Reducing waste management's contribution to climate change

From post-landfilling methane capture to pre-landfill methane prevention

Study

June 2024

ZERO WASTE EUROPE

Contents

Executive Summary

Global waste management is fraught with challenges, particularly concerning methane emissions from landfills. In 2020, over 2.1 billion tonnes of municipal solid waste (MSW) were generated, with 62% managed at controlled facilities, and nearly half of this landfilled. With 2.7 billion people lacking waste collection services, the remaining 38% was handled in an uncontrolled manner. Methane, a potent short-term greenhouse gas, is a significant byproduct of landfilling biodegradable waste, contributing substantially to global warming.

Traditional strategies focus on capturing landfill gas to reduce methane emissions, but capture rates of methane generated over time are often low, especially during the initial waste decomposition stages. Recent investigations indicate landfills may be releasing more methane than models have suggested in the past, highlighting the need for improved emission reduction strategies.

An alternative approach involves biologically treating waste before landfilling to minimise methane generation. Biostabilisation techniques (using an approach similar to composting) can significantly reduce the potential for methane production, rendering gas capture systems unnecessary. Mechanical Recovery and Biological Treatment (MRBT) further enhances this by extracting additional recyclables from leftover mixed waste (LMW), thereby reducing the climate impact of both landfilling and incineration.

MRBT systems offer a promising solution for waste management, aligning more closely with circular economy principles and mitigating short-term methane emissions. This approach minimises the global temperature impact of residual waste management and reduces the likelihood of methane emissions reaching critical levels.

In conclusion, shifting the focus from gas capture to biostabilisation of waste prior to landfilling provides a highly effective and sustainable strategy for managing waste and addressing climate change. It avoids emitting fossil-derived CO_2, as happens in the case of thermal treatments, such as incineration. Hence, this method not only reduces emissions but, where additional sorting of LMW is included, also supports a transition towards a more circular and resilient economy.

Introduction

It is far from well-understood how waste is managed at the global level. One study estimated that more than 2.1 billion tonnes of municipal solid waste (MSW) were generated in 2020, with 62% being managed at controlled facilities.[1] Of this, almost half was landfilled (see Figure 1).

The remaining 38% of MSW was managed in an uncontrolled manner (either dumped in the environment at sites without any 'environmental control', or burned). This might be after waste has been collected, but in some cases, waste may simply not be collected at all: the same study estimated that some 2.7 billion people do not have their waste collected.[2]

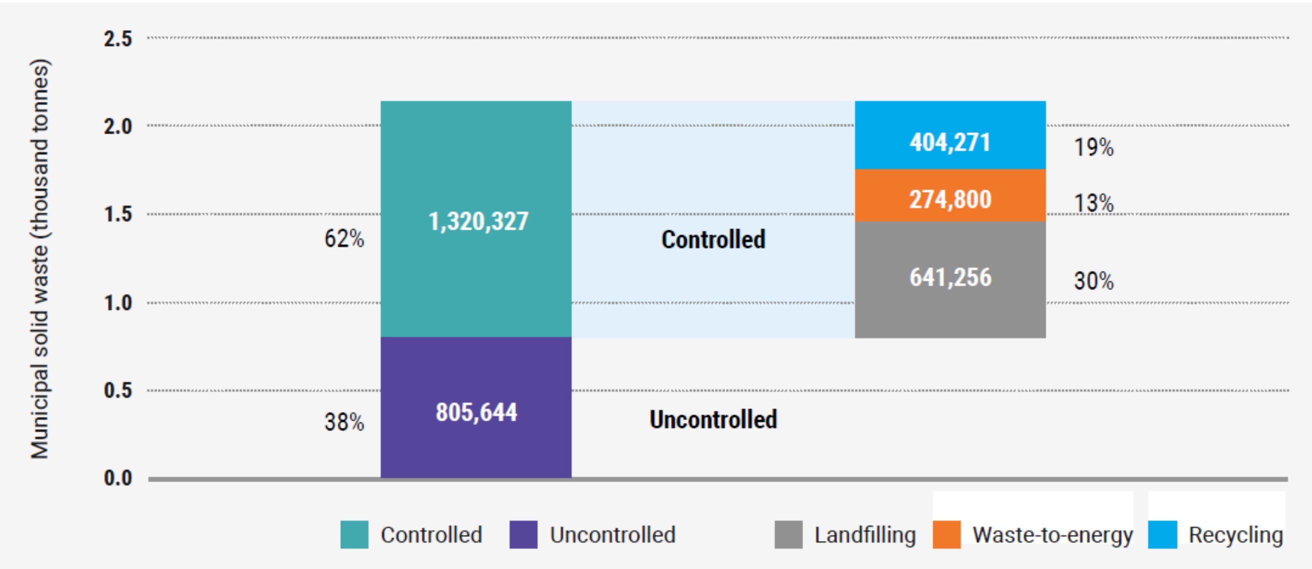

Figure 1: Global municipal solid waste destinations in 2020: Controlled (recycling, waste-to-energy and landfilling) and uncontrolled[3]

It is well known that landfilling biodegradable wastes causes the generation of methane. Methane is a greenhouse gas which exerts its warming effect over a relatively short term. This has led to considerable focus on strategies to reduce methane emissions; while emissions of carbon dioxide have a cumulate impact on temperature change over the long term, reducing methane emissions can lower methane's contribution to global temperature increase in a matter of decades.

