Zero Waste to Zero Emissions: How Reducing Waste is Climate Gamechanger 共筆翻譯區

從零廢棄到零排放：減廢如何扭轉氣候變遷（暫定標題）

給譯者的話：

完整的原文報告請由此去。
GAIA在2022年10月出版了這份報告，瞄準零廢棄的目標以及達到此目標的各種策略（廚餘堆肥、減塑、源頭減量……等）都與看守台灣協會長期以來的倡議不謀而合。報告中也論證了以零廢棄為目標及策略，如何帶動其它部門的減碳，全面扭轉氣候變遷帶來的威脅。此報告紀錄分析了八個城市實施零廢棄的潛力，結果十分驚人，顯示出零廢棄的策略將整個廢棄物部門不只淨零、甚至轉成負排放的潛力不可小覷。

基於以上原因，我們認為這分報告十分值得翻譯，分享給台灣的民眾，幫助我們也能走上零廢棄之路、並對抗氣候變遷。感謝各位願意參與的翻譯志工，在開始翻譯之前，建議先去瀏覽一遍原文報告，其中有許多製作精美的圖表或照片，在共筆翻譯區這邊是沒有的，錯過可惜喔。

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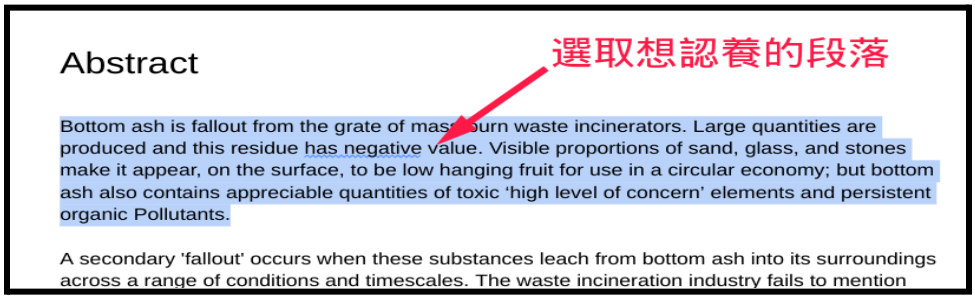

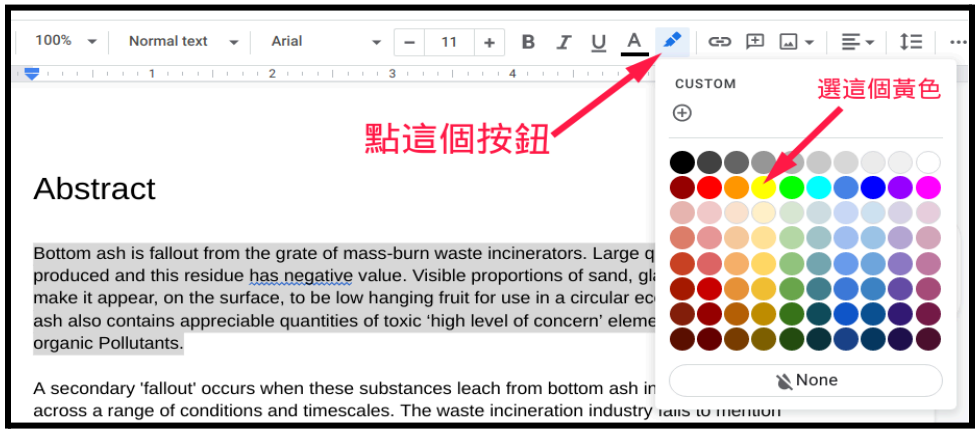

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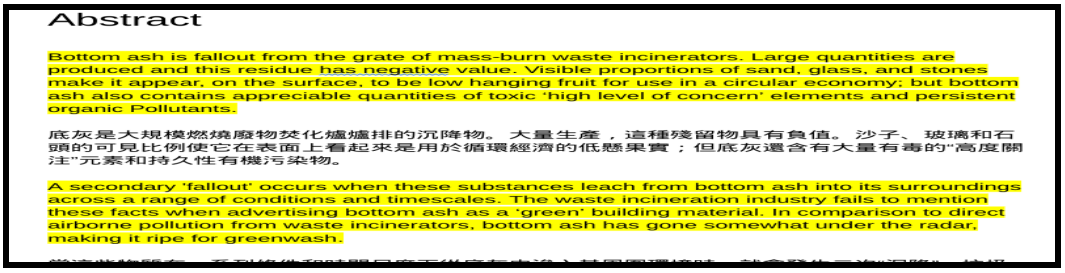

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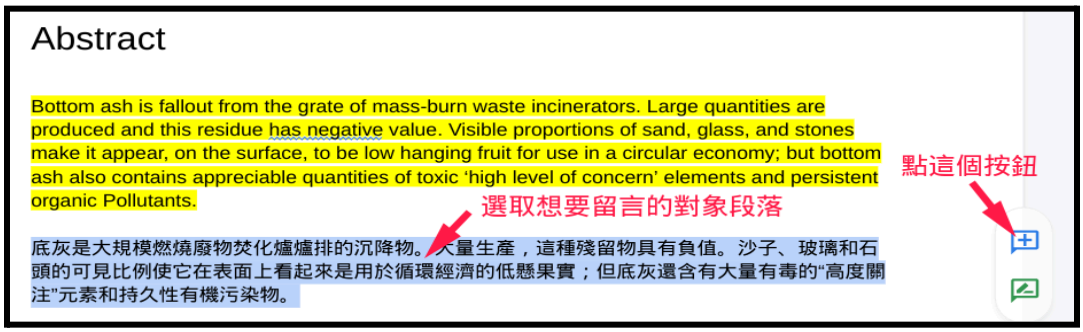

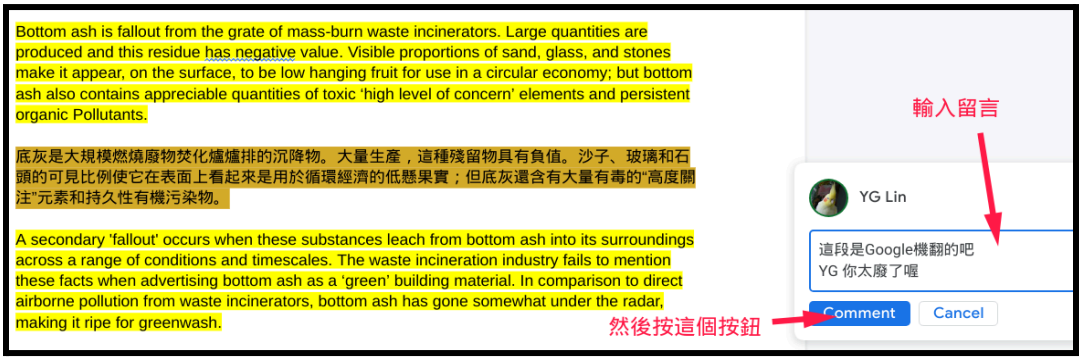

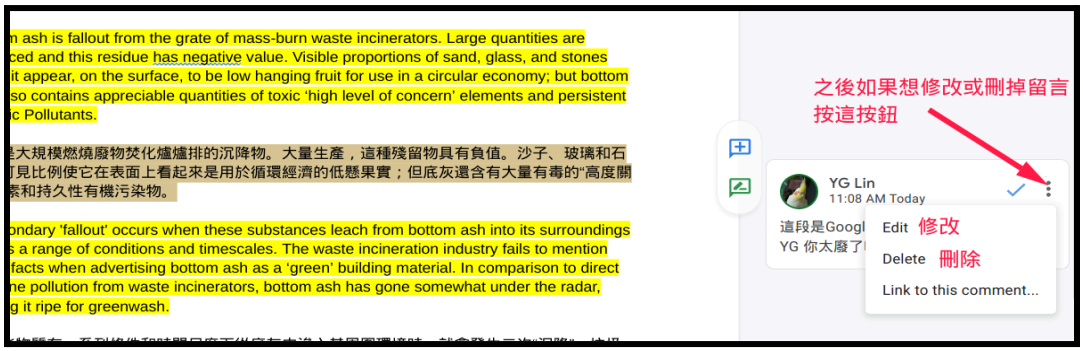

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它譯者可統一對照

- 我們歡迎任何與原文議題相關、在台灣現況的參考資料，可以針對某一段落留言，或者寫在最後的補充資料

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邱素宜				

（本文開始，目錄不用翻，摘要已有人認養，請從**Introduction**開始認養）

Zero Waste to Zero Emissions: How Reducing Waste is a Climate Gamechanger

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Executive summary

執行摘要

As the climate crisis deepens, urgent action on all fronts is required to both eliminate greenhouse gas (GHG) emissions and adapt to a rapidly changing climate. The waste sector offers a prime opportunity for cities to take action that will dramatically reduce emissions, strengthen resilience, and provide substantial public health and economic benefits. The waste sector is the third largest source of anthropogenic methane emissions, whose reduction will deliver rapid benefits through avoided warming. In fact, good waste management practices can reduce emissions in other sectors, delivering more than 100% emissions reductions. Simultaneously, this approach, known as zero waste, can reduce flooding, deter disease transmission, improve soil health, and deliver economic opportunities. This report explains how zero waste is an essential part of any climate plan.

當氣候變遷的危機加劇，我們在各方面都需要做出急迫的行動，無論是減少溫室氣體排放、或是採取調適措施因應快速變化的氣候。對城市而言，若能在廢棄物這一部門採取行動，將有很大機會可以大幅減少排放、增強韌性，同時為公共衛生和經濟方面帶來重大利益。廢棄物部門是第三大的人為甲烷排放源，而減少甲烷排放所避免掉的暖化效應，有助於快速減緩氣候變遷。事實上，良好的廢棄物管理實務也會順便減少其它部門的排放，而可達到超過100%（指相對於廢棄物部門排放量）的排放減量成效。這個被稱為「零廢棄」的策略，同時也能減少洪災發生、抑止疾病傳播、改善土壤健康、提供經濟上的機會。本報告闡述了為何零廢棄會是任何氣候行動計畫的核心。

Seventy percent of global greenhouse emissions come from the material economy, from extraction through disposal. In national inventories, these emissions are tallied in the industrial, agricultural, transportation, and energy sectors, as well as the waste sector. Yet curbing waste generation and implementing better waste management strategies avoids emissions throughout the lifecycle of material goods—from extraction to end of life. The mitigation potential of the waste management sector is therefore largely underestimated.

全球70%的溫室氣體排放來自於物質經濟，從原料開採到廢棄處理階段。在各國的溫室氣體排放清冊中，這些排放量是依其排放部門（包括工業部門、農業部門、運輸部門、能源部門以及廢棄物部門）分類統計。然而抑制廢棄物的產生、實施較佳的廢棄物管理策略，可在物質商品的整個生命週期——從原料開採到產品生命終結——避免溫室氣體排放。因此，廢棄物管理部門減緩氣候變遷的潛力，被大大地低估了。

Zero waste systems are versatile strategies that aim to continually reduce waste through source reduction, separate collection, composting, and recycling. Over 550 municipalities around the world are already implementing zero waste, in a wide range of economic, social, climatic, and legal contexts. Furthemore, these systems are cost-effective to implement and produce fast results.

零廢棄系統包含各式各樣的策略方法，目標是藉由源頭減量、分類收集、廚餘堆肥及循環利用等方式，持續減少廢棄物。全世界已有超過550個城市實施零廢棄，儘管這些城市的經濟、社會、氣候及法治的背景條件不一。此外，這些方法不僅事半功倍且能快速立竿見影。

This report is organized around the three overarching positive impacts of incorporating zero waste systems into current waste management methods: climate mitigation, climate adaptation, and additional societal benefits (also referred to as co-benefits). The final chapter of the report offers case studies that model the effects of zero waste strategies in eight different cities, demonstrating that zero waste is a powerful mitigation strategy that is highly adaptable to different needs and circumstances. Cities around the world have already implemented zero waste systems; with these eight case studies, this report offers a new quantitative assessment of the mitigation benefits of such programs.

將零廢棄系統導入現行的廢棄物管理方式，可以帶來三種重要的正面影響，包括：減緩氣候變遷、調適氣候變遷以及額外的社會利益（簡稱為「附帶利益」）；本報告即是以這三種正面影響為核心，進行鋪陳論述。最後一章提供幾個案例研究，模擬八個不同城市實施零廢棄策略的效益，證明零廢棄是一個強大的、可高度適應不同城市需求與背景條件的減緩氣候變遷策略。在世界各地，有許多城市早已落實零廢棄；本報告透過這八個案例，針對這類採取零廢棄策略的計畫所產生的減緩效益，提供了嶄新的量化分析評估。

Climate mitigation
減緩氣候變遷

Zero waste systems contribute to greenhouse gas emissions reductions in three ways: **source reduction and separate collection and treatment of organic waste** avoids landfill methane emissions; **land application of compost** or digestate enhances the carbon uptake of the soil; **and source reduction and recycling of all municipal waste streams** reduces "upstream" emissions from natural resource extraction, manufacturing, and transport;

在零廢棄策略中有三種方法可以減少溫室氣體排放：一是有機廢棄物的源頭減量、分類收集和處理，可避免掩埋場排放甲烷；二是將堆肥或沼渣沼液施用於土地，可增加土壤吸碳的能力；三是針對所有的廢棄物流採取源頭減量和循環利用措施，可減少從原料開採、生產製造到運輸等「上游」階段所產生的排放。

Key takeaway 1
重點一

Composting is a climate game changer.
堆肥可扭轉氣候變遷的趨勢

- Separate collection of different waste streams is critical to avoid cross-contamination; the most readily implementable treatment option for organic waste is composting.

- 分類收集不同的廢棄物種，可有效防止互相污染；而對於有機廢棄物目前最立即可行的處理方法就是堆肥。
- Source-separated collection and treatment of organics can reduce methane emissions from landfills by 62%, even with moderate ambition.
- 推動有機廢棄物的源頭分類收集與處理，即使是保守估計，也能使掩埋場減少 62% 的甲烷排放。
- Mechanical recovery and biological treatment of residual waste and biologically active landfill cover are good complementary measures to source separated organic waste collection; in tandem, these strategies can reduce methane emissions by an average of 95%.
- 對殘餘廢棄物採取機械回收與生物處理，以及在掩埋場上鋪覆生物活性覆蓋層，是有機廢棄物源頭分類收集的良好輔助措施；這些策略結合起來，共能減少平均95%的甲烷排放。

Key takeaway 2
重點二

The zero waste model can transform the waste sector into a net negative source of GHG emissions.
零廢棄模式能將廢棄物部門轉為溫室氣體的淨負排放源

- Introducing better waste management policies such as waste separation, recycling, and composting could cut total emissions from the waste sector by 84% or more than 1.4 billion tonnes, equivalent to the annual emissions of 300 million cars - or taking all motor vehicles in the U.S. off the road for a year.
- 推行更好的廢棄物管理政策，例如廢棄物分類、回收和堆肥，共可從廢棄物部門減少84%（或超過14億噸）的排放量，這相當於3億台汽車一年的排放量，或相當於美國所有機動車輛一年不上路所減少的排放量。
- Separate collection and treatment of organic waste is key to deep cuts in waste-sector GHG emissions.
- 有機廢棄物分類收集和處理是大幅減少廢棄物部門之溫室氣體排放量的關鍵。
- Aggressive recycling programs reduce emissions in mining, forestry, manufacturing, and energy. Increased recycling would reduce annual GHG emissions in the waste sector by 35% in Detroit, 30% in Sao Paulo, and 21% in Lviv by 2030.
- 積極做好回收可減少來自採礦、伐林、生產製造和能源生產的排放量。提升資源回收，可讓底特律於2030年時減少35%來自廢棄物部門的溫室氣體排放；聖保羅則是減少30%排放量，利沃夫則是21%。

- Combined, these two approaches can produce deeper emissions reductions than waste sector emissions. Detroit, São Paulo, and Seoul would all achieve net-negative emissions under the 'road-to-zero-waste' scenarios.
- 上述兩種作法所能減少的排放量，總計可超過廢棄物部門的總排放量。在「邁向零廢棄」情境下，底特律、聖保羅、首爾全都能達成「淨負排放」的成就。
- This is true even for relatively modest programs; full implementation of zero waste would produce even greater emissions reductions.
- 就連相對保守的計畫，也能有如此的減排潛力；如果全面落實零廢棄，將能達到更大的排放減量成果。

Key takeaway 3
重點三

Source reduction of waste is the best way to reduce GHG emissions, especially for food and plastic (better than recycling).
廢棄物源頭減量是減少溫室氣體排放最好的方式，尤其是對於食物和塑膠來說，源頭減量比起回收更重要。

- Source reduction is a critical strategy for addressing food waste, which currently comprises one-third of all food production and is responsible for 10% of global GHG emissions.
- 源頭減量是解決食物浪費最要緊的策略，目前產出的食物當中，有三分之一最後成了廢棄物，其所產生的溫室氣體約佔全球排放量的10%。
- Other strategies for source reduction include restrictions on the production and distribution of single-use items and packaging.
- 源頭減量也包含其它策略，例如限制一次用產品和包裝的生產和配銷。
- Source reduction is especially important for plastic, most of which is not recyclable and whose production is doubling every 20 years.
- 對塑膠來說源頭減量特別重要，因為大部分的塑膠無法回收，且塑膠的產量每20年就倍增。

Key takeaway 4
重點四

Energy recovery is not an effective mitigation strategy
能源回收並不能有效減緩溫室氣體排放

- Landfill gas capture is unreliable, allowing large quantities of fugitive methane emissions to escape.
- 掩埋場沼氣收集並不可靠，仍有大量甲烷逸散到大氣中。
- Incineration is a major source of GHG emissions: each tonne of plastic burned results in the release of 1.43 tonnes of CO_2, even after energy recovery.
- 焚化是溫室氣體的一個主要排放源：每噸的塑膠燃燒之後會釋出1.43噸的二氧化碳，甚至在回收其熱能之後仍是如此。
- Insufficient energy is recovered to offset the carbon footprint of these technologies.
- 回收的能量不足以折抵焚化與掩埋這些處理技術的碳足跡。

Climate adaptation
調適氣候變遷

Zero waste systems help cities build resilience against the increasingly frequent extreme weather events and health hazards brought by climate change. Poor waste collection and management are among the factors that leave cities particularly exposed to these events. Zero waste systems help cities become more resilient by: **mitigating floods**, **reducing disease transmission**, and **improving soil quality.**
零廢棄系統幫助城市提昇韌性，抵禦氣候變遷帶來的日益頻仍的極端天氣事件和公共衛生風險。貧陋的廢棄物收集和管理系統是讓城市暴露在這些災害風險中的因素之一。建立零廢棄系統可減輕洪患、降低疾病傳播和改善土壤品質，因而有助於城市提昇韌性。

Key takeaway 1
重點一

Bans on single-used plastics (SUPs) are necessary as plastic waste exacerbates flooding.
必須禁掉一次用塑膠品，因為塑膠垃圾會惡化洪患。

- Plastic bans and universal collection systems are key to flood prevention as improperly managed waste– especially plastic bags –lead to clogged drainage systems.
- 禁用塑膠和普及垃圾收集系統，是防止洪災的關鍵策略，因為若未能好好管理廢棄物——尤其是塑膠袋——常常會造成排水系統堵塞。
- After tragic flood events, many cities have successfully and swiftly adopted plastic bans.
- 許多城市都是在經歷過洪災的慘況之後，而能夠順利、迅速地實施塑膠禁令。

Key takeaway 2
重點二

Banning SUPs and better waste collection will keep disease vectors at bay.
禁掉一次用塑膠品和採取較佳的廢棄物收集系統能拒病媒於門外

- Uncollected waste, especially plastic, creates habitat (e.g., stagnant water) for disease vectors, while food waste provides a food supply for vermin.

- 沒有收集、隨意亂丟的垃圾，尤其是塑膠，容易形成病媒的棲息地（例如積水）；而食物廢棄物也會成為害蟲的食物來源。
- Reducing waste through bans on SUPs and minimizing discarded food can help to interrupt the chain of disease transmission.
- 禁用一次用塑膠品和盡量減少被丟棄的食物等減廢措施，有助於切斷疾病傳播鏈。

Key takeaway 3
重點三

Composting does wonders to improve soil resilience.
堆肥能夠神奇地改善土壤韌性

- Land application of compost helps nutrient-deficient soil by increasing nutrient storage capacity, biochemical properties, crop production, and water retention.
- 在土壤缺乏養分的土地上施用堆肥，不僅增加土壤的養分儲存能力，也改善其生化特性、作物產量以及保水能力。
- Better soil quality prevents floods, mudslides, and loss of food crops.
- 品質良好的土壤能夠防範洪災、土石流和作物的損失

Additional benefits
附帶利益

Well-implemented zero waste strategies benefit societies in ways that go beyond their ability to curb the impacts of climate change: they improve many of the most fundamental ways in which society functions–through associated **environmental**, **economic**, **social**, and **political and institutional benefits.** These additional benefits include improving public health, reducing environmental pollution, incentivizing job creation, supporting community development, and addressing inequalities and societal injustices. Furthermore, waste solutions at the top of the waste hierarchy not only have the greatest additional benefits, but also score highest on emissions reductions.
零廢棄策略若能好好落實，對社會帶來的好處不只是其抑制氣候變遷衝擊的能力，還能為環境、經濟、社會、政治與制度帶來許多好處，進而改善社會的許多根本運作模式。這些附帶利益包括改善公共衛生、減少環境污染、刺激就業的產生、支持社區發展以及解決不平等和社會不公義的現象。此外，位於廢棄物治理層級頂端的方法，不僅能產生最大效益，同時也是減少排放的最佳利器。

Key takeaway 1
重點一

Zero waste systems do more for our health and the environment than lower GHG emissions. Zero waste systems:

零廢棄系統為我們的健康和環境帶來許多好處，不只是降低溫室氣體排放而已。零廢棄系統能夠：

- Lower the risk of cancer and illnesses associated with the spread of toxic ash from incinerators and landfills by rendering them redundant;
- 降低因焚化爐和掩埋場的有毒灰渣散佈而衍生的癌症和疾病風險，因為徹底實行零廢棄之後，我們將不再需要焚化爐和掩埋場；
- Save natural resources by decreasing the need and demand for virgin materials;
- 減少對原生物料的需求、節約自然資源；
- Protect ecosystem health by decreasing plastic pollution, which currently affects all living organisms;
- 減少塑膠污染、保護生態系健康，塑膠污染正在影響所有的生命體。

Key takeaway 2
重點二

Zero waste systems contribute to a thriving economy. Zero waste systems:
零廢棄系統能促進經濟繁榮，因為零廢棄：

- Are more economical than traditional waste management strategies;
- 比起傳統的廢棄物管理策略更經濟；
- Offer more and better employment opportunities than traditional waste management jobs;
- 比起傳統的廢棄處理方法提供更多且更好的就業機會；
- Spur business development: bans of single-use plastics have opened the door to innovative businesses.
- 刺激產業發展，一次用塑膠品的禁令已為許多新創事業開啟了大門。

Key takeaway 3
重點三

Zero waste systems provide a wide range of social benefits. Zero waste systems:
零廢棄系統為社會帶來廣泛利益，因為零廢棄：

- Reduce poverty and inequality through the inclusion of informal waste pickers; .
- 融入拾荒者這些非正式工作者，因而減少貧窮與不平等現象；
- Improve public health by decreasing the amount of toxic chemicals in the environment;
- 減少環境中的毒性化學物質，因而有助於大眾健康；
- Improve food and water security via the application of compost and biodigestate, which support food and water ecosystems;
- 透過堆肥和沼渣沼液的施用，改善食物和水體的生態系，因而有助於糧食與用水的安全。
- Reduce environmental stressors associated with waste disposal facilities.

- 降低廢棄處理設施所造成的環境壓力。

Key takeaway 4:
重點四

Zero waste systems strengthen the quality of governance itself
零廢棄系統還能提昇治理品質，因為：

- Bringing together a wide range of stakeholders, zero waste systems are more collaborative and demonstrate high performance rates as a result.
- 零廢棄將各種不同的利害關係人拉在一起，更有助於彼此協同合作，因而會有高度的執行率。

Case Studies
案例研究

Modeling a business-as-usual versus a road-to-zero-waste scenario for eight cities revealed several commonalities regarding the efficiency and impact of zero waste systems. Source-separated collection and treatment (usually through composting) of organic waste is key to deep emissions reductions, as landfill methane is the primary source of GHG emissions in the waste stream in every city but Seoul. This is also the only effective method to fully address these emissions, and it is relatively easy and inexpensive to implement. Recycling is also key, as increased recycling reduces emissions, and can, in some cases, be enough to make a city's waste sector net negative. While source reduction strategies are underutilized across the board, all zero waste policy and programs, even when incompletely implemented, lead to major mitigation benefits everywhere. The 'road to zero waste' scenarios modeled here are conservative, realistic scenarios; many cities have already exceeded the benchmarks in these scenarios, and the results are thus indicative of moderately ambitious programs. Deeper emissions cuts can be expected from more ambitious zero waste implementation.

本報告模擬八個城市的「一切照舊」情境與「邁向零廢棄」情境，結果發現幾個和零廢棄系統的效率和影響有關的共通點。有機廢棄物的源頭分類收集與處理（通常採取堆肥方式）是大幅減少排放的關鍵，因為除了首爾之外，在其它城市，廢棄物部門的溫室氣體主要排放源都是掩埋場所產生的甲烷。這也是目前解決這種排放唯一有效的辦法，而且它相對簡單、落實成本又不高。資源回收是另一個關鍵，因為提昇回收可減少排放，在某些案例中甚至足以讓城市的廢棄物部門達到淨負排放。雖然所有的案例都未充分運用源頭減量策略，但其制定的零廢棄政策與計畫，即使未充分落實，也都能帶來重大的減緩氣候變遷效益。本報告模擬的「邁向零廢棄」情境是保守而務實的，然而許多城市都已超越了本報告模擬情境的標竿，因此我們的模擬結果反映的是相對保守計畫的減排潛力。如果實行更積極的零廢棄策略，預期能達到更大的排放減量成效。

Recommendations

建議

- Incorporate zero waste goals and policies into climate mitigation and adaptation plans.
  將零廢棄的目標和政策融入減緩和調適氣候變遷的計畫中
    - Cities, which have the primary responsibility for waste management, should adopt comprehensive zero waste programs, with emphasis on source separation, organics treatment, and informal sector integration.
    - 城市負有廢棄物管理的主要責任，應採取全面性的零廢棄計畫，並把重點放在源頭分類、有機廢棄物處理以及非正式部門的整合。
    - Funders and financial institutions should support city transitions to zero waste with financial and technical measures.
    - 資助者和金融機構應透過金融和技術的支援，協助城市轉型到零廢棄。
    - National governments can incorporate zero waste into their Nationally Determined Contributions (NDCs) and relevant national climate policies.
    - 各國政府可將零廢棄納入其「國家自定貢獻」(Nationally Determined Contributions)計畫及相關的國家氣候政策之中。

- Prioritize food waste prevention and single-use plastic bans.
  首重避免食物廢棄和禁止一次用塑膠品
    - Food waste prevention requires a dedicated strategy that integrates the entire supply chain, with interventions from field to fork.
    - 要阻止食物廢棄，需要針對整個食物供應鏈對症下藥，阻斷從產地到餐桌的廢棄來源。
    - Bans on single-use products and packaging, particularly plastic, can be adopted at the local or national level.
    - 可在地方或全國層級實施禁令，禁止一次用的產品和包裝，尤其是塑膠。

- Institute separate collection and treatment of organic waste.
  建立有機廢棄物分類收集與處理的制度
    - Cities should develop clear, easy-to-use systems with uniform signage and dedicated outreach programs to ensure high compliance rates.
    - 城市必須建立一套清晰、方便使用的分類收集制度，有一致性的標示、專門的宣導推廣計畫，以確保民眾高度配合。
    - Composting is the easiest, least expensive, and most scalable treatment option for organic waste.
    - 至於有機廢棄物的處理，堆肥是最簡單、成本最低、最容易擴大規模的處理方法。

- Invest in the waste management systems, recycling and composting capacity.

