost estimates.

Figure 24: Global direct costs of municipal solid waste management in 2050 under the three scenarios (US$ 2020).



Under the Waste Management as Usual scenario, by 2050 the annual global direct cost of MSW management will increase by US$165 billion as waste generation continues to increase unabated. Under the Waste Under Control scenario, waste generation will be stabilised and all MSW will be collected and treated safely. However, this scenario still represents an increase on 2020 costs of US$141.7 billion. Realistically, the only way to prevent runaway waste management costs is to implement the Circular Economy scenario, in which 2050 costs will be similar to today's but with vastly better environmental performance.

In summary, although improving waste management worldwide will require significant investments, by far the most affordable solution is to drastically reduce waste and value secondary materials as a resource (Figure 25).

Each of the three scenarios requires significant investments in infrastructure. These investments arguably need to be focused on the areas with the highest absolute and relative projected waste growth. Meanwhile, significant upstream action by governments and producers is needed in order to prevent waste and improve the recyclability of waste that is unavoidable.

As discussed in Section 2.4, the direct costs of waste management are not the whole picture. The vast externalities of mismanaged waste, including climate change, biodiversity loss and pollution, represent a significant cost to society. Since the impacts of poor waste management do not respect borders, these costs are borne by all, and especially those who are already disproportionately affected by poor environmental quality.

Working towards achieving the Waste Management Under Control and Circular Economy scenarios could offset external costs with gains: a more liveable climate, healthier ecosystems and millions of new jobs created in the transition to a circular economy (International Labour Organization [ILO] 2023). These gains would be likely to grow at an increasing rate as circular business models become more mainstream.

Figure 25 provides an assessment of the full estimated costs of global MSW management under each of the three scenarios, incorporating both the direct financial costs and the indirect external costs associated with waste management practices on a global scale.

Through considering these hidden external costs, a more complete understanding emerges of the economic implications of the three scenarios.

Gains from recycling (explored in more detail in Annex 3) play a crucial role in the overall economic assessment. These gains, represented by negative values, offset a portion of direct and external costs. While the specific numbers may vary across scenarios, they indicate the financial benefits to be derived from recycling activities. Gains from recycling contribute to cost savings and environmental sustainability by conserving resources and reducing reliance on raw materials and energy-intensive production processes.

The significant variation in total costs when externalities are factored in emphasises the crucial importance of considering external costs when assessing waste management systems.

In 2020 the externalities (negative impacts) associated with uncontrolled waste reached US$243.3 billion, an unaccounted-for cost that effectively doubles the cost of waste management in that year (from US$252.3 billion).

This figure alone highlights the economic burden of inadequate waste practices. It should act as a call to action for all concerned.

Left unaddressed, the total global cost of MSW in 2050 is projected to reach US$640.3 billion, including US$443 billion in externalities. In contrast, with the Waste Under Control scenario of implementing upstream and downstream actions, the cost of externalities can be limited to a projected US$263.6 billion, demonstrating the potential for cost savings through implementing controlled waste management methods.

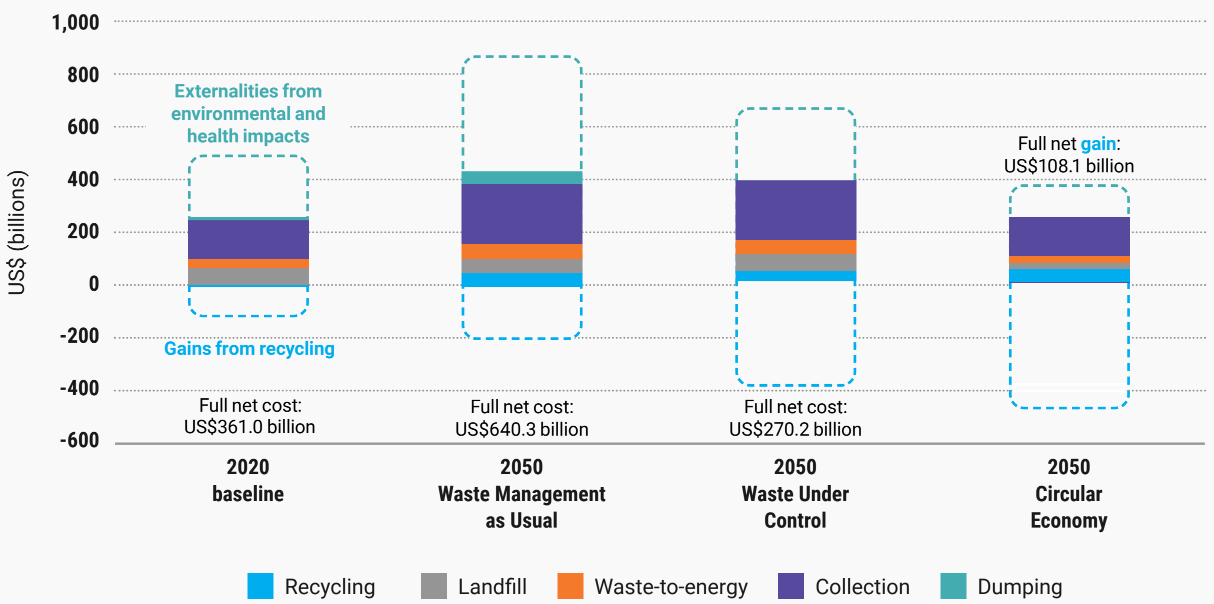
Finally, a Circular Economy approach would generate a projected annual full net gain of US$108.5 billion through waste avoidance, sustainable business practices and full waste management.

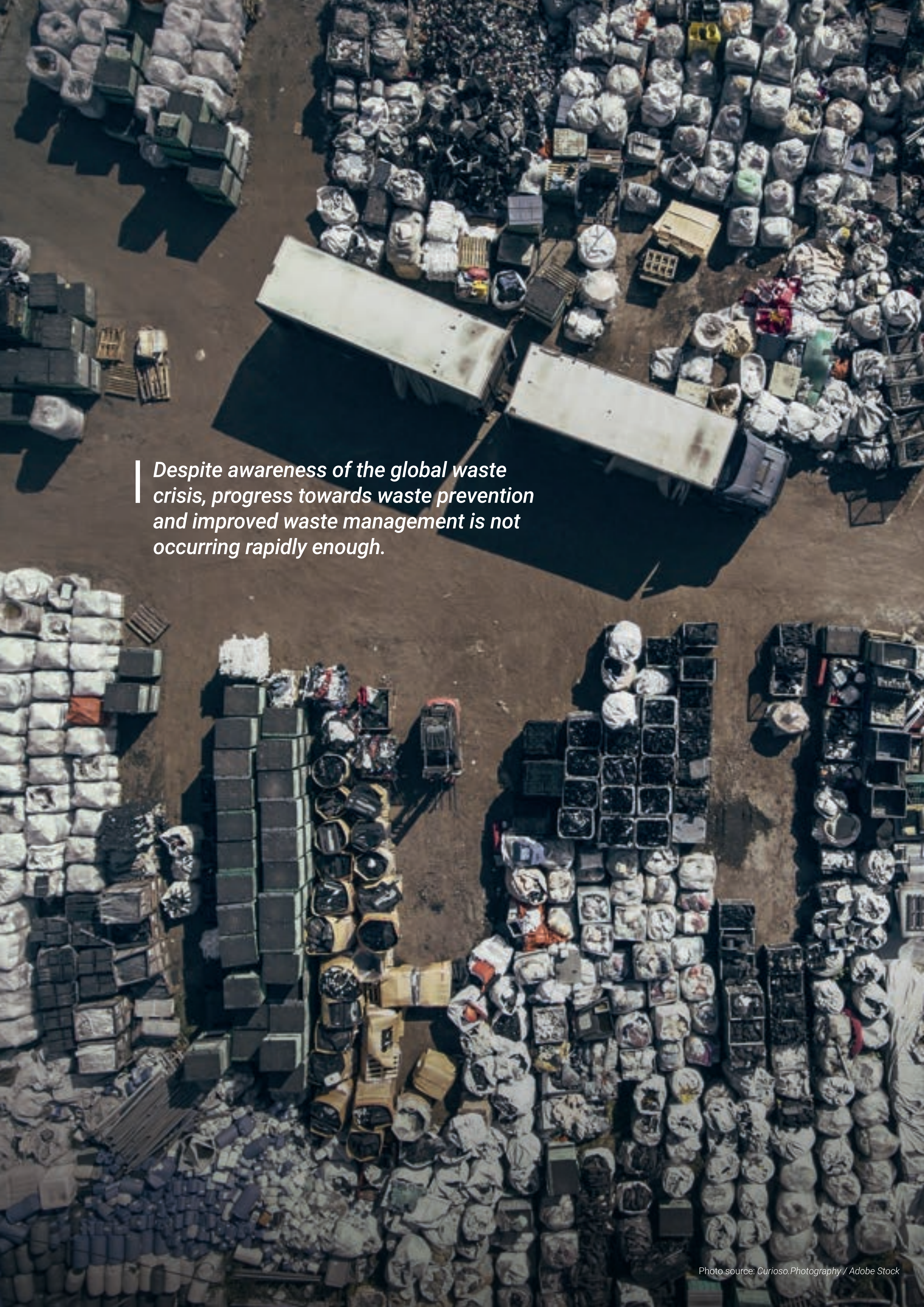
Moving towards more circular and zero-waste economies therefore makes sense economically, socially and environmentally.

Left unaddressed, the total global cost of municipal solid waste in 2050 is projected to reach **US$640.3 billion.**

Photo source: *dazb75 / Adobe Stock*

Figure 25: Overall cost of global waste management under the three scenarios (US$ 2020).





Despite awareness of the global waste crisis, progress towards waste prevention and improved waste management is not occurring rapidly enough.

Photo source: *Curioso.Photography / Adobe Stock*

04 Barriers to change

4.1. Waste as a complex problem

Waste management is a complex problem characterised by multi-layered interdependencies, compound social dynamics and webs of stakeholders (a "wicked problem", as described in Salvia *et al*. 2021). Combinations of these factors lead to unpredictable outcomes, with decisions impacted by how challenges are understood and framed (Salvia *et al*. 2021).

Photo source: *Jose Luis Stephens / Adobe Stock*

For waste management systems to be effective and efficient, behavioural change may be required in hundreds of thousands of households.

Concerted efforts have been made by institutional donors; non-governmental organisations; national and municipal governments; the private sector, including small- and medium-sized enterprises (SMEs) and micro-, small- and medium-sized enterprises; and workers in informal economies to create economic opportunities from waste and thereby "solve" the problem. Due to its complexities, however, the waste crisis requires a collective response typical of systems rather than of individuals or individual organisations (Berenjkar, Li and Yuan 2021; Demel 2021).

Crucially, in the case of waste reduction, this implies (among other factors) active participation and investment by the private sector, as decisions taken by product designers and manufacturers ultimately and directly influence waste generation. At the same time, for waste management systems to be effective and efficient, behavioural change may be required in hundreds of thousands of households.

Further complexities arise from the dependency of waste management business plans on global oil prices, which impact transport and energy costs; the market value of recyclable materials, which also affects the rights and well-being of vulnerable workers in the value chain; and even the prices of compost, which competes on the market with petrochemical fertilisers. Crowning all this are pressures related to geopolitical instability and climate change.

For these reasons, policies, toolkits and best practice guides are rarely universally applicable. The diversity of cultures, politics, economies and geographies means that solutions are rarely a matter of cutting and pasting. At the same time, the patchwork of waste management challenges leads to more waste, more complex waste and more uncontrolled disposal of waste. In other words, more GHG emissions, more biodiversity loss and more pollution.

This chapter explores the reasons why, despite awareness of the global waste crisis, progress towards waste prevention and improved waste management is not occurring rapidly enough.

4.2. Lack of recognition of the urgency of the waste challenge

Political leaders need to recognise the urgency of the waste crisis and its impacts on society.

While municipalities are typically responsible for waste management, no single stakeholder has responsibility for waste reduction despite its clear public benefits and priority position on the waste hierarchy. Consequently, zero waste and circular economy business models that could help to decouple economic growth from waste generation have too often been considered secondary to waste management.

Insufficient attention to waste reduction is largely responsible for rapid waste growth globally. Many countries are unable to provide waste management services for all citizens (which would contribute to the achievement of several SDGs (UNEP 2023a)), with corresponding increases in the negative impacts of waste. Urgent efforts will be required if zero waste societies are to be developed in which waste is minimised and unavoidable waste is collected, processed and returned to a circular economy.

Table 3 in Chapter 1 describes the waste hierarchy and responsibilities for reducing and safely managing waste throughout supply chains and society, including the roles of governments, producers, retailers, waste managers and citizens. While waste management remains an essential utility service, other actors—particularly governments and producers—need both the will and the capacity to legislate, implement, regulate and deliver based on the waste hierarchy, starting with waste prevention.

Photo source: nimon_t / Adobe Stock

Insufficient attention to waste reduction is largely responsible for rapid waste growth globally. Many countries are unable to provide waste management services for all citizens.

Box 5: UN Secretary-General António Guterres' message on International Day of Zero Waste, observed on 30 March

The first-ever International Day of Zero Waste reminds us of a fundamental and brutal truth: humanity is treating our planet like a garbage dump. Every year, more than 2 billion tonnes of municipal solid waste is created, but 33 per cent of it is not properly managed in controlled facilities.

Every minute, the equivalent of one garbage truck full of plastic is dumped into the ocean. Meanwhile, pollution and chemicals are poisoning our water, air and soil. And a staggering 10 per cent of all global greenhouse gas emissions come from growing, storing and transporting food that is never used.

We must stop trashing our only home and declare war on waste. We need those who produce waste to design products that use fewer resources and materials, while managing waste across production cycles and extending the lives of the products they sell.

We must massively invest in modern waste management systems and policies that encourage people to reuse and recycle everything from plastic bottles to ageing electronics.

And as consumers, we must all consider the origins and impacts of the goods and products we purchase, and reuse and recycle what we can, whenever we can. It's time to clean up our world, and make progress towards circular, zero-waste economies—for people and planet alike.

Source: United Nations (2023)

"Every minute, the equivalent of one garbage truck full of plastic is dumped into the ocean."

Box 6: Case study from Japan: Economic growth does not have to go hand in hand with waste generation

Waste generation can be decoupled from economic growth. The city of Kitakyushu in Japan stands out as an example of achieving waste reduction, with only 0.42 kg of municipal solid waste (MSW) generated per person per day. That is just over half the estimated global average of around 0.75 kg and less than the regional average of around 0.46 kg in Sub-Saharan Africa, which is both the lowest MSW-generating region per capita and the lowest income region (Kaza *et al*. 2018).

As an industrial city with significant pollution, Kitakyushu sought to apply an environmentally sound approach rather than a disposal-focused one. The main drivers of its efficient waste management system cover all steps from start to end points: sorting of waste at the source, composting widely at the household level, recycling and heavy engagement of citizens.

These measures are complemented by financial incentives to reduce waste through volume-based waste user fees rather than flat fees per household. Over time, Kitakyushu has also created an eco-town to increase environmental awareness and recover materials from many types of waste, including cars and appliances.

Lessons from Kitakyushu and Japan are relevant for the rest of the world in regard to working towards reducing and managing waste effectively. Citizen awareness and participation have made all the difference in Kitakyushu. Commitment by households and through to the governmental level, and alignment of incentives, has transformed the waste management sector, ultimately improving the environment, the economy and the health of the city. However, buy-in by households and change of cultural practices take time, commitment and the management of relationships to build trust.

Learning from the advances of Japanese cities, especially Kitakyushu, can help many other cities across the world, including in lower-income countries, reduce their waste generation and achieve sustainable futures for their cities and citizens.

Source: Wahba, Kaza and Ionkova (2019)

Photo source: *snowdrop* / *Adobe Stock*

The city of Kitakyushu in Japan stands out as an example of achieving waste reduction, with only

0.42 kg

of municipal solid waste generated per person per day.

Photo source: *あんみつ姫* / *Adobe Stock*

4.2.1. Data on pollution and health risks is lacking

Pollution from uncontrolled waste causes a wide range of diseases and is linked to declining fertility.

Waste data is notoriously poor, although efforts are being made to improve it (United Nations Economic Commission for Europe [UNECE] 2022; World Bank 2024b). Chain of custody records begin at the point where waste is collected. Where waste is disposed of informally or illegally through dumping and burning, there is no record that it ever existed. Consequently, the environmental and public health impacts of this waste and its management are likely to be underestimated (Ramadan *et al*. 2022). Thus, pollution from uncontrolled municipal waste is an externality that is rarely accounted for by national governments.

The costs to human health of pollution from waste are severe. It causes widespread illness and deaths, particularly among communities disproportionately impacted by poor living conditions (Williams *et al*. 2019; Tomita *et al*. 2020; Fuller *et al*. 2022; Siddiqua, Hahladakis and Al-Attiya 2022).

Inadequate waste management contributes to a rise in communicable and non-communicable diseases, as well as multigenerational risks and long-term health inequalities (Faiza *et al*. 2019; McClelland *et al*. 2022; Schmidt *et al*. 2022; Sharma, Brahmbahtt and Panchal 2022). Despite the well-known risks, however, research is still lacking on the wide range of negative health impacts related to the open burning of waste, the association between dumpsites and vector-borne diseases, and the relative health impacts of different waste disposal options (Vinti *et al*. 2021; Cook, Velis and Cottom 2022).

As products become more "advanced" or complex, so does the composition of municipal solid waste.

As products become more "advanced" or complex, so does the composition of MSW. The increase in the number of chemicals (and mixtures of chemicals) on the market have led to the recognition that hazardous chemicals and other pollutants are now "ubiquitous in humans and the environment" (UNEP 2019c).

Table 5 identifies some of the groups of chemicals of concern with respect to human health and the environment.

Table 5: Sample of chemicals of concern because of their adverse effects on human health and the environment.

Chemical group	Uses	Possible health effects	Products
Bisphenols (BPA, BPF, BPS)	A main component in the manufacture of polycarbonate plastics, epoxies, epoxy resin	Disrupts the reproductive and hormone systems, increases risk of cancer	Food can linings, plastics, electronic toys, paper receipts
Flame retardants (brominated, organophosphate, chlorinated)	Fire retardant	Persistent, bioaccumulative, and toxic; some kinds are also classified as carcinogenic, toxic, disrupting the reproductive system; some disrupt the hormone system	Furniture, electronics, building materials
Formaldehydes	Binds pigments to cloth; fire retardant; provides wrinkle resistance and water repellence; adhesive in wood products	Irritates mucous membranes and skin, can cause hypersensitivity, carcinogenic (nasal pathway)	Toys, furniture, air fresheners
Parabens	Preservative	Estrogenic effects, disrupts the hormone system, sensitising agent	Shampoos, bath additives, lotions, creams, oils, sunscreens, toothpaste, baby wipes
Perfluorinated chemicals, including perfluorooctanoic sulfonate (PFOS) **and perfluorooctanoic acid** (PFOA)	Water, grease and oil repellence	Carcinogenic, disrupts fertility	Waterproof clothing, non-stick pans, toys
Persistent Organic Pollutants (polychlorinated bisphenols or PCBs, DDT, dioxins)	Flame retardants, surfactants	Cancer risk, reproductive disorders, neuro-behavioural impairment, endocrine disruption, genotoxicity and increased birth defects	Banned under the Stockholm Convention but still widely dispersed in the environment including in recycled products
Phthalates (DEHP, DBP, BBP)	Plasticiser, usually found in soft plastic, pellets for stuffing cuddly toys; can also be used as a synthetic fragrance compound in scented toys	Disrupts development and the hormone system, impairs fertility	Plasticisers in polyvinyl chloride (PVC), furnishings, clothing and food packaging

Source: United Kingdom Environmental Audit Committee 2019

The Basel, Rotterdam and Stockholm Conventions (which, respectively, regulate the transboundary shipment of hazardous wastes; require prior informed consent to import substances of concern; and require the development and implementation of national plans to control emissions of Persistent Organic Pollutants) have a vital role but still limited reach due to problems of awareness, implementation and enforcement (Thapa *et al*. 2023). Nevertheless, the impacts of the ever-growing complex of pollutants on human and planetary health are far from being totally understood.

Pollution from chemicals and waste is a major driver of biodiversity and ecosystem change, particularly in freshwater and marine habitats (Secretariats of the Basel, Rotterdam Stockholm Conventions, and the Minamata Convention on Mercury 2021; UNEP 2023b; UNEP 2023c). Further research is needed to understand and mitigate the impacts of this pollution on planetary and human health, including gender- and age-differentiated impacts (SAICM 2017; UNEP-IETC and GRID-Arendal 2019). In addition, specific risks are emerging from growing waste streams, including plastics (UNEP 2021b) and e-waste (Forti *et al*. 2020; United Nations Institute for Training and Research 2023).