[1] United Nations Environment Programme (2024) *Global Waste Management Outlook 2024: Beyond an age of waste – Turning rubbish into a resource*.
[2] Ibid.
[3] Source: United Nations Environment Programme (2024) *Global Waste Management Outlook 2024: Beyond an age of waste – Turning rubbish into a resource*.

The IPCC's Sixth Assessment Report estimated that methane emissions are responsible for half the net contribution to radiative forcing,[4] and temperature increase, since pre-industrial times (see Figure 2).

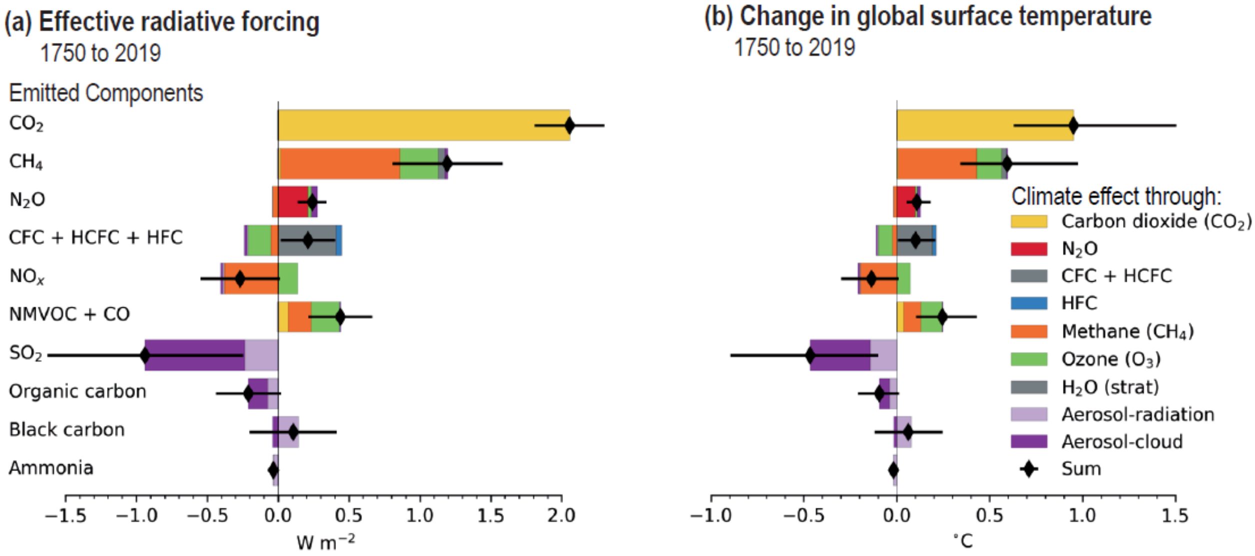

Figure 2: Contributions made to radiative forcing and temperature by different gases[5]

Waste is reckoned to account for around 20% of anthropogenic methane emissions.[6] However, the data underpinning these figures are unreliable (not least, because data on waste generation are also unreliable). Furthermore, data from recent studies appear to indicate that landfills may be emitting more methane, or emitting at a faster rate, than previously reported based on modelling.[7] What is clear is that methane emissions should be minimised. The faster these emissions can be reduced, the sooner the impact on reducing methane's contribution to global temperature increase will be observed.

Methane emissions from landfilling and dumps

Engineered landfills are generally designed to operate under anaerobic conditions (i.e., in the relative absence of oxygen). Nonetheless, landfill gas includes both methane and carbon dioxide, with the exact proportion

[4] Radiative forcing can be considered a measure of how much of the energy entering the Earth's atmosphere is trapped by a given gas, thereby contributing to increasing temperature.
[5] Source: IPCC (2021) Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.
[6] United Nations Environment Programme and Climate and Clean Air Coalition (2021) Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions.
[7] Riley Duren et al., (2019) California's methane super-emitters. See also D. Carrington and Seán Clarke (2024) Revealed: the 1,200 big methane leaks from waste dumps trashing the planet.

varying somewhat. Typically the shares, by volume of gas, will be around 55% methane and 45% carbon dioxide, with some trace gases also present.

When wastes are first deposited there, some biodegradable components start to break down more or less immediately. Different biodegradable wastes degrade at different rates; food waste, being more putrescible, degrades more rapidly than most garden and park wastes. Some notionally biodegradable wastes are not easily degraded in the anaerobic conditions of landfills, and so may degrade very slowly, if at all (woody materials which have a high lignin content, for example, may be sequestered in landfills).