投資廢棄物管理系統，提昇回收和堆肥處理量能

- Relatively small capital inputs are required for source separated collection, material recovery facilities, organics treatment, etc.
- 需要投入資金，建構源頭分類收集、物料回收設施、有機廢棄物處理.....等等；但其所需經費相較慣行作法而言並不多。
- Municipalities should create a plan to meet ongoing operational costs, which may be lower under zero waste.
- 市政單位必須擬定一份計畫，提供廢棄物管理系統持續運作所需經費；而導入零廢棄策略應可降低這些成本。

- Establish appropriate institutional frameworks for zero waste including regulations, educational and outreach programs, and provide financial incentives through subsidies to recycling and composting.
為零廢棄量身打造一套制度架構，包括法規、教育和推廣計畫，並提供財務誘因，透過補助鼓勵回收和堆肥。

  - Regulations to set up a comprehensive zero waste system are key, with strong emphasis on aligned economic incentives that promote a virtuous system, continuously improving its waste reduction rates.
  - 透過法規建立全面性的零廢棄體系很重要，且這些法規應著重在相輔相成的經濟誘因，以打造良好的體系，持續提高廢棄物減量率。
  - Subsidies and other incentives to compost production and use are instrumental in developing these virtuous systems that can counter the heavily subsidized synthetic agrochemicals.
  - 提供補助和其他誘因以鼓勵堆肥的生產與使用，有助於建構良好的體系，對抗已接受過多補助的合成化學肥料。
  - Education, communication and outreach programs which ensure all stakeholders are included are needed for high participation and compliance rates.
  - 必須建立把所有利害關係人都納入的教育、溝通和宣導推廣計畫，以提高民眾的參與度及配合度。

- Recognize the role of waste pickers and fully integrate them into the waste management system.
肯認拾荒者的角色，並將他們完全整合到廢棄物管理系統中。

  - Create a consultative mechanism through which waste pickers can actively collaborate in the design of zero waste and take advantage of new opportunities, whether as employment or as entrepreneurs.
  - 建立一套諮詢機制，讓拾荒者可透過此機制，積極參與協助零廢棄體系的規劃設計，並利用新的機會找到工作或創業。
  - In cities where informal recyclers come from historically excluded populations, this may require ending long-standing discriminatory practices.
  - 在某些城市，非正式的回收者為自古以來即被排擠的族群，這會需要去終結那些根深蒂固的歧視行為。

– End of executive summary –

1. Introduction

1. 引言

As the urgency of global efforts to curtail greenhouse gas (GHG) emissions and the effects of climate change escalates, the waste management sector remains an underutilized opportunity for climate action by municipalities in countries everywhere. The mitigation potential of waste management is greater than the sector's own emissions, as waste reduction and material recovery strategies enable cities to avoid emissions associated with natural resource extraction and production, as well as the end of life of material goods; for example, an analysis jointly conducted by the United Nations Environment Programme and International Solid Waste Association recognized the waste sector's potential of achieving a 20% reduction in global GHG emissions.[1] Our current waste crisis is itself threatening the health and wellbeing of humanity and the planet, and global waste generation is expected to increase by seventy-three percent in 2050.[2] The good news is that addressing our waste problem is a direct line of action against the climate crisis.
儘管抑制溫室氣體排放及氣候變遷效應已成為全球越來越緊急的任務，世界各國的市政當局仍未大力運用廢棄物管理部門在因應氣候變遷上所帶來的機會。廢棄物管理的減排潛力，大於該部門本身的排放，因為減廢與資源回收策略可讓城市避免掉源於自然資源開採、生產製造以及物品廢棄處理階段的排放。例如，由聯合國環境規劃署（United Nations Environment Programme）及國際固態廢棄物協會（International Solid Waste Association）共同合作的一份分析指出，廢棄物部門具有減少20%全球溫室氣體排放的潛力。[1]我們目前面臨的廢棄物危機本身就已威脅到人類與地球的健康與福祉，然而估計到2050年時，全球廢棄物產生量還會再增加73%。[2]所幸，處理廢棄物問題可直接減緩氣候危機。

Zero waste systems offer alternative solutions to traditional waste management practices with far-reaching benefits. Zero waste, as defined by the Zero Waste International Alliance and adopted by GAIA, "is the conservation of all resources by means of responsible production, consumption, reuse, and recovery of products, packaging, and materials without burning, and with no discharges to land, water, or air that threaten the environment or human health."[3] The aim of zero waste is to continually reduce waste through a range of strategies including source reduction, separate collection, composting, and recycling.

[1] Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. Global Waste Management Outlook. United Nations Environment Programme.
[2] "Solid Waste Management." World Bank. 2022. https://www.worldbank.org/en/topic/urbandevelopment/brief/solid-waste-management.
[3] "Zero Waste Definition." 2018. *Zero Waste International Alliance*. https://zwia.org/zero-waste-definition.

零廢棄體系所提供的替代方案，其效益遠高於傳統的廢棄物管理實務。根據「國際零廢棄聯盟」(Zero Waste International Alliance)的定義，零廢棄是指「透過負責任的生產、消費、再使用與回收再利用，讓產品、包裝與物料免於焚化，且不會有污染排放大地、水體或空氣，並進而威脅環境或人體健康。」這個定義也為「全球焚化爐替代方案聯盟」(GAIA)所採用。[3]零廢棄的目標是透過各種策略，包括源頭減量、分類收集、堆肥與資源回收等方法，持續減少廢棄物。

This report is the first of its kind to quantify the climate impacts of better waste management with case studies on eight cities, each in a different part of the world. This report also examines the ways in which zero waste systems not only mitigate GHG emissions, but also help cities reduce their vulnerability to the impacts of climate change and create overall healthier societies. Devastating signs of the climate crisis—including increased flooding, outbreaks of vector-borne diseases, and degrading quality of soil—are already harsh realities faced by many countries across the globe. Often, the countries suffering most from such effects are the ones least responsible for causing climate change, and the severity of the consequences are becoming increasingly apparent as the climate crisis accelerates.
本報告首開先例，量化了良好廢棄物管理對氣候的影響，並提供從世界不同角落挑出的八個城市的案例研究。本報告也檢視了零廢棄體系如何減少溫室氣體排放、幫助城市增進對氣候變遷的韌性並全面改善社會。氣候危機已然以令人驚心動魄的徵兆展現開來，包括越來越頻仍的洪水、病媒傳染病的爆發以及土壤品質劣化，這些已成為全球許多國家面臨的嚴酷事實。通常受影響最嚴重的國家，是造成氣候變遷責任最小的那些國家；而隨著氣候危機的腳步加快，其後果的嚴重性也越來越顯著。

Cities have a unique opportunity to tackle climate change through the waste sector. While many other sectors are the responsibility of national or provincial-level governments, waste management is almost always the exclusive responsibility of local governments. Waste management is also typically the single largest budget item in municipal budgets, and even so, many cities struggle to simply collect the existing waste. There is thus a need for improved and economical waste management approaches that simultaneously address climate change.[4] Zero waste offers cities a leadership opportunity on climate action, while managing known and new risks. This will help build both long-term resilience against climate change, and provide much needed short-term results, all with a relatively small budget.
城市可透過廢棄物部門的管理找到因應氣候變遷的獨特機會。雖然其他部門的管理大多是國家或省級政府責任，但廢棄物管理幾乎總是地方政府全權處理的領域。一般而言，廢棄物管理的經費預算在市政預算中是一枝獨秀、最大的預算項目；即使如此，許多城市政府光是收集既有垃圾就已左支右絀；因此有必要改善作法，讓廢棄物管理經濟有效，同時又能因應氣候變遷。[4]若採用零廢棄作法，城市有機會在氣候行動上站上領導地位，同時掌控既有或新興的風險。這有助於城市以相對較少的預算，建立面對氣候變遷的長期韌性，同時達成急需的短期成果。
Zero waste systems are no longer a novel approach: they are being implemented by over 550 municipalities around the world, in very diverse contexts, including big and small cities, towns, islands, and touristic destinations—whether wealthy or impoverished. Beyond positive climate action, zero waste systems improve many of the fundamental ways societies function. Tacloban City, Philippines, for instance, went from servicing 30% of households with waste collection to 100% in two years of implementation of a zero waste system,

[4] Kaza, Silpa, Lisa C. Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1329-0.

reducing the waste sent to landfills by 31%, and saving the annual budget by 27%.[5] Ljubljana, Slovenia, tripled jobs in the waste sector and saved costs while doubling recycling rates in eight years and reducing waste-to-landfill by 95% in 14 years through door-to-door collection combined with a pay-as-you-throw system.[6]
零廢棄策略已不是新的作法，全球有超過550個城鎮實施零廢棄，這些地方政府的背景條件相當不一，有大城市、小城市，有市鎮、島嶼及觀光景點，有的經濟富裕，有的則是貧困地區。零廢棄除了有助於因應氣候變遷，也改善了社會許多的根本運作方式。比如，在菲律賓的塔克洛班市（Tacloban City），在採行一零廢棄系統兩年後，原本只有30%家戶享有的廢棄物收集服務即普及到所有家戶，送到掩埋場的廢棄物降低了31%，年度預算節省了27%。[5]在斯洛維尼亞的盧比安納（Ljubljana），在實施到府收集垃圾服務及垃圾費隨量收費制度之後，八年內廢棄物部門的工作機會增至原來的3倍，回收率翻了一倍；送到掩埋場的廢棄物於十四年內減少了95%。[6]

An increasing number of local governments consider zero waste a powerful climate action strategy. As a sector that usually lies entirely within local control and consumes an enormous portion of city budgets, solid waste management is a prime area in which municipalities can apply zero waste strategies to reduce their climate impact and build more just and resilient cities.
有越來越多的地方政府將零廢棄視為對抗氣候變遷的有效策略。固態廢棄物部門通常是地方政府全權負責的領域，在城市預算中也佔了相當大的比例，因此是城市採行氣候行動的一個主要領域，城市可應用零廢棄策略，減少其氣候衝擊，建立更公平、更有韌性的城市。

Box: Zero waste as a speedy solution

To tackle the climate crisis, rapid solutions are essential. In contrast with major infrastructure projects such as incinerators and landfills, which take many years to site, permit, and build, zero waste implementation is extremely rapid. This is particularly true for the crucial element of source separation, which relies on high levels of public cooperation. . For example, Prelog, Croatia, tripled source separation in 5 years.[7] In Dar es Salaam, Tanzania, the zero waste system implemented by Nipe Fagio to engage 32,000 people achieved 95% compliance in source separation and reduced waste disposal by 75% in just two years.[8] In San Fernando, Philippines, waste diversion increased from 12% to 80.69% in six years after implementing a zero waste system.[9] In Besançon, France, the implementation of a pay-as-you-throw system and decentralized composting reduced overall waste generation by 13% in 7 years.[10] In Santa Juana, Chile, organic waste sent

[5] Liamzon, Catherine. 2019. "Sunshine After the Storm: A Typhoon-Ravaged City Rises to Become Zero Waste." Zero Waste Cities Asia. Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/wp-content/uploads/Tacloban.pdf.
[6] Oblak, Erika. 2019. "The Story of Ljubljana." 5. Zero Waste Case Studies. Zero Waste Europe. https://zerowasteeurope.eu/wp-content/uploads/2019/10/zero_waste_europe_cs5_ljubljana_en.pdf.
[7] Košak, Marko. 2019. "The Story of Prelog." Zero Waste Europe. https://zerowastecities.eu/bestpractice/the-story-of-prelog.
[8] "Zero Waste Systems for Climate Mitigation Tanzania." Presentation by Ana Rocha, Nipe Fagio. https://www.nipefagio.co.tz/publications-nipe-fagio.
[9] Dayrit, Felicia, Anne Larracas, and Gigie Cruz. 2019. "Picking Up the Baton: Political Will Key to Zero Waste." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/wp-content/uploads/San-Fernando-1107.pdf.
[10] Rosa, Ferran. 2018. "The Story of Besançon." Zero Waste Europe. https://zerowastecities.eu/bestpractice/besancon.

to landfill was reduced by 35% in the first 4 months of implementation of a zero waste-oriented program.[11] Sălacea, Romania, went from almost zero recycling to 40% in the first 3 months of zero waste implementation.[12] Capannori achieved a 82% separate collection rate in six years[13] and Parma, Italy, increased separate collection from 48.5% to 81% in seven years.[14] In Usurbil, Basque region, Spain, separate collection went from 28% to 80% in just two years.[15] These and other examples testify to the speed with which zero waste can take effect.

方塊：零廢棄是快速解決方案

要應付氣候危機，快速解決方案是很重要的。相對於焚化爐與掩埋場等需要多年時間進行選址、取得許可與興建設置的重大基礎設施計畫，零廢棄是可以很快實施的；尤其是零廢棄的重要元素——仰賴民眾高度配合的源頭分類措施——更可以快速推動。比如，在克羅埃西亞的布雷洛格（Prelog），廢棄物源頭分類的比例於五年內即擴增為原來的3倍。[7]在坦尚尼亞的三蘭港（Dar es Salaam），由公民團體「給我掃把」（Nipe Fagio）所推動、僱用32,000人的零廢棄體系，在僅僅兩年內就讓95%的民眾配合源頭分類，並讓需要處理的廢棄物減少了75%。[8]在菲律賓的聖費爾南多（San Fernando），在實施零廢棄制度後六年內，廢棄物回收率即從12%增加到80.69%。[9]在法國的貝桑松（Besançon），在推動垃圾費隨量收費制度及分散式堆肥後七年內，整體的廢棄物產生量就減少了13%。[10]在智利的聖胡安娜（Santa Juana），在實施一零廢棄導向的計畫後四個月內，送到掩埋場的有機廢棄物就減少了35%。[11]在羅馬尼亞的瑟拉恰（Sălacea），在實施零廢棄後三個月內，回收率即從原本的幾乎為零提升到40%。[12]義大利的卡潘諾里（Capannori）在六年內達到82%的分類收集率；[13]另一個城市帕爾馬（Parma），則是於七年內讓分類收集率從48.5%增加到81%。[14]在西班牙巴斯克地區（Basque region）的烏蘇爾維爾（Usurbil），分類收集率於僅僅兩年內就從28%增加到80%。[15]這種種的案例證明了零廢棄策略是可以快速見效的。

[11] "Estudio de Caso: Estrategia Basura Cero En Santa Juana." 2021. Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/2021/11/Serie-documentos-GAIA-Caso-7.pdf.

[12] Rastei, Elena, and Jack McQuibban. 2019. "The Story of Salacea." 12. Case Studies. Zero Waste Europe.

[13] Vliet, Aimee Van. 2018. "The Story of Capannori." Zero Waste Europe. https://zerowastecities.eu/bestpractice/best-practice-the-story-of-capannori.

[14] Rosa, Ferran. 2016. "The Story of Parma." *Zero Waste Europe*. https://zerowasteeurope.eu/library/the-story-of-parma.

[15] "Recogida puerta a puerta en Usurbil." Ministry for the Ecological Transition and the Demographic Challenge. https://www.miteco.gob.es/es/calidad-y-evaluacion-ambiental/temas/prevencion-y-gestion-residuos/buenas-practicas/Puerta_Puerta_Usurbil.aspx.

2. Zero waste and climate mitigation

2. 零廢棄與減緩氣候變遷

Chapter summary

本章摘要

- The waste sector is the third largest source of methane emissions, a powerful GHG that traps 82.5 times as much heat as CO_2 over a 20-year timespan. Organic waste in landfills is a major source of methane emissions, and proper organic waste management can dramatically lower these emissions.
    - Source-separated collection and treatment of organics can reduce methane emissions from landfills by 62%, even with moderate ambition.
    - Separate collection of organic waste, composting, mechanical recovery and biological treatment of residual waste, and biologically active landfill cover can reduce methane emissions by an average of 95%. Other treatment methods, such as animal feed and anaerobic digestion, may be appropriate in some circumstances.

- 廢棄物部門是甲烷排放的第三大來源。甲烷是很強大的溫室氣體，其於20年期間的暖化潛勢是二氧化碳的82.5倍。掩埋場中的有機廢棄物是甲烷的重大排放源，所以若能妥善管理有機廢棄物，將能大幅減少甲烷排放。
    - 有機廢棄物的源頭分類收集及處理，可降低62%的掩埋場甲烷排放，即使是採取相對保守的作為。
    - 對有機廢棄物採取分類收集與堆肥處理，對殘餘廢棄物進行機械回收及生物處理，以及在掩埋場上鋪覆生物活性覆蓋層等措施，平均共可減少95%的甲烷排放。有機廢棄物的其他處理方式，諸如餵養動物或厭氧醱酵等，在某些情況下也是妥適的處理方法。
- The mitigation potential of zero waste systems in the waste sector is largely underestimated and presents an underutilized opportunity to mitigate climate change.
    - Reducing upstream emissions from natural resource extraction, manufacturing, and transport by preventing waste and decreasing the demand for raw materials through reuse and recycling.
    - Ending waste incineration and open burning eliminate their direct emissions of fossil and biogenic CO_2.
    - Land application of compost or digestate can enhance carbon uptake of soils.
- 零廢棄系統為廢棄物部門帶來減緩氣候變遷的潛力，這項潛力被大幅低估了，且是個尚未被充分運用的機會。
    - 透過源頭減廢措施以避免廢棄物的產生，並藉由重複使用及循環利用以減少對原物料的需求，可降低來自自然資源開採、生產製造和運輸等上游階段的排放量。
    - 終結廢棄物焚化和露天燃燒，可避免那些源自化石燃料或生物質的廢棄物成為二氧化碳直接排放出去。

- 用堆肥成品或沼渣沼液來施灌土地，可增加土壤碳吸存量。

- A comprehensive zero waste strategy can reduce more emissions than the waste sector produces, resulting in a "net negative" sector.
- 全面性的零廢棄策略所能減少的排放量，比廢棄物部門所產生的排放量更多，可使此部門成為「淨負排放」部門。
- Plastic, a fossil fuel product and uniquely problematic material, has an enormous carbon footprint, two-thirds of which is in the production phase. As recycling plastic has critical limitations, forceful public policy interventions are required to reduce plastic production.
- 塑膠這種源自化石燃料、特別有問題的材質，其碳足跡十分巨大，其中有三分之二來自生產階段。而塑膠的回收又存在許多嚴重限制，因此需要具強制力的公共政策介入，以降低塑膠產量。

2.1. Introduction

2.1. 簡介

The solid waste sector is a significant source of GHGs, including methane (CH_4), nitrous oxide (N_2O), and biogenic and fossil carbon dioxide (CO_2). Traditional calculations indicate that 3.3% of global GHG emissions originate from the waste sector.[16] The mitigation potential of the waste sector through zero waste systems, however, is much larger than this figure implies. Globally, 70% of total emissions come from the material economy, from extraction through disposal.[17] In the U.S., 42% of GHG emissions are associated with the lifecycle of all products.[18] Good waste management—which includes strategies that separate organic waste and prioritize reduction, reuse, and recycling (in that order)—will sharply reduce powerful, short-lived GHGs such as methane as well as reduce emissions from other sectors (such as mining, farming, manufacturing, transportation, and agriculture). As a result, the mitigation potential of the solid waste sector is greater than its total emissions, making it a potential "net negative" sector.[19]

固體廢棄物部門是溫室氣體的重大來源，包含甲烷（CH_4）、一氧化二氮（N_2O），還有源自生物質和化石燃料的二氧化碳（biogenic and fossil CO_2）。傳統上的計算分析指出，全球溫室氣體排放量中有

[16] "Climate Data for Action–Emissions and Policies." Climate Watch. https://www.climatewatchdata.org.
[17] Wit, de Marc, and Laxmi Haigh. 2022. "The Circularity Gap Report 2022." Circle Economy. https://www.circularity-gap.world/2022.
[18] "Opportunities to Reduce Greenhouse Gas (GHG) Emissions through Materials and Land Management Practices." 2021. Reports and Assessments. U.S. EPA. https://www.epa.gov/smm/opportunities-reduce-greenhouse-gas-ghg-emissions-through-materials-and-land-management.
[19] Hogg, Dominic, and Ann Ballinger. 2015. "The Potential Contribution of Waste Management to a Low Carbon Economy." Eunomia. https://www.eunomia.co.uk/reports-tools/the-potential-contribution-of-waste-management-to-a-low-carbon-economy; Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. Global Waste Management Outlook. United Nations Environment Programme.

3.3%來自廢棄物部門[16]，然而若是實行零廢棄制度，廢棄物部門減緩氣候變遷的潛力將遠超過3.3%這個比例。全球溫室氣體總排放量有70%來自於物質經濟——從資源開採到廢棄處理等階段——的運作。[17]在美國，42%的溫室氣體排放跟所有產品的生命週期有關。[18]優良的廢棄物管理制度——包括分開收集有機廢棄物以及把施政重點依序放在源頭減量、重複使用及循環利用，不僅能大量減少像甲烷那樣強大但是短命的溫室氣體，也能減少來自採礦、物料種植、生產製造、運輸、農業等其他部門的排放。因此，固體廢棄物部門減緩溫室氣體排放的潛力遠大於其總排放量，而有可能成為「淨負排放」部門。[19]

[graphic 1] The ZW vs linear economy

Contrary to the claims of the so-called waste to energy industry, converting mixed solid waste to energy is an approach to net negative emissions that has not proved effective. The most common technology used for waste-to-energy, mass-burn incineration, emits far more GHG emissions than the energy it displaces.[20] Rather than reducing emissions in the power sector, it increases them. As countries decarbonize their electric grids, this discrepancy will only increase. Other technologies such as pyrolysis, gasification, and plasma arc have failed to achieve technological or commercial success.[21] Landfill gas collection, while frequently required to mitigate methane emissions, is of uncertain efficacy.[22] Of waste-to-energy technologies, only anaerobic digestion has proved successful, but it requires clean organic inputs rather than mixed waste.

廢棄物能源化產業宣稱，將混合的固態廢棄物轉化成能源，是達到淨負排放的方法之一；然而，這方法至今尚未被證實有效。而且目前最常見的廢棄物能源化作法就是大量焚燒，其溫室氣體排放量遠遠超過它所取代的能源。[20]這種作法不但未能幫助能源部門減排，反而增加了該部門的排放量。隨著各國想方設法為其電網減碳，這種矛盾落差只會越來越擴大。其他的能源化方法包括熱裂解、氣化或是電漿熔融，不是技術難行就是缺乏商業效益。[21]掩埋場的氣體收集，雖然是經常被要求的甲烷減排措施，其成效如何則充滿不確定性。[22]在所有的「廢棄物能源化」技術中，只有厭氧醱酵被證實是成功的，但它要處理的是無毒的有機廢棄物，而非混雜的垃圾。

Zero waste systems, on the other hand, reduce GHG emissions through multiple avenues: separate collection and treatment of organic waste avoids landfill methane emissions; waste avoidance and recycling reduce "upstream" emissions caused by natural resource extraction, manufacturing, and transport associated with

[20] Pratt, Kimberley, and Michael Lenaghan. 2020. "The Climate Change Impacts of Burning Municipal Waste in Scotland: Technical Report." Zero Waste Scotland; Tabata, Tomohiro. 2013. "Waste-to-Energy Incineration Plants as Greenhouse Gas Reducers: A Case Study of Seven Japanese Metropolises." Waste Management & Research 31 (11): 1110–17. https://doi.org/10.1177/0734242X13502385. ; Tangri, Neil. 2021. "Waste Incinerators Undermine Clean Energy Goals," February. https://doi.org/10.31223/X5VK5X.

[21] Tangri, Neil and Monica Wilson. 2017. "Waste Gasification & Pyrolysis: High Risk, Low Yield Processes for Waste Management." Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/Waste-Gasification-and-Pyrolysis-high-risk-low-yield-processes-march-2017.pdf

[22] National Academies of Sciences, Engineering, and Medicine (U.S.), ed. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States. Consensus Study Report. Washington, DC: The National Academies Press.

the production of new goods; ending waste incineration and open burning eliminate their direct emissions of fossil and biogenic CO_2; and the application of compost or digestate to land can enhance the carbon uptake of soils.

相對地，零廢棄系統能透過許多途徑來減少溫室氣體排放，如：將有機廢棄物分類收集及處理，可避免其填埋在掩埋場裡排放甲烷；從源頭避免產生廢棄物以及做好廢棄物循環利用，可減少為了供應新品而進行的自然資源開採、生產製造與運輸等「上游」活動的排放；終結廢棄物焚化和露天燃燒，可避免那些源自化石燃料與生物質的廢棄物成為二氧化碳直接排放出去；最後，用堆肥成品或沼渣沼液來施灌土地，可增加土壤碳吸存量。

2.2. Tackling landfill methane through organic waste

2.2 透過有機廢棄物管理解決掩埋場甲烷排放

2.2.1. Methane emissions

2.2.1 甲烷排放

Methane is a powerful GHG, trapping 82.5 times as much heat as CO_2 over a 20-year timespan.[23] It is responsible for approximately 0.5°C of warming in today's world. Fortunately, methane also degrades relatively rapidly over an average period of 12 years.[24] Reducing methane emissions is therefore one of the quickest ways to reduce global heating and help us stay below 1.5°C of warming, the target set by the Paris Agreement. Swift emissions reductions will buy countries and communities around the world the much needed time they require to decarbonize their economies and societies.

甲烷是種非常強力的溫室氣體，其於20年期間所吸收的地表輻射熱，是二氧化碳的82.5倍。[23]現今全球暖化所升高的溫度中，大約有0.5°C是甲烷造成的。不幸中的大幸是，甲烷分解消散的速度相對也快，平均只需12年。[24]也因此，減少甲烷排放是降低全球暖化最快的方法之一，可幫助我們將全球暖化幅度控制在低於1.5°C的範圍內——也就是巴黎協定所設定的目標。快速的排放減量將可為世界各國和各社區爭取到大家都極為需要的時間，讓我們有更多餘裕針對經濟和社會運作進行去碳化。

[23] Masson-Delmotte, Valérie, Panmao Zhai, Anna Pirani, Sarah L. Connors, Clotilde Péan, Sophie Berger, Nada Caud, et al., eds. 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. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. https://doi.org/10.1017/9781009157896.

[24] "Very Strong Atmospheric Methane Growth in the 4 Years 2014–2017: Implications for the Paris Agreement - Nisbet - 2019 - Global Biogeochemical Cycles - Wiley Online Library." https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2018GB006009.