Box 7: Household products in waste can impair fertility

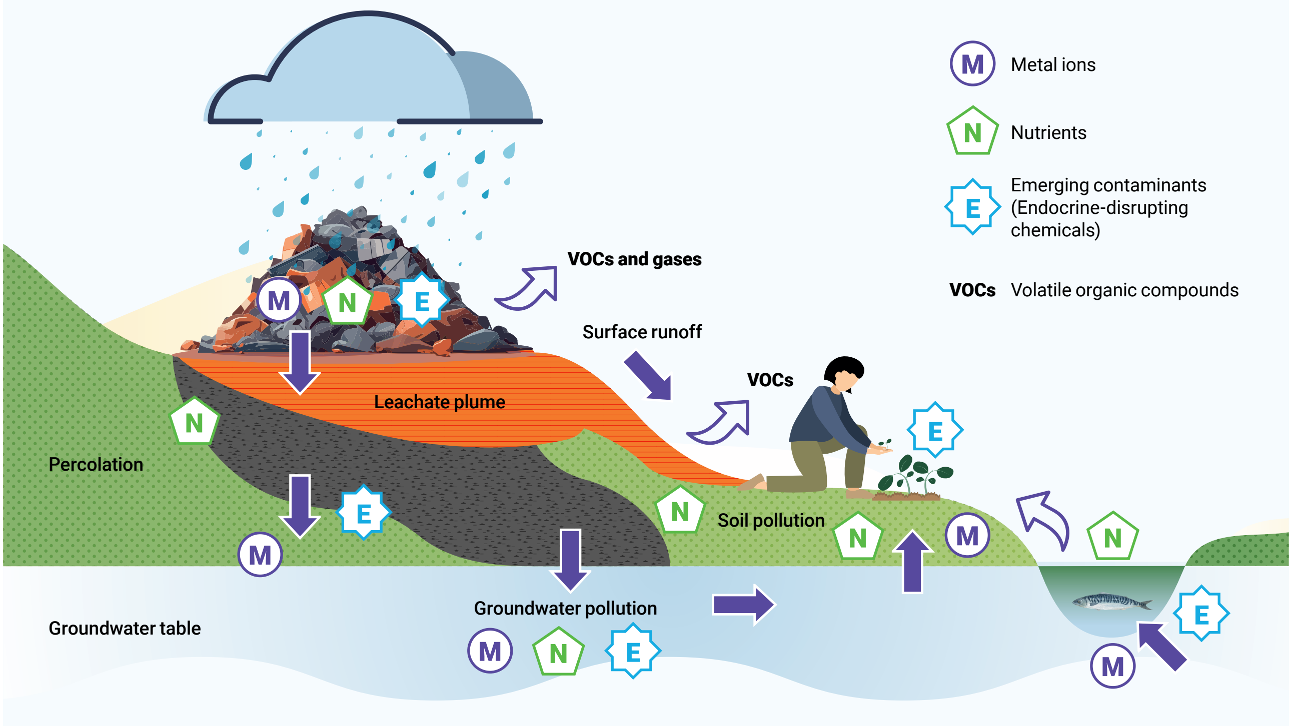
A key emerging issue is the increasing contamination of the environment by toxic compounds such as endocrine-disrupting chemicals, which mimic the activity of naturally occurring hormones and increase the risk of adverse health outcomes including cancer, reproductive impairment in both women and men, cognitive deficits and obesity (La Merrill *et al*. 2020; Akbaba 2023).

More than 1,000 chemicals have so far been classified as endocrine disrupting. Some are considered carcinogenic, including dioxins and cadmium for breast and thyroid cancer; arsenic, asbestos and dioxin for prostate cancer; and organochlorines/organohalogens for testicular cancer (Modica, Benevento and Colao 2023).

Endocrine-disrupting chemicals are found in a wide range of consumer products and in their packaging. In recent years particular emphasis has been placed on their presence in plasticisers, plastic additives and contaminants of emerging concern, including those in children's toys, pharmaceuticals, personal care products, food additives and plastic debris in the micro and nano range (D'Angelo and Meccariello 2021; UNEP and Secretariat of the Basel, Rotterdam and Stockholm Conventions 2023).

Various studies have confirmed the presence of these chemicals in leachate from waste disposal sites and their migration into waterways and entry into the human food chain (Seibert *et al*. 2019; Wijekoon *et al*. 2022; United States Environmental Protection Agency 2023).

Figure 26: Migration of endocrine-disrupting chemicals and other pollutants from waste into waterways and the human food chain (adapted from Wijekoon *et al*. 2022).



Box 8: Open burning of municipal waste emits forever chemicals

Persistent Organic Chemicals (POPs), including Unintentional Persistent Organic Pollutants (UPOPs), are known as "forever chemicals" because of their persistence in the environment and their ability to biomagnify and bioaccumulate in ecosystems. UPOPs are POPs that were not voluntarily produced or released into the environment but derived from anthropogenic sources. They are emitted during incomplete combustion processes involving organic matter and chlorine, or are created as by-products during the manufacturing of other chemicals (United Nations Environment Programme [UNEP] n.d.a).

POPs, including those that are unintentionally produced, have significant negative effects on human health and the environment. Not only are they a cause for concern at the point where they originate, but they can be transported long distances by air and water, with exposure leading to the accumulation in the fatty tissues of humans and wildlife and concentration in the food chain (Tuvalu 2018; Stockholm Convention 2019; World Health Organization [WHO] 2020; UNEP n.d.b).

Among the UPOPs regulated by the Stockholm Convention (2019) are dioxins and furans, the largest source of which is open burning of municipal waste in countries without adequate waste management services (UNEP 2019b). Like other POPs, dioxins accumulate in the food chain. More than 90 per cent of human exposure is through food, mainly contaminated meat and dairy products, fish and shellfish. Dioxins, which are highly toxic, can cause reproductive and developmental problems, damage the immune system, interfere with hormones and cause cancer (WHO 2023).

Article 5 of the Stockholm Convention states that Parties must take measures to reduce and, where feasible, eliminate releases of unintentionally produced POPs, according to the guidelines (UNEP 2021b). The UNEP/Global Environment Facility Global Monitoring project (UNEP 2022a) measures concentrations of POPs, many of which are UPOPs, in air, human milk and samples of national interest.

UNEP has also developed a toolkit (UNEP 2019d) to assist parties in establishing release inventories of UPOPs that are consistent in format and content, ensuring that it is possible to compare results, identify priorities, mark progress and follow changes over time at the country level as well as regional and global levels. In addition, the United Nations Institute for Training and Research (UNITAR) has produced a range of educational and communications materials to promote awareness of the dangers of UPOPs and ways to prevent their release (UNITAR 2023).

> ***"Persistent Organic Chemicals, including Unintentional Persistent Organic Pollutants, are known as "forever chemicals" because of their persistence in the environment and their ability to biomagnify and bioaccumulate in ecosystems."***

Photo source: Collab Media / Adobe Stock

Photo source: *panaramka / Adobe Stock*

4.2.2. Climate impacts are underestimated and mitigation opportunities are underexploited

The significant impacts of waste generation and management need to be formally addressed in NDCs (United Nations Climate 2023).

The impact of waste on climate change has been underestimated historically. This has led to underinvestment in waste reduction and waste management as effective climate change mitigation.

For example, the Intergovernmental Panel on Climate Change (IPCC) previously considered the waste sector as delivering only end-of-pipe services and infrastructure such as landfills and dumpsites. The Fifth Assessment Report (Intergovernmental Panel on Climate Change 2014) estimated the contribution of the waste sector to GHG emissions at around 3 per cent, meaning countries may have previously underestimated the potential of municipal waste management interventions in fulfilling NDCs. (Recent calculations by the International Solid Waste Association [ISWA] suggest that better waste and resource management could mitigate 15-25 per cent of global GHG emissions, and therefore must be included in every country's NDCs [Wilson, Filho and Ramola 2023].)

It is estimated that 20 per cent of anthropogenic methane emissions are caused by the anaerobic decomposition of food and other organic materials left in landfills, open dumps and wastewater (UNEP and Climate and Clean Air Coalition 2021). However, data on methane emissions from waste is lacking in many countries (UNEP and Climate and Clean Air Coalition 2022), hindering policy change and investment in organic waste collection and valorisation as a form of climate change mitigation.

Furthermore, modelling of methane emissions from waste disposal sites has assumed that methane emissions are generated gradually and over a long period after site closure, whereas recent data suggests that a larger fraction of methane is produced during a landfill's operating life (relative to post-closure) (Jain *et al*. 2021). Since methane is a short-lived climate forcer, this means that biodegradable waste being disposed of to landfills and dumpsites today will have a more near-time impact on climate change than previously understood.

Better waste management could mitigate

15%–25%

of global GHG emissions.

Likewise, there has been a lack of research into the scale of emissions from the open burning of waste. International and national policies have had to rely on estimates, but since open burning is an informal activity that often takes place in backyards or at uncontrolled disposal sites, its scale is often underestimated and under-reported.

Since waste arisings are closely linked to economic development, and the fastest growing economies include many without adequate waste management systems, GHG emissions from municipal waste disposal are expected to grow more rapidly than mitigation measures can be implemented. Without adequate data on the climate change impacts of poorly managed waste, and therefore the mitigation potential of waste reduction and management, countries have been unable to make it a policy priority and thereby attract climate finance to fund interventions.

4.3. Lack of inclusion

Policies and infrastructure for municipal waste management developed without inclusive, participatory and representative decision-making are more likely to fail due to being either ill-informed or inappropriate to the local context (Medayese *et al.* 2021).

In many countries, most urban waste collection and transportation are carried out by the informal recycling value chain.

Photo source: *chartphoto* / Adobe Stock

Input from technical teams may be given precedence over the views and experience of local communities and residents, as the latter may be considered subjective and difficult to measure (Whitten 2023). Despite local residents being considered non-experts, they often have significant expertise and contextual knowledge that can improve policies and infrastructure decisions (Whitten 2023).

When waste management systems and infrastructure fail due to lack of community participation at the planning and design phase, access to services is undermined and costs to society ultimately increase (UNDP 2022; Van Gils and Bailey 2023). Communities may become disillusioned and pessimistic about the potential for positive change, further delaying progress.

Among the local resident population, there may be a significant proportion of younger people whose voice is rarely heard. One-third of the global population is currently under the age of 20 (World Bank 2023c). These citizens will comprise the majority of service users within the planned lifetime of most new waste management systems. Excluding the views of younger generations may create long-term issues and add to the costs of waste management. Considering the benefits of engaging younger people in urban policymaking, the 2030 Agenda for Sustainable Development underlined the need to strengthen youth participation mechanisms to foster sustainable development (United Nations 2018 and Zeadat 2023).

Some 60 per cent of the global population works in informal economies (Circle Economy, World Bank Group and ILO 2023). These workers may be excluded from decision-making related to waste management despite their combined knowledge and experience and the effects that such decision-making are likely to have on them. The International Labour Organization (2023) reported that almost 40 per cent of people working in the informal sector in 2019 were in roles related to waste management and sanitation, of which 45 per cent were women and 38 per cent men (there were significant differences in these percentages among regions). In waste management policymaking there is a need to recognise the roles and respond to the voices of waste workers in the informal economy (UNDP 2022, b; Chen 2023; Khanal *et al.* 2023).

"The International Labour Organization reported that almost 40 per cent of people working in the informal sector in 2019 were in roles related to waste management and sanitation."

In many countries, most urban waste collection and transportation are carried out by the informal recycling value chain, helping cities to save money (GRID-Arendal 2022). However, many policymaking and infrastructure development projects fail to harness this local expertise. Without hearing the voices of this existing workforce, potential system design improvements may be missed while the negative consequences of policies and infrastructure may be overlooked (UNDP 2022).

4.3.1. Gendered aspects of waste are not recognised

Photo source: *Onuchcha / Adobe Stock*

Traditional gender stereotypes play out through the entire waste management value chain. While these differences remain unrecognised, progress in waste reduction, management and a just transition to a more circular economy will remain constrained.

Table 6 provides 10 examples of how women's experiences with waste and its management differ from men's.

Table 6: How waste, including its generation and management, are gendered issues.

Consumers	Women in many societies are largely responsible for day-to-day household purchases, which have a significant impact on municipal waste arisings. Women are often more receptive to messages around waste reduction and recycling, which many behavioural change campaigns have failed to recognise (Organisation for Economic Co-operation and Development [OECD] 2020; Gull, Atif and Hussain 2022).
Domestic waste managers	Women are often responsible for domestic cleaning and waste disposal (Hassan and Elsehry 2022). Where waste collection services are not available, it is women who carry waste to an informal dumpsite or burn it in the backyard, with severe health consequences for both the women and children in their care, potentially harming reproductive health and causing negative multigenerational health effects (Pintas Marques *et al*. 2021).
Service users	In locations with waste management services, it is frequently women who pay for waste collection. From an economic perspective, male policymakers may prefer centralised drop-off points, but women, as the service users, may prefer door-to-door collection due to time constraints, their multiple roles (e.g. caring for other family members) and, in some cultures, their limited mobility (United Nations Environment Programme – International Environmental Technology Centre [UNEP-IETC] 2022).
Informal waste workers	In countries where the informal sector is dominant there is often a high percentage of female participation in informal waste work, with more women than men in some cities (OECD 2021). Women's roles tend to be informal and unregulated (GA Circular and Ocean Conservancy 2019; OECD 2021), with deplorable working conditions, low social status and little support from governments.
Social hierarchies	Women are primarily found in the lower tiers of the job hierarchy, such as street sweeping, waste picking, sorting and selling lower-value recyclables (UNEP and International Solid Waste Association [ISWA] 2015; UNEP 2021b), while their male counterparts assume roles with greater authority and income. Female waste pickers are among the most vulnerable women within their communities and society at large. A study of 1,025 waste pickers carried out at Brasília's Estrutural dumpsite found that 67 per cent were female; most lived without partners (74 per cent), had three to four children (48 per cent) and had a lower monthly income (63 per cent <US$125) when compared to men (Pintas Marques *et al*. 2021).
Health risks	Informal waste work can be a high-risk activity that leads to injury and infection due to physical contact with hazardous waste and chemicals (OECD 2021). Women waste pickers suffer from worse health outcomes than their male counterparts (Pintas Marques *et al*. 2021).
Sexual discrimination and harassment	Women working in the waste sector are vulnerable to discrimination and exploitation (Aidis and Khaled 2019) and report a lack of recognition, bullying and sexual harassment at work (WIEGO 2018).
Policymaking	Due to the division of work that renders women's work invisible or less valued, women's economic contribution to waste management is largely unacknowledged in local community decision-making or waste management policies (UNEP and ISWA 2015; UNEP-IETC and GRID-Arendal 2019).
Formalisation	When waste management services become formalised, training opportunities are often inaccessible to women while the new roles are often awarded to men rather than women. Waste incineration (waste-to-energy) programmes may also displace women who previously worked as informal waste workers, denying them access to materials and replacing their roles with private businesses.
Professional roles	Whereas men tend to dominate higher paying professions, or are more likely to be represented in activities that require physical strength and some technical knowledge (e.g. managers and truck drivers), women tend to occupy communications and administrative positions and are less likely to work in management or technical fields (UNEP-IETC and GRID-Arendal 2019; GA Circular and Ocean Conservancy 2019; UNEP 2022b).

4.3.2. The informal sector is undervalued

Where formal waste management services are either non-existent or incomplete, most reuse, repair, waste collection, transportation, sorting, returning of materials to the value chain, and disposal are carried out by self-employed workers, microenterprises and small businesses. In regions where waste management systems are still under development, more than eight in 10 waste management workers are in the informal economy (ILO 2013). They possess an often undocumented wealth of expertise on the sources, quantities and composition of municipal waste, as well as the variable market value of materials.

Informal waste collection and sorting provides important opportunities for people with few or no marketable skills and education and with no alternative sources of income with which to survive (Morais *et al*. 2022). Among these workers there are often significant numbers of women, people from racial or ethnic minorities, low-income individuals and families, people with disabilities and mental health conditions, children, youth and young adults, seniors, immigrants and refugees. These communities are often disproportionately affected by low education levels, deplorable living conditions, poor health and low awareness of their rights (Kaza *et al*. 2018; Bening, Kahlert and Asiedu 2022). In addition, working conditions are often dangerous due to risks posed by hazardous, sharp or heavy waste; vermin; and harassment, and this is rarely mitigated by social or physical protections.

Photo source: *ittipol / Adobe Stock*

Despite the social, economic and environmental benefits of the informal waste management sector, its vital role has been undervalued in the development agenda (Morais *et al*. 2022). Most studies and policy approaches assume that waste workers are part of a regulated informal economy. Thus the impact of this central workforce, and its potential to inform and influence policy, remain neglected. When services become formalised, waste workers in the informal economy may consequently lose access to the materials upon which their livelihoods depend.

As societies pursue the ambition of a circular economy, social and environmental justice will not be embedded by default into the transition of systems and services (OECD 2020). If communities already impacted negatively by inequalities in society are not prioritised by policymakers, they risk becoming further marginalised and disenfranchised. Affirmative action is needed to protect the rights of waste workers in the informal economy, as they are the backbone of the global recycling system.

Box 9: A human rights-based approach

In August 2022 the United Nations General Assembly passed a resolution recognising the right to a clean, healthy and sustainable environment as a human right (United Nations Environment Programme 2022d). Although not legally binding, the resolution is seen as an important signal that countries are working together to combat the triple planetary crisis of climate change, biodiversity loss and pollution.

This basic human right will only be achieved when everyone has equal access to sound waste management, including regular collection and safe disposal sites that do not threaten human health or the environment.

> ***"The human rights implications of environmental damage are felt most acutely by disadvantaged segments of society."***

The human rights implications of environmental damage are felt most acutely by disadvantaged segments of society, including rural communities and the urban poor, women, children, ethnic minorities, people with disabilities and other marginalised groups.

"A human rights-based approach is a conceptual framework for the process of human development that is normatively based on international human rights standards and operationally directed to promoting and protecting human rights. It seeks to analyse inequalities which lie at the heart of development problems and redress discriminatory practices and unjust distributions of power that impede development progress" (United Nations Sustainable Development Group 2024).

Taking a human rights-based approach to project or programme planning and implementation can not only help ensure a fair, equitable and ethically sound course of action, but it also leads to more effective, appropriate and sustainable outcomes in the longer term.

4.4. Legislation is frequently inadequate and ineffective

Definitions are a cornerstone in the development of legislation at all levels. They need to be clear and precise. For example, in Article 3 of the 2008 EU Waste Framework Directive, waste is defined as "any substance or object which the holder discards or intends or is required to discard". Other definitions in Article 3 include hazardous and non-hazardous waste, municipal waste, construction and demolition waste, bio-waste and food waste, as well as waste management, waste prevention and related terms (European Commission 2023a).

Definitions of waste and of different types of waste, and how these definitions are applied, vary internationally, including within regions or countries. This may be due to different interpretations of terminology, lack of standardised categories, differences in legal, regulatory and policy frameworks, and major conceptual and methodological challenges with respect to the observation and measurement of waste (UNECE 2022; Maalouf and Mavropoulos 2023).

It has been suggested by van Ewijk and Stegemann (2020) that a legal requirement to recognise waste's potential for further use would highlight opportunities for reuse and recovery, reduce the likelihood of careless discarding, and reveal the interests of possible waste users to waste holders. Since one person's waste is another person's resource, defining waste as merely materials that are discarded stands in the way of repair and reuse and is thus a barrier to the circular economy.

> Since one person's waste is another person's resource, defining waste as merely materials that are discarded stands in the way of repair and reuse.

The terminology in end-of-waste legislation also needs to be clear. An end-of-waste classification signals that something has been turned into a valuable commodity which can be used again and therefore no longer falls under waste management regulations. Certainty about end-of-waste classification is needed in order to enable waste-to-resource entrepreneurs to avoid illegal activities that could result in criminal liability and prosecution, and to encourage innovation for a circular economy (European Commission 2009; Johansson and Forsgren 2020; European Environment Bureau 2021; Chartered Institution of Wastes Management 2023).

Photo source: *lenblr / Adobe Stock*

4.4.1. Lack of an enabling environment

Waste management can be fully run by the public sector, the private sector or a mix of the two (a public-private partnership). Although government-run waste management systems are functional and efficient in many countries, including the private sector to various extents can provide benefits while offsetting costs to governments. On the other hand, private sector involvement in waste management activities can be stifled by bureaucratic barriers with respect to operating permits, as well as a lack of designated sites for waste management purposes.

National recycling markets may be hindered by a lack of legislation on the collection and recycling of specific waste streams, as well as by a lack of national guidelines or requirements for the use of recycled material in new products. If such measures are not in place, it is challenging for the private sector to operate businesses and industries that depend upon, and provide demand for, secondary resources.

In addition, data sharing is often missing or impaired by the use of different data collection systems and by the different policies of various actors along the value chain, while attempts to synchronise data can lead to further errors and delays (Baralla *et al*. 2023).

“High costs of proper waste management and varying waste management standards across countries make the global waste trade vulnerable to corruption.”