Over time, compartments of a landfill may be filled, after which they can be capped. The capping allows the compartment to be partially sealed off, so that some of the gas generated in the landfill can be extracted from the body of the landfill (effectively, it is sucked out using a network of wells and pipes for landfill gas capture), and may be used to generate energy. The combustion of the gas leads to oxidation of the methane to carbon dioxide.

However, some methane may escape from the landfill through the capping layer. As it moves through this capping layer, it may be oxidised to the less potent, but longer-lived, greenhouse gas, carbon dioxide. Any methane that is not oxidised, is released into the atmosphere as methane. Methane may also be emitted directly to the atmosphere in the period before a given compartment is capped, a fact that is extremely important when looking at the more rapidly degrading food waste fraction.[8]

Reducing methane emissions from landfills by capturing landfill gas

Much conventional wisdom has focussed on improving the operation of landfills themselves as a means to increase the amount of landfill gas that is captured and reduce the extent to which landfill gas can easily migrate through the surface of the landfill. The aim is, in essence, to capture as much of the gas as possible from the landfill, and to a lesser extent, to ensure the oxidation of whatever landfill gas is not captured. In doing this, the aim is to minimise the extent to which landfill gas escapes from the site. There is a subsidiary objective of maximising the energy generated from the captured landfill gas. Note, that as parts of a landfill are capped, they tend to generate landfill gas at a lower rate over time. In later years, the focus may shift from generating energy from the captured landfill gas to flaring it. While this means that no useful energy is derived from the combustion of the gas, the methane in landfill gas is instead converted to carbon dioxide.

This approach, however, suffers from the fact that it is difficult to capture methane in the early stages of a cell's operation, while also being the period where the food waste fraction is most actively producing methane. Gas capture systems are also imperfect means of capturing landfill gas, though well-operated sites may

[8] See Max Krause et al. (2023) *Quantifying Methane Emissions from Landfilled Food Waste*.

capture large shares in the 'sweet spot' when cells are capped, and where gas generation is still relatively strong (the 'instantaneous' rate of landfill gas capture might be relatively high). Nonetheless, over the lifetime of the site (and of the waste being deposited), achieving high rates of landfill gas capture is not easy. In the UK, for example, where comprehensive gas capture systems have been in place for some time at landfills, recent studies suggest that the capture of methane over the lifetime of a site might just be around 52%.[9] This estimate was revised downwards based on the acknowledgement that gas generation seems to be much higher in earlier years than had been predicted previously.[10]

Reducing methane emissions from landfills by reducing the potential of waste to generate methane

An alternative approach to addressing methane emissions from landfills is to 'do something' to the waste before it is landfilled to ensure the likelihood of it generating far less methane. One way of doing this is to facilitate a 'controlled rotting' of the biodegradable material under aerobic conditions (i.e. in the presence of air), as opposed to anaerobic conditions (in the relative absence of air, as in landfills). This is what aerobic biological stabilisation, similar to composting, effectively achieves: it works by fostering conditions for microorganisms to degrade wastes derived from biomass in the presence of air, so that the degradation process generates minimal methane. Instead, the carbon within the material is released as carbon dioxide, with some of the carbon being converted to more stable 'humus' type matter.

Using this type of approach, the biodegradation that takes place makes the remaining material less and less susceptible to further degradation (effectively, the biomass is being consumed as feedstock for microorganisms). This renders it less able to generate methane if subsequently landfilled. Various indices have been developed to measure the extent to which the remaining material is likely to generate methane when landfilled. These indices are amenable to assessment using different test methods, essentially measuring residual microbial activity (which is in turn related to how "resilient" to further degradation the remaining waste is), and can be used as a basis for establishing a suitable level of reduction in the 'activity' of waste to ensure the likelihood of it generating minimal methane when landfilled. Methane generation might not be zero, but at landfills receiving only this type of material, the use of gas capture systems would be futile, allowing them to not be installed in the first place. Instead, the emphasis may be on the nature of the cover layers/capping used at the sites. The cover layers can be designed to maximise the oxidation of the remaining methane as it passes through the landfill cap. Since the rate of generation of gas would be much lower than in

[9] Golder Associates (2014) Review of Landfill Methane Emissions Modelling.
[10] This is also reflected in the findings in the aforementioned US-EPA study (Max Krause et al. (2023) *Quantifying Methane Emissions from Landfilled Food Waste*.

landfills where waste is not treated in this way, the flow through the surface is slower, and the potential for oxidising a higher proportion of the remaining gas generation may be correspondingly increased.

In this approach, therefore, biologically treating waste prior to landfilling can lead to more significant reductions in methane generation than are achieved through installing gas capture systems. Instead of seeking to capture methane generated in the body of the landfill, the emphasis is on preventing the generation of methane at all (and hence, the absence of gas capture systems).[11] This approach is known as 'biostabilisation' of waste.