Globally, the waste sector is responsible for approximately 20% of anthropogenic methane emissions, making it the third largest and most rapidly growing source sector.[25] Landfill methane emissions result from the decomposition of organic waste—primarily food scraps—under anaerobic (oxygen-deprived) conditions.[26] In some cities, landfills are the dominant source of methane emissions.[27] Recent studies suggest that these numbers may be significantly underestimated.[28] Measuring the exact amount of methane emitted from landfills is challenging, as the methane generation rates vary greatly between landfills and even from spot to spot on the same landfill depending on temperature, moisture, and organic content.[29] Due to the inaccuracy of conventional measuring methods such as the Intergovernmental Panel on Climate Change (IPCC)'s "first-order decay model," uncertainty of the actual scale of methane emissions remains to be addressed.[30]

全世界源自人為因素的甲烷排放量當中，約有20%來自廢棄物部門，是第三大、也是成長最快速的甲烷排放源。[25]掩埋場會排放甲烷，是因為其中的有機廢棄物（主要是食物殘渣）在缺氧狀態下醱酵分解會產生甲烷。[26]在某些城市，掩埋場是最大的甲烷排放源。[27]近期一些研究指出，這些數字可能被嚴重低估了。[28]要精準衡量到底有多少甲烷從掩埋場逸出，是非常困難的。因為不同掩埋場產生甲烷的速率彼此之間差別很大，甚至同一座掩埋場的不同地點，甲烷產生速率也不盡相同；畢竟無論是溫度、濕度或是有機質含量，都會影響甲烷產生速率。[29]因為傳統的衡量方法，例如聯合國政府間氣候變化專門委員會（IPCC）提出的「一階衰減模型」（first-order decay model），精準度

[25] Ravishankara, A. R., Johan C. I. Kuylenstierna, Eleni Michalopoulou, Lena Höglund-Isaksson, Yuqiang Zhang, Karl Seltzer, Muye Ru, et al. 2021. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.

[26] Bogner, J., M. Meadows, and P. Czepiel. 1997. "Fluxes of Methane between Landfills and the Atmosphere: Natural and Engineered Controls." Soil Use and Management 13 (s4): 268–77. https://doi.org/10.1111/j.1475-2743.1997.tb00598.x; Gonzalez-Valencia, Rodrigo, Felipe Magana-Rodriguez, Jordi Cristóbal, and Frederic Thalasso. 2016. "Hotspot Detection and Spatial Distribution of Methane Emissions from Landfills by a Surface Probe Method." Waste Management, SI:Sanitary Landfilling, 55 (September): 299–305. https://doi.org/10.1016/j.wasman.2016.03.004;Ravishankara, A. R., Johan C. I. Kuylenstierna, Eleni Michalopoulou, Lena Höglund-Isaksson, Yuqiang Zhang, Karl Seltzer, Muye Ru, et al. 2021. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.

[27] Jeong, Seongeun, Xinguang Cui, Donald R. Blake, Ben Miller, Stephen A. Montzka, Arlyn Andrews, Abhinav Guha, et al. 2017. "Estimating Methane Emissions from Biological and Fossil-Fuel Sources in the San Francisco Bay Area." Geophysical Research Letters 44 (1): 486–95. https://doi.org/10.1002/2016GL071794.; Maher, R., & Kelly, L. (2021). Maher, Ryan, and Leah Kelly. 2021. "Greenhouse Gases from Maryland's Landfills: Underestimated and Under Regulated." Environmental Integrity Project.

[28] Maasakkers, Joannes D., Daniel J. Varon, Aldís Elfarsdóttir, Jason McKeever, Dylan Jervis, Gourav Mahapatra, Sudhanshu Pandey, et al. 2022. "Using Satellites to Uncover Large Methane Emissions from Landfills." *Science Advances* 8 (32): eabn9683. https://doi.org/10.1126/sciadv.abn9683.

[29] Bogner, J., M. Meadows, and P. Czepiel. 1997. "Fluxes of Methane between Landfills and the Atmosphere: Natural and Engineered Controls." Soil Use and Management 13 (s4): 268–77. https://doi.org/10.1111/j.1475-2743.1997.tb00598.x; Gonzalez-Valencia, Rodrigo, Felipe Magana-Rodriguez, Jordi Cristóbal, and Frederic Thalasso. 2016. "Hotspot Detection and Spatial Distribution of Methane Emissions from Landfills by a Surface Probe Method." Waste Management, SI:Sanitary Landfilling, 55 (September): 299–305. https://doi.org/10.1016/j.wasman.2016.03.004; Mønster, Jacob, Jerker Samuelsson, Peter Kjeldsen, and Charlotte Scheutz. 2015. "Quantification of Methane Emissions from 15 Danish Landfills Using the Mobile Tracer Dispersion Method." Waste Management 35 (January): 177–86. https://doi.org/10.1016/j.wasman.2014.09.006.; National Academies of Sciences, Engineering, and Medicine (U.S.), ed. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States. Consensus Study Report. Washington, DC: The National Academies Press; Themelis, Nickolas J., and Priscilla A. Ulloa. 2007. "Methane Generation in Landfills." Renewable Energy 32 (7): 1243–57. https://doi.org/10.1016/j.renene.2006.04.020.

[30] National Academies of Sciences, Engineering, and Medicine (U.S.), ed. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States. Consensus Study Report. Washington, DC: The National Academies Press.

並不夠，使得廢棄物部門的甲烷排放量到底有多少，目前還是充滿不確定性，仍是有待解決的難題。[30]

While waste composition and climate affect methane emissions, the waste management techniques and technologies employed are the most important factors.[31] Open dumps, which are often found in the Global South, are prone to smolder or to catching fire, reducing methane emissions but becoming major sources of toxic air and water pollution. Fully enclosed, compacted, and sealed landfills, which are typically found in the Global North, promote anaerobic decomposition of the organic waste into methane. Bioreactors, in which landfill leachate is recirculated into the landfill, increase methane generation by filling air voids and providing water to anaerobic microbes. Biologically active cover, on the other hand, contains methanotrophic microbes that consume methane before it reaches the atmosphere, making it the obvious choice for managed landfills during the transition to separate collection, composting of organics, and other zero waste solutions.

雖然甲烷排放量會受到廢棄物成份和氣候的影響，但所採用的廢棄物管理方式與處理技術，仍是最重要的因素。[31]在「全球南方」常見的露天棄置垃圾場，很容易發生悶燒或失火，雖然因此減少了甲烷排放但也成為有毒空氣污染和水污染的一大來源。在「全球北方」，典型的掩埋場則是完全圍阻、壓實、密封，但也提供了厭氧的環境，讓有機廢棄物容易醱酵分解而產生甲烷。把掩埋場當作生物反應器（Bioreactors）、亦即將掩埋場滲出水返送的作法，會因此填滿掩埋場空隙並提供水分給厭氧菌，進而促進甲烷的產生。相對地，在掩埋場上鋪覆「生物活性覆蓋層」（Biologically active cover），則因為其中含有甲烷氧化菌（methanotrophic microbes），可在甲烷尚未逸散到大氣之前將其捕捉並消化分解。在有機廢棄物尚未分類收集與堆肥處理之前，或在轉型到其它零廢棄方案之前，鋪覆生物活性覆蓋層顯然是管理掩埋場的最佳方案。

Box 2: Global Warming Potential (GWP) and Calculations

方塊**2**：全球暖化潛勢和其計算方式

Methane is a much more powerful GHG than carbon dioxide, but has only a brief atmospheric lifetime: 12 years on average as opposed to ~400.[32] Global Warming Potential (GWP) is a tool used to aggregate the effects of GHGs with very different atmospheric lifetimes. By construction, the GWP of CO_2 is 1; for other gasses, the GWP depends on the timeframe considered. For a short-lived gas like methane, the impact is concentrated in the first decade, so the 20-year GWP (82) is much higher than the 100-year GWP. Both GWPs are scientifically correct, and the choice of which to use is a policy, not scientific matter (IPCC AR6 WG1 TS 3.3.3). Whereas the initial Paris Agreement rule book prescribed the use of 100-year GWPs for national

[31] National Academies of Sciences, Engineering, and Medicine (U.S.), ed. 2018. Improving Characterization of Anthropogenic Methane Emissions in the United States. Consensus Study Report. Washington, DC: The National Academies Press.
[32] Archer, David, Michael Eby, Victor Brovkin, Andy Ridgwell, Long Cao, Uwe Mikolajewicz, Ken Caldeira, et al. 2009. "Atmospheric Lifetime of Fossil Fuel Carbon Dioxide." Annual Review of Earth and Planetary Sciences 37 (1): 117–34. https://doi.org/10.1146/annurev.earth.031208.100206.

reporting, the growing urgency to address short-term emissions is driving increased use of 20-year GWPs in policy.

甲烷是威力遠超過二氧化碳的溫室氣體，然而甲烷在大氣中的平均壽命只有12年，相較於二氧化碳在大氣中可存續將近四百年，實在十分短暫。[32]全球暖化潛勢（Global Warming Potential，此後以GWP簡稱）則是一套衡量工具，在各種溫室氣體具有不同大氣壽命的情況下，試圖量化各溫室氣體的暖化效應。首先定義二氧化碳的GWP為1，其它溫室氣體的GWP則要看所要衡量的期間有多長。像甲烷這類較短命的溫室氣體，其暖化效應主要集中在起初的10年，所以它的20年期GWP（82）遠高於100年期GWP（27.9）。這兩個數字在科學上都是正確的，要使用哪一個數字是政策上的考量，跟科學無關（IPCC AR6 WG1 TS 3.3.3）。雖然初版的《巴黎協定規則書》（Paris Agreement Rulebook）中規定國家報告中使用100年期GWP，但解決短期溫室氣體排放的急迫性正與日俱增，使得使用20年期GWP於政策中的情形越來越普遍。

The Inédit calculator used in this report relies upon an underlying scientific literature that uses 100-year GWPs. As a result, it effectively understates the impact of methane emissions. The practical impact is that（應該少了"the mitigation potential of"，請確認）reducing the organics sent to landfill is, if anything, far greater than expressed in the case studies on page X.
本報告使用的Inédit計算器所依據的一份科學基礎文獻使用的是100年期GWP，因此實際上也低估了甲烷排放量的衝擊。這低估所造成的影響，如果有的話，是減少有機廢棄物送往掩埋場的措施之減排潛力，將遠大於本報告案例研究中（參見5.1）所示的那些數字。

2.2.2. Alternatives to landfilling

2.2.2 取代掩埋場的方案

2.2.2.1. Waste prevention and food rescue

2.2.2.1 避免食物廢棄與挽救食物

The best approach to reducing landfill methane emissions is to avoid landfilling organic waste, which represents the largest proportion of the solid waste stream. As with other waste streams, waste prevention or avoidance has the greatest impact. An astonishing one-third of all food produced is wasted, and is responsible for as much as 10% of global GHG emissions.[33] Tackling food waste reduces emissions between 0.8 and 4.4

[33] Gustavsson, Jenny, Christel Cederberg, and Ulf Sonesson. "Global Food Losses and Food Waste," 38; Gikandi, Lilian. "10% of All Greenhouse Gas Emissions Come from Food We Throw in the Bin." World Wide Fund for Nature. https://updates.panda.org/driven-to-waste-report.

tonnes CO_2e per tonne of waste prevented, and comprehensive food waste reduction could lower global GHG emissions by 2% to 5%.[34] Most of these emissions reductions occur in the production and transportation of food even before it reaches consumers, which points to the gross inefficiencies in our current food systems.[35] Of the eight cities studied, only Bandung, Indonesia considers an action plan to reduce food waste; this is a neglected strategy that deserves more attention.

要減少掩埋場的甲烷排放，最好的辦法是避免掩埋有機廢棄物，而有機廢棄物在固體廢棄物中又是佔最大比例；而如同其它種類的廢棄物，避免廢棄物產生，會有最大的效益。令人震驚的是，全世界產出的所有食物中，有三分之一成為廢棄物；而這些食物廢棄物是造成10%溫室氣體排放的元兇。[33]每避免一噸食物被丟棄，大約可減少0.8～4.4噸CO2e（二氧化碳當量）的排放。而全面性的食物廢棄物減量方案，將可降低2~5%的全球溫室氣體排放量。[34]這些可被減少的排放大多來自於食物的生產與運輸階段，都還未抵達消費者手上就被廢棄了，這亦顯示出我們目前的糧食供應系統有多麼沒效率。[35]在本報告案例研究的八個城市中，只有印尼的萬隆（Bandung）正在擬定一項行動計畫來減少食物廢棄物，這顯示出這方面的策略被忽視了，需要更多的關注。

[graphic 2] food waste as proportion of all food produced, all GHG emissions, and equivalents in terms of cars or coal-fired power plants, etc.

[graphic 3] ILSR's Hierarchy to Reduce Food Waste & Grow Community
https://ilsr.org/food-waste-hierarchy/

When prevention is not possible, recovery should be the next priority. Food rescue and redistribution programs to communities in need, through networks of food banks, food pantries, grocery stores, restaurants, and other food retailers, can yield both significant emissions reductions and increased community resilience. For example, in just three years, Milan, Italy's food rescue program has been able to divert 130 million tonnes of food waste from landfilling annually, putting the city well on track to meet its goal of 50% food waste reduction by 2030.[36]

對於未能避免廢棄的食物，就應採取下個順位的措施：回收尚可食用的食物。利用食物銀行、社區型食物倉庫（food pantry）、食品雜貨或蔬果店、餐廳、和其它零售食物的商家所組成的網絡，收集剩食並重新分配供給需要的社群，像這類的行動不只能降低大量的排放，還能增加社區的韌性。

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[34] Dorward, Leejiah J. 2012. "Where Are the Best Opportunities for Reducing Greenhouse Gas Emissions in the Food System (Including the Food Chain)? A Comment." *Food Policy* 37 (4): 463–66. https://doi.org/10.1016/j.foodpol.2012.04.006.
;Salemdeeb, Ramy, David Font Vivanco, Abir Al-Tabbaa, and Erasmus K. H. J. zu Ermgassen. 2017. "A Holistic Approach to the Environmental Evaluation of Food Waste Prevention." *Waste Management* 59 (January): 442–50. https://doi.org/10.1016/j.wasman.2016.09.042; Venkat, Kumar. 2011. "The Climate Change and Economic Impacts of Food Waste in the United States." *International Journal on Food System Dynamics* 2 (4): 431–46. https://doi.org/10.18461/ijfsd.v2i4.247.

[35] "Seeking End to Loss and Waste of Food along Production Chain." Food and Agriculture Organization of the United Nations. http://www.fao.org/in-action/seeking-end-to-loss-and-waste-of-food-along-production-chain/en.

[36] Bottinelli, Stef. 2021. "The City of Milan's Local Food Hubs Reduce 130 Tonnes of Food Waste a Year, and Win EarthShot Prize." Food Matters Live, October 18, 2021. https://foodmatterslive.com/article/milan-local-food-hubs-reduce-130-tonnes-of-food-waste-a-year-and-win-earthshot-prize.

舉例來說，在短短三年的時間，義大利的米蘭（Milan）所實施的剩食救援計畫，每年阻擋了1.3億噸的食物進入掩埋場，讓該城市能順利邁向2030減少50%食物廢棄物的目標。[36]

2.2.2.2. Separate collection and treatment

2.2.2.2. 分類收集與處理

For the organic waste that cannot be prevented or rescued, the best practice is separate collection and treatment.[37] Separate collection at the point of generation (households, businesses, etc.) is critical to avoid cross-contamination of different waste streams, which lowers the utility and value of both organic and non-organic materials. In this context, the most prevalent and easiest-to-implement treatment method for organic waste is composting.

對於那些真的無法避免產生或回收食用的有機廢棄物，最好的作法是分類收集與處理。[37]在有機廢棄物的產生點（例如住家或是商家）就做好分類收集，十分重要，因為此舉可避免不同種類的廢棄物之間互相污染，而有機和無機廢棄物的互相污染會降低它們的效用與價值。在此前提下，處理有機廢棄物最普遍、簡單的方法，便是堆肥了。

Composting, the microbially-aided aerobic (i.e. oxygenated) decomposition of organic waste, can be carried out at a range of scales, from household to city-wide. Well-run composting operations do not attract vermin or create odors. Composting prevents an average of 78% of methane emissions that would otherwise be emitted from landfills, leading to significant waste sector emissions reductions.[38] Moreover, the scalability of composting initiatives (from backyard to industrial) allows for a range of waste management approaches, including highly decentralized systems. One advantage of decentralization is that it can significantly reduce transportation costs and the climate and public health impacts of heavy truck traffic. Care must be taken to ensure sufficient aeration of the compost, which prevents anaerobic digestion and waste water and methane formation. As the organic waste breaks down, it emits water vapor, biogenic CO_2, and small quantities of nitrous oxide (N_2O). However, a significant portion of the carbon remains in the final product— a nutrient—and organic matter-rich soil amendment.[39] This compost can be used for agricultural purposes, stormwater management, and landscaping, among other uses.

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[37] Morris, Jeffrey, H. Scott Matthews, and Clarissa Morawski. 2013. "Review and Meta-Analysis of 82 Studies on End-of-Life Management Methods for Source Separated Organics." Waste Management, Special Thematic Issue: Urban Mining, 33 (3): 545–51. https://doi.org/10.1016/j.wasman.2012.08.004; MRA Consulting Group. 2019. "Review of Separate Organics Collection Legislation: A Submission to NSW Environment Protection Authority." MRA Consulting Group; Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. Global Waste Management Outlook. United Nations Environment Programme.

[38] "Methane Matters: A Comprehensive Approach to Methane Mitigation." 2022. Changing Markets Foundation, Environmental Investigation Agency, Global Alliance for Incinerator Alternatives.

[39] Brown, Sally, Kristen McIvor, and Elizabeth Hodges Snyder, eds. 2016. Sowing Seeds in the City: Ecosystem and Municipal Services. Springer.

堆肥是指在微生物的幫助下，讓有機廢棄物進行耗氧分解作用。堆肥的規模可大可小，從家戶規模到城市規模都可以。執行得宜的堆肥，不會吸引害蟲也不會產生惡臭。堆肥平均而言可減少78%的掩埋場甲烷排放，因此可為廢棄物部門帶來相當可觀的減排效益。[38]再者，堆肥的規摸可擴縮性極佳（從後院堆肥到工業堆肥都可行），可跟多種廢棄物管理途徑結合，包括高度去中心化的廢棄物管理系統。去中心化系統的優點之一是可以避免大量卡車在路上跑，從而大幅減少其運輸成本及對氣候與大眾健康帶來的影響。在堆肥時要特別注意保持足夠的曝氣，避免厭氧醱酵以及產生廢水與甲烷。當有機廢棄物分解時，會產生水氣、生物源二氧化碳（biogenic CO_2，來自生物質分解、氧化的二氧化碳）和少量的一氧化二氮。然而堆肥最終成品中仍然保有大量的碳，以養分型態存在，成為富含有機質的土壤改良劑。[39]堆肥成品可用於農業、防洪措施和綠美化等多種用途。

Box: Composting success story from Pune, India

方塊：來自印度浦納的堆肥成功故事

A composting project organized and managed by the cooperative of waste pickers SWaCH in Pune (India) serves the dual benefits of reducing methane emissions and producing compost by diverting organic waste from being dumped at a landfill (where methane is generated when organic waste decomposes) to an at source composting facility (aerobic composting). Moreover, SWaCh is India's largest cooperative wholly owned by self-employed informal waste-pickers. It creates sustainable livelihoods for the waste-pickers, particularly for disadvantaged women, producing valuable compost that combats highly problematic soil degradation.

在印度的浦納（Pune），一項由拾荒者合作社SWaCH籌劃及管理的堆肥計畫，帶來兩大成效：減少甲烷排放和產出堆肥成品。該計畫將原本會被丟棄在掩埋場、任其分解而產生甲烷的那些有機廢棄物，轉移到產源附近的堆肥設施進行好氧堆肥。此外，SWaCH 完全由一群被歸類為自僱工作者、非正式部門的拾荒者所擁有，是印度最大的拾荒者合作社 。SWaCH 提供這些拾荒者們永續生計，尤其是弱勢婦女們，讓她們可藉此產出有價值的堆肥成品，改善嚴重的土壤貧瘠狀況。

Such a project is highly suitable in the Global South because the waste produced is mostly organic: 53% and 56% in middle- and low-income countries respectively.[40] In Pune, the proportion of household organic waste (the largest source of waste) is 72%.[41] SWaCH provides the expertise and materials needed to install the new composting infrastructure in both residential and commercial spaces, and it assigns a trained waste picker to maintain the composting unit. The waste is collected by trained waste pickers from citizens' doorsteps and delivered to the in-situ composting site. Currently, 71 waste-pickers are managing 7,000 Kg organic waste daily at 121 decentralized locations. SWaCH also helps individual community members maintain their existing composting sites, which makes them eligible to apply for a 5% tax cut on their property taxes.

[40] Kaza, Silpa, Lisa Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Urban Development Series. Washington, DC: World Bank. doi:10.1596/978-1-4648 -1329-0. License: Creative Commons Attribution CC BY 3.0 IGO

[41] "Existing Situation of Solid Waste Management in Pune City, India." 2012. Research Journal of Recent Sciences 1 (ISC-2011): 348-51.

[42]

這項堆肥計畫非常適合全球南方採用，因為其廢棄物中有一大部分是有機質，所佔比例在中、低收入國家分別高達53%與56%。[40]在浦納，來自家戶的有機廢棄物是廢棄物最大來源，其佔比高達72%。[41] SWaCH 提供所需的專業知識與物資，供住家或商家於其空間中設置新的堆肥設施。他們也派出受過訓練的拾荒者維護堆肥設施。這些專業的拾荒者於民眾住家門口收走廢棄物，接著（把有機廢棄物）運送到鄰近的堆肥場所。目前總共有 71 位拾荒者，每天管理分散在121個地點、重達 7,000公斤的有機廢棄物。SWaCH 也協助個人社區成員維護其既有的堆肥場所；在申報財產稅時，擁有堆肥場所可以申請 5%的減稅。[42]

This is a clear example of how a single project can mitigate GHG emissions, increase the capacity to adapt to climate change by improving the health of land, and provide additional benefits through the creation of jobs and reducing gender inequality. SWaCH's work has been internationally recognized and it has received several awards.[43]

這個案例清楚顯示，這樣一個簡單計畫可以降低溫室氣體排放，同時可藉由改善土地健康提升因應氣候變遷的能力，還可提供諸如降低性別不平等及創造工作機會等額外益處。SWaCH 推動的工作已經獲得國際認可並且得到許多獎項肯定。[43]

Other treatment methods for source-separated organics include anaerobic digestion and animal feed.[44] Anaerobic digestion produces methane-rich biogas from organic waste in an enclosed vessel, avoiding the problem of landfill methane leakage. The biogas is usually burned on site either for heat or electricity generation. This produces biogenic CO_2 emissions (see the sidebar) but can replace fossil-based fuels, particularly for cooking. Digestate, a slurry of partially decomposed organic matter, is the principal byproduct. It is typically dewatered, composted, and used as a soil amendment. Anaerobic digestion works best at small scales; its small footprint makes it a good choice for congested urban environments with high volumes of organic waste and little space for composting facilities.[45]

對於源頭已分類的有機廢棄物而言，除了堆肥之外，還有其他處理方法，比如厭氧消化和當作動物飼料。[44]厭氧消化法是在密閉容器中讓有機廢棄物醱酵產生富含甲烷的沼氣，這樣可以避免像垃圾掩埋場一樣讓所產生的甲烷逸散出去。一般來說，厭氧消化所產生的沼氣會就地燒掉以產熱或電力，這個過程雖會有生物源二氧化碳的排放（參考側邊註解），但可以取代化石燃料的使用，特別是用於烹飪的化石燃料。使用此方法會副產沼渣液，它是一種部分分解的有機物漿液。它通常在經過脫水、堆肥等程序處理後，作為土壤改良劑。厭氧消化在小規模的情況下能達到最佳效果；它的佔地面積較小，對於擁有大量有機廢棄物卻沒什麼空間設置堆肥設施的擁擠城市環境而言，可說是相當理想的選擇。[45]

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[42] *The Indian Express*. 2021. "PMC to End Tax Benefit to 3,081 Properties," January 9, 2021. https://indianexpress.com/article/cities/pune/pmc-to-end-tax-benefit-to-3081-properties-7139044

[43] "Awards - SWaCH." https://swachcoop.com/about/awards

[44] Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. *Global Waste Management Outlook*. United Nations Environment Programme.