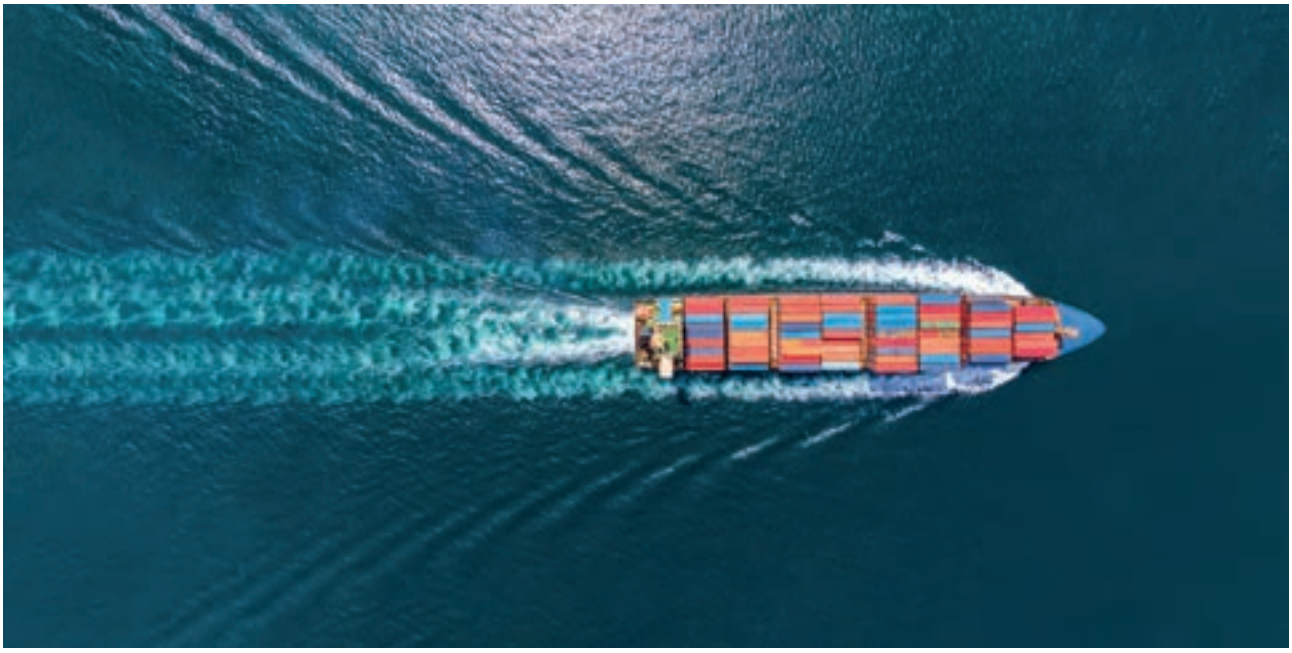


Photo source: *Yellow Boat / Adobe Stock*

4.4.2. Weak enforcement, sanctions and penalties

The risk of waste being mismanaged is heightened when waste management regulations are weak, or where waste management is a low political priority and thus regulations are enforced incompletely or inconsistently. In such cases, the risks of waste being mismanaged are heightened by actors in the service chain seeking to reduce costs and maximise profits. This can occur even in countries with high-performing waste management sectors and extensive legislation (Environment Agency, England and Wales 2023).

The most common violations of waste management rules and regulations include dumping; burning; inaccurate description of waste and its processing; facilities’ inadequate capacity and conditions to store, clean or recycle the waste; and poor health and safety practices (Isarin, Baez Camargo and Cabrejo le Roux 2023).

The management of municipal waste is usually the responsibility of local government and is often the highest budget item for these local institutions (Kaza *et al*. 2018). As such, waste collection services have been referred to as a natural monopoly (Fátharta 2018; Sousa *et al*. 2019).

Privatisation of public services, including waste management, is also at risk of corruption (Dávid-Barrett and Fazekas 2019; Bauhr *et al*. 2020), including through bribery, kickbacks, nepotism and favouritism (Isarin, Baez Camargo and Cabrejo le Roux 2023). In addition, privatisation of waste management services risks being monopolised if only large businesses are invited or qualified to bid for contracts (Lalchuanawma 2019; Bah and Artaria 2021). Multinational companies may also use their economic advantages (legally or illegally) to dominate a market, restricting the opportunities of local businesses and the development of national waste management capacity.

During the delivery of services, corrupt practices may be adopted by operators or other stakeholders, for example to enable fraudulent waste trade, falsify import/export certificates, forge monitoring and test results, issue licenses and permits, or allow improper waste treatment (Isarin, Baez Camargo and Cabrejo le Roux 2023). These practices, combined with the high costs of proper waste management and varying waste management standards across countries, make the global waste trade vulnerable to corruption (Isarin, Baez Camargo and Cabrejo le Roux 2023).

Illegal shipments of waste are further enabled by a lack of international cooperation and coherent systems. Multilateral environmental agreements have sought to address various concerns about waste, from the pollution it causes to its illegal transboundary trade, but implementation remains weak.

The International Criminal Police Organization and UNEP have estimated that environmental crime, including waste trafficking, is the fourth most lucrative illegal business in the world (International Criminal Police Organization and UNEP 2016). The Financial Action Task Force has estimated that illicit waste trafficking generates an estimated US$10–12 billion annually (Financial Action Task Force [FATF] 2021). The clean-up costs for governments from such crimes are often far more significant, as well as generating threats to public health and safety (FATF 2021).

4.5. Technical barriers: Universal and contextual

Photo source: *MatthewWilliams-Ellis / Envato*

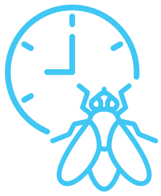
Some of the technical barriers to waste reduction and improving waste management are universal, while others are context-specific.

Universal barriers stem from the manufacture and sale of non-recyclable products and packaging. While "design for recycling" can be mandated through EPR regulations (OECD 2021), significant quantities of non-recyclables continue to be sold into markets around the world. If a product or packaging item comprises multiple materials that cannot be separated (e.g. sachets), they can only ever be part of the linear economy and are therefore destined for disposal. In countries with full coverage by waste management services, this means disposal in either a sanitary landfill or a waste-to-energy facility. In locations where waste management is not accessible it means being burned in the open, thrown on a dumpsite or leaking into the environment (Lunag, Duran and Buyucan 2019).

When mixed municipal waste is collected, it has a negative value since it is more difficult (and costly) to extract recyclable materials which will, in any case, be contaminated with food waste and so will be unattractive to recyclers (Dickella Gamaralalage, Ghosh and Onogawa 2021; Confederation of Paper Industries 2023). Likewise, food waste in a mixed waste stream will potentially be contaminated with heavy metals or other pollutants, rendering it unsuitable for valorisation for agricultural purposes (Gilbert and Ricci-Jürgensen 2023).

Some technology providers claim that organic waste extracted from mixed waste can be used for agricultural purposes, but this practice is unsafe for soils, other ecosystems and the human food chain. (As mentioned in Section 4.2.1, the health and environmental risks of certain wastes may be overlooked.)

Collecting waste from households is necessary to prevent open dumping and burning, yet many municipalities lack the funds or organisational capacity to operate a collection system. To maximise value recovery, separate containers are required for food waste, recyclables and residual waste within the household, which takes up extra space and requires ongoing awareness and behaviour change (Sarbassov *et al*. 2019) and adds to operational costs.



Warmer climates call for more frequent collections of food waste since disease-spreading house flies lay eggs on food waste that can hatch within 24 hours.

Warmer climates call for more frequent collections of food waste since disease-spreading house flies lay eggs on food waste that can hatch within 24 hours. Most residents will not want to store kitchen waste in the home for any length of time, meaning food waste collections need to take place more frequently than other waste streams (Kanan *et al*. 2023).

Photo source: *rootstocks / Adobe Stock*

Photo source: *M-Production / Adobe Stock*

Photo source: *SOLOTU / Adobe Stock*

Photo source: *nordroden / Adobe Stock*

The alternative is for service providers to install and service a dense network of communal drop-off points for different waste streams (Knickmeyer 2020). Research has shown, however, that this is less preferable for women, who are the main waste generators in a household and who may have home-based responsibilities that make it difficult to reach communal drop-off points (Table 6).

Transport usually represents the highest cost in any waste management system. The expense of transport is compounded where vehicles are old or in disrepair, road networks are poor or there are no waste transfer stations to bulk up waste for onward transport. Finally, processing and disposal sites, or recycling markets, may be far from the source of waste, meaning what works in one place may not be appropriate elsewhere.

Waste management technologies have been developed in regions with high-performing waste management systems. Their transfer to other regions has met with varied success. Technologies developed in and for high-income countries are designed around a set of assumptions, including:

- The municipality can deliver a guaranteed quantity and consistent quality of material over a long time frame;
- The high cost and low availability of manual labour means a technological solution is more cost-effective than "people power";
- The technical expertise to design, build, operate and regulate the facility is available within the local (or regional) population;
- The municipality can collect user fees (e.g. per quantity of waste or per household) to offset the costs of operation;
- The municipality will be able to secure finance at an affordable rate and has the expertise, systems and checks and balances in place to manage a high-value and long-term contract; and
- Where a facility is designed to serve a number of municipalities, trust and transparency are embedded in agreements so as to withstand political differences and electoral changes.

Where these points are overlooked, the result is often "white elephant" waste management infrastructure that is not functioning, representing a political failure and creating pessimism and suspicion among the local population with respect to future waste management solutions.

> ***"Transport usually represents the highest cost in any waste management system. The expense of transport is compounded where vehicles are old or in disrepair."***

4.6. Persistent market and financial barriers

Despite extensive studies and online content regarding the concept of a circular economy, implementation of circular economy models is limited (Rizos and Bryhn 2022; Baldassarre and Calabretta 2023). The private sector has a vital role to play in improving circularity by reducing the consumption of virgin materials in production processes. However, much private sector attention remains on downstream (waste management) improvements rather than on upstream (waste avoidance) initiatives (Romero-Perdomo *et al*. 2023).

Waste management has a significant funding shortfall that is growing every year. The value of materials in MSW is consistently insufficient to cover the costs of a waste management system, meaning that systems require ongoing funding to prevent waste leaking into the environment and causing additional, higher costs.

Barriers to establishing sustainable markets and finance for waste management include:

- Waste generation continuing to grow due to a lack of focus and private sector investment in waste reduction (UNDP 2022);
- Lack of willingness to pay for waste management services, for reasons that include ability to pay, perceived value for money, and competition with the ostensibly "free" option to dump or burn (Ansori 2023; Makanga and Zahiga 2023; Suryawan and Lee 2023; Xu *et al*. 2023);
- Insufficient financial incentives for (source-separated) waste collection, low or no gate fees for disposal sites, and a lack of legislation and suitable fines to prohibit open dumping and burning (Bonnet *et al*. 2023);
- Commercial barriers to private sector investment in waste management facilities (Gálvez-Martos *et al*. 2018);
- Lack of access to capital and operating expenditures (CapEx and OpEx) to build and operate a waste collection or waste processing facility;
- Rapid urbanisation and unplanned developments making the provision of waste collection and transportation services logistically complicated (Smart Cities Dive 2017; Chen 2018);
- A need for waste management system design to meet the needs of local populations, which vary from place to place;
- Low, volatile and geographically patchy markets for recyclable materials (Williams *et al*. 2020);
- Energy recovery from waste competing with recycling (UNEP 2019a).

Photo source: *Gudellaphoto / Adobe Stock*

4.6.1. Financing mechanisms are not always fit-for-purpose

Many municipalities are faced with the responsibility of delivering waste management services but without financial support from government or producer responsibility schemes. They therefore rely on local user fees, which often take into account fairness and willingness to pay although they do not cover the costs of the municipal waste management system (Suryawan and Lee 2023).

Finance for municipal waste management needs to cover the costs of infrastructure (CapEx, including for waste containers, vehicles and facilities) and ongoing operational expenses (OpEx, including fuel, wages and insurance).

Despite the largest cost component of a waste management system being collection, external donors often focus on the financing of processing and disposal facilities since these are considered more tangible and discrete projects to fund. In many cases, however, the municipality is unable to fund the ongoing costs of collection and operation, leading to project failure.

Many national governments are reluctant to take on debt to finance waste management plans due to unfavourable borrowing conditions (United Nations Conference on Trade and Development 2024). African countries borrow, on average, at rates four times higher than those of the United States of America and eight times higher than those of Germany, while half the world's countries spend more on servicing their debt than on health and education (Lahn and Schröder 2023).

Other key challenges include a mismatch in institutional requirements from financiers and the ability of municipalities to provide certified guarantees of project viability, and national and sub-national entities not knowing how to access funds (Waste Management World 2023).

Photo source: artifirsov / Adobe Stock

The externalities of poorly managed waste are borne by all of society.

4.6.2. Polluters are not paying... or changing

The externalities of poorly managed waste and reflow borne by all of society, particularly communities disproportionately affected by pollution and those vulnerable to the effects of climate change. In many cases, these communities are one and the same, exacerbating global inequalities.

The Polluter Pays Principle, part of the 1992 Rio Declaration to guide sustainable development worldwide, states that "National authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment."

Various fiscal policy instruments are available to correct for market failures in the area of waste and its externalities, such as a plastic packaging tax (incentivising businesses to use more recycled plastic in their packaging or reduce packaging altogether) or pay-as-you-throw fees for waste management services. However, depending on how these policies are implemented, they may have disproportionate impacts on the lowest-income households, further embedding inequalities.

The Intergovernmental Negotiating Committee, which is developing an international legally binding instrument on plastic pollution, including the marine environment, is continuing its discussion (UNEP 2022e) and shining a spotlight on the role of stakeholders at all levels in taking responsibility for plastic pollution.

Among the many initiatives being trialled to tackle plastic pollution, plastic credits have emerged as a voluntary tool for the private sector to support the collection of low-value plastics in areas with poor waste management. While plastic credits can provide much-needed revenue to finance collections of plastic waste, concerns have arisen from such schemes being unregulated, not sustainable in the long term and potentially at risk of being used to greenwash. Introducing third party auditors and regulating plastic credits risks excluding informal waste collectors, as they would be unable to meet due diligence requirements (UNEP 2022f).

In another voluntary example, the Global Commitment led by the Ellen MacArthur Foundation in collaboration with UNEP involved more than 1,000 organisations over five years (Ellen MacArthur Foundation 2023a) but showed disappointing progress on its three headline commitments:

- Eliminate problematic or unnecessary plastic packaging —minimal efforts to design out the need for single-use packaging were reported;
- Take action to move from single-use towards reuse models where relevant — the share of reusable plastic did not increase;
- Decrease the use of virgin plastic in packaging — virgin plastic use has remained relatively constant since 2018; while uptake in post-consumer recycled content continues to grow, so does the amount of plastic packaging used.

> *"National authorities should endeavour to promote the internalisation of environmental costs and the use of economic instruments."*

It is logical to maintain that in order to reduce packaging waste, producers must reduce single-use packaging. Returnable plastic packaging can achieve meaningful environmental benefits compared to single-use plastic packaging, with the potential to reduce emissions and water use by 35–70 per cent and material use by 45–75 per cent in the case of selected applications (Ellen MacArthur Foundation 2023b).

The most common alternative to voluntary commitments, adopted in many countries, is mandatory Extended Producer Responsibility (EPR) schemes which have two principal environmental goals (UNEP 2023d):

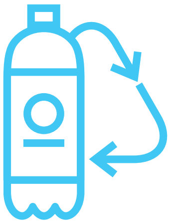
- To provide incentives for manufacturers to design resource-efficient and low-impact products;
- To ensure effective end-of-life collection, the environmentally sound treatment of collected products and improved rates of reuse and recycling.

While EPR has proven effective in terms of the second goal, raising funds to pay for waste management based on fees per tonne rules, it has been broadly ineffective in incentivising waste reduction (Asian Development Bank 2021).

Furthermore, the global nature of supply chains and secondary material value chains highlights weaknesses in a national approach to EPR: once a product crosses a border it falls under different regulations or evades them altogether. To address this issue, UNEP is working to improve global and national capacity to develop, implement and mainstream EPR approaches, initially for plastic products (UNEP 2023d; UNEP 2024). Harmonisation of polluter pays regulations is also needed to address competition between heavily regulated and less regulated countries, reduce the externalities of the international trade in secondary materials and products, and combat waste crime.

Collectively, the evidence suggests that while price instruments such as levies and EPR schemes can be helpful, they do more to raise revenues than to reduce demand. The report *Turning off the Tap: How the World Can End Plastic Pollution and Create a Circular Economy* (UNEP 2023e) concluded that fiscal policies "need to be combined with bans on single-use plastic products and additives and polymers that are particularly hazardous for human health and the environment."

The same rationale can arguably be applied to all products—not just plastic—that result in disproportionate externalities. It could thus be argued that any waste that has such low recoverable value as to not be "worth" collecting and processing needs to be redesigned or eliminated from use.



Returnable plastic packaging can achieve meaningful environmental benefits compared to single-use plastic packaging, with the potential to reduce emissions and water use by

35%–70%.

Photo source: *Kalyakan / Adobe Stock*

Moving towards a circular economy and taking a zero-waste approach is the only route to a safe, affordable and sustainable future.

Photo source: *Curioso.Photography / Adobe Stock*

05 Converging pathways to preventing and managing waste

Photo source: *Timothy Bouldry*

As the preceding chapters discussed, moving towards a circular economy and taking a zero-waste approach (UNEP 2023a) is the only route to a safe, affordable and sustainable future.

Since national contexts vary significantly, there is no one-size-fits-all approach or formula for systemic change. There is, instead, a tapestry of potential responses to this challenge. Each country can weave its own fabric of solutions to suit its own geographical, economic and cultural context and, importantly, the needs of its citizens.

Countries can be considered as located on a gradient, which has at each end:

- Low-income countries, generating little waste per capita but lacking the finance and infrastructure to manage it, and so bearing the heavy cost of uncontrolled waste in the environment;
- High-income countries, living beyond the planet's means, generating large quantities of waste per capita, and having a disproportionate impact on the triple planetary crisis.

The tools a government chooses to use, and the pace of change, will be determined by national circumstances. For example, Small Island Developing States may have different priorities and practical capabilities than large emerging economies with fast-growing megacities.

Whatever the context, understanding constraints and barriers (explored in Chapter 4) is a critical step to identifying the most appropriate solutions.

The ultimate goal is to decouple resource use and waste generation from economic growth.

There is no blueprint. Actions may be taken in sequence or concurrently. In addition, some countries may have the opportunity to leapfrog to more circular models. For example, digital technologies may enable a country to reduce both the impacts of uncontrolled waste and the need for expensive waste management systems.

The aim of this report is to make clear the shared direction in which countries need to travel so as to become more resource efficient, less GHG intensive and to have better public health, and to offer actionable pathways to deliver change at pace.

All countries can take steps towards ensuring goods and services are provided in such a way as to avoid unnecessary waste.

5.1. Pathways to prioritising waste

Without clear local, national, regional and global evidence of the scale of the municipal waste challenge, attracting political support and finance will remain difficult. The need for irrefutable evidence calls for improved data.

In the "Age of Information and Industry 5.0" (Adel 2022), the tools are now available to improve waste data collection and management (including gender-disaggregated data), as well as to harness the power of that data to make waste reduction and waste management a global priority.

Photo source: *tong2530 / Adobe Stock*

Countries with the least formal waste management systems have perhaps the most to gain from digitalisation.

5.1.1. Data and digitalisation to strengthen the waste management value chain

Data supplied by all stakeholders in the recycling value chain needs to be trustworthy and validated to address the life cycle of waste generation, prevent contamination of recycled materials by hazardous substances (Chibwe *et al*. 2023), and protect recycling operations from legal risks, financial losses and reputational damage (Undas *et al*. 2023). Transparency in waste data is also a powerful tool in the fight against corruption, waste crime and greenwashing (D'Onofrio 2023; Isarin, Baez Camargo and Cabrejo le Roux 2023).

Digitalisation offers the means to strengthen the recycling value chain by reducing risks for all partners. Countries with the least formal waste management systems have perhaps the most to gain from digitalisation. For example, the growing adoption of "waste apps", which connect waste collectors to both waste generators and the value chain, can help formalise waste collection service providers and secure the financial inclusion of both female and male waste workers. These apps can improve the transparency of value chain transactions and help government agencies make informed policy decisions and reduce costs (Adeniran, Shakantu and Ayesu-Koranteng 2022; Kolade 2023; Kolade, Oyinlola and Rawn 2023; Lendelvo *et al*. 2023; Odumuyiwa and Akanmu 2023; Schröder and Oyinlola 2023).

Digital technologies are also being employed to deliver public information campaigns, notify authorities of infractions, optimise collection routes, track vehicles, sort waste, trace the movement of materials through the supply chain, select suitable sites for waste management facilities, and deliver training and capacity building. In addition, artificial intelligence is being increasingly adopted to predict waste composition (Thomaz, Mahler and Pereira Calôba 2023), identify and sort waste materials (Moore 2023), reduce food waste and food loss (Onyeaka *et al*. 2023; Said *et al*. 2023) and predict hotspots of pollution from waste in marine environments (Fazri *et al*. 2023; Seyed *et al*. 2023).

The Waste Wise Cities Tool, developed by UN-Habitat details the methodology for monitoring SDG Indicator 11.6.1, which focuses on the proportion of MSW managed in controlled facilities compared to the total generated waste. It emphasizes the importance of reliable data collection for better waste management. The Waste Wise Cities Tool guides cities through assessing their MSW management performance and links to other SDG indicators, and highlights the challenges in data availability and quality.

It should be noted that access to digital technologies and the internet is far from equal. Yet due to its ubiquity in modern life, online access could now be considered a human right (Reglitz 2023). For example, there is a distinct gender gap in access to mobile internet. Women are 19 per cent less likely than men to use mobile internet; of the 900 million women who are still not using it, almost two-thirds live in South Asia and Sub-Saharan Africa (Global System for Mobile Communications Association 2023). A slowdown in digital inclusion is concerning. As the world becomes increasingly connected in developing digital-based services, authorities and businesses need to ensure that such inequalities do not become entrenched.