Note that the business-as-usual approach, which is based on capturing landfill gas, can lead to the generation of energy. This might be considered a benefit too good to forego. However, the emissions which are avoided by generating energy in this way are small compared to the impact of the emitted methane (see Figure 3). Additionally, these benefits will decline as energy systems decarbonise as a result of countries' efforts to address climate change. As the greenhouse gas benefits of energy generation diminish over time, the potential value in reducing methane emissions in the short term appears to be increasing (see Figure 2 above).

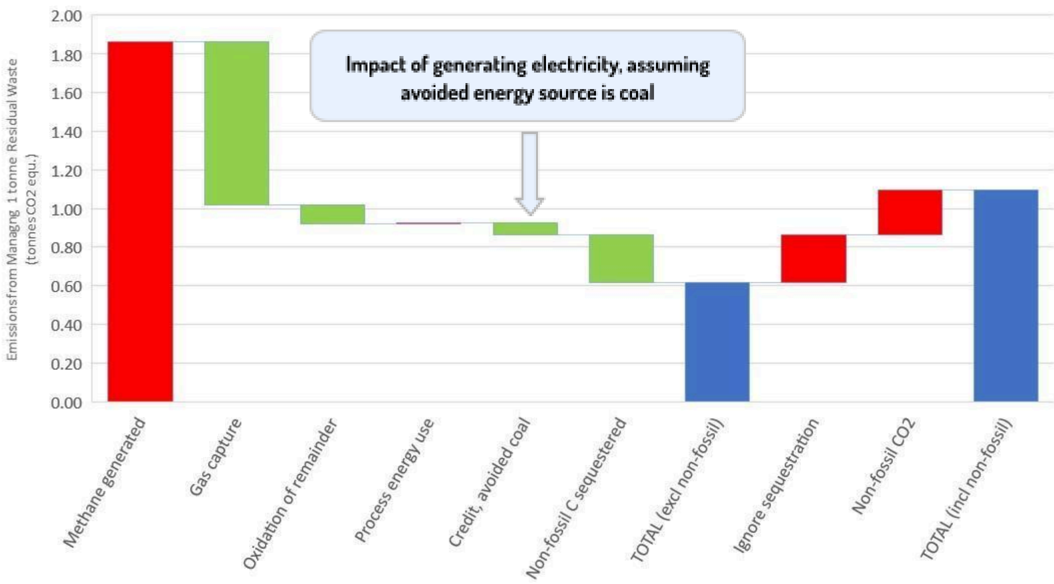

Figure 3: Greenhouse gas emissions from landfill showing avoided emissions from energy generation (totals shown with and without non-fossil CO_2 emissions)[12]

[11] It is possible to include an 'anaerobic step' in this type of process, where methane is generated under controlled conditions in an anaerobic digester (thereby producing a renewable source of energy to replace fossil ones) before being transferred to an aerobic facility.

[12] Source: Equanimator. Notes: assumed composition of MSW is that after a well-performing recycling system in EU; assumes 50% landfill gas capture; 10% oxidation at the cap (typical); captured landfill gas used for power (CHP engine) and flaring; assumed GWP for methane = 34.

M(R)BT: a solution to the issue of methane from waste

The sheer quantity of waste currently landfilled and mismanaged suggests that for the foreseeable future, especially if waste that is not currently collected is included in future waste management schemes, there will be a large amount of unrecycled waste to be managed. This is not to deny that far more can be done to recycle 'dry' materials, and that more of the organic waste that is currently not separately collected could be collected and treated in suitable facilities, or used, directly or indirectly, as feed for livestock and/or fish. In high-income countries in particular, there is an urgent need to reduce material consumption, while there is scope for shifting consumption everywhere to more durable products, and to systems of reuse and refill. Nonetheless, there will still be what we call 'leftover mixed waste' (LMW). A basic representation of what is meant by this is shown in Figure 4. Hence, while policies and schemes aim at increasing the share of reusables, and at increasing recycling and composting rates, thereby progressively reducing LMW, one has to consider strategies to minimise impacts (foremost among these being climate impacts) of LMW still in the system. This should be done in a way that minimises methane, while avoiding fossil CO_2, and does not cause operational lock-in.

Figure 4: Schematic showing LMW as 'leftover waste' after separate collection[13]

Depending on the collection system used, the composition of the waste stream and the extent of positive engagement with the service, there may be scope to extract additional materials for recycling from the LMW. Sorting systems are capable of sorting 'leftover' plastics, metals, some fibres, and some textiles; separation of glass is also technically feasible, though more expensive. We call this 'leftover mixed waste sorting', or LMWS.

[13] Source: Equanimator.

In previous work in Europe, we highlighted the scope for additional recycling through the use of LMWS as a means to extract additional recyclable materials, even after the achievement of relatively high recycling rates through separate collection. Of the order, 200kg of material may be extracted, per tonne of LMW, for recycling as a result of LMWS.