[45] Prasad, R. 2012. "Efficient Way to Turn Waste into Resource." The Hindu, October 17, 2012, sec. Science. https://www.thehindu.com/sci-tech/science/Efficient-way-to-turn-waste-into-resource/article12561275.ece

While the prospect of generating energy from organic waste is enticing, anaerobic digestion should be employed with caution. It is much more costly to implement than composting and requires technical training to operate effectively.[46] If the process is mismanaged, there can be significant negative repercussions. Mismanagement includes landfilling the digestate, flaring the biogas instead of burning it for energy generation, burning fossil fuels to increase the processing temperature, and processing purpose-grown crops instead of food waste.
雖然厭氧消化法可以運用有機廢棄物來發電或產熱，看起來相當不錯，但仍須謹慎為之。要讓厭氧消化能有效運作需要專業的訓練，其成本也遠比堆肥來得高；[46]且若管理不當，就可能會造成重大的不良後果。不當管理方式包括將沼渣液拿去掩埋、將沼氣直接燒掉而未利用其燃燒過程來產能、為了提高處理溫度而燃燒化石燃料、還有收受專門種植的作物（例如能源作物）而不是收受食物廢棄物來處理。

Using organic waste as animal feed is another way of diverting organic waste from landfills. Food scraps have been fed to animals for millenia, and it remains a common strategy in rural areas worldwide. Animal feed is a good way to capture the nutrient value in food waste; it is also a good substitute for resource-intensive feed crops. The methane reduction potential of animal feed has yet to be robustly quantified, but one lifecycle analysis found that this treatment method outcompetes compost and anaerobic digestion in terms of its overall GHG emissions reduction performance. [47]However, precautions must be taken to avoid potential disease transmission, and industrial agriculture is, of course, a major source of GHG emissions.
將有機廢棄物當作飼料是另一個避免其進入掩埋場的方法。拿剩餘食物來餵養動物，是已有數千年歷史的作法，如今在世界各地的農村地區，這作法仍相當常見。當作飼料餵養動物，可以保存食物廢棄物中的營養價值不會浪費，還可以取代那些需要耗費大量資源種植的飼料作物，且是個不錯的飼料替代品。但此作法究竟能減少多少甲烷排放，目前還無法精確量化，不過有一項生命週期評估分析發現，其整體溫室氣體排放減量效益，還贏過堆肥和厭氧消化。[47]然而，還是要謹慎為之，避免傳染病藉此擴散，而且別忘了，工業化的畜產養殖本身就是個溫室氣體重大排放源。

[Pull quote/takeaway?] In all the cities we analyzed, except Seoul, separate collection and treatment of organics has the greatest potential to reduce GHG emissions. Separately collecting and treating the waste—usually through composting—reduced GHG emissions by at least 43% in each city (range: 43%-83%, mean: 62%)(section X). This impact is, if anything, understated, because it uses the 100-year GWP value for methane (see box). Seoul is an exception because it already diverts 96% of its organic waste through source-separate collection, so its emissions are primarily from incineration rather than landfilling.
[Pull quote/takeaway?] 在我們所分析的城市中，除了首爾以外，其他城市的分析結果均指出，有機物的分類收集與處理（通常是透過堆肥），具有最大的溫室氣體排放減量潛力，至少可以減少43%的溫室氣體排放（範圍：43%-83%；均值：62%）（參見第X節）。而且其影響是被低估的，因為我們使用了甲烷的百年期GWP來進行評估分析。首爾之所以是個例外，是因為該城市已經透過源頭分類收集，回收了96%的有機廢棄物，故其排放主要是源於焚化，而非掩埋。

[46] "Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions." 2021. UN Environment Programme. http://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions.
[47] Salemdeeb, Ramy, David Font Vivanco, Abir Al-Tabbaa, and Erasmus K. H. J. zu Ermgassen. 2017. "A Holistic Approach to the Environmental Evaluation of Food Waste Prevention." Waste Management 59 (January): 442–50. https://doi.org/10.1016/j.wasman.2016.09.042

Chart showing original emissions and reductions potential for 80% organics diversion across cities
Data here (a snapshot of either GHG or residual reduction)

The bottom line is that good source separation is the key to success with any organic waste management program. Source separation and separate treatment of organics can obviate the need for downstream mitigation measures such as landfill gas collection.[48] Source-separated waste can be successfully diverted from disposal through recycling or composting. Cross-contamination, on the other hand, reduces the quantity and quality of the recyclable and compostable materials, and can cause operational failures in some treatment technologies, such as anaerobic digestion.[49] Source separation is particularly important to ensure high-quality compost for land application. In California, high-quality compost fetches a premium market price, which significantly offsets the costs of waste management. The state's preliminary budget also includes USD 180 million to implement state requirements to separate and compost organic waste.[50]
結論是良好的源頭分類，是任何有機廢棄物管理計畫成功的關鍵。若能在源頭就把有機廢棄物分開來並單獨處理，就不用於後端採取諸如掩埋場沼氣收集等減緩氣候變遷的措施。[48]透過回收再利用或堆肥，可使源頭分類好的廢棄物，免於廢棄處理的命運。相對地，若源頭沒有做好分類，而讓不同種類的廢棄物交相混雜污染，會降低可回收與可堆肥物質的質與量，且可能會造成某些處理技術（比如厭氧消化）運作失敗。[49]源頭分類更是確保高品質堆肥成品的關鍵。在加州，高品質堆肥成品可賣到相當不錯的價錢，而大幅抵銷廢棄物管理成本。加州的預算草案也編列了1.8億美元的經費，以落實該州要求有機廢棄物應予分類與堆肥的規定。[50]
Good source separation practices rely on the cooperation of individuals and businesses, which in turn depend on continual outreach and culturally competent engagement from the local waste management authority, along with a clear, easy-to-use source separation scheme. Successes in locales as different as Italy, India, South Korea, and the U.S. attest to the viability of source separation schemes, regardless of culture, climate, or political circumstances.
要做好源頭分類，有賴於個人與企業的合作，而這又有賴於地方廢棄物主管機關持續宣導推廣及採取符合民情文化的安排，再搭配上明確、簡單的源頭分類計畫。在義大利、印度、南韓與美國等如此不同的地方，儘管文化、氣候與政治環境的差異如此之大，源頭分類計畫都能成功落實，表示其確實是可行的。

2.2.3 Residual waste
2.2.3 殘餘廢棄物

Even with the best food waste prevention, source separation, and treatment practices in place, some organic waste will continue to be mixed into residual waste for the foreseeable future. To address emissions from this "dirty organic fraction," the European Union has implemented policies to dramatically reduce the landfilling of untreated waste.[51] As one of the aims of zero waste systems is to continually reduce the quantity of waste sent

[48] Morris, Jeffrey, Enzo Favoino, Eric Lombardi, and Kate Bailey. 2013. "What's Best to Do with the 'Leftovers' on the Way to Zero Waste?" Ecocycle.
[49] Hoornweg, Daniel, and Perinaz Bhada-Tata. 2012. What a Waste: A Global Review of Solid Waste Management. Urban Development Series. Washington, DC, USA: World Bank Group; Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. Global Waste Management Outlook. United Nations Environment Programme.
[50] Rosengren, Cole. "California's Local Governments Grapple with Financial and Logistical Demands of Organics Recycling Law." Waste Dive. https://www.wastedive.com/news/sb-1383-part-three-california-local-government-budget-pandemic/625818.

[51] Directive 1999/31/EC of the European Parliament and of the Council of 26 April 1999 on the landfill of waste (OJ L 182 16.7.1999).

to disposal, it is important to not over-build infrastructure for residual waste management; otherwise, the sunk costs of this infrastructure create a financial incentive to continue generating large quantities of waste, thus disincentivizing waste reduction and diversion practices.
就算採取了最好的措施來預防食物廢棄及推動源頭分類和處理，仍可預期未來還是會有部份的有機廢棄物混入殘餘廢棄物中。為了解決這些「骯髒的有機成份」所造成的排放量，歐盟已實行一些政策，以大幅減少未處理廢棄物進入掩埋場。[51]由於零廢棄制度的目標之一是持續減少被廢棄處理的垃圾量，所以非常重要的是，不應蓋過多設施來處理殘餘廢棄物；否則，投入這類處理設施的「沉沒成本」（sunk cost；指已發生且無法收回的成本），會形成財務上的誘因，驅使著人們持續產生大量垃圾，而沒什麼動機去做好廢棄物減量和分類回收。

As long as some organics remain in the residual waste, such mixed material should undergo "biological stabilization," which refers to a range of treatments from mixing and aeration techniques to more complex material recovery and biological treatment systems. The aim of biostabilization is to reduce the potential of the residual waste to generate methane. Although the process is similar to composting, it does not generate usable compost because the residual waste is mixed and contaminated. One common approach to stabilizing residual waste prior to landfilling is mechanical recovery and biological treatment, which has been shown to reduce landfill methane generation by 80-90% or more.[52]
只要殘餘廢棄物中還存在著有機物，這些混合物就必須再經過一道「生物穩定化」的處理程序。「生物穩定化」的目的是要減少殘餘廢棄物產生甲烷的潛力，方法有多種，從簡單的混拌和曝氣到較為複雜的物料回收和生物處理系統。雖然這道程序跟堆肥有點類似，卻無法產出有用的堆肥成品，因為殘餘廢棄物的成份混雜、不單純。在殘餘廢棄物掩埋之前，常見的穩定化方法之一是機器回收與生物處理，已有實例顯示這樣做可減少80-90%的掩埋場甲烷產生量，甚至更多。[52]

A final mitigation step for landfills that continue to receive a dirty organic fraction or for older landfills with organic waste in place is the use of biologically active landfill cover (biocover). Although one study found that only 9% of landfill methane emissions originate in decommissioned landfills, these sites can continue to emit methane decades after being rendered out of operation.[53] Biocover refers to soil and compost that contain methanotrophic microbes, which feed on fugitive methane emissions from the landfill. Studies have shown

[52] Bayard, R., J. de Araújo Morais, G. Ducom, F. Achour, M. Rouez, and R. Gourdon. 2010. "Assessment of the Effectiveness of an Industrial Unit of Mechanical–Biological Treatment of Municipal Solid Waste." Journal of Hazardous Materials 175 (1): 23–32. https://doi.org/10.1016/j.jhazmat.2009.10.049.
;Gioannis, G. De, A. Muntoni, G. Cappai, and S. Milia. 2009. "Landfill Gas Generation after Mechanical Biological Treatment of Municipal Solid Waste. Estimation of Gas Generation Rate Constants." Waste Management 29 (3): 1026–34. https://doi.org/10.1016/j.wasman.2008.08.016.
; Scaglia, Barbara, Roberto Confalonieri, Giuliana D'Imporzano, and Fabrizio Adani. 2010. "Estimating Biogas Production of Biologically Treated Municipal Solid Waste." Bioresource Technology 101 (3): 945–52. https://doi.org/10.1016/j.biortech.2009.08.085; Smith, Alison, Keith Brown, Steve Ogilvie, Kathryn Rushton, and Judith Bates. 2001. Waste Management Options and Climate Change. European Commission DG Environment
[53] Powell, Jon T., Timothy G. Townsend, and Julie B. Zimmerman. 2016. "Estimates of Solid Waste Disposal Rates and Reduction Targets for Landfill Gas Emissions." Nature Climate Change 6 (2): 162–65. https://doi.org/10.1038/nclimate2804; "Landfill Gas Primer - An Overview for Environmental Health Professionals." 2001. Agency for Toxic Substances and Disease Registry. https://www.atsdr.cdc.gov/HAC/landfill/html/toc.html.

biocover to reduce fugitive methane emissions by an average of 63%.[54] In some cases, biocover is so effective it not only consumes all the fugitive methane emissions but draws down ambient atmospheric methane.[55]
至於那些還在收受骯髒有機垃圾的掩埋場，或者是有掩埋有機廢棄物的老舊掩埋場，要減緩其對氣候的衝擊，就得靠生物活性覆蓋層了（生物覆蓋）。雖然有一份研究發現只有9%的掩埋場甲烷來自那些已除役的掩埋場，但這些掩埋場停用後的數十年間，還是會持續排放甲烷。[53]生物覆蓋是指含有甲烷氧化菌的土壤或是堆肥，甲烷氧化菌會吃掉從掩埋場逸散出來的甲烷。一些研究證實生物覆蓋可以減少平均63%的甲烷逸散。[54]在某些個案中，生物覆蓋的效果好到不只吃掉所有從掩埋場逸散出來的甲烷，甚至還將周遭大氣中的甲烷捕捉吸收。[55]

Biocover compares favorably to landfill gas capture systems, which aim to capture and burn the methane-containing landfill gas. Landfill gas capture has highly variable mitigation efficacy and is subject to uncertainties about fugitive emission rates.[56] Long-term problems include breakage of the pipes that collect landfill gas, an inability to recover energy from landfill gas that is low in methane content, and air pollution from the gas combustion. Landfill gas collection systems are one of the costliest approaches to methane mitigation, which creates a perverse incentive to maintain high rates of methane generation by landfilling organic waste that could have been returned to the soil.
比起捕捉並燒掉含甲烷氣體的掩埋場沼氣收集系統，生物覆蓋的效益更佳。掩埋場沼氣收集技術的減排效益之變動性相當大，而且也受限於沼氣逸散排放速率的不確定性；[56]其它長期會發生的問題包括收集沼氣的管線會破漏、若沼氣中甲烷含量太低則無法回收能源、還有燃燒沼氣時會產生的空氣污染問題。掩埋場沼氣收集系統也是最昂貴的甲烷減排技術之一，因而產生一個不當誘因，寧願把有機廢棄物送到掩埋場中繼續製造高量的甲烷，而非讓其成為肥份回歸土壤。

Organic waste prevention, source separation, and separate treatment are essential elements to mitigate methane emissions; they are also all essential to the broader goal of building zero waste systems. As organic waste is one the largest fractions of municipal solid waste, successful organic waste diversion programs dramatically reduce the quantity of residual waste requiring additional treatment and disposal.

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[54] Boldrin, Alessio, Jacob K. Andersen, Jacob Møller, Thomas H. Christensen, and Enzo Favoino. 2009. "Composting and Compost Utilization: Accounting of Greenhouse Gases and Global Warming Contributions." *Waste Management & Research* 27 (8): 800–812. https://doi.org/10.1177/0734242X09345275; Lou, X. F., and J. Nair. 2009. "The Impact of Landfilling and Composting on Greenhouse Gas Emissions – A Review." Bioresource Technology, Selected papers from the International Conference on Technologies and Strategic Management of Sustainable Biosystems, 100 (16): 3792–98. https://doi.org/10.1016/j.biortech.2008.12.006; Stern, Jennifer C., Jeff Chanton, Tarek Abichou, David Powelson, Lei Yuan, Sharon Escoriza, and Jean Bogner. 2007. "Use of a Biologically Active Cover to Reduce Landfill Methane Emissions and Enhance Methane Oxidation." Waste Management 27 (9): 1248–58. https://doi.org/10.1016/j.wasman.2006.07.018.
; Barlaz, M. A., R. B. Green, J. P. Chanton, C. D. Goldsmith, and G. R. Hater. 2004. "Evaluation of a Biologically Active Cover for Mitigation of Landfill Gas Emissions." *Environmental Science & Technology* 38 (18): 4891–99. https://doi.org/10.1021/es049605b.

[55] Barlaz, M. A., R. B. Green, J. P. Chanton, C. D. Goldsmith, and G. R. Hater. 2004. "Evaluation of a Biologically Active Cover for Mitigation of Landfill Gas Emissions." *Environmental Science & Technology* 38 (18): 4891–99. https://doi.org/10.1021/es049605b; Mønster, Jacob, Jerker Samuelsson, Peter Kjeldsen, and Charlotte Scheutz. 2015. "Quantification of Methane Emissions from 15 Danish Landfills Using the Mobile Tracer Dispersion Method." *Waste Management* 35 (January): 177–86. https://doi.org/10.1016/j.wasman.2014.09.006

[56] Gonzalez-Valencia, Rodrigo, Felipe Magana-Rodriguez, Jordi Cristóbal, and Frederic Thalasso. 2016. "Hotspot Detection and Spatial Distribution of Methane Emissions from Landfills by a Surface Probe Method." *Waste Management*, SI:Sanitary Landfilling, 55 (September): 299–305. https://doi.org/10.1016/j.wasman.2016.03.004; Morris, Jeffrey. 2010. "Bury or Burn North America MSW? LCAs Provide Answers for Climate Impacts & Carbon Neutral Power Potential." Environmental Science & Technology 44 (20): 7944–49. https://doi.org/10.1021/es100529f; Smith, Alison, Keith Brown, Steve Ogilvie, Kathryn Rushton, and Judith Bates. 2001. *Waste Management Options and Climate Change*. European Commission DG Environment.

要減少甲烷的排放，重點是避免有機廢棄物的產生，若產生則於源頭做好分類，使之與其他廢棄物分開來處理；這些也是打造零廢棄系統這遠大目標所需的基本功。畢竟有機廢棄物在城市垃圾中的佔比最大，若能成功將有機廢棄物分流，將能大大減少最終的殘餘廢棄物數量及其後續所需的處理與處置措施。

2.3. Scaling up reduction, reuse, and recycling of non-organic waste

2.3. 提昇非有機廢棄物的減量、再使用和再利用

2.3.1 Waste hierarchy
2.3.1 廢棄物治理層級

While tackling organics is critical to deep emissions cuts in the waste sector, other materials—particularly paper, cardboard, metal, glass, textiles and plastic—hold the key to net negative emissions. Here, the waste hierarchy is the best guide to minimizing GHG emissions, with source reduction being the most impactful and preferred option. Source reduction, reuse, and recycling all reduce emissions by decreasing the demand for raw materials, the energy required to manufacture goods, and the need for associated transport. In national inventories, these emissions are tallied in the industrial, agricultural, transportation, and energy sectors—not the waste sector—which explains how zero waste can reduce more emissions than the waste sector produces.
雖說有機廢棄物的處理是廢棄物部門要大幅減排的重點，然而其它種類廢棄物的管理也很重要，是決定能否邁向淨負碳排的關鍵，尤其是紙張、紙板、金屬、玻璃、紡織品和塑膠。下圖所示的廢棄物治理層級是溫室氣體減排的最佳指引，其中源頭減量是最有影響力、最優先的選項。源頭減量、再使用、再利用等三策略皆能減少排放，因為它們可降低對原生物料的需求、減少產品生產過程的能源消耗以及相關的運送需求。在國家溫室氣體排放清冊中，上述排放被歸類在工業、農業、運輸和能源部門中，而非統計於廢棄物部門中，這也就是為何實行零廢棄所能減少的排放量比廢棄物部門自身產生還多的原因。

[graphic 4] waste hierarchy

A study conducted by the U.S. EPA demonstrated that waste prevention showed net negative impacts and the biggest climate benefits among existing waste management methods, such as recycling, composting, incineration, and landfilling.[57] Strategies for source reduction include restricting the production and distribution of single-use items and packaging and designing products to be durable, repairable, reusable, and fully recyclable or compostable. In the circular economy, products should be sourced from reused, recycled, or renewable non-toxic materials to minimize the need for extraction and the use of virgin natural resources, and cities should institutionalize alternative delivery systems to enable and strengthen reuse and refill models.
由美國環保署執行的一份研究顯示出：相較於其它既有的廢棄物管理措施，如回收、堆肥、焚化和掩埋，預防廢棄物產生（源頭減量）可以達到淨負排放的效果，對於減緩氣候變遷而言具有最大效

[57] EPA, Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices (2009), https://www.epa. gov/sites/production/files/2016-08/documents/ ghg-land-materials-management.pdf

益。[57]一些源頭減量策略包括：限制一次用製品和包裝的生產與配銷，設計更加耐用、可維修、可再使用、可全部拿去再利用或堆肥的產品。在循環經濟中，產品應以無毒的二手料、再生料或可自然再生的材料來製作，以將開採和使用原生天然資源的需求降到最低。城市也應透過制度建構，打造有利於再使用與重複充填的產品與服務提供系統。

The emissions reductions from source separation and recycling can also be quite substantial. Our analysis shows that Detroit, Lviv, and São Paulo could each reduce their GHG emissions by more than 20% through effective source-separated collection of readily recyclable materials—metals, glass, paper, and cardboard, as well as small quantities of plastic and textiles. Other cities, which already have efficient formal (Seoul) or informal (Durban) recycling sectors, have less scope to improve; in these cases, it is important to avoid problematic approaches such as waste incineration that would negatively affect existing recycling systems.
源頭分類和回收再利用能夠減少的排放量也是相當可觀。我們的分析顯示，底特律、利沃夫、聖保羅等城市，若能透過有效的源頭分類收集方式，將容易回收再利用的物質——金屬、玻璃、紙張、紙板，還有少量的塑膠和紡織品——予以回收，那麼這些城市皆各自能減少超過20%的溫室氣體排放量。其它城市，因為已存在著有效運作的正式（首爾）或非正式（德班）的回收部門，所以這部份的改善空間較有限；在這種情形下，重點是避免採用像焚化這類會衍生許多問題的方法，免得負面影響既有的回收體系。

The mitigation potential of recycling depends on the energy and emissions intensity of the material, which ranges widely; for energy-intensive materials, such as metals, the reductions can be as high as 96% of the emissions associated with producing the original product.[58] The potential for mitigation through waste avoidance and recycling often goes unrealized due to misaligned economic incentives. For example, recycled plastic resin struggles to compete with subsidized virgin resin, depressing recycling rates well below technically feasible levels.[59]
回收再利用的減排潛力，取決於所回收物質的能源與排放的密集度，而這項數據在不同材料間差異極大。對於像金屬這種能源密集度高的材料，其回收再利用相對於從頭生產原生物料，能夠減少高達96%的排放。[58]避免廢棄物產生和回收再利用的減排效益，往往因為一些錯位的經濟誘因，而無法實現。舉例來說，再生塑膠料必須跟受到補助的原生塑膠料競爭，而使得其回收率遠低於技術可行的水準。[59]

2.3.2 Plastic

2.3.2 塑膠

[58] Friedrich, Elena, and Cristina Trois. 2013. "GHG Emission Factors Developed for the Collection, Transport and Landfilling of Municipal Waste in South African Municipalities." Waste Management 33 (4): 1013–26. https://doi.org/10.1016/j.wasman.2012.12.011; Hillman, Karl, Anders Damgaard, Ola Eriksson, Daniel Jonsson, and Lena Fluck. 2015. Climate Benefits of Material Recycling : Inventory of Average Greenhouse Gas Emissions for Denmark, Norway and Sweden. Nordisk Ministerråd. http://urn.kb.se/resolve?urn=urn:nbn:se:norden:org:diva-3965.

[59] OECD. 2018. "Improving Plastics Management: Trends, Policy Responses, and the Role of International Co-Operation and Trade." Policy Perspectives 12. OECD Environment Policy Paper. Organization for Economic Co-operation and Development.

Plastic is a ubiquitous and uniquely problematic material. Plastic production is growing at 3.5-4% per year, doubling every 20 years.[60] As 70% of plastic becomes waste within a year of its production, plastic waste generation is also growing at a similar rate.[61] As a fossil fuel product, plastic has an enormous carbon footprint, two-thirds of which is in the production phase. Additional CO_2 is emitted when carbon is burned, e.g., in incinerators. Judging by current investments in expanded plastic production capacity, from 2015 to 2050, the world's plastic GHG footprint will be 129 billion tonnes combined.[62] In the U.S. alone, the GHG emissions from plastic production and destruction is projected to exceed the power sector's GHG footprint.[63] If plastic were a country, its global carbon footprint would be the fifth largest among all nations.[64]
塑膠這種材料不但無處不在而且特別麻煩。塑膠產量每年以 3.5-4% 的速度增長，每 20 年翻一倍。[60]由於 70% 的塑膠在生產後一年內就變成垃圾，於是塑膠垃圾的產生量也以同等級的速度增長。[61]作為一種化石燃料產品，塑膠的碳足跡相當巨大，其中三分之二來自其生產階段；另外的三分之一，主要來自其廢棄燃燒（例如在焚化爐中）階段。從目前對擴大塑膠產能的投資來看，預期全球塑膠溫室氣體足跡從2015到2050年的總和將達到1,290億噸。[62]僅僅在美國，塑膠的生產和廢棄處理所產生的溫室氣體排放量預計就會超過能源部門的溫室氣體足跡。[63]如果把塑膠產業當成是一個國家，其全球碳足跡將在所有國家中排名第五。[64]

Unfortunately, recycling is not as effective for plastic as for other materials: plastic waste is a mix of different polymers, additives, contaminants, and other materials that are difficult or impossible to effectively separate. As a result, very little plastic (9%) is successfully recycled.[65] Alternative processes such as pyrolysis and solvolysis, which the plastic industry calls "chemical recycling," have high energy demands, low efficiencies, and enormous carbon footprints.[66] However, even perfected recycling technologies would not address the upstream emissions of growing plastic production, which is incompatible with a net-zero emissions goal. Source reduction is therefore the key to constraining plastic's GHG footprint.
不幸的是，塑膠的回收再利用並不如其他物質那麼有效：塑膠垃圾中通常混了各種不同的聚合物、添加物、污染物、還有其它幾乎無法有效分離的物質。因此目前只有極少部份（9%）的塑膠成功被回收。[65]被塑膠產業稱為「化學回收」的其它替代處理技術，例如熱裂解（pyrolysis）和溶劑分解（solvolysis），需要大量能源、效率差、又會產生巨大碳足跡。[66]然而再完美的回收處理技術，都無法

[60] Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." Science Advances 3 (7): e1700782. https://doi.org/10.1126/sciadv.1700782.
[61] Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." Science Advances 3 (7): e1700782. https://doi.org/10.1126/sciadv.1700782.
[62] Zheng, Jiajia, and Sangwon Suh. 2019. "Strategies to Reduce the Global Carbon Footprint of Plastics." *Nature Climate Change* 9 (5): 374–78. https://doi.org/10.1038/s41558-019-0459-z
[63] Vallette, Jim. 2021. "The New Coal: Plastics & Climate Change." Beyond Plastic. https://www.beyondplastics.org/plastics-and-climate
[64] Hamilton, Lisa Anne, Steven Feit, Matt Kelso, Samantha Malone Rubright, Courtney Bernhardt, Eric Schaeffer, Doun Moon, Jeffrey Morris, and Rachel Labbé-Bellas. 2019. "Plastic & Climate: The Hidden Costs of a Plastic Planet." Center for International Environmental Law. https://www.ciel.org/plasticandclimate.
[65] Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." *Science Advances* 3 (7): e1700782. https://doi.org/10.1126/sciadv.1700782.
[66] Rollinson, Andrew Neil, and Jumoke Oladeho. 2020. "Chemical Recycling: Status, Sustainability, and Environmental Impacts." Global Alliance for Incinerator Alternatives, June. https://doi.org/www.doi.org/10.46556/ONLS4535; Patel, Denise, Doun Moon, Neil Tangri, and Monica Wilson. 2020. "All Talk and No Recycling: An Investigation of the U.S. 'Chemical Recycling' Industry." Global Alliance for Incinerator Alternatives. https://doi.org/10.46556/WMSM7198; Tabriz, Shanar, Andrew Neil Rollinson, Marieke Hoffmann, and Favoino Enzo. 2020. "Understanding the Environmental Impacts of Chemical Recycling Ten Concerns with Existing Life Cycle Assessments." Zero Waste Europe. https://zerowasteeurope.eu/wp-content/uploads/2020/12/zwe_jointpaper_UnderstandingEnvironmentalImpactsofCR_en.pdf.

解決上游不停成長的塑膠生產所產生的排放，這跟淨零排放的目標背道而馳。因而要限制塑膠的溫室氣體足跡，關鍵是源頭減量。

Plastic production needs to shrink rather than grow in the coming years.[67] But reduced production is not in the interests of the oil, gas, and petrochemical industries, which are currently investing billions of dollars in expanding capacity. Plastic use is driven not by increasing demand but by increasing supply, with the industry actively seeking out new markets for plastic to compensate for stagnant sales of transportation fuels.[68] Demand-side measures, such as promoting plastic-free and reuse-based business models, while important, are thus insufficient to check growth in plastic production. Forceful public policy interventions are required. The most popular policies enacted to date are bans on categories of plastic, such as single-use plastics and hard-to-recycle packaging. Additional policies will probably be required, such as banning new plastic production facilities and expanding the categories of banned plastic. Other potential policy measures, such as a plastic tax, have yet to gain consensus. The universally recognized need for stronger policies is captured in resolution UNEP/EA.5/Res.14 of the United Nations Environment Assembly, which initiated a negotiation process toward a new global treaty on plastic. For the first time, a global cap on plastic production is on the table.

在未來幾年，我們得減少塑膠產量而不是讓它一直成長。[67]然而減少塑膠生產，並不符合石油、天然氣和石化等產業的利益，而這些產業目前可是投資了幾十億的資金在擴張產量。其實，帶動塑膠用量成長的驅力，並非不斷成長的需求，反而是不斷成長的供給；因為產業界為因應運輸燃料的銷售停滯，而積極開發新的塑膠市場。[68]在需求端實行減塑策略，例如推行無塑或重複使用的商業模式，雖然也很重要，卻不足以抑制塑膠生產端的成長。我們需要強制性的公共政策進場干預。至今制定的一些政策中，最受歡迎的是禁止特定種類的塑膠製品，例如一次用塑膠或是難以回收的包裝。應該也需要額外的政策，例如禁止設立新的塑膠生產設施、擴大禁塑範圍。其它有潛力的政策措施，例如課塑膠稅，目前尚未取得共識。需要更強而有力的禁限塑政策，已是各界共識，並已呈現在聯合國環境大會（United Nations Environment Assembly）的決議UNEP/EA.5/Res.14中；根據該決議，已展開一協商程序，目標是產出一份管制塑膠的新全球公約。這是有史以來第一次，關於塑膠生產的全球總量管制議題被拉到檯面上討論。

The plastic that is produced should be designed for reuse and recyclability. This means avoiding the use of additives, toxicants, mixed polymers, unrecyclable polymers (such as polyvinyl chloride) and multi-material packaging that deter mechanical recycling. At the same time, there is little sense in investing heavily in heavy industrial facilities (such as chemical recycling and incineration) to handle waste streams that are slated for phase-out; these sunk costs will create incentives to continue production of problematic plastic.