5.1.2. Data to enable clear vision and consistent leadership

To make waste reduction and waste management a political priority, clear and reliable data is needed on waste arisings and the costs to society of the Waste Management as Usual scenario (Chapter 3).

At present, national municipal waste data collection methodologies are inconsistent, acting as a barrier to change. Currently the United Nations Statistics Division collects municipal waste data from countries using the UNSD/UNEP Questionnaire on Environment Statistics,which includes methodological recommendations (UNSD n.d.). Additional methodological recommendations on municipal waste are also provided in the metadata for SDG indicator 11.6.1. A unified approach to municipal waste data collection and management, for example through a Global Waste Observatory, would:

- Strengthen society's understanding of the challenge;
- Improve recognition of gender-differentiated experiences with and impacts of waste and its management;
- Provide the evidence needed to prioritise and invest in waste prevention;
- Enable governments, communities and the private sector to plan for adequate services and infrastructure;
- Promote the cost-effectiveness of municipal waste management as a public service, taking into account both the direct costs and externalities.

Regional examples of waste data cooperation exist, such as the European Observatory on municipal waste performances (Observatory ACR+ 2023) and the Regional E-waste Monitor for Latin America (Wagner *et al*. 2022). Other examples of best practice include:

- A United Nations Economic Commission for Europe (UNECE) Task Force framework on waste statistics that considers waste in a broader context of flows of products and materials (UNECE 2022). The UNECE Working Group on Environmental Monitoring and Assessment supports Member States in improving their waste monitoring systems and the use of data and indicators for improved policymaking (UNECE n.d.).
- The Inter-American Development Bank's Technical Cooperation for the Digitalization of Information and Measurement of the Performance of Solid Waste Management within the Framework of the Circular Economy, the SDGs and Climate Change (Inter-American Development Bank n.d.). The objective of this initiative is to design and develop a regional online system for data management and dissemination on solid waste management in Latin America and the Caribbean, as well as to monitor existing developments, follow trends and detect opportunities for improvement and allow comparisons. It also aims to support decision-making, effective public policies and adequate funding and governance.

Since pollution from waste knows no borders, international cooperation on waste tracking and management offers the most rational approach to addressing the impacts of waste on the triple planetary crisis.

Box 10: Increasing penalties for illegal waste practices

The significant rise in waste trafficking has severe negative impacts on the environment and human health, significant economic impacts through the diversion of resources such as tax revenue, and an adverse effect on trade and competition, putting law-abiding businesses at an economic disadvantage (United Nations Office on Drugs and Crime [UNODC] 2023).

In the European Union, illegal trade in plastic waste alone has been estimated to be worth up to EUR 15 billion (Environmental Investigation Agency 2021). By miscategorising and transporting containers of waste to countries with weaker enforcement capacity, organised criminals take advantage of the complexity of waste regulations and the few resources available for monitoring, inspection and enforcement. While the risks for these criminals remain low, the illicit profits from waste crime are high.

Mapping of waste flows; better knowledge of the modus operandi of waste trafficking networks; and national, regional and inter-regional cooperation are essential in tackling waste trafficking (UNODC 2023).

In 2022, the United Nations Office on Drugs and Crime launched a legislative guide to combating waste trafficking. It also joined the Environmental Network for Optimizing Regulatory Compliance on Illegal Traffic to help improve international cooperation and coordination to combat waste crime and ensure compliance with the Basel Convention, which regulates the control of transboundary movements of hazardous wastes (including mixed plastics) and their disposal.

Crimes that affect the environment are now recognised as some of the most lucrative transnational criminal activities. They are often closely interlinked with different forms of crime and corruption. Furthermore, money laundering and the illicit financial flows derived from them may contribute to the financing of other transnational organised crimes and terrorism. In 2023, the European Parliament provisionally agreed to use criminal law to protect the environment. Illegal collection, transport and treatment of waste will be punishable by up to five years in prison and up to EUR 40 million in fines (European Commission 2023b).

5.2. Pathways to waste prevention

5.2.1. Zero waste and circular economy models

Zero waste strategies are enablers of a circular economy, which aims to prevent waste by keeping products and materials in use for as long as possible, and to protect human health and the environment by the elimination of harmful chemicals.

The spiralling costs of waste and its management (Chapter 3) provide ample motivation for policymakers and the private sector to work together to pursue zero waste models of product and service delivery (Ahmed *et al*. 2023). The report *Towards Zero Waste: A Catalyst for Delivering the Sustainable Development Goals* (UNEP 2023a) contains an extensive range of case studies that can help move society towards sustainable development via zero waste models.

Addressing unnecessary consumption is at the heart of zero waste and circular economy frameworks. Many actionable steps are straightforward, for example:

- Government bodies and businesses can show leadership by installing water dispensers in meeting rooms, eliminating the need for single-use plastic water bottles;
- Governments can introduce bans on unnecessary and polluting products such as disposable e-cigarettes and packaging materials that cannot be economically recycled;
- Information and behaviour campaigns can be tailored towards women as the main influencers at the household level of waste generation and management.

Private sector investment in reuse and refill models are vital for sustainable consumption and production, contributing to meeting every multilateral agreement from the SDGs to the 2015 Paris Agreement to the Post-2020 Global Biodiversity Framework.

To achieve a zero-waste society, governments, industry and citizens need to work together to implement a rapid transformation in the way products and services are delivered. Industries also need to work on reducing waste within the value chain for their products. Such initiatives can achieve significant financial savings for both businesses and consumers while drastically reducing the quantity of waste arising in the municipal waste stream and its negative environmental impacts.

Photo source: *ChayTee/ Adobe Stock*

Box 11: Case study: In the Philippines, Quezon City leads the fight against plastic pollution through sari-sari store-based refill hubs

An initiative establishing community-based refill hubs in sari-sari (small neighbourhood) stores was launched in Quezon City in the Philippines to celebrate World Refill Day on 16 June 2023 (Greenpeace 2023).

“Being sustainable and eco-friendly doesn’t have to be expensive… [this initiative] only proves that shifting to zero waste and limiting our plastic generation is inclusive, affordable and accessible to all, including those from socioeconomic sectors and urban areas,” said Quezon City Mayor Joy Belmonte.

Refill stations have been installed in 20 sari-sari stores across the city. Residents are encouraged to bring their own reusable containers to refill basic commodities such as liquid detergent, fabric conditioner and dishwashing liquid.

In the Philippines, studies have shown that over 164 million sachets are being used every day. The initiative was designed with communities and store holders in order to provide a simple, affordable and convenient alternative to sachets and other single-use plastic packaging.

The project seeks to build on the Filipino “tingi culture” of small-volume retailing in refillable containers and purchasing only what is needed. High quality products are offered at competitive prices, bringing savings to customers and higher profits for sari-sari store owners. The project hopes to encourage corporations to reduce plastic production and phase out single-use plastics by investing in resources to transition to and adopt reuse and refill systems in their operations.

Photo source: StockImageFactory / Adobe Stock

Box 12: **Case study: The economics of reuse for street vendors in India**

Across India, the thriving street food sector currently relies heavily on single-use plastics, including plates, bowls, cups and takeaway containers. Although single-use plastic items are affordable and accessible, they represent a nationwide waste management burden and cost to society.

In October 2023, a cost-benefit analysis was undertaken to compare a proposed reuse system, tailored to Indian street food vendors, with the current single-use plastic system (Zero Waste Europe 2023). The study encompassed the perspectives of street vendors, customers and policy makers, and potential cost savings, revenue implications and overall viability in five cities: Kolkata, Delhi, Mumbai, Nagpur and Ranchi.

The findings of the study revealed that reuse systems presented a compelling business case. It reduced costs for vendors and customers, significantly reduced the amount of materials required, and had a 21 per cent return on investment with a two- to three-year payback period. Important considerations included material choice, retention time, return rate, deposit amounts and government incentives.

Overall, the study found that adopting a reusable packaging system in India's street food sector would be both economically viable and environmentally sustainable, benefiting all stakeholders and paving the way for a more resilient and sustainable future for Indian cities.

Figure 27: **High-level comparison of linear single-use system and proposed reuse system for Indian street vendors (after Zero Waste Europe 2023).**

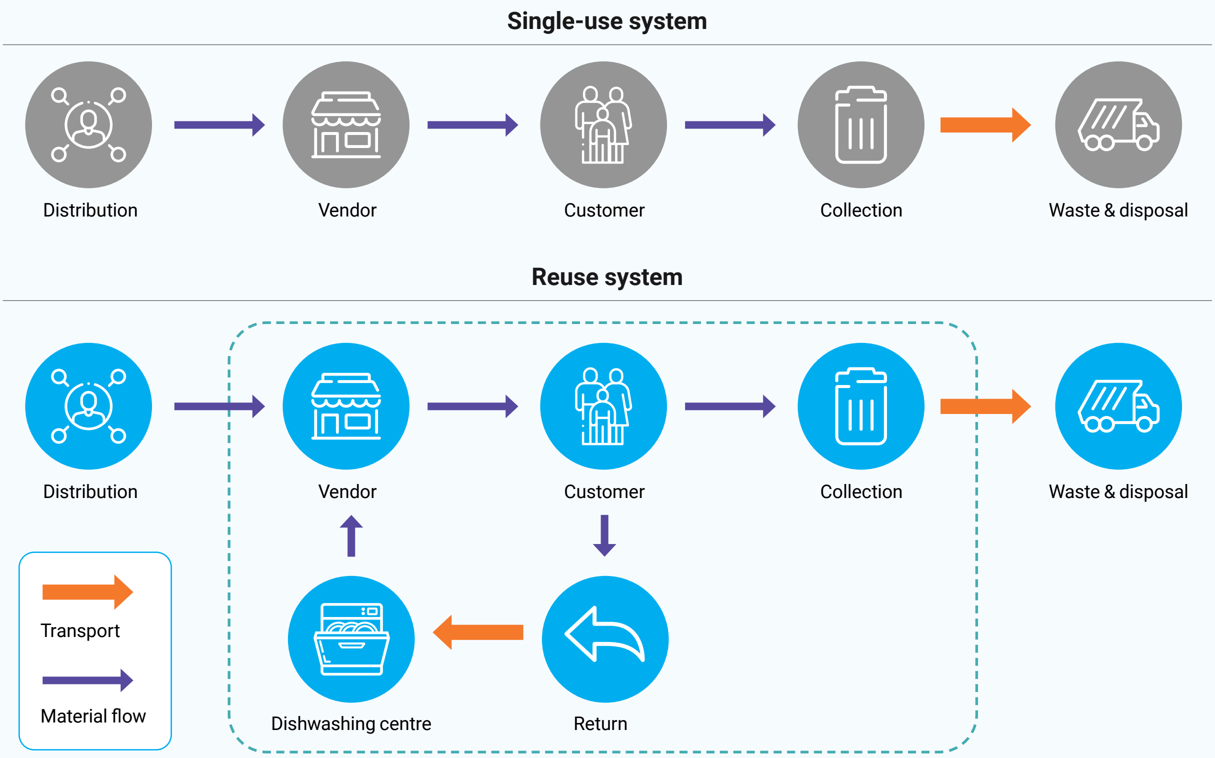


Photo source: *EmmaStock / Adobe Stock*

Box 13: Case study: China's zero waste cities

Between 2019 and 2021, the Government of China operated a national zero-waste pilot city programme in 11 cities with the aim of promoting sustainable consumption and production and the circular economy at the city level. The pilot sought to create an urban development model that avoids waste generation and minimises negative environmental impacts of consumption throughout the whole life cycle. Crucially, the programme aims for cities to reach a carbon dioxide emissions peak by 2030 and carbon neutrality by 2060 (Dong 2023).

Due to the success of the pilot, in China's 14th Five-Year Plan period (2021–2025) the national zero-waste city programme was scaled up in 100 cities (SWITCH-Asia 2023).

"Zero waste city" refers to an urban development model that emphasises innovation, coordination, greenness, openness and sharing, to minimise solid waste generation. It promotes the establishment of green developments and green lifestyles, as well as the reduction and recycling of solid waste, thus minimising the need for waste disposal (UNEP 2023f).

The city programmes involve promoting green practices in construction, industry, agriculture and tourism, as well as low-waste lifestyles and the separation of waste for recycling. For waste management, a series of circular economy eco-parks were constructed to turn "not in my backyard" into "benefiting my backyard", significantly improving the quality of the solid waste treatment system (Lee *et al*. 2020).

Social participation is a pillar of the success of zero waste cities. Social media has been adopted to attract the public's attention to this policy and increase its participation in environmental governance. A review of the social dimension of the zero-waste city programme (Gong *et al*. 2022) identified transferable approaches, including using popular and accessible communication platforms and focusing on people's livelihood interests.

"The pilot sought to create an urban development model that avoids waste generation."

5.2.2. A focus on food waste

Food waste is both a societal and environmental issue of concern. One-third of all the food produced worldwide is wasted on its way through the supply chain or in homes—enough to feed 1.26 billion people a year (Food and Agriculture Organization of the United Nations [FAO] 2019; UNEP 2021c). Food waste represents a loss not just of the food itself, but also of the energy, water and human resources used to produce it.

The prevention of food waste, due to its significant environmental footprint and climate change impact, has been identified as a key UNEP priority (UNEP 2023g). It will require cooperation among stakeholders in agriculture, enterprises, the environment and climate change. In particular, since women are usually responsible for food purchases, preparation and cooking, and household-level waste management, targeted information and behaviour change campaigns can make significant impacts.

UNEP's Regional Food Waste Working Groups are assisting 25 countries in Africa, Asia and Latin America to act on food waste. Sharing knowledge and building capacity among food service businesses can help reduce municipal food waste significantly, while food redistribution schemes leverage much needed social benefits from excess food that is still fit to eat. Governments and municipalities can also provide awareness raising and guidance to businesses and residents with culturally appropriate advice on reducing food waste in commercial kitchens and homes (FAO 2020; Champions 12.3 2022).

Unavoidable food waste can be utilised to produce compost, cooking fuel and animal feed. It also increasingly has higher value uses in a circular bioeconomy (Lenkiewicz 2023). Recent innovations include using squalene from broken rice in skincare products and wound healing applications (Zamil *et al*. 2022) and upgraded lignin from woody biowaste in the chemical, pharmaceutical, cosmetic and textile industries (Solarte-Toro *et al*. 2021).

In essence, there is no need for food to reach waste disposal sites where it attracts flies and vermin and ultimately contributes to global climate change.

Photo source: *wirestock / Envato*

Box 14: Case study: Insect bioconversion – Scaling up recycling with tiny heroes

Insect bioconversion is a natural process that harnesses the abilities of insects to transform organic waste into valuable resources. Two types of insects, black soldier flies *(Hermetia illucens)* and mealworms *(Tenebrio molitor)*, possess unique digestive systems that allow them to digest a variety of organic materials, including food waste, agricultural residues and even sewage sludge (Sarwono 2023; (Insect Engineers 2023; Sarwono 2023; Wu *et al*. 2023)).

In larval form these insects can consume vast quantities of organic matter in a short period, efficiently converting it into biomass. This reduces the need for landfills and incineration, ultimately decreasing greenhouse gas emissions and environmental pollution (Rehman *et al*. 2023).

Insect bioconversion produces a protein- and nutrient-rich insect biomass suitable for livestock farming and aquaculture (Radhakrishnan *et al*. 2023). The insects also produce a nutrient-rich frass (excreta) containing essential nutrients such as nitrogen, phosphorous and potassium, which makes a valuable alternative to chemical fertiliser (Aziz *et al*. 2023).

The insect bioconversion industry presents significant economic opportunities, enabling the development of local enterprise, job creation and economic growth. This industry not only helps to address the triple planetary crisis of climate change, biodiversity loss and pollution, but also stimulates innovation and entrepreneurship.

5.3. Pathways to delivering societal change

There is a common saying in the waste management sector: waste management is 20 per cent about technology and 80 per cent about people. Everyone on the planet generates some kind of municipal waste and faces the personal choice of how to manage it. Likewise, it is people who collect waste, sweep streets and make decisions about community- and city-scale systems and infrastructure. All this means that people really are the key to change.

Photo source: *Kzenon / Adobe Stock*

5.3.1. Adopting behavioural science

Engaging people in waste reduction and improved waste management practices may feel at times like an uphill struggle. However, evidence from communities and countries the world over suggests that with clear and consistent messaging, and by making it easy to "do the right thing", most people will eventually adopt the desired behaviour change.

Examples from different countries show that behavioural science can be applied to encourage public participation in waste reduction and waste management initiatives. At its core, "successful waste management depends on stakeholder participation, social support and a strong social contract with citizens" (International Bank for Reconstruction and Development and the World Bank 2023).

It is also important to remove barriers and make it easy for people to participate by providing the right infrastructure (e.g. food waste containers with lids) and designing services around users (e.g. collecting waste directly from households). Incentives and behavioural nudges can also be effective, for instance by collecting recyclables and food waste more frequently than residual waste, or providing larger containers for recyclables and food waste than for residual waste, thereby encouraging people to segregate their waste. Behaviour change research and initiatives are strengthened when gender-differentiated experiences and impacts on household waste are recognised and addressed.

Knowledge is not enough in itself to change behaviours. People make decisions based on their own experiences and perspectives and by what they see other people doing. They also respond better to positive than negative messaging, so that celebrating and reinforcing the desired behaviour is more effective than focusing on undesired ones.

Communities include different groups of people with different needs and priorities. Campaigns need to take these differences into account. For example, a campaign might adopt a range of messages delivered by local influencers via different channels, such as public meetings, radio interviews and social media.

Community leaders are excellently positioned to understand the populations they serve and to experiment with different messages and approaches in order to reduce waste and improve participation in waste management schemes. Providing opportunities for community involvement and inviting feedback can also be a useful way to generate original ideas and build a sense of local ownership and accountability.

> ***"By making it easy to 'do the right thing', most people will eventually adopt the desired behaviour change."***

5.3.2. Ensuring inclusion and representation

To maximise the benefits of waste reduction and improved waste management for all of society, a single focus on the waste itself is not enough. Equally important is a shift in perspective to include socioeconomic impacts so as to deliver a just transition (Impact Investing Institute 2023). Three equal and interlinked elements are applicable across geographies for determining local priorities (Table 7).

Table 7: Just transition elements as applied to waste reduction and waste management (after Impact Investing Institute 2023)

Advance climate and environmental action	Improve socioeconomic distribution and equity	Increase community voice
• Focus on upstream waste prevention and reducing greenhouse gas emissions from linear resource use. • Protect and restore natural capital, including biodiversity. • Support adaptation and resilience to climate change.	• Efforts to reduce and manage waste must be complemented by activities that support the needs of people. • Investments should not entrench or exacerbate existing burdens for people already disproportionately affected by poor environmental quality or lack of access to services and to safe, dignified livelihoods.	• Improve social dialogue and agency, from local engagement to participation and decision-making. • Any financing transaction that claims to contribute to a just transition must involve stakeholders and ensure that their voices are heard. These stakeholders include workers, communities, consumers and indigenous and marginalised communities.

A key example of the integration of just transition elements into waste management decision-making is the involvement of women and informal waste workers, as discussed below.

Waste management services are often (but not always) designed and delivered by men, whereas women often have more influence over waste generation in the household. For these reasons (and many others, as described in Section 4.3.1), it is beneficial to involve women in community-level waste management decision-making.

Governments and municipalities are encouraged to:

- Collect gender-disaggregated data to make women's experiences and contributions visible (UNEP-IETC and GRID-Arendal 2019; UNEP 2021c; UNEP-IETC 2022);
- Recognise women as key players in waste management as consumers and service users (GA Circular and Ocean Conservancy 2019; UNEP-IETC 2022);
- Ensure that the transition of the informal waste sector is inclusive of women and their specific needs and constraints (such as combining work with family and household responsibilities), for example by providing flexible work schedules and proximity to residence and suitable care services for children (UNEP and International Solid Waste Association [ISWA] 2015; GA Circular and Ocean Conservancy 2019);
- Ensure women's representation in decision-making, leadership and entrepreneurship roles, by bringing all voices to the table (UNEP-IETC 2022; Khaled 2023).

As waste management systems develop, it is also important that municipalities actively seek to integrate informal waste workers into formal systems, ensuring that women workers have an equal seat at the table and are able to influence discussions and decisions like their male counterparts.

Inclusion of existing workers into formalised systems helps to address inequalities, improve livelihoods and secure their social, economic and political inclusion (Kaza *et al.* 2018; Department of Environment, Forestry and Fisheries and Department of Science and Innovation of South Africa 2020; World Bank 2022).

In many countries, particularly in Latin America and South Africa, informal waste workers have been successfully integrated into municipal waste management systems. This approach is now recognised as global best practice (DEFF 2020). When informal waste workers join together in cooperatives or associations they can provide more efficient services and generate more income (Castro Iglesias 2022), while their organisation can offer a pathway to formalisation.

Informal waste workers can be further supported by offering them business training, microcredit, streamlined routes to formalisation and access to suitable markets. When barriers to formalisation are removed, these waste workers are better able to move up the value chain, handle a larger quantity of materials and generate a more reliable income stream (Ocean Conservancy 2021; Shinozaki 2022).