Where this is justified (through assessment of the composition of LMW once quality and convenient systems for collection are in place), this can add additional benefit to the management of LMW. Instead, therefore, of sending LMW directly to mechanical and biological treatment (MBT) prior to landfilling, the deployment of LMWS can introduce additional recycling of the LMW. We call this system MRBT – mechanical recycling and biological treatment. A schematic for waste in the European context is shown in Figure 5, below.

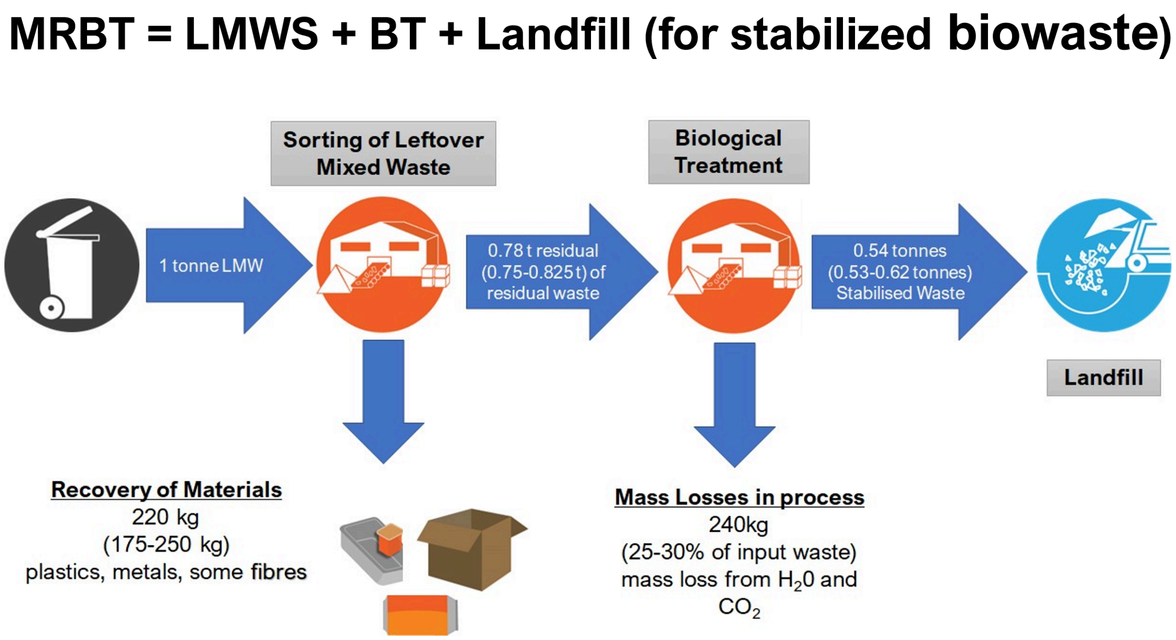

Figure 5: Schematic Depicting MRBT and Landfilling of Leftover Mixed Waste (LMW)[14]

This approach implies that we can extract additional materials for use in the economy prior to the deployment of an approach designed to minimise the amount of methane released from landfilling.

In Figure 6, we show that integrating LMWS can reduce the climate change impact of both landfilling and incinerating LMW. Although the landfill (with no prior biological stabilisation) performs worse than the incinerator under our analysis, this changes completely once LMWS is combined with biological stabilisation of waste prior to landfilling.[15]

[14] Source: Equanimator.
[15] The environmental benefits of biostabilising waste prior to landfill were also explored by Ricardo for Zero Waste Scotland (see Ricardo (2022) _Alternative Residual Waste Treatment: Biostabilisation_.