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[67] Bergmann, Melanie, Bethanie Carney Almroth, Susanne M. Brander, Tridibesh Dey, Dannielle S. Green, Sedat Gundogdu, Anja Krieger, Martin Wagner, and Tony R. Walker. 2022. "A Global Plastic Treaty Must Cap Production." *Science* 376 (6592): 469–70. https://doi.org/10.1126/science.abq0082; Lau, Winnie W. Y., Yonathan Shiran, Richard M. Bailey, Ed Cook, Martin R. Stuchtey, Julia Koskella, Costas A. Velis, et al. 2020. "Evaluating Scenarios toward Zero Plastic Pollution." *Science* 369 (6510): 1455–61. https://doi.org/10.1126/science.aba9475; Borrelle, Stephanie B., Jeremy Ringma, Kara Lavender Law, Cole C. Monnahan, Laurent Lebreton, Alexis McGivern, Erin Murphy, et al. 2020. "Predicted Growth in Plastic Waste Exceeds Efforts to Mitigate Plastic Pollution." *Science* 369 (6510): 1515–18. https://doi.org/10.1126/science.aba3656.

[68] Fernandez Pales, Araceli, and Peter Levi. 2018. "The Future of Petrochemicals.Towards More Sustainable Plastics and Fertilisers." International Energy Agency (IEA). https://iea.blob.core.windows.net/assets/bee4ef3a-8876-4566-98cf-7a130c013805/The_Future_of_Petrochemicals.pdf.

塑膠產品應該一開始就被設計成可再使用和再利用。要達到這樣的目的，意味著必須避免使用添加劑、毒性物質、混合聚合物、無法回收的聚合物（例如聚氯乙烯）和阻礙機械式回收的多重材質包裝。與此同時，為處理不利於回收、應該要淘汰的廢棄物而大舉投資重工業設施（例如化學回收和焚化設施），是沒什麼意義的；這些沉沒成本還會誘使人們持續生產這些製造麻煩的塑膠。

Cities have taken the lead in banning unnecessary and non-recyclable plastic, and these bans have often been stepping stones to state/provincial-level and even national bans. Municipal-level bans of single-use plastic have been proposed for seven of the cities in this study. Despite the relatively small tonnage of waste these bans target, the GHG emissions reductions can be sizable, particularly in cities that use large quantities of plastic. In addition to reducing GHG emissions, these bans are important for flood control, reduction of waste management costs, and preventing plastic pollution in the environment.
許多城市率先禁用了非必要或是無法回收的塑膠，且這些禁令通常會成為州、省、甚至國家層級的禁塑政策的墊腳石。本報告中有七個城市提出了城市層級的一次用塑膠禁用政策。雖然這些禁塑政策所管制的廢棄物噸位相對很少，但能減少的溫室氣體排放量卻很可觀，尤其是在那些大量使用塑膠的城市。除了可減少溫室氣體排放，這些禁塑政策對於防洪、減少廢棄物管理費用、以及防止塑膠污染環境等方面，也是十分重要。

[graphic 5] Chart showing total BAU emissions vs. SUP ban reductions
Data here

2.4. Ending waste combustion

2.4. 終結廢棄物焚燒

Incineration and open burning of waste (the latter usually in concert with open dumping) are common practices in the Global North and Global South, respectively. Both emit large quantities of GHG, primarily fossil CO_2 (from the combustion of plastic), biogenic CO_2 (from the combustion of paper, cardboard, and food waste), and N_2O, as well as particulates. Although there is relatively little data about the impact of open burning, it is universally acknowledged to be a problematic practice that must be phased out for both climate and environmental health reasons. Open burning and open dumping primarily occur where local authorities lack the resources to collect and properly manage waste. These practices are aggravated by the dramatic rise in plastic production, which is both increasing the quantity of waste and changing its composition, leading to higher GHG and toxic emissions when burned.
廢棄物焚化是全球北方常見的措施，而露天燃燒（其常伴隨著垃圾露天堆置而來）則常見於全球南方。這兩種方式都會排放大量溫室氣體，其主要包括源自燃燒塑膠的化石源二氧化碳；源自燃燒紙張、紙板及廚餘的生物源二氧化碳；還有一氧化二氮和懸浮微粒。雖然目前關於露天燃燒所造成影響的資料相對很少，全世界普遍認為這種作法大有問題，不管是為了氣候還是環境衛生，都應淘汰這種作法。因為會出現垃圾露天燃燒和露天堆置的地方，當地政府通常缺乏收集和妥適管理廢棄物所需的資源；而隨著塑膠產量的大幅成長，廢棄物的數量跟著增加、組成越趨複雜，導致其焚燒後產生更多溫室氣體和毒性物質排放，使得這些處理方法所造成的問題更加惡化了。

Incineration is the most expensive waste management strategy and a major source of GHG and toxic emissions.[69] Even with emission savings from electricity generation taken into account, each tonne of plastic burned at that incinerator would result in the release of around 1.43 tonnes of CO_2.[70] Its high capital costs and required technical expertise create a risk of locking cities into undesirable practices for decades.[71] Incinerators have performed best in cities where the waste heat can be used in a district heating network; otherwise, the electricity produced is more carbon intensive than the electric grid, implying that it will displace lower-emitting forms of electricity.[72] In developing countries, incineration is not practical due to high moisture content and low calorific value (heating value) of the municipal waste stream.[73]
焚化不但是最昂貴的廢棄物處理方法，也是溫室氣體和毒性物質的重大排放源之一。[69]雖然焚化發電會省下為發同等電量所產生的碳排，但就算扣掉那部份的排放量，每噸進焚化爐燒的塑膠垃圾還是會產生約1.43噸的二氧化碳。[70]焚化爐所需的巨額建置成本和技術專業，反而可能讓城市在往後數十年不得不依賴垃圾焚化。[71]在某些城市，焚化廢熱可運用於區域供熱網路，而使得焚化爐的運作效益大幅提高；然而在其它地方，焚化爐發電的碳排密集度其實更高於電網，這意味著廢棄物焚化會排擠其他較低碳排的發電方式。[72]在發展中國家，因為廢棄物的含水率較高、熱值較低，所以焚化發電並不切實際。[73]

Nevertheless, many studies continue to tout incineration as a mitigation measure because it avoids landfill gas emissions and produces energy. These studies rely on worst-case comparisons in order to conclude that incineration is superior. In particular, they usually assume that unseparated municipal waste, with high organic content, will be sent to landfill without significant methane remediation measures.
然而，許多研究還在繼續吹捧焚化，將其視為減少排放的措施，因為其避免了掩埋場沼氣排放、而且還能發電。這些研究靠著與最差情境的比較，得出「焚化超讚」這種結論。特別是，他們總是假設城市垃圾含有很高比例的有機物、而且在沒有分類的情況下被送進掩埋場，另外也假設掩埋場沒有任何防制甲烷排放的重要措施。

While that situation describes current practice in many locations around the world, it is by no means universal. Most importantly, it is unlikely to continue. The establishment of net zero emissions goals under the Paris Agreement means that landfills, as significant methane emitters, can no longer be regarded as an acceptable part of the status quo "business as usual." In the European Union, for example, pretreatment for landfilled

[69] Moon, Doun. 2021. "The High Cost of Waste Incineration." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/beyondrecovery.
[70] United Kingdom Without Incineration Network. 2018. "Evaluation of the climate change impacts of waste incineration in the United Kingdom".
[71] Corvellec, Hervé, María José Zapata Campos, and Patrik Zapata. 2013. "Infrastructures, Lock-in, and Sustainable Urban Development: The Case of Waste Incineration in the Göteborg Metropolitan Area." Journal of Cleaner Production, Special Issue: Advancing sustainable urban transformation, 50 (July): 32–39. https://doi.org/10.1016/j.jclepro.2012.12.009; Hoornweg, Daniel, and Perinaz Bhada-Tata. 2012. What a Waste: A Global Review of Solid Waste Management. Urban Development Series. Washington, DC, USA: World Bank Group.
[72]Hogg, Dominic, and Ann Ballinger. 2015. "The Potential Contribution of Waste Management to a Low Carbon Economy." Eunomia. https://www.eunomia.co.uk/reports-tools/the-potential-contribution-of-waste-management-to-a-low-carbon-economy; Smith, Alison, Keith Brown, Steve Ogilvie, Kathryn Rushton, and Judith Bates. 2001. Waste Management Options and Climate Change. European Commission DG Environment; Vähk, Janek. 2019. "The Impact of Waste-to-Energy Incineration on Climate." Policy Briefing. Zero Waste Europe. https://zerowasteeurope.eu/library/the-impact-of-waste-to-energy-incineration-on-climate.
[73] Barton, J. R., I. Issaias, and E. I. Stentiford. 2008. "Carbon – Making the Right Choice for Waste Management in Developing Countries." Waste Management, OECD Workshop - Soils and Waste Management: A Challenge to Climate Change, 28 (4): 690–98. https://doi.org/10.1016/j.wasman.2007.09.033; Hoornweg, Daniel, and Perinaz Bhada-Tata. 2012. What a Waste: A Global Review of Solid Waste Management. Urban Development Series. Washington, DC, USA: World Bank Group.

waste is now obligatory, and countries must put in place plans to avoid landfilling organic waste. The Paris Agreement has established a clear benchmark—zero emissions[74]—against which to measure climate projects. A project can no longer claim to mitigate emissions on the basis that its emissions, although high, are lower than a hypothetical and completely preventable (as section XX shows) alternative; all projects must aim for zero emissions. For incinerators, this implies shutting down, which both removes a major source of emissions and contributes to a cleaner electric grid.[75]

雖然以上情境確實反映了世界上許多地方的現況，但絕不是全世界都是這樣。最重要的是，這種情況不太可能一直下去。巴黎協議訂定了淨零排放的目標，意味著像掩埋場這種重大的甲烷排放源，其現況不再能被視為可接受的而能「照常運作」。舉例來說，歐盟目前規定送進掩埋場的廢棄物必須經過前處理，而各成員國必須為「防止有機廢棄物的掩埋處理」訂立有效計畫。巴黎協議制定了明確的標竿——零排放[74]——並以此來衡量氣候計畫。因此，一項計畫即使其排放低於一假定的、且可完全避免的作法（參見section XX），只要其排放是高的，就不再能夠宣稱其可減排；所有的計畫都須以零排放為目標。對於焚化爐而言，這意味著必須停止運作，如此既能移除一重大排放源，也能對乾淨電網做出貢獻。[75]

This is precisely the situation in Seoul, the only city in the study that relies significantly on incineration. In Seoul, emissions from incineration are five times higher than from landfills and nearly twice as high as replacement energy sources. Eliminating incineration would transform Seoul's waste sector, increasing its emissions reductions by an order of magnitude. Similarly, ending open burning of waste in cities where it is prevalent is important, although much harder to quantify due to lack of data on the practice.

上面描述的正是首爾現況。首爾是本研究中唯一一個極端仰賴焚化的城市。在首爾，焚化產生的排放量是掩埋場的五倍，也幾乎是其它替代能源的兩倍。若能廢除所有焚化設施，首爾的廢棄物部門將能搖身一變，排放量將大幅降低達10倍以上。同樣地，終結露天燃燒，對於露天燃燒行為猖獗的城市也很重要，雖然目前因為缺乏數據，無法量化這種行為所產生的排放到底有多少。

2.5. Advantages of soil carbon storage

2.5. 土壤碳吸存的優點

Composting has many benefits (see section 3.4.), including direct and indirect mitigation effects. The mitigation effects of applying compost, including the digestate resulting from anaerobic digestion of organic waste, to soil are manifold: GHG emissions associated with the use of synthetic fertilizer, peat, and/or pesticides are avoided; N_2O emissions related to use of synthetic fertilizer are reduced; emissions associated

[74] There is considerable controversy about the "net" element of the net zero emissions goals established in the Paris Agreement. What is clear is that opportunities for real CO_2 removal and sequestration are small and uncertain, particularly in comparison to the growing flux of anthropogenic emissions. As such, every sector that can achieve zero emissions must do so; effectively, zero anthropogenic emissions is the appropriate target.

[75] Tangri, Neil. 2021. "Waste Incinerators Undermine Clean Energy Goals," February. https://doi.org/10.31223/X5VK5X.

with tilth and irrigation are decreased; and the uptake of atmospheric carbon by the soil and plants is enhanced.[76]

堆肥可帶來非常多的好處(見章節3.4)，包括直接或間接減緩氣候變遷的效益。土壤施用堆肥(包括有機廢棄物經過厭氧消化後產出的沼渣液)具有多重減緩效益：可避免因使用化學肥料、泥炭及/或殺蟲劑所造成的溫室氣體排放；減少使用化學肥料所造成的一氧化二氮(N_2O)排放；翻耕和灌溉所產生的排放也減少了；而土壤與植物從大氣中吸收的碳則增加了。[76]

Compost is a carbon-rich soil amendment. When applied to soil, it stimulates myriad biological processes that result in a portion of the carbon being emitted as CO_2, and another portion stored in the soil and below-ground biomass. How much carbon can be stored in soil, and for how long, are open scientific questions. In Marin County, California, a single application of compost on degraded rangeland resulted in dramatic increases in water holding capacity, forage productivity, and carbon sequestration.[77] Soil carbon storage is strongly affected by temperature, precipitation, land use, soil type, and degree of soil degradation, and thus its potential is highly variable and site-specific. While soil carbon storage is no substitute for emissions reductions, degraded agricultural land is a global problem, and returning it to health would imply a drawdown of 15.12-23.21 GT of carbon,[78] 11-17% of the amount of soil carbon that has been lost since humans first settled into agricultural life around 12,000 years ago.[79] At a minimum, compost provides an excellent alternative to synthetic fertilizer, which is an energy- and emissions-intensive fossil fuel product.

堆肥是富含碳的土壤改良劑。堆肥施加於土壤中會激發無數生化反應，導致一部分的碳形成二氧化碳排放出去，剩下的部份就儲存在土壤和地下生物質中。土壤中可以儲存多少碳、存多久時間，都還是未知的科學問題。在加州的馬林郡(Marin County)，有一塊牧地土壤已退化，但施用了一次堆肥之後，就大大增加了保水力、牧草產量和碳吸存量。[77]氣溫、降雨量、土地用途、土壤性質、土壤退化程度，都會強烈影響土壤的碳存量，所以土壤的碳儲存潛力變異極大、因地而異。雖然把碳儲存在土壤中的目的並非要取代減排措施，但農地退化已成為全球性的問題，而要回復所有這些土地的健康，可能需要存回151.2-232.1億噸的碳；[78]相當於人類自12,000年前開始農業活動以來，土壤所損失碳量的11-17%。[79]至少，比起化肥這種高耗能、高排放的化石燃料產品而言，堆肥不但可取而代之且是相當不錯的選擇。

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[76] Favoino, Enzo, and Dominic Hogg. 2008. "The Potential Role of Compost in Reducing Greenhouse Gases." Waste Management & Research 26 (1): 61–69. https://doi.org/10.1177/0734242X08088584; Pezzolla, Daniela, Roland Bol, Giovanni Gigliotti, Takuji Sawamoto, Aranzazu Louro López, Laura Cardenas, and David Chadwick. 2012. "Greenhouse Gas (GHG) Emissions from Soils Amended with Digestate Derived from Anaerobic Treatment of Food Waste." Rapid Communications in Mass Spectrometry 26 (20): 2422–30. https://doi.org/10.1002/rcm.6362; Qdais, Hani Abu, Christoph Wuensch, Christina Dornack, and Abdallah Nassour. 2019. "The Role of Solid Waste Composting in Mitigating Climate Change in Jordan:" Waste Management & Research, June. https://doi.org/10.1177/0734242X19855424; Silver, Whendee, Sintana Vergara, and Mayer Allegra. 2018. "Carbon Sequestration and Greenhouse Gas Mitigation Potential of Composting and Soil Amendments on California's Rangelands." University of California. https://www.energy.ca.gov/sites/default/files/2019-11/Agriculture_CCCA4-CNRA-2018-002_ADA.pdf.

[77] Silver, Whendee L., Marcia S. DeLonge, and Justine J. Owen. 2013. "Climate Change Mitigation Potential of California's Rangeland Ecosystems." Department of Environmental Science, Policy, and Management University of California, Berkeley. https://nicholasinstitute.duke.edu/sites/default/files/w_silver_et_al_april_3013_carb.pdf.

[78] "Regenerative Annual Cropping." 2020. Project Drawdown. February 6, 2020. https://drawdown.org/solutions/regenerative-annual-cropping.

[79] Sanderman, Jonathan, Tomislav Hengl, and Gregory J. Fiske. 2017. "Soil Carbon Debt of 12,000 Years of Human Land Use." *Proceedings of the National Academy of Sciences* 114 (36): 9575–80. https://doi.org/10.1073/pnas.1706103114.

Box: The informal sector and GHG mitigation

方塊：非正式部門和溫室氣體減量

The informal sector plays a critical role in waste management, particularly but not exclusively in developing countries. In most developing countries, the informal sector is responsible for the great majority of recycling, collecting up to 45% of the total waste stream.[80] This collection happens at the doorstep, at intermediate transfer points, and at open dumps. This activity, also known as waste picking, reduces collection costs to the public, provides raw materials to formal businesses, and reduces GHG emissions.[81]

非正式部門在廢棄物管理中扮演了舉足輕重的角色，特別是在發展中國家，但也不只是在發展中國家。在大多數發展中國家，非正式部門負責了資源回收很大一部份的工作，收集的回收物佔整體廢棄物數量的45%。[80]他們或挨家挨戶收集，或在垃圾轉運站或露天堆置場翻撿；這項被稱為「拾荒」的行為，幫民眾減少了垃圾收集成本，提供正式企業所需原物料，並能減少溫室氣體排放。[81]

The recycling market is largely unregulated and highly volatile, resulting in the collection of only high-value recyclables (metals, glass, paper products, and a few types of plastic). Plastic recycling markets are further undermined by additives and contaminants in the plastic and the low cost of virgin polymer, making most plastic collection uneconomical. Source-separated organics could provide an additional income stream for waste pickers, but the market value of the final product (compost) is usually not enough to justify the labor and transportation costs. In addition, there are practical challenges in getting householders to practice source separation and in finding land and equipment for composting. Many projects have successfully overcome these hurdles through collaborations between NGOs and local governments. Householders, local governments, or both bear the cost of the program, which is defrayed by sales of compost. The benefits of the program, in terms of reduced GHG emissions alone, outweigh its costs.

回收市場大多不受規管，且波動性大，導致拾荒者們只收集高價回收物，例如金屬、玻璃、紙製品和少數幾種類型的塑膠。塑膠中常見添加劑和污染物，還有原生塑料太便宜，這兩個因素使得大部分塑膠回收賺不到錢，大大削弱了塑膠回收市場。源頭就分出來的有機廢棄物，有可能成為拾荒者額外收入來源，不過其最終產品（堆肥）的市場價值，往往無法彌補勞力和運輸的成本。另外，在實務上，要讓一般家戶做好垃圾分類不是很容易的，要找到堆肥用的土地和設備也有困難。不過，許多計畫藉由非政府組織與當地政府之間的合作，克服了這些難題。這些計畫的成本由參與的家戶或當地政府負擔，或兩者共同負擔，而堆肥產品的銷售收入也分攤了這項成本。而光是計畫所帶來的溫室氣體減量效益，就遠遠超值了。

Constituting between 0.5% and 2% of the global population (12.5-56 million people), the informal waste sector is an important stakeholder in existing waste management systems and must be incorporated into

[80] Linzner, Roland, and Ulrike Lange. 2013. "Role and Size of Informal Sector in Waste Management – a Review." *Proceedings of the Institution of Civil Engineers - Waste and Resource Management* 166 (2): 69–83. https://doi.org/10.1680/warm.12.00012.

[81] Dias, Sonia Maria. 2016. "Waste Pickers and Cities." *Environment and Urbanization* 28 (2): 375–90. https://doi.org/10.1177/0956247816657302; Mathys, Ted. 2009. "Cooling Agents: An Examination of the Role of the Informal Recycling Sector in Mitigating Climate Change." Chintan.

planning for system improvements.[82] Experts in the field of informal recycling have recommended a participatory governance framework including legal recognition of the access to waste, proper contracts, support for member-based organizations, provision of infrastructure, and social protection schemes.[83] Informal sector integration can yield beneficial social and economic outcomes while unlocking the potential for greater GHG mitigation, e.g., through cost-effective collection and treatment of source-separated organics.[84]

非正式回收部門的人口佔全球人口的0.5-2%（約1,250-5,600萬人），他們是既有的廢棄物管理體系中重要的利害關係人，在規劃如何改善體系時必須被納入考量。[82]非正式回收領域的專家們推薦一種參與式治理架構，包括法定認可拾荒者取得廢棄物的權利、提供適當的契約、支持會員制的拾荒組織、提供基礎設施和社會保障方案。[83]整合非正式部門不但能衍生社會和經濟利益，透過他們收集與處理源頭已分類好的有機廢棄物，不但更具成本效益，還能大大解放其減少溫室氣體的潛力。[84]

Box: Biogenic CO_2

方塊：生物源二氧化碳

Biogenic CO_2 is defined as CO_2 emitted to the atmosphere from the combustion or decomposition of recently-living biomass, including wood, paper, food, and other plant materials. It is distinct from fossil CO_2, which results from the combustion of carbon that has been locked in the earth's crust over geologic time. Accounting for biogenic CO_2 is more complicated than accounting for fossil CO_2 because it is also emitted by plants, animals, and microbes as part of the natural carbon cycle. Absent human influence, this natural carbon cycle is assumed to be roughly in balance, at least over policy-relevant time scales (e.g., less than 100 years). The challenge is in determining how much biogenic CO_2 human activity adds to the atmosphere *additional* to the natural baseline. Unfortunately, the natural baseline is difficult to calculate; there is considerable scientific uncertainty about the pools and dynamics of soil carbon, for example. There are also significant challenges in measuring biogenic CO_2 fluxes from land, crops, and forest. (Fossil carbon, on the other hand, has virtually no natural transfer to the atmosphere, so all fossil CO_2 emissions are anthropogenic in nature).

藉由燃燒或是分解那些近期還存活的生命的生物質（包括木頭、紙、食物和其他植物材料），而釋放到大氣中的二氧化碳，我們稱之為「生物源二氧化碳」。化石源二氧化碳則不同，其來自於燃燒那些曾被鎖在地殼中漫長地質時間的碳。生物源二氧化碳的盤查計量遠比化石源二氧化碳來得複雜，因為植物、動物和細菌都會排出生物源二氧化碳，它們都是自然界碳循環的一部分。

[82] Linzner, Roland, and Ulrike Lange. 2013. "Role and Size of Informal Sector in Waste Management – a Review." *Proceedings of the Institution of Civil Engineers - Waste and Resource Management* 166 (2): 69–83. https://doi.org/10.1680/warm.12.00012; Wilson, David C, Ljiljana Rodic, Prasad Modak, Reka Soos, Ainhoa Carpintero Rogero, Costas Velis, Mona Iyer, and Otto Simonett. 2015. *Global Waste Management Outlook*. United Nations Environment Programme.

[83] Dias, Sonia Maria. 2016. "Waste Pickers and Cities." *Environment and Urbanization* 28 (2): 375–90. https://doi.org/10.1177/0956247816657302.

[84] Allen, Cecilia, Virali Gokaldas, Anne Larracas, Leslie Ann Minot, Maeva Morin, Neil Tangri, Burr Tyler, and Bill Walker. 2012. "On the Road to Zero Waste: Sucesses and Lessons from around the World." Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/On-the-Road-to-Zero-Waste.pdf.

如果沒有人類的干預，自然的碳循環應會處於平衡狀態，至少在對政策有意義的時間尺度（少於100年）上如此。問題是要如何求得：因人類活動而排放到大氣中的生物源二氧化碳，到底使自然界的碳循環較其基本量額外增加了多少？不幸的是，這個基本循環量本身就難以計算，例如關於土壤中碳的存量及動態，在科學上仍有相當大的不確定性。另一個大難題是如何測量生物源二氧化碳在土地、作物和森林之間循環的通量？（相對地，化石中的碳則幾乎不會自然地釋放到大氣中，所有化石源二氧化碳本質上都是人為排放的。）

In its guidelines for national emissions inventories, the IPCC instructs national authorities to report biogenic emissions separately from fossil CO_2 emissions. This is, in part, to prevent the greater uncertainties around biogenic CO_2 from obscuring the picture of fossil emissions. The IPCC also indicates that biogenic CO_2 should not be included in the total emissions of the power sector (which includes waste-to-energy incinerators and biomass-fired power plants) because these emissions are already accounted for in the Agriculture, Forestry, and Land Use (AFOLU) sector; reporting them twice would amount to double-counting. This guidance has been widely misinterpreted as indicating that biogenic emissions do not add to climate change or do not need to be reported at all. This misinterpretation has been thoroughly discredited[85] yet remains common practice, allowing waste-to-energy (WTE) incinerators and cement kilns to take advantage. The scientific best practice is to report biogenic and fossil CO_2 emissions separately, as the U.S. EPA does.

「聯合國政府間氣候變化專門委員會」（IPCC）在國家溫室氣體排放清冊的撰寫指引中，要求各國政府將生物源二氧化碳跟化石源二氧化碳的排放量分開報告，部份原因是為了避免生物源二氧化碳排放量的不確定性掩蓋了化石源二氧化碳的排放狀況。IPCC也指出：生物源二氧化碳不應計入電力部門的總排放量中，儘管所謂的「廢轉能」焚化爐和生質能發電廠會排放生物源二氧化碳，但這部份的排放量已被算進「農業、林業和其他土地利用部門」（AFOLU）中，所以應該從電力部門中拿掉，否則會有重複計量的問題。然而這段指引常常被誤解成：生物源二氧化碳的排放不會惡化氣候變遷，或者完全不須報告。雖然這樣的誤解已經完全被推翻，[85]但仍然是常見的解讀，而被廢轉能焚化爐和水泥窯拿來運用宣傳。科學上最好的作法還是將生物源和化石源二氧化碳的排放量分開報告，就像美國環保署做的一樣。

Biogenic CO_2 emissions in the waste sector derive largely from the combustion or aerobic decomposition of biomass (food waste, yard/garden waste, wood, and paper products). In addition, the CO_2 that results from the combustion or decomposition of methane (from landfills or anaerobic digesters) is biogenic. (If the methane itself is released, that is not considered biogenic, since methane generation is the result of human activity.

在廢棄物部門中，生物源二氧化碳的排放很大部份來自於生物質（諸如食物廢棄物、園藝廢棄物、木頭或紙製品）的燃燒或好氧分解。另外，把來自掩埋場或厭氧消化設施的甲烷燒掉或分解

[85] Schlesinger, William. 2010. "90 Scientists Urge Congress Not to 'Cook the Books' in CO2 Accounting for Biofuels, Other Bioenergy Sources." Cision, May 24, 2010. https://www.prnewswire.com/news-releases/90-scientists-urge-congress-not-to-cook-the-books-in-co2-accounting-for-biofuels-other-bioenergy-sources-94741714.html.