Box 15: Case study: Waste picker associations in Colombia increase incomes through formalisation

Colombia has a well-established tarriff system whereby wealthier residents subsidise the cost of public services, including waste management, for their lower-income neighbours. This tariff covered the costs of waste collection, disposal and street cleaning carried out by private contractors. However, the collection of recyclable materials was traditionally carried out by highly organised workers in the informal sector, whose services were not covered by the tariff system.

Over a number of years, waste picker associations successfully lobbied the government and in 2016 achieved a change in the law, which now formally recognises and values the work of the informal sector. To help formalise their services, the government set out a sympathetic and structured process requiring that the associations:

- Receive training in technical, operational and administrative competencies;
- Develop a portfolio of services, a website and a database of service users;
- Comply with standardised reporting requirements;
- Formalise the operational and technical aspects of service provision, with emergency plans, financial statements and georeferenced maps of the areas served.

In this way, Colombian waste picker organisations have become formally recognised, and their incomes and working conditions have improved. The waste picker associations now receive payment for their services, providing an important financial buffer since the value of recyclable materials fluctuates and can be very low. By 2021, there were 697 waste picker organisations formally registered as service providers, with around 56,800 waste pickers (SSPD 2021) each earning US$127–170 per month (US$4.23–5.66 per day) While this pay is still below the 2022 adjusted poverty line for Colombia at US$6.85 per day, the improvements in working conditions for the waste pickers has been significant. (Parra and Abizaid 2021).

Their social inclusion and economic empowerment is improving and many have become independent waste management entrepreneurs with their own businesses.”

Their social inclusion and economic empowerment is improving and many have become independent waste management entrepreneurs with their own businesses.

Photo source: *Mikolette Moller/peopleimages.com / Adobe Stock*

5.4. Building national capacity

The widespread shortage of professional waste management expertise needs to be addressed globally. A rapid acceleration of knowledge sharing, training programmes and diplomas is needed in order to create the pipeline of skilled workers required for the enormous shift in behaviours urgently needed for human and planetary health. Countries with adequate professional capacity and clear and consistent leadership can make more rapid impacts with regard to waste reduction and improved waste management.

Photo source: visoot / Adobe Stock

The following section describes a range of tools that governments may choose to use in order to set the direction they are going and achieve significant change within a generation.

National governments have it within their power to mandate for universal waste collection (SDG 1.4: the provision of basic services for all). These services are most effective when they operate door-to-door (considering women's domestic responsibilities and often-restricted ability to leave the household). Where that is not feasible, centralised points with regular collections can still meet the needs of society.

Once waste collection is provided, governments and municipalities can move to prohibit the open dumping and burning of waste, thereby making significant improvements to public health and environmental quality and reducing GHG emissions. In this way, waste collection services can attract climate finance and ought to be included in NDCs (Section 4.2.2 and Box 16).

National governments can legislate for clear recycling targets, cascading national targets down to the municipal level with sanctions for municipalities that fail to meet the targets. To support municipalities, governments are encouraged to share guidance on minimum service standards for separate collection, technical support and capacity building.

Separate collection targets for specific waste streams such as food waste, plastics and e-waste send a clear signal to the market and incentivise private sector investment. Waste streams can be targeted according to national priorities, taking into consideration the cost of not managing these materials in a safe and sustainable manner.

> ***"Waste collection services are most effective when they operate door-to-door."***

Box 16: Including waste reduction in Nationally Determined Contributions

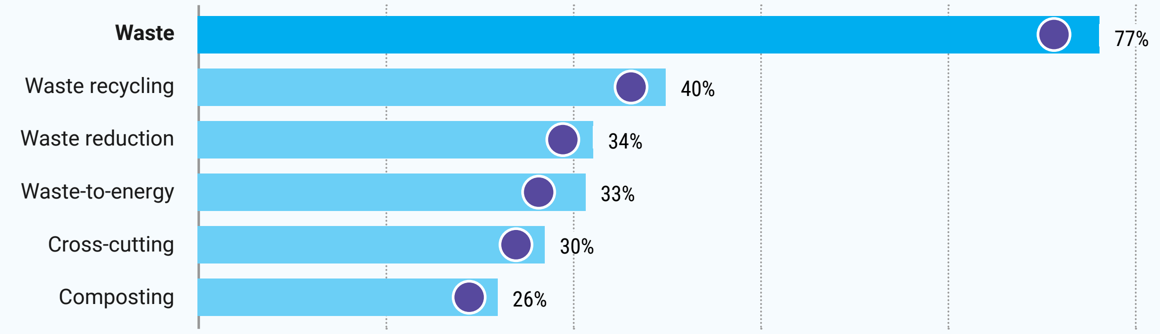
Nationally Determined Contributions (NDCs) are submitted by signatory countries to the Paris Agreement, describing their plans and goals for reducing greenhouse gas (GHG) emissions. Waste management has been repeatedly identified as a sector with significant potential to reduce temperature rise in the next 15–20 years.

Countries have a significant opportunity to reduce GHG emissions by scaling up domestic best practices in waste prevention and reduction strategies. There is also a clear opportunity for the contribution of the informal sector to be recognised in NDCs in view of its role in collecting and recovering materials and reducing waste.

Despite the huge opportunity to reduce GHG emissions offered by waste reduction and circular economy pathways, the 2023 NDC Synthesis Report (United Nations Climate Change 2023) found that only 77 per cent of Parties had referred to waste as a specific priority area.

Specific mitigation options were identified even less frequently (Figure 28).

Figure 28: Share of Parties referring to the specific priority areas and frequently indicated mitigation options in Nationally Determined Contributions (Source: UN Climate Change 2023).



Diverting food waste from landfills and dumpsites, which remains one of the most valuable waste management activities for reduction of GHG emissions, costs below US$20 per tonne of CO_2 equivalent. Still, some 30 per cent of Parties have omitted reduction of methane emissions from solid waste in their NDCs, representing a significant missed opportunity.

Photo source: piyaset / Adobe Stock

Furthermore, reducing food waste and moving to a circular economy produce a variety of social, environmental and economic side benefits. Since the waste sector is intrinsically linked to many other sectors, developing more circular material flows and coordination across sectors and value chains have been proven to reduce environmental degradation and GHG emissions (Intergovernmental Panel on Climate Change 2023).

If interventions are to benefit from climate finance, they must be embedded in NDCs.

Significant finance, knowledge, data and capacity gaps exist between the circular and climate agendas. In particular, there is a need in NDCs to replace general statements with specific waste reduction and circular economy interventions and policy. To support countries in assessing, prioritising, implementing and tracking circular economy interventions for increased ambition and implementation of their NDCs, the United Nations Environment Programme, the United Nations Development Programme and the United Nations Framework Convention on Climate Change secretariat have published the Building Circularity into NDCs user guide and digital toolbox (United Nations Environment Programme, United Nations Development Programme and United Nations Framework Convention on Climate Change secretariat 2023).

Photo source: *Andrey / Adobe Stock*

Materials can be diverted from disposal by building market demand (a pull factor). Governments can lead by example through public procurement policies that favour products with recycled content. They can also legislate for recycled content in products and provide tax breaks on products containing recycled materials. This in turn incentivises the separate collection of these materials to make them available for industry.

National guidance, standards and certification for recycling processes can help give confidence to producers and consumers and strengthen national markets for recycled products. This is especially pertinent in the case of composting initiatives, as it helps develop a strong supply of good quality compost which in turn builds demand for source-separated food waste. In addition, safety standards are needed to protect waste workers from hazards, as well as to protect the environment and neighbouring communities from emissions to air, land and water. Research and guidance are most effective when gender-differentiated impacts and associated precautions are considered.

Box 17: A new Global Framework on Chemicals

In September 2023, a new Global Framework on Chemicals was agreed to based on 28 targets that aim to improve the sound management of chemicals and waste. Governments have committed to create by 2030 the regulatory environment to reduce chemical pollution and implement policies to promote safer alternatives.

The new Framework includes programmes that require manufacturing processes to use waste from one industry as an input to another, rather than creating a synthetic material. With the adoption of the Global Framework on Chemicals, the pollution and waste crises are recognised as being at the same level as the crises of climate change and nature and biodiversity loss, which already have frameworks in place (UNEP 2023d).

National guidance, standards and certification for recycling processes can help give confidence to producers and consumers and strengthen national markets for recycled products.

EPR schemes can be effective at reducing waste, promoting design for recycling and providing funds for waste collection, sorting and recycling. The waste hierarchy can be used as a guide when establishing producer responsibility rules so as to ensure waste reduction is prioritised. However, EPR systems rely upon well-regulated industries but, where borders are porous and economies are predominantly informal, such schemes may be challenging to implement (UNEP and GRID-Arendal 2020; Adejumo and Oluduro 2021; WWF 2019).

Where governments and municipalities are considering waste processing technologies and infrastructure, care must be taken to ensure that they are fit-for-purpose and meet local needs and technical capacity (including gender-differentiated needs and ensuring opportunities for women are equal to those for men; as systems become formalised and technologies introduced, they often replace roles undertaken by women such as sorting). In countries with high labour costs and efficient road networks, large-scale, centralised, technology-based infrastructure may be the most appropriate solution. Conversely, in countries where transport is slow and costly, unemployment high and labour costs low, alternative people-centred strategies may be preferable (including opportunities for both women and men) as they will help meet social needs at the same time as high environmental standards (Gutberlet and Carenzo 2020; Kurniawan *et al*. 2022; Morais *et al*. 2022).

By developing national capacity and selecting appropriate technologies, governments can protect their own industries and promote sustainable development.

Box 18: Case study: (B)energy – tackling energy poverty without aid

(B)energy is a social business that promotes mobile biogas technology with one strict rule: no aid money involved. The business aims to make biogas an attractive source of cooking energy by giving it a price.

By offering technology, services, training and a business model, (B)energy enables local partners to bring biogas products to their markets either through import or local manufacturing. That approach empowers these partners to build a thriving private biogas sector in their respective countries, using their resources and responding to the specific needs of their communities. The focus is on creating income-generating opportunities for small-scale biogas producers and providing easy access to clean cooking energy for biogas buyers.

(B)energy's sister organisation Biogas Unite is a global movement that aims to repair failed biogas systems in Africa and boost the private biogas sector. This initiative seeks to create fair market conditions, protect the future of the biogas industry, and advocate for clear and fair rules including strict restrictions and regulations on foreign aid. The goal is to create reliable and protected environments where all biogas systems can function, and to promote competitive markets while providing equal opportunities for all. This collaborative effort involves African biogas entrepreneurs, energy corporations, financial institutions, academia, local governments and various private entities across other sectors.

An inspiring example of the impact of (B)energy's approach is Tahani Aljak, a resident of the Alredaise 2 refugee camp in South Sudan. The camp is one of the densely populated camps in the country's White Nile State that since 2013 have been housing refugees who have fled conflict. In these camps, women bear the responsibility of meeting their families' basic needs, including searching for firewood for cooking which exposes them to violence and exacerbates their vulnerability.

To address this challenge and enable clean cooking for her community, Aljak became involved with Sudan's (B)energy hub, the Estidama Incubator for Clean Energy Products located on the Engineering Campus at Sudan University of Science and Technology. Through her entrepreneurial efforts, she aims to showcase biogas technology and its potential benefits to the residents of the refugee camp.

By making cooking accessible to every woman, this initiative can significantly alleviate the difficulties women face, positively impacting their safety, food security and overall well-being. Additionally, the availability of clean cooking energy has the potential to foster peace and harmony between the refugee and host communities while promoting a sustainable and dignified lifestyle (B-energy 2021). Since biogas can be generated from food waste, clean cooking fuel can be available wherever people live.

Photo source: *Riccardo Niels Mayer / Adobe Stock*

Following the waste hierarchy in technology selection avoids locking society into linear resource use (e.g. via waste-to-energy). Technology procurement processes also need to consider carbon emissions to avoid investments in infrastructure that work against NDCs, and to help attract vital climate finance.

Private sector participation initiatives that reduce waste and improve its management (particularly from local SMEs) can help reduce costs and divert more waste from disposal. Business-friendly policies that encourage and de-risk investments are essential to attract sufficient interest and create a competitive and enabling environment for business, which can then boost a country's resource efficiency and economic growth.

Box 19: Involving the private sector

Involving the private sector through public-private partnerships can bring benefits in terms of both environmental and service delivery standards, together with economic opportunity. A variety of models exist for private sector participation in waste management, including service contracts, design-build-operate contracts for waste management facilities, and concessions. Such arrangements require legal and institutional frameworks as well as sufficient capacity within the public sector to monitor and hold the private sector to account for service quality (European Bank for Reconstruction and Development 2018; Olukanni and Nwafor 2019).

> *"A variety of models exist for private sector participation in waste management."*

Financing mechanisms that help to "crowd in" private sector competition, support national waste management sectoral development and involve local banks are essential to make finance for waste management accessible.

ISWA's Scientific and Technical Committee has brought forward a new "financing waste management solutions" initiative (ISWA 2023) to identify and assess the pathways and conditions that need to be acknowledged and disseminated to enable companies and governments to access affordable funding for waste management. This initiative is exploring different instruments and mechanisms to help financial institutions gain practical insights into issues that face waste management business developers with respect to securing bankability.

Photo source: *Martin Barraud/KOTO / Adobe Stock*

For countries with nascent waste management systems, South-South and Triangular cooperation are helpful in guiding choices that are appropriate for countries with similar socioeconomic characteristics. In particular, circulareconomy.earth (Chatham House 2023) allows users to explore the policy and trade dynamics associated with transitioning from linear to circular economy models and provides analyses of the opportunities and trade-offs associated with such transitions. Other knowledge-sharing programmes and platforms that enable countries with shared opportunities and constraints to learn effectiveness strategies from each other include the Africa Circular Economy Network (2023), the European Circular Economy Stakeholder Platform (2023), the Circular Economy Coalition for Latin America and the Caribbean (2023) and SWITCH-Asia (2023).

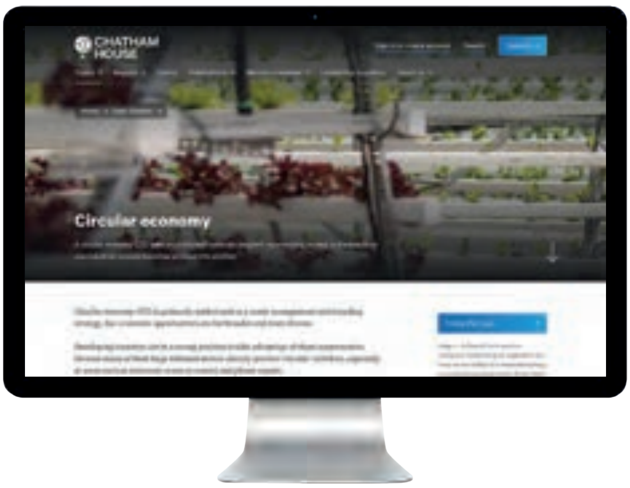


Photo source: *https://www.chathamhouse.org*

For a liveable future, the current pattern of linear resource use needs to be halted with urgency.

Photo source: *leungchopan / Adobe Stock*

06 Conclusions and recommendations

Photo source: *Chanchai / Adobe Stock*

For a liveable future, the current pattern of linear resource use needs to be halted with urgency, and zero waste and circular economy strategies must be implemented to protect future generations' human rights.

Urgent change is needed to prevent the costs of waste spiralling out of control. All stakeholders—public, private and civil society—must work together to reduce waste, reduce its complexity and reduce the leakage of legacy pollutants into the environment.

Materials need to be kept in use for as long as possible and at their highest possible value. Recyclability and accountability need to increase. Waste crime must fall.

Finally, the safety and quality of the livelihoods of people who work with waste need to be prioritised to ensure a just transition with social and environmental justice at its core.

The three scenarios explored in this report underscore that if change does not happen at speed and scale, humanity will face unmanageable quantities of waste with potentially irreversible impacts on biodiversity, human health and climate change. Thus, alongside improving waste management capacity—particularly in places where waste generation is increasing rapidly—all parts of society need to focus on moving towards zero waste and circular economy practices.

Some promising developments are taking place—the Plastics Treaty negotiations have the potential to drastically reduce the quantity of plastic entering municipal waste streams; a science-policy panel has been established to contribute further to the sound management of chemicals and waste; and reform within multinational banks is securing a stronger focus on climate change and equity. These high-level initiatives can influence action at all levels and in all countries to carry forward the zero waste and circular economy approach.

This report is intended be a guide for policymakers, governments, industry and international organisations, providing knowledge, insights and actionable steps that can be taken towards a less wasteful world. It does not offer a blueprint nor a single route to the goal, since every country will have its own contextual, socioeconomic and cultural preferences and priorities.

Industry invests following leadership and direction from government. The following recommendations therefore focus on the shape of that leadership, including how governments and industry can engage to create the enabling conditions for a circular economy, and ultimately zero-waste societies.

Multinational development banks, donors and philanthropic organisations

- Recognise the importance of integrating improved waste management zero-waste waste and circular economy strategies.
- Identify proven solutions and support their replication and scaling up in different cities, countries and regions.
- Share lessons learned openly so that repetition of failures can be avoided and successes replicated; take into account the track record of a particular solution when assessing proposals so that the most effective approaches are those that receive the greatest support.
- Require governments, municipalities and other partners to collect gender-disaggregated data on experiences with and impacts of waste, to better inform policies and other interventions.

National governments

- Legislate for the waste hierarchy; pursue all opportunities to encourage waste reduction and circular economy initiatives at a national and sub-national level, for example by introducing incentives for zero waste service delivery models, and modulated fees that promote waste reduction in producer responsibility schemes.
- Integrate policies for waste management and circular economies to prioritise waste reduction and maximise the value of secondary resources within society.
- Use national legislation to protect the rights of the informal waste sector and ensure their support and involvement in developing waste management services.
- Legislate for equal access to a waste management service; provide guidance for municipalities in how to provide waste services economically and efficiently, including by encouraging citizens to reduce waste, reuse and recycle within the home.
- Provide guidance for municipalities in waste management system design, ensuring inclusion and representation from women and the informal sector, and that systems are tailored for the needs of the local community.
- Build national waste management and circular economy expertise; pursue opportunities to share knowledge and learn from other countries with similar contexts. Use national expertise to ensure strategies meet the resource needs of the national population; take care to ensure strategies and technologies are fit-for-purpose and tailored to the needs of the country's economy, geography and culture; avoid technologies that lock in linear resource use.

Photo source: *Seventyfour / Adobe Stock*

- Focus on data to build the evidence case and business case for waste management; use this data to: include waste reduction strategies in NDCs and pursue opportunities for climate finance, and to attract private sector investment in the delivery of waste management services and infrastructure.
- Recognise that waste generation is largely influenced by business practices; use public procurement, incentives and tax breaks to support SMEs that deliver goods and services according to zero waste and circular economy models.

Municipalities

- Cooperate between municipalities to share and replicate good practice and achieve economies of scale in service delivery.
- Recognise the specific experience and expertise of both women and the informal sector and to advance waste reduction and involve them in waste management service design.
- Lead by example in the community by identifying opportunities to drive resource efficiency; raise awareness through positive and targeted messaging; and make it easy for residents and local businesses to reduce waste and participate in waste segregation programmes.
- Encourage residents to reduce waste and where possible manage waste in the home, for example through home composting, to reduce the cost of municipal waste management.
- Involve the local community and provide meaningful opportunity for feedback on waste reduction and waste management strategies; ensure systems are co-designed with service users to promote ownership and accountability and to embed behaviour change.
- Be patient and stay motivated—behaviour change around waste reduction and waste segregation takes time and consistency; keep going one step at a time.

Producers and retailers

- Recognise the vital role and responsibility of the private sector in waste prevention; take responsibility for waste generation and respond to society's demands and needs to reduce the resource-use footprint of commercial activities.
- Pursue business models that achieve financial savings through resource efficiency, such as refill, deposit return and design-for-recycling.
- Support governments with efforts to regulate waste generation, recognising that regulation creates a level playing field and gives certainty; favour regulation over voluntary targets which only add to uncertainty; avoid greenwashing.

Waste management sector

- At all times seek opportunities to move waste management practices up the waste hierarchy; use expertise about material resources to support waste reduction, resource efficiency and circular economy models.
- Help governments and municipalities to design systems that are locally appropriate, fit-for-purpose and future-proofed, ensuring they do not lock-in linear resource use and can be adapted to meet the changing needs of society.

Citizens

- Pursue conscious consumerism, buying only what is needed and avoiding goods that are over-packaged, unnecessarily single-use or have a short lifespan; use refill and deposit return schemes where they exist.
- Where possible, reuse and recycle at home to reduce waste and its burden on municipalities and the environment, for example by home composting.
- Segregate unavoidable waste into three streams for its economical and sustainable management: food and garden waste, dry and clean recyclables, and residual waste.
- Use consumer power to influence business practices; support local businesses that offer goods and services in a way that promotes zero waste and a circular economy.


Photo source: *Joaquin Corbalan / Adobe Stock*


Photo source: *Seventyfour / Adobe Stock*


Photo source: *Tomasz Zajda / Adobe Stock*

The Global Waste Management Outlook 2024 echoes the 2015 Global Waste Management Outlook's call to action to scale up efforts to prevent waste generation; to extend adequate, safe and affordable municipal solid waste management to everyone worldwide; and to ensure that all unavoidable waste is managed safely.