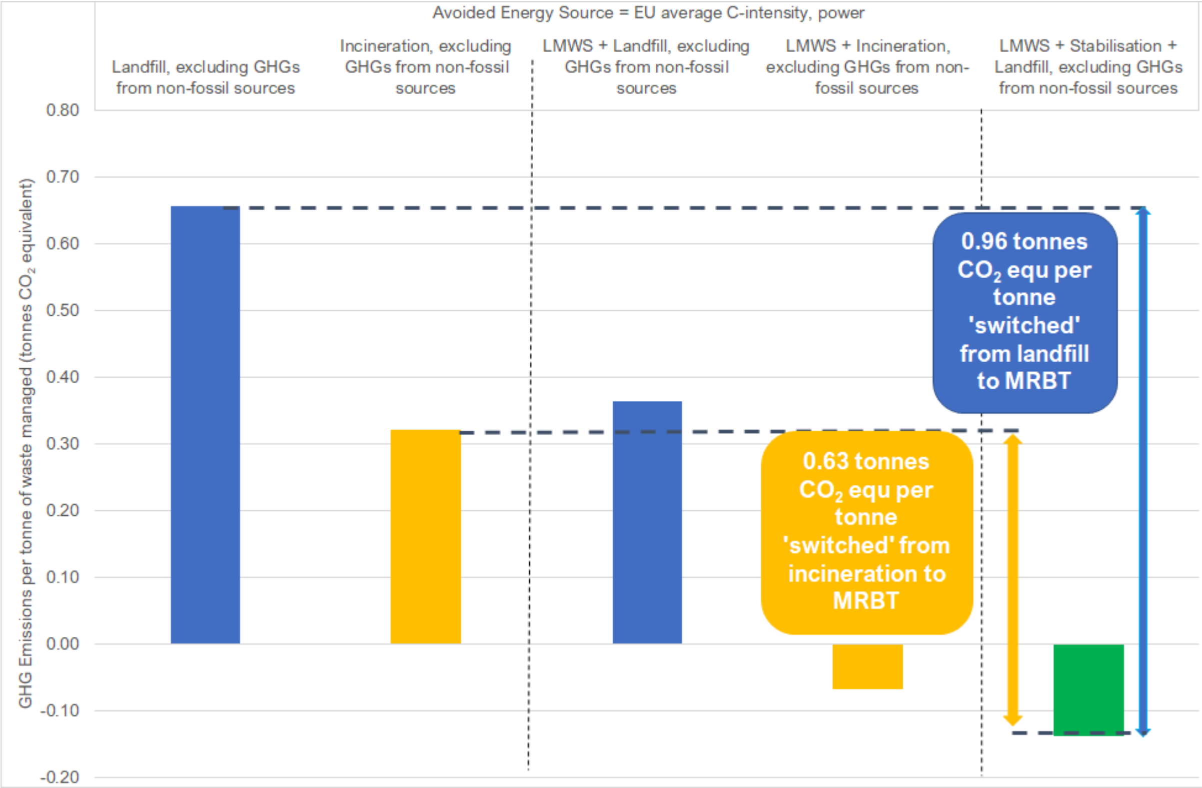

Figure 6: Comparative GHG Performance of Landfill, Incineration, Landfill with LMWS, Incineration with LMWS and MRBT[16]

There is an important discussion about how best to aggregate the effects of short- and long-lived climate pollutants, such as methane and carbon dioxide, respectively. In the above analysis, we have adopted what might be considered a 'conventional' approach in converting the effect of methane into 'carbon dioxide equivalent' emissions through use of the 'global warming potential' measured over 100 years (the GWP_{100}).

Our view is that the conversion to carbon dioxide equivalents is an unnecessary step: given that the world is rightly focussed on the impact of greenhouse gases on global temperature change, we believe this – the impact of gases on global temperature—provides a more sensible basis for aggregating their effect over time. The results of this analysis are shown in Figure 7.

[16] Source: Equanimator. Notes: LMW composition is what is left after well-performing recycling system in EU; assumes 50% landfill gas capture; 10% oxidation at the cap (typical); captured landfill gas used for power (CHP engine) and flaring; assumed GWP for methane = 34; incinerator generating power only at net efficiency 25%; avoided energy source was assumed at 220gCO_2/kWh (EU average at time of analysis).