掉所產生的二氧化碳，同樣算是生物源二氧化碳（不過如果甲烷本身直接排放到大氣中，則因為甲烷是因人類活動而產生，而不能將其視為生物源）。

Waste management techniques differ significantly in their biogenic CO_2 emissions. Incinerators and open burning convert virtually all carbon in the waste to CO_2, immediately emitting it to the atmosphere. Landfills convert much of the organic carbon to methane or CO_2, but more slowly; best estimates indicate that approximately 50% of the organic carbon buried in landfills will remain there for at least one year.[86] Wood, in particular, is resistant to decomposition in landfills and may persist for centuries. Composting also loses a large proportion of its organic carbon as CO_2 during the composting process, but can be an effective way to increase carbon storage in soil, particularly degraded soils.[87] In many cases, this has resulted in significant long-term soil carbon storage.

不同的廢棄物處理技術所產生的生物源二氧化碳排放量差異極大。焚化爐和露天燃燒幾乎是把廢棄物中的碳完全轉化成二氧化碳，並立即排放到大氣中。掩埋場也會將大部份的有機碳轉化成甲烷或二氧化碳，但這過程緩慢許多。目前最佳估計顯示，埋在掩埋場中的有機碳大約有50%會留存在掩埋場中至少一年；[86]特別是木頭在掩埋場中很難分解，可能留存好幾個世紀。堆肥過程中也會有高比例的有機碳變成二氧化碳，但堆肥可有效增加土壤中的碳存量，特別有益於已經劣化的土壤。[87]在許多案例中，堆肥促成了碳長期留存在土壤中這一重要結果。

Accounting for the different fates of biogenic carbon is complex. The most accurate approach is to account for all fluxes. The calculator used in this study omits biogenic emissions because it relies on the underlying published literature, which is inconsistent in its approach to biogenic CO_2. As a result, our calculations understate the benefits of composting and ending incineration and open burning.

要闡明生物源碳在碳循環過程中的不同命運，是很複雜的課題。最精準的作法是去計算所有的通量。本研究中使用的計算器捨去了生物源的排放，因為其所根據的基礎公開文獻在計算生物源二氧化碳的方法上是不一致的。因此本報告中的計算結果低估了堆肥的效益，也未能如實彰顯終止垃圾焚化和露天焚燒的好處。

3. Zero waste and climate adaptation

3. 零廢棄和調適氣候變遷

Chapter summary

[86] Towprayoon et al., 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Chapter 3: Solid Waste Disposal

[87] Brown, Sally, Kristen McIvor, and Elizabeth Hodges Snyder, eds. 2016. Sowing Seeds in the City: Ecosystem and Municipal Services. Springer

本章摘要

- Cities can withstand the impacts of climate change and build climate resilience by implementing zero waste strategies.
- 透過實施零廢棄策略，城市更能承受氣候變遷的衝擊，增進面對氣候變遷的韌性。
- Cities can lower flood risks through plastic bans and universal collection systems that keep waste from blocking drains and stream flows. Countries including Bangladesh, India, Botswana, Rwanda, South Africa, Tanzania, and Uganda have already adopted plastic waste reduction measures to prevent flooding.
- 透過禁用塑膠製品、普及垃圾收集系統，能夠避免城市的排水系統和河道遭垃圾堵住，進而降低洪災風險。已有許多國家如孟加拉、印度、波札那、盧安達、南非、坦尚尼亞和烏干達，為了防範洪災而採取減塑政策。
- Proper organic waste management and prevention of drain blockages can prevent disease transmission via rodents, flies, and other disease vectors. The interlinkages between improper solid waste management, drain blockages from waste—especially plastic— and increased breeding sites were observed in Ghana and India, among other countries.
- 完善的有機廢棄物管理及避免排水系統堵塞，能夠防止疾病透過老鼠、蚊蟲和其它病媒傳播。過去在加納、印度和其它國家，都曾觀察到不當的垃圾管理導致垃圾（尤其是塑膠）堵塞排水系統，並增加病媒繁殖場域的因果關係。
- Composting creates multiple benefits to climate adaptation; it increases nutrient level in soils, improves soil structure, mitigates surface and groundwater contamination, and prevents soil erosion and associated natural disasters such as flooding and mudslides.
- 堆肥對調適氣候變遷的好處多多：它可增加土壤中的養分、改善土壤結構、減輕地表和地下水的污染、以及防止土壤被侵蝕所引起的自然災害，例如洪災和土石流。

3.1. Introduction

3.1 簡介

Climate change is expected to increase the frequency and severity of extreme weather events and health hazards. Poor waste collection and management are among the factors that leave cities exposed to the threat of climate impacts and their related public health risks. These include waste-blocked drains and water channels that contribute to flooding; improperly managed collection sites that harbor rodents, flies, and other disease vectors; and toxic emissions and leachates from waste facilities that kill plants and animals essential to aquatic or terrestrial systems, resulting in compromised soil health and harm to biodiversity.

氣候變遷將會提高極端天氣和公衛災害發生的頻率和嚴重性。有許多因素會讓城市暴露於氣候變遷所帶來的威脅和相關的公衛風險之中，貧陋的廢棄物收集和管理就是其中之一。廢棄物若堵塞城市中的排水系統和水道，會引發洪患；管理不當的垃圾收集場所會滋生老鼠、蒼蠅和其它病媒；廢棄物處理設施的有毒排放和滲出水，會殺死水生或陸域生態系中的關鍵動植物，導致土壤品質劣化、也損害生物多樣性。

Yet conversations about climate change adaptation—measures to reduce the vulnerability of natural and human systems against the impacts of climate change—rarely recognize the role of waste management, usually limiting such discussion to the relocation of waste facilities and to the reinforcement of infrastructure in response to high temperatures, floods, droughts, storms, and rising sea levels.
調適氣候變遷目的是降低大自然和人類社會面對氣候變遷衝擊的脆弱性，然而到目前為止，圍繞此議題的討論卻很少體認到廢棄物管理可扮演的角色，通常頂多會討論到廢棄物處理設施的遷移，以及如何加強一些基礎建設以因應高溫、洪水、乾旱、颶風和海平面上升。

While these strategies focus on disaster risk reduction and safe continuation of key services related to waste management, zero waste solutions hold great potential to protect communities from climate-induced environmental health risks. Research and best practices already exist, providing evidence that implementing zero waste strategies can help cities withstand the impacts of climate change.
上述策略的重點在於降低災害風險、以及如何讓有關廢棄物管理的關鍵公共服務能安全持續運作，不過零廢棄解決方案也具有極大潛力，可保護社區避免氣候引起的環境衛生風險。已經有研究和最佳實務經驗足以證實：實施零廢棄策略可以幫助城市承受氣候變遷的衝擊。

This chapter discusses three zero waste strategies that can help cities adapt to and further prevent climate change:
1) plastic bans and universal collection systems to lower flood risks;
2) proper organic waste management and prevention of drain blockages to prevent disease transmission;
3) composting to increase soil resilience.

本章討論能夠幫助城市調適甚至防範氣候變遷的三個零廢棄策略。
1) 實施塑膠禁令和普及垃圾收集系統，以降低洪災風險。
2) 良好的有機廢棄物管理、避免排水系統堵塞，以預防疾病傳播。
3) 堆肥以增加土壤韌性。

3.2. Zero waste and flood prevention

3.2 零廢棄和洪災防範

3.2.1. Impacts of flooding

3.2.1. 洪災造成的衝擊

As the global temperature rises, the occurrence and intensity of extreme flood events are expected to increase.[88] A warmer atmosphere holds more moisture and heat, resulting in frequent intense downpours, heavy rains, and rain storms that increase the chance of floods.[89] Floods can have disruptive and distressing consequences to communities; they threaten lives, inundate properties, and damage essential infrastructure. Massive floods destroy livelihoods, hinder economic growth, and can even lead to politically volatile situations, as seen in Africa, Asia, and the Middle East in the past decade.[90]

隨著全球氣溫的上升，極端洪災的發生率和強度都會上升。[88]暖化的大氣會容納更多濕氣、擁有更多熱量，容易形成驟雨、強降雨和暴風雨，連帶也提高洪災的發生機率。[89]洪災威脅所有的生命、淹沒財產、破壞基礎建設，為地區帶來毀滅和悲慘的後果。巨大洪水使人民生計破滅、阻礙經濟成長、甚至引起政治動盪情勢，過去十年曾在非洲、亞洲和中東上演。[90]

Common impacts on human health include injuries, infections, and mental health problems. A study of flood hazards documented testimonials from local residents in poor districts of Manila, Philippines, who experienced respiratory infections, skin allergies, and gastro-intestinal illnesses, with children at higher risk.[91] Some of the respondents of the survey even stated that they witnessed sudden deaths or serious illness after certain floods, as the community lacked proper medical care.[92] Although post-flood outbreaks of infectious disease are relatively rare, cholera cases have been reported in Zambia in 2010, where the Ministry of Health confirmed 564 cases after a flood, with 30 deaths in Lusaka.[93] Poor wastewater management and inadequate access to safe drinking water exacerbates these health threats.[94] Longer-term health effects of floods can be caused by displacement, continued shortages of safe water, lack of access to public services, and delayed recovery of health conditions.[95]

洪水對人類健康常見的影響包括造成身體受傷、感染以及心理健康出現問題。有一份對洪災的研究調查報告紀錄了在菲律賓馬尼拉貧民區的災民證言，這些人在災後遭受了呼吸道感染、皮膚過敏和胃腸疾病，對兒童來說特別危險。[91]某些受訪者提到其中幾次洪災過後，由於社區缺乏適當醫

[88] Brunner, Manuela I., Daniel L. Swain, Raul R. Wood, Florian Willkofer, James M. Done, Eric Gilleland, and Ralf Ludwig. 2021. "An Extremeness Threshold Determines the Regional Response of Floods to Changes in Rainfall Extremes." Communications Earth & Environment 2 (1): 1–11. https://doi.org/10.1038/s43247-021-00248-x.

[89] Denchak, Melissa. 2019. "Flooding and Climate Change: Everything You Need to Know." NRDC. https://www.nrdc.org/stories/flooding-and-climate-change-everything-you-need-know.

[90] Ide, Tobias, Anders Kristensen, and Henrikas Bartusevičius. 2021. "First Comes the River, Then Comes the Conflict? A Qualitative Comparative Analysis of Flood-Related Political Unrest." Journal of Peace Research 58 (1): 83–97. https://doi.org/10.1177/0022343320966783.

[91] Zoleta-Nante, Doracie B. 2000. "Flood Hazard Vulnerabilities and Coping Strategies of Residents of Urban Poor Settlements in Metro Manila, The Philippines." In Floods, by Dennis J. Parker. Peeters Publishers.

[92] Zoleta-Nante, Doracie B. 2000. "Flood Hazard Vulnerabilities and Coping Strategies of Residents of Urban Poor Settlements in Metro Manila, The Philippines." In Floods, by Dennis J. Parker. Peeters Publishers.

[93] Jha, Abhas K., Robin Bloch, and Jessica Lamond. 2012. Cities and Flooding. The World Bank. https://doi.org/10.1596/978-0-8213-8866-2.

[94] Jha, Abhas K., Robin Bloch, and Jessica Lamond. 2012. Cities and Flooding. The World Bank. https://doi.org/10.1596/978-0-8213-8866-2.

[95] "Floods and Health: Fact Sheets for Health Professionals." 2014. World Health Organization. https://www.euro.who.int/__data/assets/pdf_file/0016/252601/Floods-and-health-Fact-sheets-for-health-professionals.pdf.

療照護，[92]而目睹到猝死或重症的情況。雖然洪災過後傳染病大爆發的例子相對罕見，2010年在尚比亞（Zambia）即曾經傳出霍亂疫情，該國衛生部確認在洪災之後，首府路沙卡（Lusaka）發生564起霍亂病例，其中30起死亡。[93]貧陋的廢水處理系統和缺乏安全飲用水加劇了這個事件的健康威脅。[94]洪災對健康的長期影響可能來自於遷徙、持續缺乏安全用水、無法獲得公共服務以及無法快速恢復健康狀態。[95]

While poor waste management can be a major contributing factor to floods (as discussed in the following section), flooding itself poses a threat to solid waste infrastructure like landfills. Without proper water catchment systems in place, heavy rain and subsequent flooding from extreme storms can undermine landfill foundations, releasing leachate into groundwater and causing waste to clog other infrastructure.[96] In Austria, about 30% of landfills were located in flood-prone areas, only 5% of which were equipped with proper protection facilities.[97] The burden borne by impacted communities is expected to intensify as climate change escalates, especially among people in low-income communities located in flood-prone sites.[98]

雖說貧陋的廢棄物管理系統可能是造成洪災的元兇（下一節會討論此原因），洪災本身對於固體廢棄物處理設施（例如掩埋場）來說，也是一大威脅。掩埋場若是少了適當的集水系統，那麼極端暴風雨帶來的強降雨以及接踵而來的洪水，會破壞掩埋場的基礎，讓滲出水進入地下含水層，也會導致垃圾堵塞其它基礎設施。[96]在澳洲，約有30%的掩埋場位於容易發生洪災的地區，而這些掩埋場中只有5%有建置適當防護設施。[97]當氣候變遷的情勢惡化，受影響的社區將承受更多磨難，尤其是那些居住在易淹水地區的貧民。[98]

3.2.2. Waste worsens flooding

3.2.2. 廢棄物使洪災惡化

Unmanaged or improperly managed waste exacerbates flooding, especially in informal settlement areas with insufficient drainage systems. Even in planned urban environments, waste clogging up drainage systems

[96] Climate change can have negative impacts on landfill operations in different ways; landfills near the coast or in low-lying areas are vulnerable to sea level rise and storm surge. Water infiltration of the pit can lead to an overflow of waste from the landfill. Saltwater infiltration from below can deteriorate the impermeable lining of sanitary landfill facilities. Temperature increases may necessitate more frequent waste collection schedules and rigorous landfill management practices, as odors will be stronger. Higher temperatures and drought may also increase the risks of fire at waste facilities. "Solid Waste Management: Addressing Climate Change Impacts On Infrastructure." 2012. U.S. EPA. https://www.climatelinks.org/sites/default/files/asset/document/Infrastructure_SolidWasteManagement.pdf.

[97] Laner, David, Johann Fellner, and Paul H. Brunner. 2009. "Flooding of Municipal Solid Waste Landfills — An Environmental Hazard?" Science of The Total Environment, Thematic Issue - BioMicroWorld Conference, 407 (12): 3674–80. https://doi.org/10.1016/j.scitotenv.2009.03.006.

[98] Few, Roger. "Flooding, Vulnerability and Coping Strategies: Local Responses to a Global Threat." Progress in Development Studies 3, no. 1 (January 2003): 43–58. https://doi.org/10.1191/1464993403ps049ra.

increases vulnerability to flooding. The Covid-19 pandemic further exacerbated this problem, with discarded personal protective equipment increasing the volume of litter that makes its way into storm drains.[99]

不當管理或毫無控管的廢棄物會惡化洪災，尤其在缺乏排水系統的非正式聚落。就算在有規劃的都市地區，一旦廢棄物堵塞排水系統，也很容易引發洪患。嚴重特殊傳染性肺炎（Covid-19）的疫情使這問題雪上加霜，許多被隨意丟棄的個人防護用具造成垃圾量大增，並隨著暴雨進入排水系統。[99]

The World Bank's guide to urban flood risk management, published in 2013, recognizes poor waste collection as a factor that may cause or worsen the following adverse impacts:[100]

- blocked drains that lead to flooding
- increased diseases (e.g, waste provides material on which flies lay their eggs or serves as food for rats)
- infections, especially from clinical waste and sewage
- chemical toxicity, especially from discarded medicines along with commercial and industrial waste
- contamination of surface and groundwater
- contamination of the food chain

世界銀行在2013年發表了一份針對都市洪災風險管理的指引，其中指出「貧陋的廢棄物收集系統」是造成或惡化以下負面衝擊的因素：[100]

- 堵塞排水系統而導致洪災。
- 促進疾病流行（垃圾提供蒼蠅產卵的場所或是老鼠的食物來源）。
- 提高感染風險（尤其是來自醫療廢棄物和污水的感染風險）。
- 惡化化學毒性污染（尤其是來自廢棄藥物和商業、工業廢棄物中的有毒化學物質）。
- 污染地表水和地下水。
- 污染食物鏈。

Dumping of uncollected waste is the most prevalent cause of flooding in places with inadequate waste collection systems. In Saint Louis, Senegal, the lack of household waste collection systems coupled with wastewater discharged from households and other establishments was the main cause of blockage in natural drains; inadequate drainage systems aggravated the situation.[101] In Manila, Philippines, dumping of solid waste was identified as a key factor in the prevalence of infections during and after flood events, along with

[99] Talavera, Catherine. 2021. "Group Pushes Waste Management to Prevent Floods." Philstar.Com, July 25, 2021. https://www.philstar.com/nation/2021/07/25/2114927/group-pushes-waste-management-prevent-floods.

[100] Jha, Abhas K., Robin Bloch, and Jessica Lamond. 2012. Cities and Flooding. The World Bank. https://doi.org/10.1596/978-0-8213-8866-2.

[101] Diagne, Khady. 2007. "Governance and Natural Disasters: Addressing Flooding in Saint Louis, Senegal." Environment and Urbanization 19 (2): 552–62. https://doi.org/10.1177/0956247807082836.

blockages to drainage channels and poor sanitation systems.[102] In Lagos, Nigeria, uncollected municipal solid waste dumped in unauthorized places is also one of the major causes of flooding. Between 2007 and 2013, waste that clogged drainage channels and impeded the free flow of storm water during heavy rainfall resulted in floods on 126 streets.[103]

在廢棄物收集系統不完善的地區，未經收集的垃圾被隨意傾倒，是洪災發生最普遍的原因。在塞內加爾的聖路易（Saint Louis），缺乏家戶垃圾的收集系統、加上從家戶和其它機構場所逕自排出的廢水，造成自然排水道的堵塞；不完善的排水系統則使情況更加惡化。[101]在菲律賓的馬尼拉，任意傾倒垃圾被認為是洪災期間及過後感染性疾病大流行的重要因素之一，其它因素包括排水道的堵塞和貧乏的下水道系統。[102]在奈及利亞的拉哥斯（Lagos），未被收集的城市垃圾被棄置在未經許可的地方，也是形成洪災的主因之一。從2007到2013年，總計有126條街道曾因垃圾堵住了排水渠道、使得暴雨帶來的洪流積水無法宣洩而發生洪災。[103]

Drainage issues have provoked swift waste reduction measures, as seen in Rwanda, Tanzania, and Uganda—countries that all banned plastic bags to prevent flooding. Similarly, South Africa and Botswana have imposed taxes on the distribution of plastic bags in recent years.[104] After experiencing a tragic flood in Accra in 2015, in which at least 150 people died, Ghana is also considering implementing restrictions on the production and use of plastic bags.[105]

前述排水問題已促使某些政府採取雷厲風行的垃圾減量措施，舉例來說：盧安達、坦尚尼亞和烏干達這些國家，為了防範洪災，都已禁用塑膠袋。類似政策也出現在南非和波札那，這兩國近年已對塑膠袋的配銷課稅。[104]迦納的阿克拉（Accra）市在2015年曾經歷一場嚴重的洪患，造成至少150人死亡，災難過後該國政府也在考慮限制塑膠袋的生產和使用。[105]

3.2.3. Implementing zero waste systems as flood prevention measures

3.2.3.實施零廢棄措施以防範洪災

The blockage of drains resulting from poor management of waste can effectively be prevented by minimizing waste generation and subsequent waste leakages.
盡量減少廢棄物的產生以及後續流竄，可有效防止因廢棄物管理不好而導致排水系統阻塞。

[102] Few, Roger. "Flooding, Vulnerability and Coping Strategies: Local Responses to a Global Threat." Progress in Development Studies 3, no. 1 (January 2003): 43–58. https://doi.org/10.1191/1464993403ps049ra.
[103] Ojolowo, S., and B. Wahab. 2017. "Municipal Solid Waste and Flooding in Lagos Metropolis, Nigeria: Deconstructing the Evil Nexus." Journal of Geography and Regional Planning 10 (7): 174–85. https://doi.org/10.5897/JGRP2016.0614.
[104] Hinshaw, Drew. 2015. "Ghana's Growth Spurs Uncontrollable Trash." The Wall Street Journal, June 21, 2015. https://www.wsj.com/articles/ghanas-growth-spurs-uncontrollable-trash-1434928945.
[105] Hinshaw, Drew. 2015. "Ghana's Growth Spurs Uncontrollable Trash." The Wall Street Journal, June 21, 2015. https://www.wsj.com/articles/ghanas-growth-spurs-uncontrollable-trash-1434928945.

In Bangladesh and India, there is a clear link between plastic waste and flooding. In 2002, Bangladesh became the first country in the world to ban all polythene bags, after finding that such waste was responsible for a 1988 flood that submerged half the country, and for the ongoing spread of water-borne diseases.[106] India also banned most plastic bags in 2005 following a flood, caused by mismanaged waste and drainage systems, that incurred deaths of more than 1,000 people, mostly in Mumbai.[107] In these cases, the devastating impacts of floods prompted legislation banning the use of plastic bags, which shows how cities can take action to help prevent future flood events by applying precautionary principles to minimize environmental, social, and economic risks associated with plastic bags blocking waterways.[108]

在印度和孟加拉，洪災發生和塑膠垃圾之間的關聯性顯而易見。1988年，一場洪患淹沒了孟加拉一半的國土，其後水媒傳染病四處蔓延，而該國政府發現，塑膠袋一類的垃圾是造成這兩場災難的元兇之一；[106]於是，2002年，孟加拉成為世界上第一個禁止所有PE塑膠袋的國家。印度在2005年也禁用了大部分的塑膠袋，其緣由也是起於一場因廢棄物和排水系統缺乏控管所導致的洪災，該次洪災造成了超過1,000名死者，多數在孟買（Mumbai）。[107]這些案例中，洪災所帶來毀滅性的衝擊促使了立法禁用塑膠袋，可見城市能夠採取行動來防止下一次的洪災發生，應用預警原則將塑膠袋阻塞水道引起的環境、社會和經濟風險降到最低。[108]

An academic study estimates that improving existing drainage canals and proper solid waste management would help prevent about 322 hectares of land from flooding in Sylhet, Bangladesh.[109] It proposes: (i) source separation of organic waste; (ii) proper management of plastic waste; and (iii) local composting of organic waste or proper disposal in landfills as possible solutions, with a note that "such interventions can be implemented within reasonable and short time periods."[110]

據一份學術研究估計：若改善在孟加拉錫爾赫特市（Sylhet）現有的排水渠道和廢棄物管理系統，將能防止該地區約322公頃的土地遭洪水侵襲。[109]該研究建議：（一）在源頭就分離出有機廢棄物；（二）適當管理塑膠垃圾；（三）有機廢棄物須在地堆肥，或者妥善進行掩埋處置，同時指出：「這些措施可在合理且短暫的期間內落實。」[110]

[106] Ritch, Elaine, Carol Brennan, and Calum MacLeod. 2009. "Plastic Bag Politics: Modifying Consumer Behaviour for Sustainable Development." International Journal of Consumer Studies 33 (2): 168–74. https://doi.org/10.1111/j.1470-6431.2009.00749.x.

[107] Waghmode, Vishwas. 2016. "Rewind: Plastics Continue to Clog Nullahs across Mumbai." The Indian Express, March 22, 2016. https://indianexpress.com/article/cities/mumbai/rewind-plastics-continue-to-clog-nullahs-across-mumbai.

[108] Ritch, Elaine, Carol Brennan, and Calum MacLeod. 2009. "Plastic Bag Politics: Modifying Consumer Behaviour for Sustainable Development." International Journal of Consumer Studies 33 (2): 168–74. https://doi.org/10.1111/j.1470-6431.2009.00749.x.

[109] Pervin, Ismat Ara, Sheikh Mohammad Mahbubur Rahman, Mani Nepal, Abdul Kalam Enamul Haque, Humayun Karim, and Ganesh Dhakal. 2019. "Adapting to Urban Flooding: A Case of Two Cities in South Asia." Water Policy 22 (S1): 162–88. https://doi.org/10.2166/wp.2019.174.

[110] Pervin, Ismat Ara, Sheikh Mohammad Mahbubur Rahman, Mani Nepal, Abdul Kalam Enamul Haque, Humayun Karim, and Ganesh Dhakal. 2019. "Adapting to Urban Flooding: A Case of Two Cities in South Asia." Water Policy 22 (S1): 162–88. https://doi.org/10.2166/wp.2019.174.

3.3. Zero waste and insect-vector control

3.3. 零廢棄和病媒蟲防治

3.3.1. Climate change and increase in vector-borne diseases

3.3.1. 氣候變遷與蟲媒傳染病的增加

As climate change accelerates, raising global temperatures and causing heavier rainfalls and subsequent flooding, the changing climate can provide conditions that are favorable to breeding of blood-feeding arthropods, such as mosquitoes, ticks, triatomine bugs, sandflies, and blackflies,[111] which transmit vector-borne diseases such as dengue fever, malaria, and lyme disease. The risk of transmission increases because the cold-blooded arthropod vectors are especially sensitive to climatic factors; in warmer climates, they grow and reproduce faster, partly due to faster digestion of blood.[112] More rainfall can also provide more breeding sites and higher food availability.[113] Warmer climate and shorter winter periods also contribute to an increase in rodent population,[114] and heavy rainfall can spread rodent-borne bacterial diseases.[115]

隨著氣候變遷的加速，全球氣溫跟著上升，降雨更加猛烈，隨之而來的洪災也更具破壞性。正在改變的氣候型態可提供吸血節肢動物（例如蚊子、蜱蟲、錐蟲、沙蠅、蚋）[111]適合生存繁衍的環境條件，這些動物會傳播如登革熱、瘧疾和萊姆病等傳染病。這些蟲媒傳染病的傳播風險增加是因為作為病媒的冷血節肢動物，對於氣候非常敏感，牠們在暖化的氣候條件下會加快成長與繁殖，部分原因是牠們消化血液的速度變快了。[112]降雨增加也提供牠們更多繁殖棲地和食物。[113]暖化的氣候和縮短的冬季也導致嚙齒動物數量增加，[114]而強降雨會幫助傳播由嚙齒動物媒介的細菌性傳染病。[115]

[111] "Vector-Borne Diseases." European Centre for Disease Prevention and Control. https://www.ecdc.europa.eu/en/climate-change/climate-change-europe/vector-borne-diseases.

[112] Githeko, A. K., S. W. Lindsay, U. E. Confalonieri, and J. A. Patz. 2000. "Climate Change and Vector-Borne Diseases: A Regional Analysis." Bulletin of the World Health Organization 78 (9): 1136–47.

[113] Githeko, A. K., S. W. Lindsay, U. E. Confalonieri, and J. A. Patz. 2000. "Climate Change and Vector-Borne Diseases: A Regional Analysis." Bulletin of the World Health Organization 78 (9): 1136–47.

[114] Roy-Dufresne, Emilie, Travis Logan, Julie A. Simon, Gail L. Chmura, and Virginie Millien. 2013. "Poleward Expansion of the White-Footed Mouse (Peromyscus Leucopus) under Climate Change: Implications for the Spread of Lyme Disease." PLOS ONE 8 (11): e80724. https://doi.org/10.1371/journal.pone.0080724.