Photo source: *tampatra / Envato*

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Annex 1:
Data sources for waste generation and management

1A: Main regional reports and data sources consulted

Region	Report or data source
Global	Organisation for Economic Co-operation and Development. (2021). OECD Environment Statistics. Waste: Municipal waste (Edition 2020). https://www.oecd-ilibrary.org/environment/data/oecd-environment-statistics/waste-municipal-waste-edition-2020_52fe37f0-en Organisation for Economic Co-operation and Development. (n.d.). OECD.STAT. Municipal waste, Generation and Treatment. https://stats.oecd.org/Index.aspx?DataSetCode=MUNW United Nations Environment Programme (UNEP) (2021). *Food Waste Index Report 2021* – Appendix. https://wedocs.unep.org/handle/20.500.11822/35356 United Nations Statistics Division (2023). UNSD Environmental Indicators: Waste. https://unstats.un.org/unsd/envstats/qindicators.cshtml World Bank. (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Urban Development Series. https://openknowledge.worldbank.org/handle/10986/30317
Latin America and the Caribbean	UNEP (2018). *Perspectiva de la Gestión de Residuos en América Latina y el Caribe*, https://wedocs.unep.org/handle/20.500.11822/26448 UNEP (2018). *Waste Management Outlook for Latin America and the Caribbean*. https://www.unep.org/ietc/resources/publication/waste-management-outlook-latin-america-and-caribbean UNEP (2021). Baseline – Coalition for the Progressive Closure of Dumpsites in Latin America and the Caribbean. https://wedocs.unep.org/handle/20.500.11822/34804 UNEP (2021). *Roadmap for the Progressive Closure of Dumpsites in Latin America and the Caribbean*. https://wedocs.unep.org/handle/20.500.11822/34919
Europe	Eurostat (2023). Waste statistics. European Union. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Waste_statistics
Asia	UNEP, Asian Institute of Technology (AIT) and International Solid Waste Association (ISWA) (2017). *Asia Waste Management Outlook*. https://www.unep.org/ietc/resources/publication/asia-waste-management-outlook
West Asia	UNEP, International Solid Waste Association (ISWA), International Environmental Technology Centre (IETC) and Centre for Environment and Development for the Arab Region and Europe (CEDARE) (2019). *Waste Management Outlook for West Asia: Waste to Wealth*. https://www.unep.org/resources/publication/waste-management-outlook-west-asia
Africa	UNEP (2018). *Africa Waste Management Outlook*. https://wedocs.unep.org/handle/20.500.11822/25514 Scarlat, N., Motola, V., Dallemand, J.F., Monforti-Ferrario, F. and Mofor, L. (2015). Evaluation of energy potential of Municipal Solid Waste from African urban areas. *Renewable and Sustainable Energy Reviews* 50, 1269-1286. https://doi.org/10.1016/j.rser.2015.05.067
Middle East and North Africa	Thabit, Q., Nassour, A., and Nelles, M. (208). Facts and figures on aspects of waste management in Middle East and North Africa Region. Waste 1(1), 52-80. https://doi.org/10.3390/waste1010005

1B: Main country-specific sources consulted

Country	Year	Source
Argentina	2019	Ministerio de Ambiente y Desarrollo Sostenible. (2019). Gestión de residuos sólidos urbanos. https://www.argentina.gob.ar/ambiente/control/rsu
Bangladesh	2021	Asia-Europe Foundation (ASEF) Education Department. (2021). Urban Waste Management in Bangladesh: An Overview with a Focus on Dhaka. Background Paper 23rd ASEF Summer University
	2019	Ashikuzzaman, Md & Howlader, Md. (2019). Sustainable Solid Waste Management in Bangladesh: Issues and Challenges. In S. Paul, R. Sikder, & N. M. Mishra (Eds.), Handbook of Research on Sustainable Development and Governance Strategies for Economic Growth in Africa and Asia (pp. 26-47). IGI Global. https://doi.org/10.4018/978-1-7998-0198-6.ch002
Bolivia (Plurinational State of)	2022	UNEP. Análisis sobre la situación de la temática de desperdicio de alimentos en Bogotá. https://wedocs.unep.org/bitstream/handle/20.500.11822/40741/situacio%cc%81n_de_la_tematica_desperdiciosalimentos_bogota.pdf?sequence=3&isAllowed=y
Brazil	2021	Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais (ABRELPE). Panorama dos resíduos sólidos no Brasil 2021. São Paulo. https://abrelpe.org.br/panorama
	2021	Brasil. Diagnóstico Temático Manejo de Sólidos Urbanos – visão geral: ano de referência 2020. SNIS - Sistema Nacional de Informações sobre Saneamento. Brasília. http://www.snis.gov.br/diagnosticos/residuos-solidos
Canada	2022	Environment and Climate Change Canada. (2022). Canadian Environmental Sustainability Indicators: Solid waste diversion and disposal. https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/solid-waste-diversion-disposal.html
	2020	Environment and Climate Change Canada. National waste characterisation report: The composition of Canadian residual municipal solid waste. https://publications.gc.ca/collections/collection_2020/eccc/en14/En14-405-2020-eng.pdf
China	2020	National Bureau of Statistics of China. (2020). China Statistical Yearbook 2020. Beijing
	2019	National Bureau of Statistics of China. (2019). China Statistical Yearbook 2019. Beijing.
Democratic Republic of the Congo	2018	United Nations Industrial Development Organization (UNIDO). (2018). Promotion of Waste to Energy Options for Sustainable Urban Management in the Democratic Republic of the Congo. Global Environment Facility (GEF). https://www.thegef.org/projects-operations/projects/9683
Egypt	2020	Hashem, E. (2020). Factors affecting Solid Waste Recycling in Egypt. Journal of International Business and Economics, 8(1), 1-21. http://jibe-net.com/journals/jibe/Vol_8_No_1_June_2020/1.pdf
French Polynesia	2016	Pacific Regional Environment Programme (SPREP). (2016). Cleaner Pacific 2025: Pacific Regional Waste and Pollution Management Strategy 2016-2025. Apia, Samoa: SPREP
India	2021	Chaudhary, P., Garg, S., George, T., Shabin, M., Saha, S., Subodh, S., & Sinha, B. (2021). Underreporting and open burning – the two largest challenges for sustainable waste management in India. Resources, Conservation and Recycling, 175, 105865. https://doi.org/10.1016/j.resconrec.2021.105865
Indonesia	2019	World Bank. (2019). International Bank for Reconstruction and Development project appraisal document on a proposed loan in the amount of $100 million to the Republic of Indonesia for improvement of solid waste management to support regional and metropolitan cities. http://documents1.worldbank.org/curated/en/608321575860426737/pdf/Indonesia-Improvement-of-Solid-Waste-Management-to-Support-Regional-and-Metropolitan-Cities-Project.pdf
Iran (Islamic Republic of)	2017	Islamic Republic of Iran. (2017). Third National Communication to United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/national-communications-under-the-convention
Iraq	2022	Ministry of Construction and Housing and Municipalities and Public Works. (2022). Data Collection Study on Solid Waste Management in Iraq. Japan International Cooperation Agency. https://openjicareport.jica.go.jp/pdf/12367256.pdf

1B: Main country-specific sources consulted

Country	Year	Source
Jamaica	2019	National Environment and Planning Agency. (2019). State of the Environment Report 2017 Jamaica. Kingston, Jamaica. https://www.nepa.gov.jm/sites/default/files/2022-03/State-of-the-Environment-Report-Jamaica-2017_0.pdf
Malaysia	2020	Iacovidou, E., & Ng, K.S. (2020). Malaysia Versus Waste. Brunel University, London. https://www.brunel.ac.uk/news-and-events/news/articles/Mal
Maldives	2019	United Nations Environment Programme, Ministry of Environment and Energy - Maldives, and Environmental Protection Agency - Maldives. (2019). Regional waste management strategy and action plan for zone 6 in Maldives. https://wedocs.unep.org/handle/20
Mexico	2020	Secretaría de Medio Ambiente y Recursos Naturales. (2020). Diagnóstico Básico para la Gestión Integral de los Residuos (1st ed.). https://www.gob.mx/cms/uploads/attachment/file/554385/DBGIR-15-mayo-2020.pdf
Nigeria	2021	UNIDO. (2021). Study on plastics value-chain in Nigeria. https://www.unido.org/sites/default/files/files/2022-01/Plastic_value_chain_in_nigeria.pdf
Pakistan	2022	Asian Development Bank. (2022). Solid Waste Management Sector in Pakistan: A Reform Road Map for Policy Makers. http://dx.doi.org/10.22617/TCS220086-2
Philippines	2022	Filipino Environmental Planner. (2022). 15 Statistics about Solid Waste Management in the Philippines that Every Filipino should Know. https://enptinio.com/statistics-philippines-solid-waste-management/
	2020	United States Agency for International Development (USAID). (2020). Clean Cities, Blue Ocean – Initial Solid Waste Management Assessment – Philippines. https://pdf.usaid.gov/pdf_docs/PA00XWPH.pdf
	2017	Senate Economic Planning Office. (2017). 2017 Philippine Solid Wastes at a Glance. https://senate.gov.ph/publications/SEPO/AAG_Phil
Qatar, Bahrain	2022	Mariyam, S., Cochrane, L., Zuhara, S., & McKay, G. (2022). Waste Management in Qatar: A Systematic Literature Review and Recommendations for System Strengthening. Sustainability, 14(15), 8991. https://doi.org/10.3390/su14158991
Moldova	2021	Biroul Național de Statistică al Republicii Moldova. (2021). Resursele naturale și mediul în Republica Moldova, ediția 2021. [Natural resources and the environment in the Republic of Moldova, 2021 edition.] https://statistica.gov.md/files/files/publicatii_electronice/Mediu/Resursele_naturale_2021.pdf
Russian Federation	2022	Wünsch, C., & Tsybina, A. (2022). Municipal solid waste management in Russia: potentials of climate change mitigation. International Journal of Environmental Science and Technology, 19, 27-42. https://doi.org/10.1007/s13762-021-03542-5
American Samoa	2014	Asian Development Bank. (2014). Solid Waste Management in the Pacific: Samoa Country Snapshot. https://www.adb.org/sites/default/files/publication/42925/solid-waste-management-pacific-samoa.pdf
Saudi Arabia	2016	Anjum, M., Miandad, R., Waqas, M., Ahmad, I., Alafif, Z.O.A., Aburiazaiza, A.S., & Akhtar, T. (2016). Solid waste management in Saudi Arabia. Applied Agriculture and Biotechnology, 1, 13-26. https://www.researchgate.net/publication/303348044_Solid_waste_management_in_Saudi_Arabia_A_review
South Africa	2020	Polasi, Letlotlo, Matinise, Sihle, & Oelofse, Suzan. (2020). South African Municipal Waste Management Systems: Challenges and Solutions. UNEP. https://wedocs.unep.org/bitstream/handle/20.500.11822/33287/SAM.pdf?sequence=1&isAllowed=y
	2018	Statistics South Africa Department. (2018). Only 10% of waste recycled in South Africa. https://www.statssa.gov.za/?p=11527
United Republic of Tanzania	2018	United Republic of Tanzania, et al. (2018). National Solid Waste Management Strategy for United Republic of Tanzania. https://wedocs.unep.org/handle/20.500.11822/31292
United States of America	2020	United States Environmental Protection Agency (US EPA). Advancing Sustainable Materials Management: 2018 Fact Sheet. https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf

Annex 2:
Methodology – Waste generation and management

2A: Regression outputs and calculations for global municipal solid waste generation

2A.1. Methodology: Baseline estimates for global municipal solid waste generation

Producing consistent and reliable estimates of MSW generation at a global level remains a challenge due to limited data availability, inconsistent data quality and lack of harmonised concepts and definitions across regions and periods of time. (For recent reviews of different methodologies and applications at local levels, see Kolekar *et al*. 2016; Dunkel *et al*. 2022; Izquierdo-Horna *et al*. 2022; Maalouf and Mavropoulos 2022; Velis *et al*. 2023).

In this report, socioeconomic data, along with waste data, have been used to determine the best statistical approach to projecting waste generation in different years, mainly relying on data from the World Bank.

Data were collected for several indicators, and models were estimated. Sources included:

- Population: UN World Population Prospects;
- GDP based on purchasing power parity (PPP): current and historical GDP data obtained from the World Bank's World Development Indicators;
- Future projections: International Monetary Fund (IMF) and OECD forecasts. Regional averages were calculated in the case of countries for which individual forecasts were unavailable;
- Human Development Index (HDI): UNDP reports;
- International Wealth Index (IWI): UNEP Inclusive Wealth Reports;
- Urbanisation rates: World Development Indicators (WDI);
- Waste: sources for MSW were those supplying specific relevant data (e.g. Associação Brasileira de Empresas de Limpeza Pública e Resíduos Especiais [ABRELPE] in Brazil, Eurostat for the EU, United States Environmental Protection Agency [US EPA]). The main sources consulted are listed in Annex 1.

In terms of choosing variables to include in the model, Velis *et al*. (2023) combine several socioeconomic variables to investigate the best predictors of waste generation. Although there are significant relationships between waste generation and indicators such as the HDI, share of urban population, gross national income (GNI) and adult literacy rates, analysis shows that the best model fit is
a linear regression using only GDP per capita.

In this report a parsimonious linear regression model of waste generation per capita and GDP per capita has been used. Different model specifications that use these variables have been used to make the most appropriate choice and determine a weighted linear regression model of quadratic GDP per capita.

The same model has been used to adjust waste data from different years to 2020, as well as to project global MSW generation in 2030, 2040 and 2050. For this, the model developed by Kaza *et al*. (2018) and Kaza, Shrikanth and Chaudhary (2021), both published by the World Bank in the What a Waste series, was built on. Population weights were added to account for different country sizes since the aim was to estimate a parameter at the global level. The following model with weighted least squares was therefore estimated:

$$Waste_{i,t_i} = \alpha + \beta_1\, GDP_{i,t_i} + \beta_2\, GDP^2_{i,t_i} + \varepsilon_i$$

Where data were built on as a cross-section of countries wherein for each country i (for which the most recent data on waste were from the year t_i) the values for waste generation per capita and a quadratic polynomial of GDP PPP per capita in that year were included, with the regression weighted by each country's population in the same year. Estimates from the model were then used to calculate proxies for waste generation in each country in the base year and this estimate was used to calculate waste generation in 2020, again following the procedure developed by Kaza *et al*. (2018):

$$Waste_{i,\,2020} = \frac{Estimated\ Waste_{\ i,\,2020}}{Estimated\ Waste_{\ i,\,t_i}} \times ActualWaste_{i,\,t_i}$$

The same approach was used for 2030, 2040 and 2050.

GDP per capita was used as the single explanatory variable for different reasons:

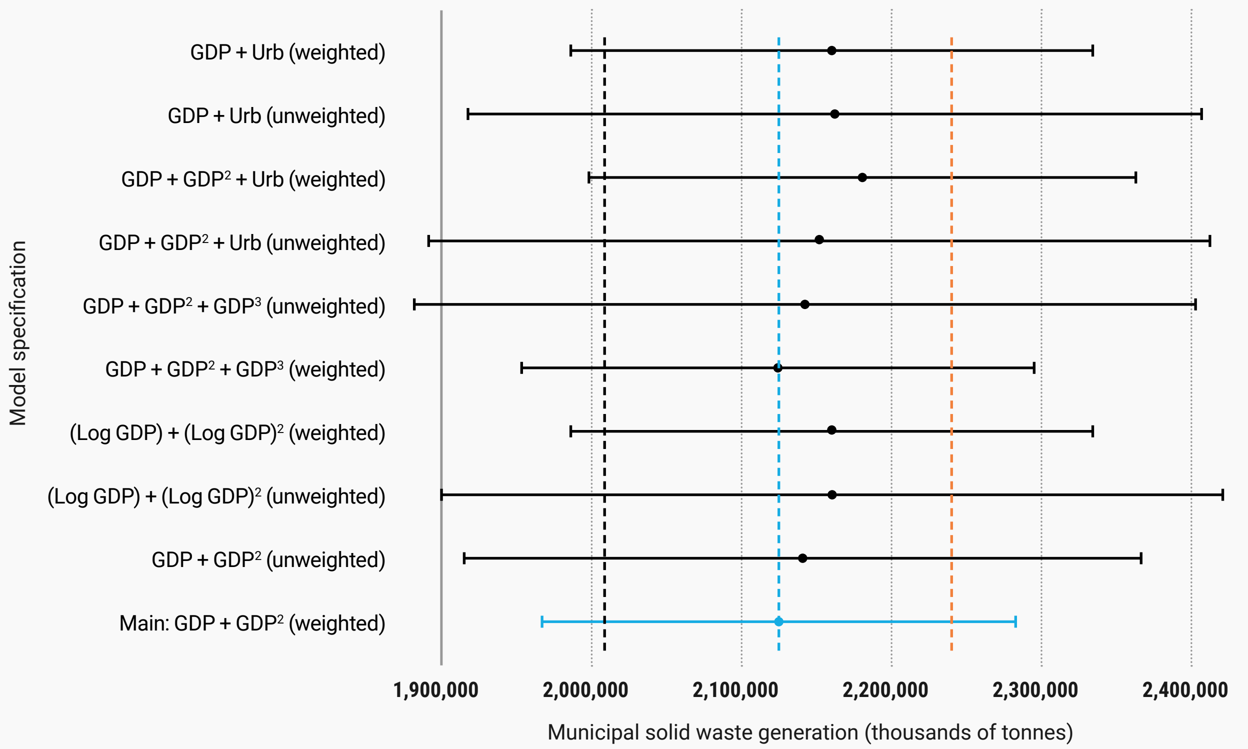
- This is an established methodology used in analysis by the World Bank and others to estimate MSW generation at the global level (e.g. see Kaza *et al*. 2018; Lebreton and Andrady 2019; Kaza, Shrikanth and Chaudhary 2021).
- While other variables can explain variations in waste generation, such as urbanisation rates, the HDI, the International Wealth Index (IWI) and literacy rates, the data are incomplete and are not comparable between countries. Many of these variables are largely explained by income levels, and GDP per capita alone can serve as an adequate predictor of waste generation in this situation (Velis *et al*. 2023).
- GDP per capita is one of the few socioeconomic indicators for which there are current data, as well as long-term forecasts, for a representative number of countries.

There were still arbitrary choices to be made in the specification of the regression model. Sensitivity analyses were therefore conducted, comparing results using different alternatives.

Figure 2A.1.1 shows estimated total MSW generation in 2020 according to the model specification used.

In Figure 2A.1.1 are comparisons of the estimated value of global MSW generated in 2020 using different model specifications, with corresponding 95 per cent confidence intervals. Models vary with respect to the inclusion of urbanisation rates, the polynomial degree of the GDP term and the weighting strategy (either weighted by population or unweighted). The blue line indicates the main specification, calculated as described in the methodology section.
The black line indicates the value for 2016 estimated by Kaza *et al*. (2018) and the red line indicates the value for 2020 estimated by Kaza, Shrikanth and Chaudhary (2021).

Figure 2A.1.1: Estimated value of global municipal solid waste generated in 2020 using different model specifications, with corresponding 95 per cent confidence intervals.



2A.2. Socioeconomic data

Figures 2A.2.1 to 2A.2.3 show the relationship between MSW generation rates and urbanisation rates, the Human Development Index (HDI) and the International Wealth Index (IWI), as well as the line of best fit and the associated 95 per cent confidence interval. There is a clear positive correlation between urbanisation, the HDI and waste generation. On the other hand, the IWI seems to have a negative correlation with waste generation due to the fact that it considers depletion of natural capital, which is negatively affected by the harmful environmental impacts of waste.

As shown in Figure 2A.2.4, urbanisation rates have a non-linear relationship with GDP per capita. They tend to increase dramatically as countries move from low income to middle income, but generally stabilise once that process is consolidated. This is in line with the development and economics literature, which shows higher urbanisation rates in developing countries (Chen *et al*. 2014).

In all four of these figures, waste data refer to MSW and are for the most recent year available (between 2010 and 2020). Urbanisation rates and HDI data are for the corresponding year. IWI data are for the most recent year available (2014). GDP data are for the corresponding year and are measured in purchasing power parity (PPP) constant 2017 international dollar. The line of best fit (quadratic polynomial) is shown in blue.

Figure 2A.2.1: Municipal solid waste generation (kg/person/year) and urbanisation.
Source: own elaboration using data from several sources.