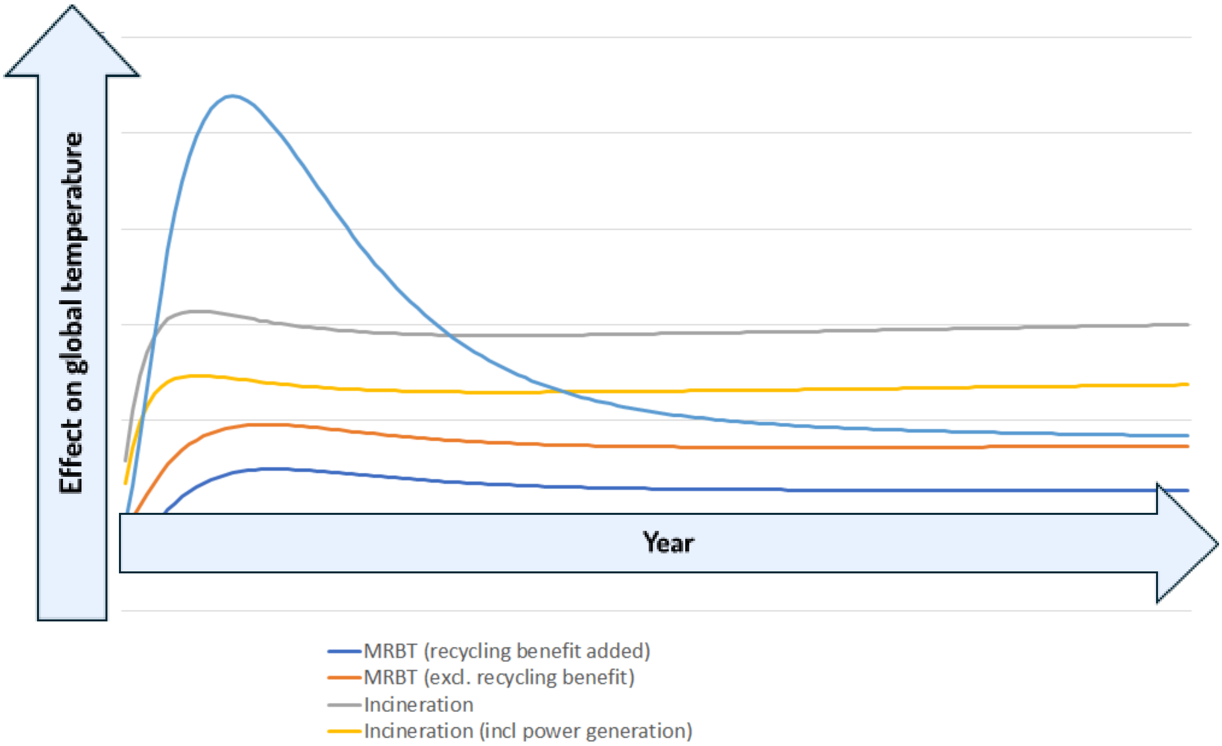

Figure 7: Comparative GHG Performance of Landfill (50% gas capture), Incineration (power generation @25% net efficiency) and MRBT (incineration and MRBT shown with and without credits for energy and recycling, respectively)[17]

There are some important insights.

i. The short-term contribution of landfills to global temperature increase is dominated by methane. The longer-term effect, though, is dominated by carbon dioxide emissions. In the long term, carbon dioxide dominates. So, in the long term, landfills make a smaller contribution to global temperature change than incinerators. The reason is clear: combustion of waste at incinerators releases not just non-fossil carbon, but also fossil carbon (from plastics for example) as carbon dioxide. Even with an energy credit added in for incineration assuming displacement of gas-fired power, this remains the case;[18]

ii. Nonetheless, at 50% lifetime gas capture, for a period of 50 years or so, the methane from the landfill exerts a strong effect on global temperature increase. In this scenario, only if the landfill had a lifetime gas capture of the order 80% or more would the landfill 'temperature line' for the landfill without biostabilisation be below that for the incinerator in all years (the exact level of capture at which this turns out to be the case is slightly different depending on the relative amounts of degradable non-fossil carbon, and fossil carbon, in each tonne of waste);

[17] Source: Equanimator. Notes: LMW composition is that after well-performing recycling system in EU; assumes 50% landfill gas capture; 10% oxidation at the cap (typical); captured landfill gas used for power (CHP engine) and flaring; assumed GWP for methane = 34; incinerator generating power only at net efficiency 25%; avoided energy source was assumed at 350gC02/kWh (broadly equivalent to carbon-intensity of electricity from efficient combined cycle gas turbine).

[18] We chose 'gas' as the comparator here since it is diminishingly likely, in most situations, that the marginal displaced source will be coal over the lifetime of an incinerator (and if it is likely, then we should all be even more concerned than we may already be as to how far global temperature will increase in future).

iii. If the methane from the landfill can be largely eliminated, as in the M(R)BT case, then the MRBT 'temperature line' lies below that for the incinerator in all years: the option is always better than incineration. This is an important insight since the incinerator is typically considered the superior alternative. The reason is that the short-term peak associated with conventional landfilling is largely eliminated;

iv. The effect of adding in the recycling benefit from leftover mixed waste sorting (LMWS) is comparable with the 'credit' for energy generation from an incinerator, assuming the carbon intensity of the avoided source of power is akin to a gas-fired power station.

In short, as well as M(R)BT systems enable the elimination of the peak contribution to global temperature increase in the short-term, treating waste prior to landfilling (as opposed to trying to capture landfill gas once the waste is deposited in the landfill) offers a system which is superior to incineration once it becomes no longer reasonable to assume that energy from incineration displaces coal-fired power generation.[19]

[19] Note that the point about which energy source is 'avoided' or 'displaced' by energy generated at an incinerator needs to be taken in the context of the counterfactual—what would happen in the absence of the incinerator being built, taking into account the contribution made by the energy being generated. Incinerators tend to treat waste on a more or less continuous basis so that their energy output is not 'dispatchable'. As such, the displacement tends to be with respect to 'firm power' or 'base load'. It also matters whether a country's power consumption is increasing, flat, or in decline. For a discussion, see D. Hogg (2022) *Incineration: What's the Effect on Gas Consumption?*

Conclusion

Conventionally, strategies have focussed on implementing, and improving, gas capture over the lifetime of the landfill site. This is not straightforward.

Where waste is biologically stabilised prior to landfilling, the system objective is to ensure the material is likely to generate far less methane prior to its being landfilled. This reduces the problem of gas management at the landfill, while also having some other benefits in terms of reducing leachate generation and reducing susceptibility to settlement over time. Furthermore, with additional ('second attempt') sorting of plastics from waste leftover after the first attempts to sort recyclables, additional greenhouse gas savings can be made as a result of the fact that emissions associated with primary production are avoided.[20]

The widely-held view of landfilling is that it is worse for the global climate than incineration. That is largely true in landfills with low rates of gas capture, and where the material landfilled has not been biologically stabilised. It is not true, however, if one makes use of the GWP100 figure as the basis for expressing the 'equivalence' between methane and carbon dioxide, and as the appropriate 'credit' for energy generation drops, as it will if the world is to address the problem of climate change. Incinerators are not 'low carbon' sources of energy.[21]

Making comparisons of waste management systems using metrics that express the equivalence of methane and CO_2 through reference to global warming potential (GWP) are undermined by the simple fact that the value of the GWP changes with the time horizon considered appropriate for the assessment of the impact of each gas: the chosen time horizon is arbitrary. Many who seek to encourage early action on methane suggest using GWP20, as though it were a 'superior' choice. But what we ought to be most interested in is the impact of greenhouse gases on global temperature. We should be seeking to minimise the maximum contribution to temperature change made by waste management.