[115] Tian, Huai-Yu, Peng-Bo Yu, Angela D. Luis, Peng Bi, Bernard Cazelles, Marko Laine, Shan-Qian Huang, et al. 2015. "Changes in Rodent Abundance and Weather Conditions Potentially Drive Hemorrhagic Fever with Renal Syndrome Outbreaks in Xi'an, China, 2005–2012." PLoS Neglected Tropical Diseases 9 (3): e0003530. https://doi.org/10.1371/journal.pntd.0003530.

3.3.2. Correlation between waste and vector-borne diseases

3.3.2. 廢棄物和蟲媒傳染病之間的關聯

In addition to the existing factors in vector-borne diseases, such as seasonal weather variation, socioeconomic status, insufficient vector control programs, environmental changes, and drug resistance, improper waste management can further add to the challenge of disease control.
蟲媒傳染病的防治，除了會受到諸如季節性的天氣變化、社經狀況、缺少蟲媒防治計畫、環境變遷和抗藥性等幾項既有因素的影響之外，也會因為不當的廢棄物管理而更為困難。

As seen in the previous section on flooding, waterways clogged with inadequately managed waste cause floods, which offer favorable breeding grounds for many disease vectors. Plastic bags are often the major obstacle to proper waste management and drainage improvement, prompting bag bans in a number of countries and cities, notably in the African region. In Southern Ghana, improper solid waste management and drainage channels blocked by waste—especially plastic litter—increased the presence of permanent mosquito breeding sites.[116] Another study conducted in coastal cities in Ghana drew similar conclusions on the correlation between waste management and the breeding of mosquitoes, further emphasizing the potential impact of future climate conditions.[117]
上一節講到洪患時提到，當水道被未妥善管理的垃圾堵住時就會淹水，然後形成許多病媒喜愛的繁殖場域。不管是要做好廢棄物管理或是想改善排水系統，塑膠袋通常是最大的阻礙，也因此促成許多國家或城市禁用塑膠袋，特別是非洲地區。在迦納南部，不當的廢棄物管理以及廢棄物（尤其是塑膠垃圾）堵塞排水渠道，形成越來越多蚊子能長久棲息的繁殖場域。[116]在加納的沿海城市進行的另一項研究，對於廢棄物管理和蚊子繁衍的關聯性也得出了類似的結論，進一步地突顯了未來氣候條件可能帶來的衝擊。[117]

Discarded containers, cans, and car tires may also provide breeding spaces for disease vectors by holding rainwater in them, where mosquitoes—which transmit filariasis, yellow fever, dengue fever, and several other arboviral infections—can breed.[118] A study on Aedes mosquitoes warned against continued, indiscriminate usage of plastic and poor waste management, as they increase the possibility of dengue fever transmission.[119]

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[116] Mattah, Precious A. Dzorgbe, Godfred Futagbi, Leonard K. Amekudzi, Memuna M. Mattah, Dziedzorm K. de Souza, Worlasi D. Kartey-Attipoe, Langbong Bimi, and Michael D. Wilson. 2017. "Diversity in Breeding Sites and Distribution of Anopheles Mosquitoes in Selected Urban Areas of Southern Ghana." Parasites & Vectors 10 (1): 25. https://doi.org/10.1186/s13071-016-1941-3.

[117] Mattah, P. a. D., G. Futagbi, L. K. Amekudzi, and M. M. Mattah. 2020. "Climate Variations, Urban Solid Waste Management and Possible Implications for Anopheles Mosquito Breeding in Selected Cities of Coastal Ghana." West African Journal of Applied Ecology 28 (1): 21–34. https://doi.org/10.4314/wajae.v28i1.

[118] "Disease Prevention Through Vector Control: Guidelines for Relief Organisations." Oxfam Policy & Practice. https://policy-practice.oxfam.org/resources/disease-prevention-through-vector-control-guidelines-for-relief-organisations-121159.

[119] Banerjee, Soumyajit, Gautam Aditya, and Goutam K Saha. 2013. "Household Disposables as Breeding Habitats of Dengue Vectors: Linking Wastes and Public Health." Waste Management 33 (1): 233–39. https://doi.org/10.1016/j.wasman.2012.09.013.

廢棄的容器、罐子跟輪胎會積雨水而形成病媒蟲的繁殖場。蚊子會在積水處繁殖，而蚊子傳播淋巴絲蟲病、黃熱病、登革熱和其它數種蟲媒病毒性傳染病。[118]一項針對埃及斑蚊的研究提出警告：持續濫用塑膠製品和糖糕的廢棄物管理，會提高登革熱的傳播機率。[119]

Improperly managed organic waste is another major factor in breeding of disease vectors in the waste sector. Organic waste from households and businesses attracts flies and cockroaches and other potential hosts of infections.[120] In particular, a study found that sweet waste, such as unfinished chocolate cake, increased transmission of dengue vectors, with a similar effect to feeding dengue mosquitoes on sucrose, an important source of nutrition.[121]
有機廢棄物的不當管理更是刺激病媒蟲繁衍的另一個重要因素。來自家戶或商家的有機廢棄物會引來蒼蠅、蟑螂或其它傳染病的可能宿主。[120]有一項研究還特別發現到：甜點廚餘——例如沒吃完的巧克力蛋糕，促進了登革熱的傳播；這跟直接拿蔗糖餵食登革熱病媒蚊的效果類似，而蔗糖是病媒蚊重要的養分來源。[121]

When organic waste pollutes surface waters already contaminated with other forms of waste, mosquitoes and domestic flies can reproduce more easily.[122] In Kolkata, India, sewage channels were likely to serve as mosquito breeding sites when beverage container waste was also present.[123]
當已遭到其它種類廢棄物污染的地表水又被有機廢棄物污染的話，會更利於蚊子和家蠅繁衍。[122]在印度的加爾各答（Kolkata），下水道如果有廢飲料瓶罐的存在，就更可能形成蚊子的繁殖地。[123]

[graphic 6] Waste and disease transmissions
[圖6] 廢棄物和疾病傳播

3.3.3. Zero waste as a solution

3.3.3. 解決之道：零廢棄

The combination of climate change and increased waste from growing urban populations has created novel conditions that allow disease vectors to thrive. Poor waste management further creates ideal conditions for

[120] Rottier, Erik, and Margaret E. Ince. 2003. Controlling and Preventing Disease: The Role of Water and Environmental Sanitation Interventions. Loughborough University. https://repository.lboro.ac.uk/articles/book/Controlling_and_preventing_disease_The_role_of_water_and_environmental_sanitation_interventions/9585086/1.
[121] Dieng, Hamady, Tomomitsu Satho, Fatimah Abang, Nur Khairatun Khadijah Binti Meli, Idris A. Ghani, Cirilo Nolasco-Hipolito, Hafijah Hakim, et al. 2017. "Sweet Waste Extract Uptake by a Mosquito Vector: Survival, Biting, Fecundity Responses, and Potential Epidemiological Significance." Acta Tropica 169 (May): 84–92. https://doi.org/10.1016/j.actatropica.2017.01.022.
[122] Rozendaal, Jan Arie, and World Health Organization. 1997. "Vector Control : Methods for Use by Individuals and Communities." World Health Organization. https://apps.who.int/iris/handle/10665/41968; Rottier, Erik, and Margaret E. Ince. 2003. Controlling and Preventing Disease: The Role of Water and Environmental Sanitation Interventions. Loughborough University.
[123] Banerjee, Soumyajit, Gautam Aditya, and Goutam K Saha. 2013. "Household Disposables as Breeding Habitats of Dengue Vectors: Linking Wastes and Public Health." Waste Management 33 (1): 233–39. https://doi.org/10.1016/j.wasman.2012.09.013.

germ-carrying pests that can spread serious, and even fatal, diseases. Implementing proper waste management is crucial to the prevention of disease epidemics and public health risks related to pests, especially in urban environments. Setting up timely and efficient waste collection systems is a critical element of pest control as it prevents waste from becoming litter, unmanaged, or overflowing. Reducing waste generation in the first place is even more effective; this can be accomplished through bans on single-use containers that serve as breeding spaces for disease vectors, and by minimizing the amount of discarded food entering the waste system through waste prevention and home composting.

氣候變遷的影響、再加上不斷成長的都市人口所製造的越來越多的廢棄物，已為傳染病病媒的繁茂興旺創造了新利基。糟糕的廢棄物管理更是提供了絕佳條件，讓帶有病菌的害蟲能傳播那些嚴重、甚至致死的傳染病。要預防傳染病流行及避免跟害蟲相關的公衛風險，必須妥善地管理廢棄物，尤其是在都市環境中。設置及時、有效率的廢棄物收集系統，能防止垃圾亂丟、未經處置而四處逸散，這對於病蟲害防治非常重要。更有效的作法是在一開始就減少廢棄物的產生，例如禁止一次用容器，因為這些容器會形成病媒的繁殖場；還有透過一些避免食物廢棄的方法以及居家堆肥，盡可能減少食物廢棄物進入廢棄物處理系統的量。

3.4. Soil improvement effect of composting

3.4. 堆肥的土壤改善效果

3.4.1. Climate change and soil health

3.4.1. 氣候變遷與土壤健康

Climate change has a major impact on the physical, chemical, and biological functions of soil, a vital element of our ecosystems and agriculture. As land ecosystems are the second largest natural carbon sink after oceans,[124] healthier soils are key to tackling and adapting to the changing climate. There are several different ways in which climate change impacts the functions of soil:

土壤是自然生態系和農業中的一個相當重要的元素，然而其物理、化學、生物功能卻受到氣候變遷的重大影響。由於陸域生態系是僅次於海洋的第二大天然碳匯，[124]因此維持土壤的健康是處理和適應氣候變遷的關鍵。氣候變遷以如下幾種不同方式影響土壤的功能：

- Higher air and soil temperatures increase aridity, a permanent state of water deficiency.[125] Significant **decreases in soil moisture** have been documented in a number of literature, including the IPCC AR5 which reported reduction in soil moisture in the Mediterranean, southwest USA, and southern African regions.[126] A report by the European Environmental Agency projects similar effects for the coming

[124] Directorate-General for Environment (European Commission). 2011. Soil :The Hidden Part of the Climate Cycle. LU: Publications Office of the European Union. https://data.europa.eu/doi/10.2779/57794.

[125] Huang, J., Y. Li, C. Fu, F. Chen, Q. Fu, A. Dai, M. Shinoda, et al. 2017. "Dryland Climate Change: Recent Progress and Challenges." *Reviews of Geophysics* 55 (3): 719–78. https://doi.org/10.1002/2016RG000550.

[126] Intergovernmental Panel on Climate Change. 2013. "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K.

decades, with the rise in average temperatures and continued changes in rainfall patterns.[127] Losing the capacity to capture and store water can exacerbate **desertification**. Research shows that as much as 40% of the existing Amazon forest is already at the tipping point of shifting to a savannah-like mix of woodland and grassland.[128] Meanwhile, as of 2018 a total of 13 European Union Member States have declared that they are affected by desertification, both a consequence and a cause of climate change.[129]

- 較高的氣溫與土壤溫度會增加土壤乾燥度，使其處於持續性缺水狀態。[125]許多文獻已記載了土壤濕度顯著降低的現象，比如政府間氣候變化專門委員會第五次評估報告（IPCC AR5）即指出地中海、美國西南部和非洲大陸南部地區有此情形。[126]歐洲環境署的一篇報告也預測未來數十年，隨著平均溫度的上升與降雨型態的持續改變，會出現類似影響。[127]隨著土壤失去集水和儲水能力，沙漠化現象將日漸惡化。研究顯示，現存亞馬遜雨林有多達40%面積已處於臨界點，即將轉變成混合林地與草原的熱帶稀樹草原。[128]同時，截至 2018 年，總共有 13 個歐盟會員國宣布他們受到沙漠化的影響；而沙漠化既是氣候變遷的後果，也是成因。[129]
- Climate impacts on soil also include **erosion**, a process by which soil is carried away by wind and, primarily, water. It can be accelerated by extreme climate events, such as intense rain, drought, heat waves, and storms. Soil erosion is expected to be on the rise around the world for the next 50 years due to climate change and intensive land cultivation.[130] Soil erosion may worsen flooding, as increased pollution and sedimentation in streams and rivers can clog waterways.[131]
- 氣候對土壤的影響也包含侵蝕，亦即土壤被風或水（主要是後者）帶走的過程。極端氣候事件，諸如強降雨、乾旱、熱浪和風暴，會加速土壤侵蝕。由於氣候變遷和密集地耕種，預期未來五十年內全球各地的土壤侵蝕現象將持續惡化。[130]土壤侵蝕會導致溪流及河川中的污染和沈積物增加，進而堵塞水道，而可能使洪水更加嚴重。[131]
- Continuing declines in soil moisture, desertification, and erosion can all **hinder agriculture** with potentially dramatic impacts on food production. A recent report by the IPCC warns that land degradation and climate change could result in a 25% food production deficit by 2050.[132] The

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Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

[127] "Climate Change, Impacts and Vulnerability in Europe 2016." 2017. Publication. European Environment Agency. https://www.eea.europa.eu/publications/climate-change-impacts-and-vulnerability-2016.

[128] Staal, Arie, Ingo Fetzer, Lan Wang-Erlandsson, Joyce H. C. Bosmans, Stefan C. Dekker, Egbert H. van Nes, Johan Rockström, and Obbe A. Tuinenburg. 2020. "Hysteresis of Tropical Forests in the 21st Century." Nature Communications 11 (1): 4978. https://doi.org/10.1038/s41467-020-18728-7.

[129] "Background Paper: Desertification in the EU." 2018. European Court of Auditors. https://www.eca.europa.eu/en/Pages/DocItem.aspx?did=46244.

[130] Borrelli, Pasquale, David A. Robinson, Panos Panagos, Emanuele Lugato, Jae E. Yang, Christine Alewell, David Wuepper, Luca Montanarella, and Cristiano Ballabio. 2020. "Land Use and Climate Change Impacts on Global Soil Erosion by Water (2015-2070)." Proceedings of the National Academy of Sciences 117 (36): 21994–1. https://doi.org/10.1073/pnas.2001403117.

[131] Sulaeman, Dede, and Thomas Westhoff. 2020. "The Causes and Effects of Soil Erosion, and How to Prevent It," February. https://www.wri.org/insights/causes-and-effects-soil-erosion-and-how-prevent-it.

[132] "Special Report on Climate Change and Land." 2019. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/srccl.

European Parliament also recognized that irrigated crop yields will decrease by up to 20% across all of Europe by mid-2030, compared to current yields, due to warming temperature.[133]

- 土壤濕度的持續下降、沙漠化和侵蝕都不利於農業，而可能使糧食生產受到大幅打擊。IPCC 最近的報告警告，至2050年時，土地退化和氣候變遷可能導致糧食產量不足25%。[132]歐洲議會也認知到，由於變暖的氣溫，至2030年代中期時，整個歐洲的灌溉作物產量與目前產量相比，減少幅度可達到20%之多。[133]

3.4.2. Composting as a climate adaptation measure

3.4.2. 透過堆肥來適應氣候變遷

Composting of organic matter helps communities adapt to climate consequences by reducing pollution and strengthening the resilience of the soil. Such benefits of composting include the recovery of discarded materials, reduction in landfill waste and pollution from incinerators, reduced surface and groundwater contamination, reduction in soil erosion, and improvement of soil structure.[134]
有機質的堆肥，可減少污染、強化土壤韌性，因而有助於社區適應氣候變遷衝擊。堆肥的效益包括：讓被拋棄的物質回收再利用、減少掩埋場中的廢棄物或從焚化爐排出的污染、減少地表水與地下水的污染、降低土壤侵蝕以及改善土壤結構。[134]

3.4.2.1. Composting as a solution to nutrient deficiency in soil

3.4.2.1.利用堆肥解決土壤養分不足問題

Compost application increases the level of soil organic matter, which significantly improves the soil's capacity to store nutrients through pore spaces created by soil organisms, absorbing essential nutrients, such as nitrogen, phosphorus, potassium, calcium, and magnesium; feeding billions of crucial microorganisms; and improving water absorption.[135] Research demonstrates that compost has a higher absorption and storage capacity than other common agricultural soil amendments.[136] High organic matter content also increases soil resistance to changes in soil acidity and allows faster mineral decomposition.[137] The extensive beneficial effects of composting on soil health have been abundantly documented across the globe, and the below list categorizes some of the studies into four groups:

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[133] McEldowney, James. 2020. "EU Agricultural Policy and Climate Change." https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/651922/EPRS_BRI(2020)651922_EN.pdf.
[134] Taiwo, Adewale M. 2011. "Composting as A Sustainable Waste Management Technique in Developing Countries." https://doi.org/10.3923/jest.2011.93.102.
[135] "Soil Organic Matter Matters."2016. The agricultural European Innovation Partnership (EIP-AGRI). https://ec.europa.eu/eip/agriculture/en/news/soil-organic-matter-matters.
[136] Cuneen, Gary. 2018. "Analysis of the Barriers and Opportunities for the Use of Compost in Agriculture." Seven Generations Ahead. https://hub.compostingcouncil.org/wp-content/uploads/2021/08/Barriers_Opportunities_Use_of_Compost_Agriculture_2018.pdf.
[137] "Soil Organic Matter Matters."2016. The agricultural European Innovation Partnership (EIP-AGRI). https://ec.europa.eu/eip/agriculture/en/news/soil-organic-matter-matters.

施用堆肥會增加土壤的有機質含量，大幅提高土壤儲存養分的能力：土壤把養分儲存在各種生物創造的孔隙中，這些孔隙可吸附氮、磷、鉀、鈣、鎂等必要養分，養活無數重要微生物並提高土壤吸水量。[135]研究顯示，堆肥比其他常見的農用土壤改良劑，更能提高土壤吸附和儲存養分的能力。[136]有機質含量的提高也有助於穩定土壤酸度，且能加速礦物質分解。[137]全球已有大量文獻記錄堆肥對土壤健康的廣大效益，現將其中幾項研究分為四大主題羅列如下：

Improved biochemical properties

改良土壤生化特性

- A study conducted in Spain showed the soil quality improvement effects of compost, which increased the organic matter content of degraded soils and improved soil biological and biochemical properties.[138]
- 西班牙一項研究顯示堆肥可改良土壤品質，提高退化土壤中的有機質含量並改善土壤的生物與生化特性。[138]
- An experiment conducted over a four-year period in Southern Italy presented the benefits of compost in maintaining an adequate level of soil organic carbon and sustaining biological activities. The addition of compost resulted in stable vegetable crop productivity and showed the best outcome for the restoration of soil carbon mineralization among various fertilization strategies.[139]
- 南義大利一項長達四年的實驗顯示，堆肥有助於維持土壤中足量的有機碳，且可維繫生物活動。在土壤中加入堆肥可以穩定蔬菜產量，而且比其他各種施肥方法都更能恢復土壤碳礦化。[139]
- A study conducted in West Africa pointed out that the effects of compost were clearer with a long-term experiment, in which compost amendment improved soil morphological and chemical properties.[140] As a result, composting was recommended as a sound solution for combating soil degradation and alleviating food shortage and poverty in the Sahel.
- 西非一項研究透過長期實驗，更清楚驗證堆肥的效果：堆肥有助於改善土壤型態及其化學特性。[140]因此，該研究建議利用堆肥有效解決土壤退化問題，藉以緩解薩赫爾（Sahel）地區食物短缺和貧窮危機。
- Particularly on the effects of municipal solid waste compost, results of a study conducted in central Spain have shown that the use of compost had positive effects on the soil quality with microbial biomass carbon and enzyme activities, which improved soil perturbation or restoration over a relatively short time.[141]

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[138] García-Gil, J., C. Plaza, P. Soler-Rovira, and A. Polo. 2000. "Long-Term Effects of Municipal Solid Waste Compost Application on Soil Enzyme Activities and Microbial Biomass." https://doi.org/10.1016/S0038-0717(00)00165-6.

[139] Morra, Luigi, Luca Pagano, Paola Iovieno, Daniela Baldantoni, and A Alfani. 2010. "Soil and Vegetable Crop Response to Addition of Different Levels of Municipal Waste Compost under Mediterranean Greenhouse Conditions." Http://Dx.Doi.Org/10.1051/Agro/2009046 30 (September). https://doi.org/10.1051/agro/2009046.

[140] Ouédraogo, E., A. Mando, and N. P. Zombré. 2001. "Use of Compost to Improve Soil Properties and Crop Productivity under Low Input Agricultural System in West Africa." Agriculture, Ecosystems & Environment 84 (3): 259–66. https://doi.org/10.1016/S0167-8809(00)00246-2.

[141] García-Gil, J., C. Plaza, P. Soler-Rovira, and A. Polo. 2000. "Long-Term Effects of Municipal Solid Waste Compost Application on Soil Enzyme Activities and Microbial Biomass." https://doi.org/10.1016/S0038-0717(00)00165-6.

- 西班牙中部一項針對城市固體廢棄物堆肥效果的研究顯示，施用堆肥能提高微生物生質碳量及酵素活性，而能有效改善土壤品質，可在相當短時間內促進土壤擾動，幫助土壤復原。[141]

Increase in crop production

提高作物產量

- A field study conducted in Puerto Rico—under tropical conditions—demonstrated that the addition of compost increased both the quantity and the quality of soil organic matter, improving soil quality and crop production.[142]
- 在波多黎各熱帶地區進行的一項田野調查發現，施用堆肥可同時提升土壤有機質的質和量，提高土壤品質和作物產量。[142]
- A study conducted in Pakistan found that the use of rice and wheat straw compost improved soil fertility and productivity.[143] Reduction in the cost of crop production was also noticed, which implied higher yield and income for the farmers practicing composting.[144] As a result, composting rice and wheat straw was recommended as an alternative to chemical fertilizers in Pakistan and countries with similar climatic and soil conditions.
- 巴基斯坦一項研究發現，稻稈和麥稈製成的堆肥有助於提高土壤肥分和生產力。[143]該研究還注意到農作成本因此降低，亦即農民若能堆肥將可同時增加農產和收入。[144]有鑑於此，該研究建議巴基斯坦及具有相似氣候和土壤條件的國家，用稻、麥稈來堆肥以取代化學肥料。

High levels of nutrients

富含養分

- A study conducted in Truro, Nova Scotia, demonstrated that compost-amended soils produced similar or higher yields of certain crops than fertilizer-amended soils and contained higher levels of carbon, nitrogen, phosphorus, calcium, magnesium, manganese, zinc, and boron compared with the fertilized plots.[145]
- 加拿大新蘇格蘭省杜魯羅（Truro）的一項研究顯示，和施用化肥相比，施用堆肥的土壤可以維持甚至增加特定農作物產量，而且土壤中會含有更多碳、氮、磷、鈣、鎂、錳、鋅和硼。[145]
- In the UK, it was observed that compost consisting of green materials that are high in nitrogen, such as fresh grass clippings, enhanced low-grade soils.[146]
- 英國研究發現，堆肥中如果有含氮量高的綠色物質（例如新鮮草屑），有助於修復退化土壤。[146]

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[142] Rivero, Carmen, T. Chirenje, L. Q. Ma, and G. Martinez. 2004. "Influence of Compost on Soil Organic Matter Quality under Tropical Conditions." Geoderma 123 (3): 355–61. https://doi.org/10.1016/j.geoderma.2004.03.002.

[143] Sarwar, G., H. Schmeisky, N. Hussain, S. Muhammad, M. Ibrahim, and E. Safdar. 2008. "Improvement of Soil Physical and Chemical Properties with Compost Application in Rice-Wheat Cropping System." Pakistan Journal of Botany (Pakistan).

[144] Sarwar, G., H. Schmeisky, N. Hussain, S. Muhammad, M. Ibrahim, and E. Safdar. 2008. "Improvement of Soil Physical and Chemical Properties with Compost Application in Rice-Wheat Cropping System." Pakistan Journal of Botany (Pakistan).

[145] Warman, P. R. 2005. "Soil Fertility, Yield and Nutrient Contents of Vegetable Crops after 12 Years of Compost or Fertilizer Amendments." Biological Agriculture & Horticulture 23 (1): 85–96. https://doi.org/10.1080/01448765.2005.9755310.

[146] Rainbow, Arnie, and F N Wilson Ma. 2002. "Composting for Soil Improvement in the United Kingdom." In 12th ISCO Conference, 5. https://www.tucson.ars.ag.gov/isco/isco12/VolumeIII/CompostingforSoilImprovement.pdf.

- Similarly in Beijing, China, green waste-dominated compost increased the total nitrogen and available phosphorus in soil, showing a favorable effect on strengthening soil microbial abundance albeit an insignificant influence on soil microbial diversity. The application of compost improved levels of soil organic matter content, pH, available phosphorus, and rapidly available potassium contents on bacterial communities in soil.[147]
- 中國北京也有類似研究發現，以富氮的綠色廢棄物為主製成的堆肥會提高土壤總氮及有效磷的含量，且能大幅增加土壤微生物含量，不過對微生物多樣性影響有限。施用堆肥可以改善土壤的有機質、PH值、有效磷及速效鉀含量，對土壤細菌群落有極大助益。[147]
- A study conducted in Kerala, India, showed that vermicomposting (worm composting)[148] increased the nutrient contents of compost, in particular nitrogen, phosphorus, and potassium, improving the quality of produce. It was also noted that the transition from chemical fertilizers to sustainable vermicomposting can happen in a short period of time, maintaining the yield efficiency.[149]
- 印度喀拉拉邦一項研究發現，蚯蚓堆肥（蠕蟲堆肥）[148]可增加堆肥中的養分，特別是氮、磷、鉀，從而提高農作品質。該研究還指出，要從化肥轉換到永續的蚯蚓堆肥不需要花太多時間，可以維持住農產效率。[149]

Water retention

保留水分

- In two towns in Greece (Aliartos in Biotia and Kiourka in Attiki), all physical properties of the soils analyzed improved with the application of compost, in proportion to the compost rate. In particular, total porosity and saturated hydraulic conductivity, level of water content, retention ability, and aggregate stability were increased.[150]
- 在希臘兩個城鎮——比歐提亞（Biotia）的亞里亞多斯（Aliartos）和阿提基（Attiki）的基烏爾卡（Kiourka）——的研究發現，其檢驗的土壤物理特性全都因堆肥的使用而獲得改善，且改善幅度與堆肥用量成正比，尤其能夠增加土壤總孔隙率和飽和水力傳導度（透水性）、含水量及保水力，還有土壤團粒穩定度。[150]
- In Ile de France, France, both immature and mature composts increased aggregate stability by enhancing microbial activity and adding humified organic matter respectively.[151]
- 法國法蘭西島（Ile de France）的研究發現，不論熟成或未熟成的堆肥，都會增加微生物活性和腐植質，因此都能增加土壤團粒穩定度。[151]

[147] Tong, Jing, Xiangyang Sun, Suyan Li, Bingpeng Qu, and Long Wan. 2018. "Reutilization of Green Waste as Compost for Soil Improvement in the Afforested Land of the Beijing Plain." Sustainability 10 (7): 2376. https://doi.org/10.3390/su10072376.

[148] Vermicomposting relies on earthworms and microorganisms to convert organic waste to nutritious soil amendments.

[149] Padmavathiamma, Prabha K., Loretta Y. Li, and Usha R. Kumari. 2008. "An Experimental Study of Vermi-Biowaste Composting for Agricultural Soil Improvement." Bioresource Technology 99 (6): 1672–81. https://doi.org/10.1016/j.biortech.2007.04.028.