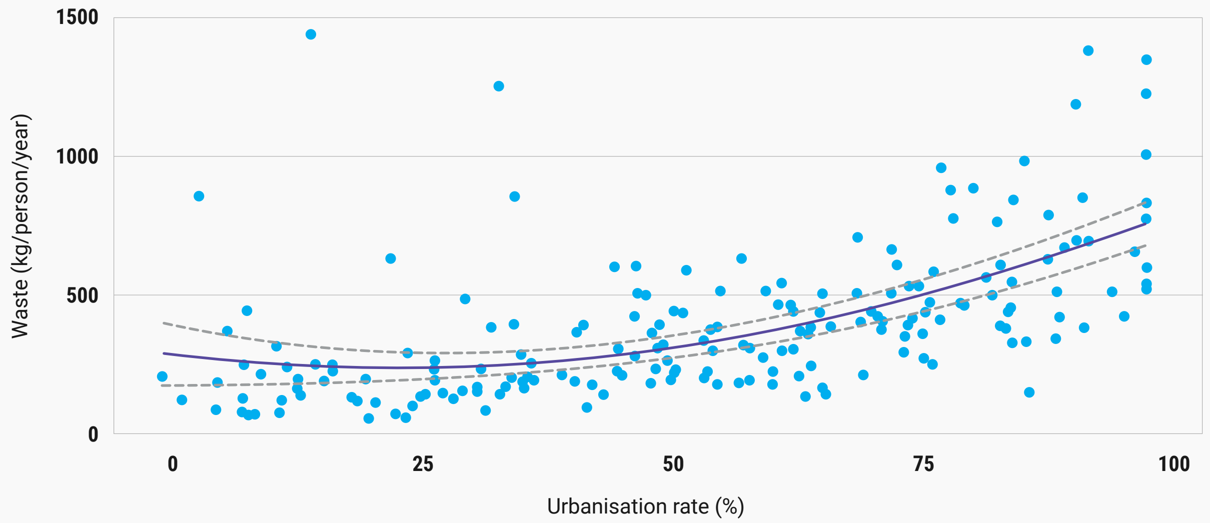


Figure 2A.2.2: Municipal solid waste generation (kg/person/year) and the Human Development Index (HDI).
Source: own elaboration using data from several sources.

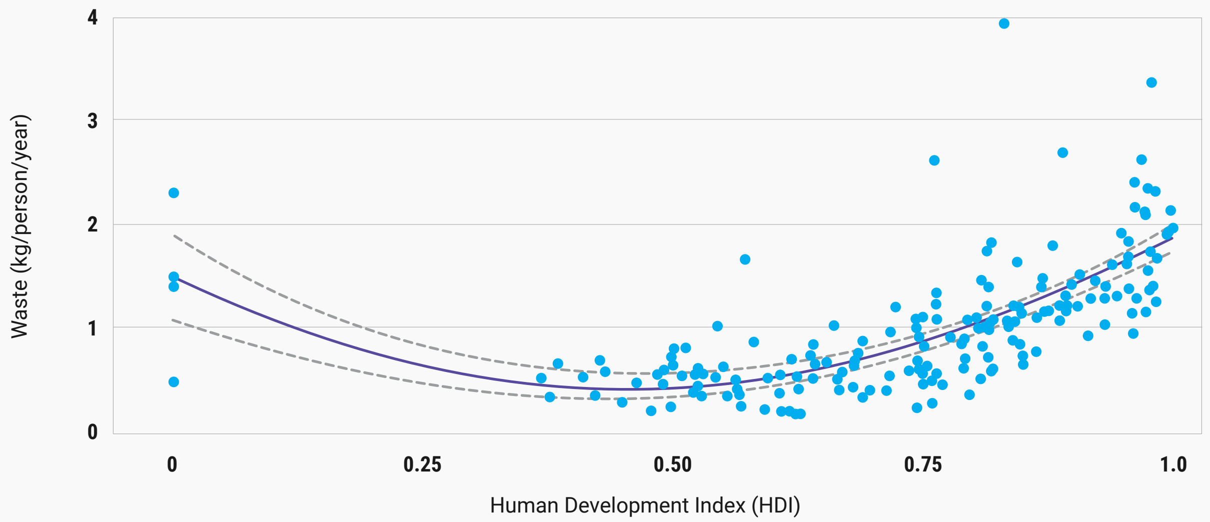


Figure 2A.2.3: **Municipal solid waste generation (kg/person/year) and the International Wealth Index (IWI).**
Source: own elaboration using data from several sources.

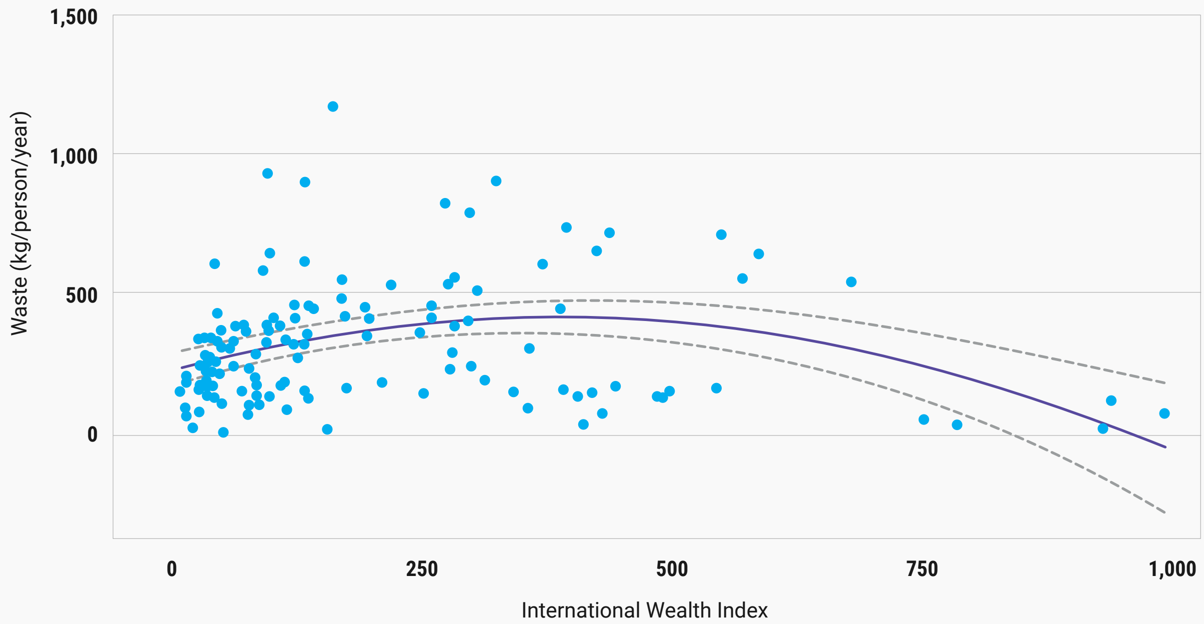
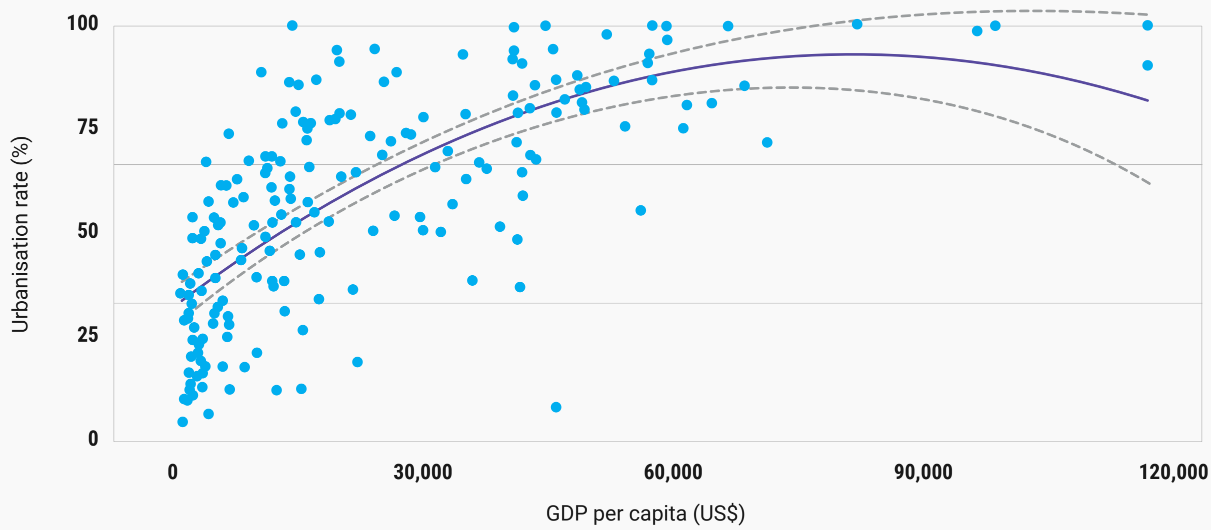


Figure 2A.2.4: **Rate of urbanisation and GDP per capita.**
Source: own elaboration using data from several sources.



Estimates of growth of GDP and population growth between 2020 and 2050 are shown in Figures 2.A.2.5 and 2.A.2.6. CAGR refers to the compound annual growth rate, which measures average yearly growth.

Figure 2A.2.5: **Estimated GDP growth per region, 2020-2050.**
Source: own elaboration using data from several sources.

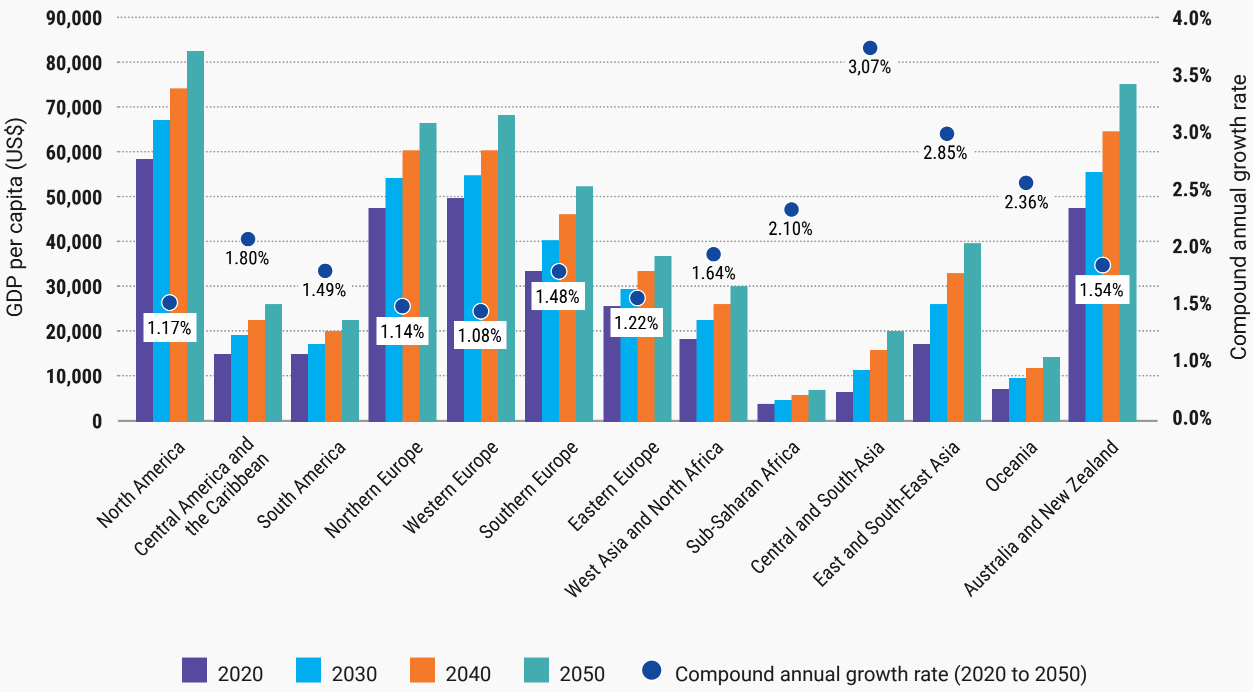
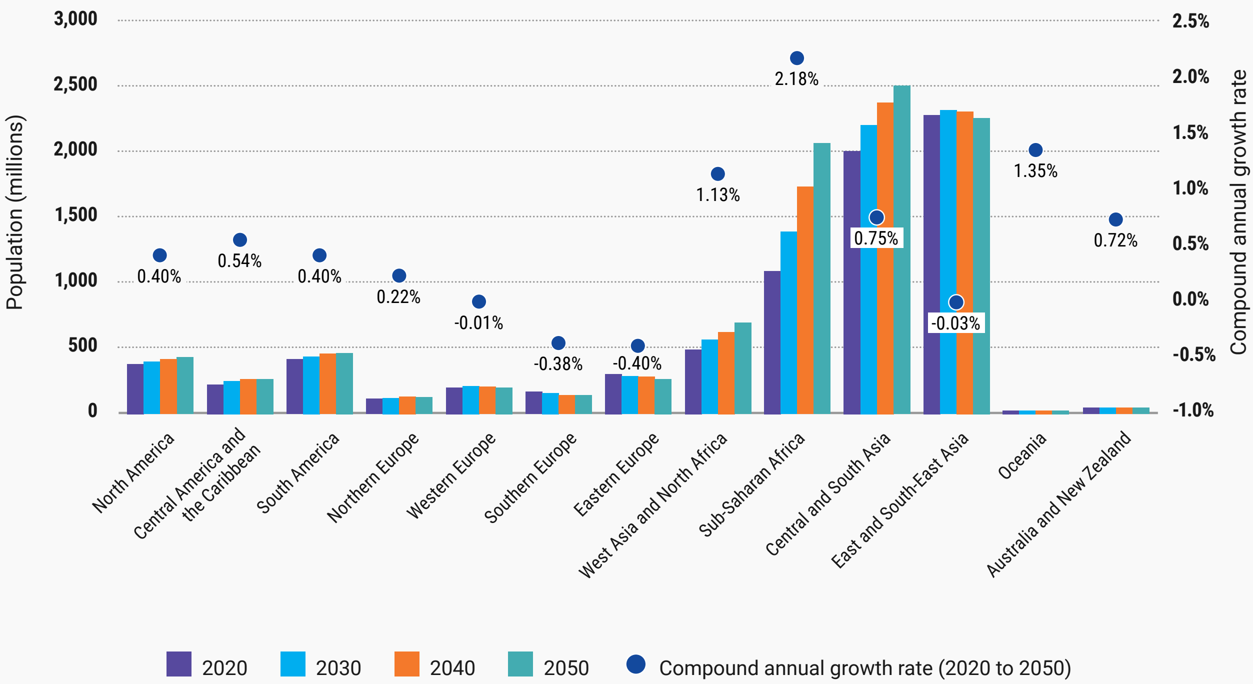


Figure 2A.2.6: **Estimated population growth per region, 2020-2050.**
Source: own elaboration using data from several sources.



2A.3. Methodology: Scenarios for global municipal solid waste generation

The methodology outlined above details how MSW generation estimates are produced under the baseline scenario (Scenario 1) Waste Management as Usual (WMU). These estimates serve as the starting point for the projection of changes in waste generation under Scenarios 2 and 3: Waste under Control (WUC) and Circular Economy (CE).

2A.3.1 MSW generation – Scenario 2 (WUC)

Under this scenario the main assumption is that the same trend in consumption patterns will continue until 2030; that is, MSW generation per capita will continue to grow as under the WMU scenario until 2030 across all regions, but will remain constant from 2030 onwards. In regions where projected per capita generation levels in 2050 are lower than the global average in 2020 (Central and Southern Asia, Oceania and Sub-Saharan Africa) the same rates are shown as in the WMU scenario.

2A.3.2 MSW generation – Scenario 3 (CE)

Under this scenario the main assumption is that total MSW generation in 2050 will remain the same as in 2020. It is assumed that total MSW generation will keep growing until 2030, remain stable from 2030 to 2040, and then return to 2020 levels by 2050. Because the projections in this report are based on changes in MSW generation rather than on population growth, this return to 2020 levels will require a drastic reduction in per capita rates. If the rate of economic growth also remains unchanged, it will be increasingly important to decouple waste generation and economic growth. It should be noted that this is a strong assumption, as the relationship between waste generation and economic growth, although it is not linear, is extremely robust (Velis *et al*. 2023).

To introduce that aspect into the calculations, the necessary global MSW generation reductions in regions have been introduced into total waste according to the relationship between income and MSW generation in each region. A constant reduction of the ratio between the amount of MSW generated per capita and GDP per capita for each region has been considered. In other words, it is assumed that reducing waste generation, given income growth, will be easier as regions already have high income rates with not-as-high waste generation rates. A smaller reduction is considered in the case of regions where projected per capita generation levels in 2050 are lower than the global average in 2020.

2B: Methodology for waste management, treatment and disposal

2B.1 Municipal solid waste destinations and collection

To estimate waste destination patterns across regions, a logic based on the Pareto Principle was applied (also known as the “80/20” rule, meaning that for many events, roughly 80% of effects come from 20% of the causes), suggesting that a significant portion of global MSW waste generation can be attributed to a small number of countries. The analysis carried out for the GWMO2 revealed that over 80 per cent of MSW generation worldwide is concentrated in only 30 countries which account for 77 per cent of the global population. Hence, thorough data collection efforts were directed towards those countries to obtain a more comprehensive understanding of the current global MSW management and destination situation (collection rate, recycling rate, landfilling rate, thermal treatment rate).

Data available in official cross-country databases were also gathered for other countries. The final sample for waste management statistics has data on 114 countries, which represent about 90 per cent of global MSW generation. With this data, weighted averages were calculated by region. In other words, regional averages were attributed to countries for which data were not available.

Collection rates were then calculated as the total amount of MSW collected divided by the total amount generated. In the case of countries for which no waste generation data were available for the same year as the waste collection data, total MSW generation was estimated using a regression model based on GDP. Similarly, rates of recycling, landfilling and thermal treatment were calculated as the total amount of waste handled in each of these ways divided by total amount of waste generated. However, there is a great variation among countries: in higher income regions comprehensive data are available for all countries, but in lower income regions these data are extremely scarce. Table 2B.1.1 presents sample size by region. The greatest challenges with respect to data availability and data quality are in Oceania, Sub-Saharan Africa, Central America and the Caribbean.

Table 2B.1.1: Municipal solid waste collection rates by region (2020)

Region	Number of countries in the region	Municipal solid waste collection rate (2020)
North America	3	100%
Central America and the Caribbean	7	71%
South America	6	95%
Northern Europe	10	100%
Western Europe	9	100%
Southern Europe	14	100%
Eastern Europe	10	100%
West Asia and North Africa	17	86%
Sub-Saharan Africa	13	43%
Central and South Asia	9	91%
East and South-East Asia	10	96%
Oceania	4	18%
Australia and New Zealand	2	100%
World	**114**	**89%**

2B.2 Forecast and scenarios

For MSW waste management and destination the scenario assumptions are as follows:

- **Scenario 1:** Waste treatment and collection rates remain constant from 2020 to 2050. That is, for each region the calculated values for recycling rates in 2020, for example, are used for all other years.
- **Scenario 2:** The baseline assumption for this scenario is that the rate of uncontrolled disposal is zero in 2050 for all regions. Regions that already have low rates achieve zero by 2030, while for others we assume a constant trend of reduction and calculate the change in rates through linear interpolation. For each decade the waste that would go untreated is distributed in the three treatment methods (recycling, landfilling, waste-to-energy) according to the share that each treatment method represents of the total treated waste in 2020, for each region. For example, a region that has 50 per cent controlled disposal in 2020 (40 per cent landfilling and 10 per cent recycling) would reach 100 per cent controlled disposal in 2050 (80 per cent landfilling and 20 per cent recycling).
- **Scenario 3:** The baseline assumptions for this scenario are that the rate of uncontrolled disposal will be zero in 2050 in all regions, and that there will be a global recycling rate of 60 per cent in that year. It is assumed that each region will reach a minimum 50 per cent and a maximum 70 per cent recycling wate (there is a fraction of waste that cannot be recycled). Recycling increases are distributed across regions according to their recycling capacity in 2020 (regions already able to recycle more in terms of quantity will continue recycling more); the share of treated waste recycled in 2020 (regions that historically prefer recycling over other methods will recycle more); and their relative recycling rates compared to the rest of the world (regions that are lagging behind need to increase recycling at a greater rate).

2C: Methodology for monetary costs

Table 2C.1 shows estimated MSW management costs by regions' income level. Waste collection and treatment is more expensive in upper income regions, where it can cost several times more than in lower income ones.

Table 2C.1: Costs of municipal solid waste management (US$/tonne).

	Low income		Lower middle-income		Upper middle-income		High income	
	Reported	Expert assessment	Reported	Expert assessment	Reported	Expert assessment	Reported	Expert assessment
Collection	40	20-50	16	30-75	98	50-100	121	90-200
Landfill	NA	NA	NA	15-40	NA	25-65	53-99	40-100
Recycling	NA	0-25	NA	5-30	NA	5-50	202	30-80
Waste-to-energy	NA	NA	NA	NA	NA	60-150	134	40-200
Open dumping	7	2-8	25	3-10	NA	NA	NA	NA

NA = not available

Source: Kaza et al. 2018

Global cost figures are obtained by applying average regional costs per tonne according to the forecasts developed in the scenario study. These forecasts are based on data from *What a Waste 2.0* (Kaza *et al*. 2018), as shown in Table 2C.1, calculated as weighted averages considering each country's income level and updated with inflation and currency data from the IMF and World Bank. Calculations for the scenario study do not consider changes in prices throughout the years.

Photo source: *Seventyfour / Adobe Stock*

Annex 3:
Life cycle assessment as an Environmental Management Tool

Life cycle assessment (LCA) is a valuable environmental management tool used to comprehensively evaluate the environmental impacts associated with a product or service throughout its entire life cycle. When applied to waste management, LCA enables a holistic assessment of the environmental burdens and benefits of various waste management practices. In this study a streamlined LCA was conducted according to International Organization for Standardization (ISO) standards ISO 14040 (2006) and ISO 14044 (2006), focusing on waste management scenarios in selected regions.