Looking at the issue through the lens of global temperature, then landfills always look better than incinerators over the long term, since they do not release fossil-derived carbon. However, their short-term effect on temperature is 'peaky', even where landfill gas capture is at respectable levels. This changes if the system which includes landfilling is one where the focus shifts away from capturing landfill gas, and towards treating waste such that it barely generates any methane. In terms of the system's impact on global temperature, the short-term peak observed from conventional landfills is flattened. Instead of the 'landfill system' being (sometimes far) worse than incineration in the fifty years or so after landfilling, by biologically treating waste

[20] Note that these benefits are likely to be greater than were estimated in the figures included in this report since recent changes in key life-cycle assessment inventories have recognised that primary products made from fossil fuels incur greater carbon dioxide emissions than had previously been thought (see Renewable Carbon Initiative (2024) *Products made from crude oil have a significantly higher CO_2 footprint than previously assumed*. ; also Nihan Karali, Nina Khanna, Nihar Shah (2024) *Climate Impact of Primary Plastic Production*.

[21] See Equanimator (2021) *Rethinking the EU Landfill Target*; D. Hogg (2023) *Debunking Efficient Recovery: The Performance of EU Incineration Facilities*; also S. Dowen (2021) *Guide warns incinerator GHG emissions often worse than predicted*.

prior to landfilling, the situation can be reached where the landfill system makes a smaller contribution than incineration to global temperature change in all years.

A strategy based on improving, one-by-one, the performance of landfills which deliberately seek to generate gas for capture as a contribution to so-called renewable energy (how can energy derived from a substance – waste – which we seek to minimise, ever be considered 'renewable'?) seems naïve at a global level. We strongly propose that efforts be reoriented to stabilising waste prior to landfilling, with the express intent of minimising the amount of methane generated and emitted in fugitive form at landfills, with sites designed without any gas capture mechanism as a result.

Such a system offers a way to reduce emissions in a responsible way, whilst avoiding the lock-in effect so often observed with incineration facilities. In developing countries, approaches based on biological treatment may be more familiar, and this may be implemented also with low-tech, low-cost systems, such as on-site windrowing. Also, the use of sorting systems for LMW may offer further opportunities for employment which are likely to have relevance in the context of a move to better-managed landfills. It is also possible to design the biological treatment systems such that they are 'flexible' to respond to improving rates of separate collection of bio-waste: 'double duty' sites, dealing with both source-separated material, and the biological fraction of leftover mixed wastes, have been in place in Europe at various times.

In an era where changes in global temperature are already causing catastrophic climate events around the globe, M(R)BT systems ought to be considered a central plank of a strategy to deal with waste. They help to 'buy time', as countries seek to reduce emissions of longer-lived greenhouse gases, such as CO_2, with a view to constraining global temperature increases. They are also conducive to a flexible move towards a circular economy, offering a pathway to minimising the maximum contribution made by waste management to global temperature change, and reducing the likelihood that methane emissions from waste contribute to irreversible tipping points being met.

Zero Waste Europe (ZWE) is the European network of communities, local leaders, experts, and change agents working towards a better use of resources and the elimination of waste in our society. We advocate for sustainable systems; for the redesign of our relationship with resources; and for a global shift towards environmental justice, accelerating a just transition towards zero waste for the benefit of people and the planet. www.zerowasteeurope.eu

Zero Waste Europe gratefully acknowledges financial assistance from the European Union. The sole responsibility for the content of this material lies with Zero Waste Europe. It does not necessarily reflect the opinion of the funder mentioned above. The funder cannot be held responsible for any use that may be made of the information contained therein.

Zero Waste Europe gratefully acknowledges financial assistance from the Global Methane Hub (though the Windward Fund) and the Urban Movement Innovation Fund, a project supported by Rockefeller Philanthropy Advisors. The sole responsibility for the content of this material lies with with Zero Waste Europe. It does not necessarily reflect the opinion of the funders mentioned.

Authors: Dominic Hogg
Editors: Janek Vahk, Shlomo Dowen, Enzo Favoino, Nanna Bille Cornelsen
Date: June 2024

General information: hello@zerowasteeurope.eu
Media: news@zerowasteeurope.eu
Cities-related topics: cities@zerowasteeurope.eu

zerowasteeurope.eu
www.zerowastecities.eu
www.missionzeroacademy.eu