The LCA was applied using SimaPro® 9.2.0.2 software. The inventory of scenarios used secondary data for foreground processes, obtained mainly from the estimates in previous chapters, and generic datasets for the background processes obtained from the Ecoinvent version 3.7.1 (Moreno-Ruiz *et al*. 2020), using allocation at the point of substitution (APOS) database. The Global (GLO) and rest-of-the world (RoW) datasets were selected, and the attributional modelling was used in this LCA. The goal and scope of this LCA were to estimate the overall potential environmental impacts associated with different waste management scenarios worldwide. The main function of MSW treatment and disposal systems is to prevent entry of hazardous contaminants into the environment, ensuring both human and environmental health.

The system boundaries of the study encompassed the entire waste management process, from cradle (when an item becomes valueless and is typically discarded) to grave (where value is restored through recycling or energy recovery, or waste is transformed into emissions or inert material placed in a landfill). This included collection, waste treatment (including waste-to-energy and recycling), and final disposal (including landfill and uncontrolled disposal).

Inputs such as materials, energy, infrastructure, and relevant by-products were considered. A key aspect of LCA studies of waste management systems where recycling activities are present is to account for resource recovery and the related substitution effects. The so-called "system expansion" as a substitution, which is the most common modelling approach in systems where resources are recovered, was used and is consistent with the approach of other studies (Christensen *et al*. 2020). However, although multiple scientific papers assume a 1:1 substitution ratio between similar materials/products, this is often incorrect as the actual ratio is likely to vary (Rigamonti *et al*. 2020).

The substitution ratio represents the proportion of avoided extraction of virgin materials corresponding to the recycling of a specific material. For instance, a substitution ratio of 0.9 means that for every kilogram (kg) of that particular material sent for recycling, approximately 0.9 kg of the equivalent virgin material are avoided from being extracted. This implies that recycling 1 kg of the material contributes to the avoidance of 0.9 kg of raw material extraction. The determination of these substitution ratios involves a comprehensive analysis considering various factors, including the properties of the recycled material, the efficiency of the recycling process, and market dynamics. It is important to note that the specific ratios can vary for different materials and recycling scenarios.

Table A3.1 shows the substitution ratio of similar materials/products assumed in this LCA as related to recycling practices.

Table A3.1:
Substitution ratio of similar materials/products (adapted from Rigamonti *et al*. 2020)

Material	Substitution ratio
Steel and iron	1:0.9
Paper	1:0.8
Glass	1:0.8
Mixed plastics	1:0.6
Aluminium	1:0.9

Along with the benefits derived from recycling through avoided products, the analysis in this report incorporates the assumption that for each tonne of recycled material additional consumption of 39 kilowatt hours (kWh) of electricity is allocated to material sorting. There is associated transport of 50 tonnes/kilometre (km) from collection point to sorting facility.

The functional unit is one (metric) tonne of waste for treatment and disposal. The total amount of MSW generated per region was calculated according to waste generation estimates related to the different scenarios and defined timeframes.

Potential environmental impacts were calculated using the IPCC 2013 method, as well as the USEtox 2 model. The selected methods and indicators are presented in Table A3.2.

This LCA is designed to inform decision-makers and stakeholders about the overall impacts of waste management practices on a global scale. The focus is on synthesising the impacts of waste management systems and comparing their overall performance.

While the results are based on estimations and generic data, due to data limitations, they serve as a starting point for rough comparisons between different system options and can guide strategic planning despite uncertainties. For more accurate estimations of impacts at the regional level, higher-quality data would be necessary.

Table A3.2: Selected methods of calculating environmental impacts with environmental impact categories

Characterisation factor	Indicator	Method	Description
Midpoint	Global warming potential (kg CO_2 equivalent)	IPCC (2013)	Developed by the IPCC, this method contains the IPCC climate change factors with a timeframe of 100 years. Greenhouse gas emissions are expressed in terms of kg carbon dioxide (CO_2) equivalent (kg CO_2 eq), which provides the global warming potential (GWP) of each gas as follows: CO_2 – GWP of 1, methane (CH_4) – GWP of 28-36, and nitrous oxide ($_{N2O}$) – GWP of 265-298, all over a 100-year time horizon (IPCC 2006, 2019).
Endpoint	Ecosystem quality	USEtox 2	USEtox is a model based on scientific consensus that provides midpoint and endpoint characterisation factors for human toxicological and freshwater ecotoxicological impacts of chemical emissions in life cycle assessment. It was developed under the auspices of the UNEP and the Society for Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative (Fantke *et al*. 2017).
Endpoint	Human health		

A3.1 Estimating greenhouse gas emissions: Considerations

Different waste management practices have distinctive GHG emission profiles. Open dumps and landfills primarily produce methane (CH_4) due to anaerobic decomposition of organic waste, with smaller amounts of carbon dioxide (CO_2) and nitrous oxide (N_2O) also released (Zhang *et al.* 2019). In contrast, waste-to-energy facilities, which incinerate waste, primarily emit CO_2, along with smaller amounts of CH_4 and N_2O. Emissions from waste-to-energy facilities, however, may be offset by the energy produced from the waste combusted, reducing demand for energy from fossil fuel sources (Pfadt-Trilling, Volk and Fortier 2021).

On the other hand, open burning of waste can release significant amounts of CO_2, CH_4 and N_2O. It can also emit black carbon, a short-lived climate pollutant that contributes to global warming and has significant health impacts (Reyna-Bensusan *et al.* 2019). Composting emits mainly CO_2, with smaller amounts of CH_4 and N_2O (Yasmin *et al.* 2022). Nevertheless, emissions from composting are generally lower than those from landfilling or open dumping due to the aerobic conditions, which favour the formation of CO_2 over CH_4, a much more potent GHG. Additionally, recycling processes mainly lead to indirect GHG emissions, resulting from the energy consumed during the process, which primarily results in CO_2 emissions. However, these emissions are typically lower than the emissions that would result from the extraction and processing of virgin materials.

Lastly, transport activities in waste management, such as waste collection and transportation to treatment facilities or landfills, contribute to GHG emissions. These emissions primarily stem from fuel combustion in vehicles, resulting in the release of CO_2, nitrogen oxides (NO_x) and particulate matter, including black carbon particles, released through incomplete combustion of fossil fuels.

The IPCC has estimated that the direct contribution of the solid waste and wastewater sectors to GHG emissions to be 3-5 per cent. Of this total, the largest source is methane from landfills followed by wastewater emissions. Although the IPCC guidelines play an important role in producing GHG estimates for the waste sector, they account only for emissions from landfills, incineration without energy recovery and composting. Thus, there is a lack of activities such as recycling and waste-to-energy in the IPCC guidelines. Several tools in addition to the IPCC guidelines have been developed to estimate GHG emissions (Table A3.3). Each tool has its advantages and disadvantages. The choice depends on the specific context and requirements of the analysis. Factors to consider include scope, scale, data availability and the tool's intended purpose. However, many of these tools (e.g. WARM) are based on the life cycle perspective. To understand the full implications of MSW management practices, including activities related to recycling and energy recovery, a life-cycle approach is required.

Table A3.3: Tools for calculating greenhouse gas emissions from various waste management activities

Intergovernmental Panel on Climate Change (IPCC) Guidelines	The IPCC guidelines provide a comprehensive framework for estimating greenhouse gas (GHG) emissions from various sources, including waste management activities. They furnish standardised methodologies, emission factors and calculation approaches to ensure consistency and comparability in estimating and reporting GHG inventories from specific activities within the waste sector, such as solid waste disposal on land (landfills), waste incineration, anaerobic digestion of wastewater and related processes.
Life cycle assessment (LCA)	LCA has been extensively employed for GHG accounting in waste management. It allows consideration of the benefits that stem from materials recycling, composting and energy recovery. These processes substitute the use of virgin materials or energy from alternative sources, thereby mitigating associated GHG emissions.
Solid Waste Management (SWM) GHG Calculator (Institut für Energie- und Umweltforschung 2023)	The SWM-GHG Calculator is a tool designed to assist decision makers in developing countries and emerging economies in understanding the GHG emission impacts of solid waste management practices. Its main purpose is to provide guidance and information on GHG emissions associated with different waste management options and to help assess the potential GHG mitigation benefits of adopting alternative waste management strategies.
Waste Reduction Model (WARM) (US EPA 2023)	WARM is a tool developed by the United States Environmental Protection Agency (US EPA) to help estimate GHG emissions associated with waste reduction activities. WARM specifically focuses on estimating emissions related to source reduction, recycling and composting efforts. It provides users with emission factors for various waste management activities.
Solid Waste Emissions Estimation Tool (SWEET) (CCAC 2021)	Also developed by the US EPA, this tool was designed to estimate GHG emissions from solid waste management activities such as landfilling, composting and recycling. It takes into account factors such as the type and amount of waste processed and landfill gas capture rates and energy recovery rates in order to assist users in determining first-order city-level estimates of annual emissions of CH_4, black carbon and other pollutants (e.g. CO_2).
Reducing Greenhouse Gas Emissions through Inclusive Recycling: Methodology & Calculator Tool (Women in Informal Employment Globalizing and Organizing [WIEGO] 2021)	A methodology and calculator tool enabling the estimation of GHG emissions that waste picker groups prevent. This tool, developed by the global non-governmental organization WIEGO for waste picker organizations and their supporters, allows the measurement of GHG emissions avoided through the following waste treatment methods: diversion of waste from decay in landfills and dumps; recycling; manual sorting and transportation; and diversion of materials from open burning.

A3.2 External costs

Environmental costs are metrics utilised to quantify the societal cost of environmental pollution. These costs indicate the economic welfare losses that ensue when an additional kilogram of pollutant is discharged into the environment. To estimate external costs, LCA results were calculated using the Recipe method (Goedkoop *et al*. 2009) at the midpoint level, following the approach from de Bruyn *et al*. (2018) for the impact categories shown in Table A3.4. The damage costs are used as a basis for the valuation of environmental impacts, representing the material and immaterial damage of the environmental impacts on those affected. They equal the willingness of the affected party to prevent environmental damage. However, when valuation with damage costs was too uncertain, valuation with abatement costs was considered preferable (de Bruyn *et al*. 2018).

Table A3.4: Selected environmental impact categories with characterisation factors at midpoint level

Indicator	Unit
Climate change	kg CO_2 equivalent
Ozone depletion	kg CFC-11 equivalent
Terrestrial acidification	kg sulphur dioxide (SO_2) equivalent
Freshwater eutrophication	kg phosphorus (P) equivalent
Marine eutrophication	kg nitrogen (N) equivalent
Human toxicity	kg 1,4-dichlorobenzene (1,4-DCB)
Photochemical oxidant formation	kg non-methane volatile organic compound (NMVOC)
Particulate matter formation	kg PM_{10} eq
Ionizing radiation	kBq U235 eq
Terrestrial ecotoxicity	kg 1,4-dichlorobenzene (1,4-DCB)
Marine ecotoxicity	kg 1,4-dichlorobenzene (1,4-DCB)
Freshwater ecotoxicity	kg 1,4-dichlorobenzene (1,4-DCB)

This methodology allows the conversion of diverse emissions from waste streams, which depend on their processing route, into quantifiable environmental prices. Environmental prices were adjusted from their 2015 EUR value to their 2020 EUR value, accounting for the average European inflation rate, and these figures were converted to 2020 United States dollars (US$). Regarding future external cost, a choice was made to adopt a conservative approach by assuming price constancy in future emissions valuations, even though environmental prices could potentially increase over time.

The estimates, based on average European conditions, have inherent limitations. For instance, the averages may show considerable variation when applied on a global scale. Despite these uncertainties, the environmental prices discussed in this report should be interpreted as "minimum prices". As scientific understanding continues to evolve, particularly with respect to non-degradable or poorly degradable substances, it is becoming increasingly apparent that these substances are more harmful to the environment than previously thought (de Bruyn 2018).

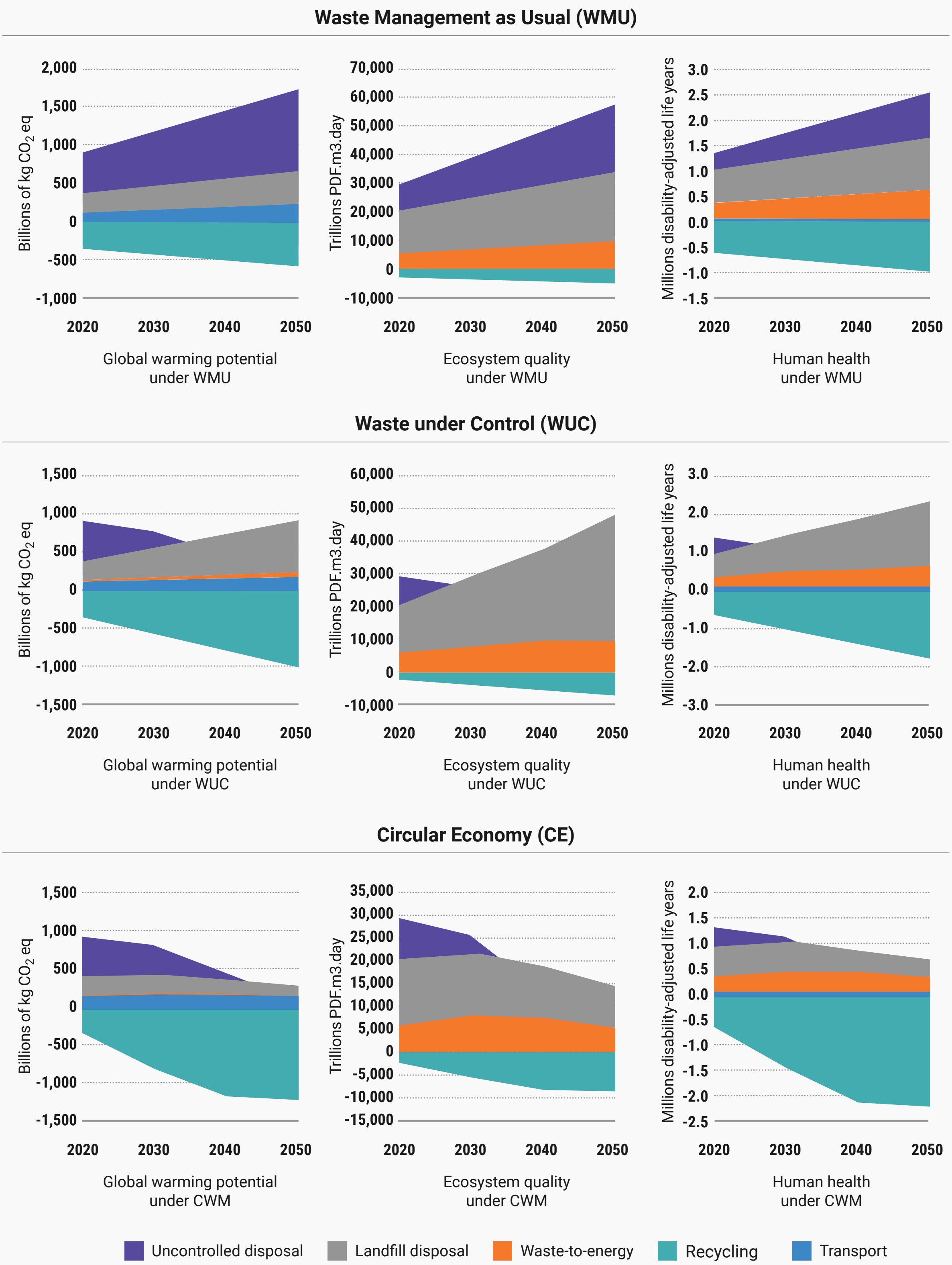
A3.3 Sensitivity analysis

Recycling materials involves a multifunctional process that serves two purposes: waste treatment and the production of new secondary materials. This dual function requires a specific approach to effectively manage the multifunctionality of recycling. In the analysis in this report, the Allocation at the Point of Substitution approach was initially used to address this multifunctionality. Recognising the ongoing debate surrounding multifunctional processes and recycling in LCA and, in order to further evaluate the influence of recycling impacts and assess the robustness of our findings, it was proposed to conduct a sensitivity analysis.

In the proposed sensitivity analysis there is an emphasis on the implications of different allocation methods specifically related to recycling impacts. The cut-off approach to be applied involves excluding the benefits of recycling (i.e. avoided products) from the system boundary. By applying the cut-off approach, it is intended to gain a better understanding of the environmental implications and potential trade-offs of recycling without considering the avoided products. This analysis would provide valuable insights into the sensitivity of the findings to different allocation approaches and help to assess the robustness of the conclusions.

Figure A3.1 shows global projections for global warming potential, ecosystem quality and human health with respect to waste management practices globally from 2020 to 2050, under the Waste Management as Usual (WMU), Waste Under Control (WUC) and Circular Economy (CE) scenarios (Scenarios 1-3), according to the proposed sensitivity analysis.

Figure A3.1 Sensitivity analysis of global projections of global warming potential, ecosystem quality and human health associated with waste management under the WMU, WUC and CE scenarios (Scenarios 1-3), 2020-2050. *Source: Prepared by the authors, based on the USEtox 2 model and IPCC (2013).*



When not accounting for the benefits of avoided products in recycling, the results obtained using the cut-off approach provide a more conservative estimate of the environmental impacts associated with waste management practices. By focusing on the direct environmental burdens of each waste management option (e.g. uncontrolled disposal, landfill disposal, thermal treatment, plus transport) the cut-off approach provides valuable insights into the immediate consequences of these practices. However, it is crucial to recognise that the exclusion of avoided product credits does not diminish the overall importance and benefits of recycling. Recycling plays a vital role in reducing the amount of waste managed using other options such as landfilling and thermal waste-to-energy treatment.

Furthermore, the analysis highlights the continued critical importance of waste reduction for minimising environmental impacts in the long term. Prioritising waste reduction and implementing effective recycling strategies offers the opportunity to substantially decrease the volume of waste that needs disposal. By embracing waste reduction practices, it will be possible shift towards more sustainable waste management practices that prioritise resource conservation, energy efficiency and environmental protection.

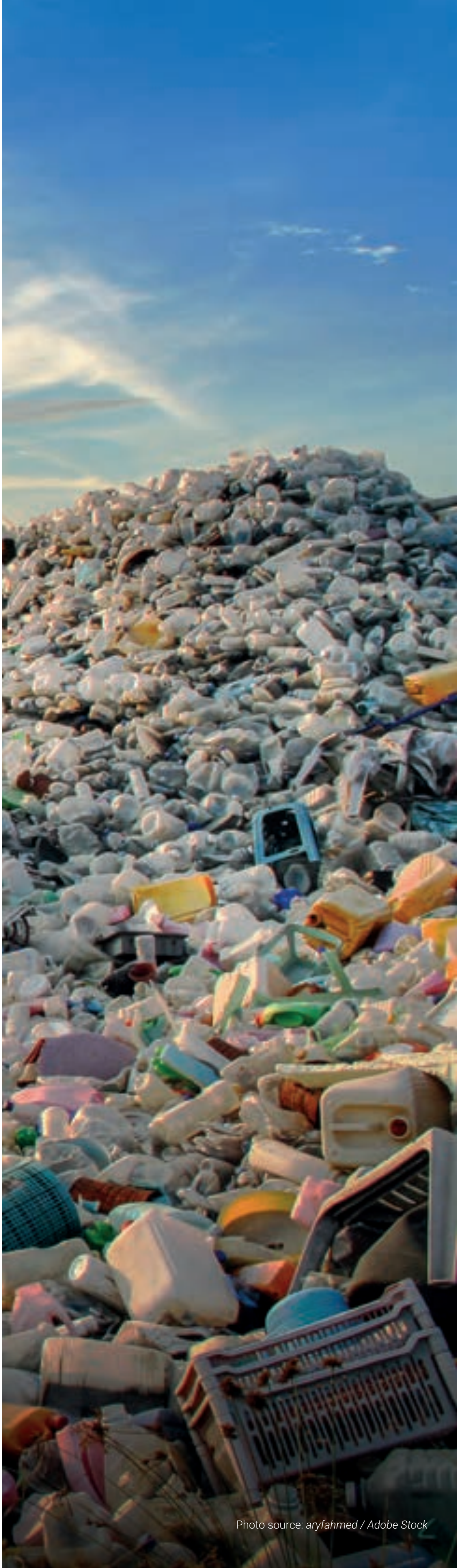


Photo source: *aryfahmed / Adobe Stock*

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This publication is supported by the Environment Fund - UNEP's core financial fund The Fund is used to provide scientific evidence on the state of the global environment, identify emerging environmental issues and innovative solutions, raise awareness and advocacy, bring together stakeholders to agree on action, and for building capacity of partners. Core funding gives UNEP the strength and flexibility to implement the programme of work (in support of the 2030 Agenda) as approved by its Member States, and to strategically respond to emerging challenges. UNEP is grateful to all the Member States that contribute to the Environment Fund.

For more information: unep.org/environment-fund

For more information:
unep-communication-director@un.org
United Nations Avenue, Gigiri
P O Box 30552, 00100
Nairobi, Kenya

unep.org