[150] Aggelides, S. M., and P. A. Londra. 2000. "Effects of Compost Produced from Town Wastes and Sewage Sludge on the Physical Properties of a Loamy and a Clay Soil." Bioresource Technology 71 (3): 253–59. https://doi.org/10.1016/S0960-8524(99)00074-7.

[151] Annabi, M., S. Houot, C. Francou, M. Poitrenaud, and Y. Le Bissonnais. 2007. "Soil Aggregate Stability Improvement with Urban Composts of Different Maturities." Soil Science Society of America Journal 71 (2): 413–23. https://doi.org/10.2136/sssaj2006.0161.

3.4.2.2. Composting for remediation of soil contamination

3.4.2.2.利用堆肥整治受汙染的土壤

The widespread use of synthetic agricultural fertilizers has exposed farmers and communities to soil quality and contamination issues, as it has released large amounts of organic and inorganic pollutants into the soil. These include polycyclic aromatic hydrocarbons (PAHs), dibutyl phthalate (DBP), and di-n-octyl phthalate (DOP), and heavy metals such as cadmium and manganese.[152]

廣泛應用合成化肥導致農民和農業社區面臨土質退化及土壤汙染問題，因為化肥會在土壤中留下大量有機與無機汙染物，包括多環芳香烴（PAH）、鄰苯二甲酸二丁酯（DBP）、鄰苯二甲酸二正辛酯（DOP）以及鎘和錳等重金屬。[152]

Composting is an effective solution, as it nurtures microbes, the key agents for degradation of organic contaminants in soil. In an experiment, it was shown that the application of compost also lowered concentration levels of heavy metals in soils such as lead, copper, and zinc.[153] The U.S. EPA also noted that composting is a cost-effective way to restore soils contaminated with toxic organic compounds (such as solvents and pesticides) and inorganic compounds (such as toxic metals).[154] According to the agency, hydrocarbons, a common industrial contaminant, degrade rapidly during the composting processes, and the addition of mature compost to contaminated soil accelerates plant and microbial degradation of organic contaminants. Moreover, mature compost also showed disease control effects on plants without the help of synthetic chemicals.[155]

堆肥可以有效解決問題，因為堆肥能培養微生物，而微生物是分解土壤中有機汙染物的關鍵角色。有實驗顯示，施用堆肥還能降低土壤中的鉛、銅、鋅等重金屬的濃度。[153]美國環保署也表示，如果要修復受到有毒有機化合物（如溶劑和殺蟲劑等）或無機化合物（如有毒金屬）汙染的土壤，堆肥是成本效益高的方法。[154]美國環保署同時還指出，碳氫化合物這種常見的工業汙染物會在堆肥過程中快速分解，而把熟成堆肥加入受汙染的土壤，也會加速植物和微生物分解有機汙染物。此外，熟成堆肥還能在沒有施加化學農藥的情況下，幫助控制植物病蟲害。[155]

3.4.2.3. Composting as a disaster prevention measure

3.4.2.3. 利用堆肥預防災害

Composting strengthens soil structures, increases the water-holding capacity of soil, and reduces stormwater runoff, which prevents soil erosion, floods, mudslides, and loss of food crops. The use of compost for

[152] Lin, Weiwei, Manhong Lin, Hongyan Zhou, Hongmiao Wu, Zhaowei Li, and Wenxiong Lin. 2019. "The Effects of Chemical and Organic Fertilizer Usage on Rhizosphere Soil in Tea Orchards." PLoS ONE 14 (5): e0217018. https://doi.org/10.1371/journal.pone.0217018.

[153] Nwachukwu, O., and I. Pulford. 2008. "Comparative Effectiveness of Selected Adsorbant Materials as Potential Amendments for the Remediation of Lead-, Copper- and Zinc-contaminated Soil." https://doi.org/10.1111/J.1475-2743.2007.00141.X; Brown, Sally, Rufus L. Chaney, Judith G. Hallfrisch, and Qi Xue. 2003. "Effect of Biosolids Processing on Lead Bioavailability in an Urban Soil." Journal of Environmental Quality 32 (1): 100–108. https://doi.org/10.2134/jeq2003.1000.

[154] "An Analysis of Composting As an Environmental Remediation Technology." 1998. U.S. EPA. https://19january2017snapshot.epa.gov/sites/production/files/2015-09/documents/analpt_all.pdf.

[155] "An Analysis of Composting As an Environmental Remediation Technology." 1998. U.S. EPA. https://19january2017snapshot.epa.gov/sites/production/files/2015-09/documents/analpt_all.pdf.

reforestation further stabilizes soil. Compost is also commonly used as an erosion and sediment control method.[156] A compost blanket, a layer of compost applied on the soil surface as a mulch in disturbed areas, protects soil surfaces from wind and water erosion and conserves water.[157] Composting socks are mesh tubes filled with composted material. They are used to filter sediments, nutrients, bacteria, heavy metals, and petroleum oil residues in stormwater runoff; control erosion; and retain sediment in disturbed areas.[158] Similarly, composting berms act as a silt fence, controlling erosion and keeping sediment in place.[159]
堆肥可以強化土壤結構、提高土壤保水力、減少暴雨逕流，從而預防土壤侵蝕、洪水、土石流和農損，使用堆肥重新造林也可以鞏固土壤。堆肥也常被用來防制土壤侵蝕與水體淤積，[156]在土壤受擾動地區鋪設「堆肥毯」(在土壤表面覆蓋一層堆肥)可以保護土壤表層免受風雨侵蝕，同時還可保留水分。[157]「堆肥襪」則是在網管中填入堆肥料，用來過濾雨水逕流中的沉積物、養分、細菌、重金屬和石油殘留物；防止土壤流失並將沉積物留在受擾動地區內。[158]功能相似的還有「堆肥堤」，就像一道泥土護欄，防止土壤流失並把逕流中的沉積物留下來。[159]

3.4.2.4. Challenges

3.4.2.4.堆肥遇到的挑戰

One of the major barriers to scaling up composting is the lack of institutional and financial support from municipalities.[160] Because short-term costs of composting can be higher than government-subsidized synthetic fertilizers, the compost market requires subsidies for stable compost production and application. Researchers observed that the constraints in applying compost are mainly economic, with technical or cultural factors playing a minor role, which could be effectively addressed by providing incentives to compost producers and farmers.[161]
擴大堆肥規模的主要困難在於市政機關在制度和財務上提供的支持不足。[160]由於堆肥的短期成本可能會高於政府補助的合成化肥，堆肥市場也會需要政府補助才能穩定供需。研究人員發現施用堆肥的主要限制在於經濟面，技術或文化因素影響較小，若能提供堆肥業者和農民經濟誘因就能有效解決此問題。[161]
Variable compost quality and toxics in compost could also pose a challenge to compost application. Immature compost can cause odors and develop toxic compounds after becoming anaerobic. When compost continues active decomposition, it can hamper plant growth due to reduced available oxygen and nitrogen, or the presence of phytotoxic compounds.[162] Toxic substances present in compost have been addressed by many

[156] "Erosion Control Uses - US Composting Council." US Composting Council. https://www.compostingcouncil.org/page/CompostErosionControlUses.
[157] "Compost Blankets." CalRecycle. https://calrecycle.ca.gov/organics/compostmulch/toolbox/compostblankets.
[158] "Compost Filter Socks." CalRecycle. https://calrecycle.ca.gov/organics/compostmulch/toolbox/compostsock.
[159] "Compost Filter Berms." 2019. U.S. EPA.https://www.epa.gov/system/files/documents/2021-11/bmp-compost-filter-berms.pdf.
[160] Viaene, J., J. Van Lancker, B. Vandecasteele, K. Willekens, J. Bijttebier, G. Ruysschaert, S. De Neve, and B. Reubens. 2016. "Opportunities and Barriers to On-Farm Composting and Compost Application: A Case Study from Northwestern Europe." Waste Management 48 (February): 181–92. https://doi.org/10.1016/j.wasman.2015.09.021.
[161] Viaene, J., J. Van Lancker, B. Vandecasteele, K. Willekens, J. Bijttebier, G. Ruysschaert, S. De Neve, and B. Reubens. 2016. "Opportunities and Barriers to On-Farm Composting and Compost Application: A Case Study from Northwestern Europe." Waste Management 48 (February): 181–92. https://doi.org/10.1016/j.wasman.2015.09.021.
[162] Lakhdar, Abdelbasset, Mokded Rabhi, Tahar Ghnaya, Francesco Montemurro, Naceur Jedidi, and Chedly Abdelly. 2009. "Effectiveness of Compost Use in Salt-Affected Soil." Journal of Hazardous Materials 171 (1): 29–37. https://doi.org/10.1016/j.jhazmat.2009.05.132.

researchers.[163] Certain composts were found to contain concentrations of metals including lead, cadmium, copper, and zinc, which are usually added by oils, solvents, and paper products found in the municipal waste stream.[164] Heavy metals and other toxic substances can potentially cause an adverse impact to biochemical processes essential for the growth of plants;[165] it is therefore recommended to use segregated food waste and yard waste for composting.[166] In this context, the practice of using incineration ash as a soil additive raises concern. The guidelines on best available techniques and provisional guidance on best environmental practices of the Stockholm Convention notes that "Fly ash from electrostatic precipitators and residues from air pollution equipment almost certainly contain significant amounts of chemicals listed in Annex C of the Convention, so these wastes have to be disposed of in a controlled way."[167]

堆肥品質的不穩定以及毒性物質殘留也會對堆肥應用的推廣構成挑戰。未熟成堆肥在變成缺氧狀態後，就開始產生異味及有毒化合物；如果堆肥施用後繼續進行活躍的分解，就會因為消耗了土壤的氧和氮，或是因為產生具植物毒性的化合物，而妨礙植物生長。[162]許多研究也提到堆肥裡的毒性物質，[163]有些堆肥被檢驗出含有鉛、鎘、銅和鋅等金屬，而這些有毒金屬通常來自都市垃圾當中的油脂、溶劑和紙製品。[164]重金屬和其他有毒物質可能會對影響植物生長的關鍵生化過程產生不良影響[165]，因此學者建議堆肥應使用已和其他垃圾分開來的食物廢棄物和園藝廢棄物當作料源[166]。這麼說來，使用焚化飛灰做為土壤改良劑的作法當然也會有疑慮。《斯德哥爾摩公約》的最佳可行技術指引和最佳環境實務暫行指南指出：「靜電集塵器攔下的飛灰及空氣污染防制設備濾除的殘餘物，幾乎都含有大量附件C所列毒性化學物質，因此這類廢棄物處理必須受到管控。」[167]

4. Additional benefits of zero waste

4. 零廢棄的額外效益

Chapter summary

[163] Lakhdar, Abdelbasset, Mokded Rabhi, Tahar Ghnaya, Francesco Montemurro, Naceur Jedidi, and Chedly Abdelly. 2009. "Effectiveness of Compost Use in Salt-Affected Soil." Journal of Hazardous Materials 171 (1): 29–37. https://doi.org/10.1016/j.jhazmat.2009.05.132.

[164] Lakhdar, Abdelbasset, Mokded Rabhi, Tahar Ghnaya, Francesco Montemurro, Naceur Jedidi, and Chedly Abdelly. 2009. "Effectiveness of Compost Use in Salt-Affected Soil." Journal of Hazardous Materials 171 (1): 29–37. https://doi.org/10.1016/j.jhazmat.2009.05.132.

[165] García-Gil, J., C. Plaza, P. Soler-Rovira, and A. Polo. 2000. "Long-Term Effects of Municipal Solid Waste Compost Application on Soil Enzyme Activities and Microbial Biomass." https://doi.org/10.1016/S0038-0717(00)00165-6.

[166] Aulinas Masó, Montserrat, and August Bonmatí Blasi. 2008. "Evaluation of Composting as a Strategy for Managing Organic Wastes from a Municipal Market in Nicaragua." Bioresource Technology, Exploring Horizons in Biotechnology: A Global Venture, 99 (11): 5120–24. https://doi.org/10.1016/j.biortech.2007.09.083; Van Fan, Y., Lee, C. T., Klemeš, J. J., Bong, C. P. C., & Ho, W. S. (2016). Van Fan, Yee, Chew Tin Lee, Jiří Jaromír Klemeš, Cassendra Phun Chien Bong, and Wai Shin Ho. 2016. "Economic Assessment System towards Sustainable Composting Quality in the Developing Countries." *Clean Technologies and Environmental Policy* 18 (8): 2479–91. https://doi.org/10.1007/s10098-016-1209-9.

[167] Petrlik, Jindrich, and Lee Bell. 2020. "Toxic Ash Poisons our Food Chain." IPEN. https://ipen.org/documents/toxic-ash-poisons-our-food-chain

本章摘要

- Well-implemented zero waste strategies offer a host of additional benefits beyond mitigation that can be especially attractive to cities.
- 除了減緩氣候變遷以外，落實良好的零廢棄策略還能提供許多額外效益，而這些效益可能對城市特別具有吸引力。
- Environmental benefits: through waste reduction and phase-out of polluting waste management practices such as incineration, cities can reduce air pollution and toxic residues, save environmental resources, protect biodiversity, and improve soil quality.
- 環境效益：透過廢棄物減量以及淘汰污染性的廢棄物處理方式（諸如焚化），城市可降低空污與有毒殘渣、節約環境資源、保護生物多樣性及改善土壤品質。
- Economic benefits: cities can generate green jobs by expanding reuse, composting, and recycling; improve economic performance; achieve fiscal sustainability; and trigger innovative businesses.
- 經濟效益：透過再使用、堆肥與資源回收的推展，城市可創造綠色工作機會，同時零廢棄還能改善經濟表現、達成財政永續及刺激商業創新。
- Social benefits: zero waste strategies enhance energy access and security by recovering material and generating energy; reduce poverty and inequality through the inclusion of waste pickers; contribute to agriculture with strengthened food and water security; improve public health; and reduce stressors such as noise, traffic, and congestion.
- 社會效益：零廢棄策略透過資源回收與能源產生，可提高能源取得、促進能源安全；透過讓拾荒者一起參與，可降低貧窮、促進社會平等；在農業方面能強化糧食與用水安全；可改善公共衛生，也能減少噪音、交通流量與阻塞等壓力源。
- Political and institutional benefits: the process of designing and implementing zero waste policies and programs involves collaboration between civil society, local authorities, and other stakeholders, which improves democratic quality of governance.
- 政治與制度效益：零廢棄政策與計畫的規劃設計與執行過程，需要公民社會、地方政府與其他利害關係人的通力合作，可促進民主治理的品質。
- The waste solutions at the top of the waste hierarchy have the greatest additional benefits, and score highest on emissions reductions.
- 在廢棄物治理層級中被列為最優先的廢棄物解決方案，帶來最大的額外效益，在排放減量方面的貢獻度也最高。

4.1. Introduction

4.1. 簡介

In a world beset by poverty, disease, conflict, and other interconnected maladies, the positive benefits related to the reduction of GHGs are more important than ever. Effective climate action will not only reduce GHG emissions, but also improve many of the most fundamental ways in which society functions through associated environmental, economic, social, and political and institutional benefits. Focusing on these more

tangible benefits is an opportunity to gain increased support from multiple constituencies, who can easily relate to issues that immediately impact their lives such as air quality, employment, food security, etc.

在這個深受貧窮、疾病、衝突及其他盤根錯節的諸多問題所困擾的世界上，溫室氣體減量所帶來的諸多正面效益，具有空前重要性。有效的氣候行動不僅可減少溫室氣體排放，也可透過其帶來的環境、經濟、社會、政治與制度上的效益，改善許多最基本的社會運作方式。聚焦於這些實實在在的效益，即有機會贏取更多來自各行各業的選民的支持，因為他們很容易把這些效益和直接衝擊其生活的問題（諸如空氣品質、就業、糧食安全等）關聯起來。

Because climate change is partially the result of systemic problems not directly related to environmental degradation, solutions cannot just focus on the market or unilateral policies.[168] They need to be addressed from a systemic point of view that connects them to interrelated factors like poverty, gender inequality, corruption, conflict, and war. Taking a particular climate action without an overall understanding of how mitigation, adaptation, and sustainable development actions interact and reinforce each other can be counterproductive and exacerbate the root causes of climate change.[169]

造成氣候變遷的原因有部份是源自於非和環境退化直接相關的系統性問題，因此其解決方案不能只是聚焦於市場或單一面向的政策；[168]必須從系統面出發，將貧窮、性別不平等、貪污腐敗、衝突與戰爭等互相關聯的因素考量在內，然後提出解決方案。若未能全面性理解氣候變遷的減緩、調適與促進永續發展的行動之間如何交互作用、互相加乘，即採取特定的氣候行動，可能適得其反，並惡化氣候變遷的根源。[169]

Linkages across issues or problem areas reveal both the complexity of global environmental challenges, and potential opportunities.[170] Additional benefits of zero waste systems are an important reason to change waste management systems. In this way, pursuing climate policies focused on additional benefits can drive forward environmental policy in places that would otherwise find it challenging. For example, in many cities around the world, lack of political will, insufficient technical capacity, and competing priorities make it difficult for local governments to prioritize recycling. Much of the waste management work is therefore handled by the informal sector. In this context, waste reuse and recycling is often driven by economics (the monetary value that informal workers can extract from the waste they collect), rather than environmental or social policy itself.[171]

不同議題或問題範疇之間的互相關聯，突顯全球環境問題的複雜度，也彰顯了其提供的潛在機會。[170]零廢棄系統帶來的額外效益，是改變廢棄物管理系統的重要理由之一；同樣地，在制定氣候政策時聚焦於額外效益，可能促使有些原本很難浮上檯面的環境政策受到正視而被推出。比如說，全球許多城市缺乏政治意願、技術能力，同時又有其他重要議題競爭，使得地方政府很難將資

[168] Rotmans, Jan, and Derk Loorbach. 2009. "Complexity and Transition Management." Journal of Industrial Ecology 13 (2): 184–96. https://doi.org/10.1111/j.1530-9290.2009.00116.x.

[169] Ayers, Jessica M., and Saleemul Huq. 2009. "The Value of Linking Mitigation and Adaptation: A Case Study of Bangladesh." Environmental Management 43 (5): 753–64. https://doi.org/10.1007/s00267-008-9223-2.

[170] O'Neill, Kate. 2018. "Linking Wastes and Climate Change: Bandwagoning, Contention, and Global Governance." WIREs Clim Change 10 (2). https://doi.org/10.1002/wcc.568.

[171] Scheinberg, Anne, Sandra Spies, Michael H. Simpson, and Arthur P. J. Mol. 2011. "Assessing Urban Recycling in Low- and Middle-Income Countries: Building on Modernised Mixtures." Habitat International 35 (2): 188–98. https://doi.org/10.1016/j.habitatint.2010.08.004

源回收列為優先政策，因此廢棄物管理工作有大部分是由非正式部門在承擔。在此情況下，廢棄物的再使用與再利用，通常是由經濟力量（也就是非正式工作者可從所收集的廢棄物中獲取的金錢價值）所驅使，而非環境或社會政策本身。[171]

This chapter provides an overview of the additional benefits related to implementation of zero waste strategies, organized across four main categories: environmental, social, economic, and political-institutional. Taken together, they show clearly that the waste solutions at the top of the waste hierarchy have the greatest additional benefits, and also score highest on emissions reductions. These additional benefits include improving public health, reducing environmental pollution, incentivizing job creation, supporting community development, and addressing inequalities as well as various justice issues.[172]

本章帶領讀者綜覽實施零廢棄策略的額外效益，並將這些效益彙整為環境、社會、經濟以及政治/制度等四大面向來分別說明。總體來看，即可清楚看到，在廢棄物治理層級中被列為最優先的廢棄物解決方案，帶來最大的額外效益，在排放減量方面的貢獻度也最高。這些額外效益包括改善公共衛生、減少環境污染、促進工作機會的產生、支持社區發展、解決不平等及其他各種攸關正義的問題。[172]

4.2. Environmental benefits

4.2 環境效益

Zero waste strategies deliver great additional environmental benefits, on top of reducing GHG emissions. They reduce air pollution and toxic residues, protect biodiversity and natural resources, reduce littering, and improve soil quality.

零廢棄策略除了可減少溫室氣體排放，還可以達成許多額外的環境效益，比如減少空汙與有毒殘渣，保護生物多樣性與自然資源，減少垃圾亂丟行為及改善土壤品質。

4.2.1. Reduction of air pollution and toxic waste

4.2.1. 減少空污與有毒廢棄物

Zero waste ends the practice of burning waste, whether in the open, in dedicated incinerators, or in cement kilns as "alternative fuel," and dramatically reduces the quantity of waste sent to landfills. Burning and landfilling waste results in leachate leakage, water contamination, air pollution, and the spread of toxic ash.[173] Waste-to-energy incinerators and cement kilns are particularly significant sources of these harms.

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[172] This chapter follows the co-benefits model presented by: Mayrhofer, Jan P., and Joyeeta Gupta. 2016. "The Science and Politics of Co-Benefits in Climate Policy." *Environmental Science & Policy* 57 (March): 22–30. https://doi.org/10.1016/j.envsci.2015.11.005.

[173] Ma, Shijun, Chuanbin Zhou, Jingjin Pan, Guang Yang, Chuanlian Sun, Yijie Liu, Xinchuang Chen, and Zhilan Zhao. 2022. "Leachate from Municipal Solid Waste Landfills in a Global Perspective: Characteristics, Influential Factors and Environmental Risks." *Journal of Cleaner Production* 333 (January): 130234. https://doi.org/10.1016/j.jclepro.2021.130234; Bihałowicz, Jan Stefan, Wioletta Rogula-Kozłowska, and Adam Krasuski. 2021. "Contribution of Landfill Fires to Air Pollution – An Assessment Methodology." *Waste Management* 125 (April): 182–91. https://doi.org/10.1016/j.wasman.2021.02.046; "Pollution and Health Impacts of Waste-to-Energy Incineration." 2019. Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/Pollution-Health_final-Nov-14-2019.pdf.

零廢棄可終結燃燒廢棄物的作法，不管是露天燃燒，還是在專用的焚化爐燒，或以「輔助燃料」在水泥窯中燒；而且零廢棄還可大幅減少送到掩埋場的廢棄物數量。焚化與掩埋廢棄物，會造成滲出水洩漏、水污染、空氣污染與有毒灰渣的散布；[173]尤其是廢轉能的焚化爐與水泥窯，更是這些危害的重大來源。

Air pollution from waste disposal in incinerators and cement kilns increases the risk of cancer and other illnesses in local communities.[174] These emissions include lead, mercury, dioxins and furans, particulate matter, carbon monoxide, nitrogen oxides, acidic gasses (i.e., SO_x, HCl), metals (cadmium, lead, mercury, chromium, arsenic, and beryllium), polychlorinated biphenyls (PCBs), and brominated polyaromatic hydrocarbons (PAHs).[175] Moreover, these polluting industries are often sited in low-income and marginalized communities,[176] with greater impacts on children,[177] which in turn burdens the care labor load of women, who tend to carry most of the child-rearing work.

以焚化爐及水泥窯處理廢棄物所產生的空污，會造成在地社區罹患癌症與其他疾病的風險增加。[174]這些污染排放包括了戴奧辛與呋喃、懸浮微粒、一氧化碳、氮氧化物、酸性氣體（如硫氧化物、氯化氫）、重金屬（鎘、鉛、汞、鉻、砷與鈹）、多氯聯苯（PCBs）與溴化的多環芳香烴（PAHs）。[175]甚者，這些污染性的產業通常選擇設在低收入、邊緣化的社區，[176]且對於兒童有更高的衝擊，[177]從而增加婦女的照料勞力負擔——因為養兒育女工作通常大部分會落在婦女身上。

Approximately 26 - 40% of waste becomes bottom ash, and the toxic residues from incineration, such as ash and wastewater, require special treatment and separate disposal.[178] However, they are mostly sent to landfills, where the ash can spread via wind and air; in some places, they are mixed into concrete, buried in salt mines, mixed into asphalt for roads, or even spread on agricultural lands, mislabeled as soil fertilizer.[179]

廢棄物焚化後會產生底渣，以及諸如飛灰與廢水等有毒殘餘物，這些衍生廢棄物重量大約為焚化的廢棄物重量的26-40%，需要特別的處理並與其他廢棄物分開處置。[178]然而，它們大部份會送到

[174] García-Pérez, Javier, Gonzalo López-Abente, Adela Castelló, Mario González-Sánchez, and Pablo Fernández-Navarro. 2015. "Cancer Mortality in Towns in the Vicinity of Installations for the Production of Cement, Lime, Plaster, and Magnesium Oxide." Chemosphere 128 (June): 103–10. https://doi.org/10.1016/j.chemosphere.2015.01.020.
; "The True Toxic Toll: Biomonitoring of incineration emissions." 2021. Zero Waste Europe; "Hidden emissions: A story from the Netherlands Case Study." 2018. Zero Waste Europe and Toxico Watch; "The not-that-well hidden risks of incineration: the case of the Danish Norfors Plant." 2019. Zero Waste Europe and Toxico Watch.
[175] Baptista, Ana Isabel, and Adrienne Perovich. 2019. "U.S. Municipal Solid Waste Incinerators: An Industry in Decline." The New School Tishman Environment and Design Center. https://www.no-burn.org/u-s-municipal-solid-waste-incinerators-an-industry-in-decline.
[176] "Pollution and Health Impacts of Waste-to-Energy Incineration." 2019. Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/Pollution-Health_final-Nov-14-2019.pdf.
[177] Lundqvist, Christofer, Moniek Zuurbier, Marike Leijs, Carolina Johansson, Sandra Ceccatelli, Margaret Saunders, Greet Schoeters, Gavin ten Tusscher, and Janna G. Koppe. 2006. "The Effects of PCBs and Dioxins on Child Health." Acta Paediatrica (Oslo, Norway: 1992). Supplement 95 (453): 55–64. https://doi.org/10.1080/08035320600886257; Winneke, Gerhard, Ulrich Ranft, Jürgen Wittsiepe, Monika Kasper-Sonnenberg, Peter Fürst, Ursula Krämer, Gabriele Seitner, and Michael Wilhelm. 2014. "Behavioral Sexual Dimorphism in School-Age Children and Early Developmental Exposure to Dioxins and PCBs: A Follow-Up Study of the Duisburg Cohort." Environmental Health Perspectives 122 (3): 292–98. https://doi.org/10.1289/ehp.1306533.
[178] Petrlik, Jindrich, and Ralph Anthony Ryder. 2015. "After Incineration: The Toxic Ash Problem." International Pollution Elimination Network. https://ipen-china.org/sites/default/files/documents/After_incineration_the_toxic_ash_problem_2015.pdf.
[179] Petrlik, Jindrich, and Ralph Anthony Ryder. 2015. "After Incineration: The Toxic Ash Problem." International Pollution Elimination Network. https://ipen-china.org/sites/default/files/documents/After_incineration_the_toxic_ash_problem_2015.pdf.

掩埋場，其中灰渣可能會隨風與氣流飄散出去；在某些地方，它們也可能與水泥混拌成為混凝土，或埋在鹽礦區，混到瀝青中以鋪馬路，甚至以虛偽標示假冒為土壤肥料而散布到農地。[179]

In Oporto, Portugal, environmental samples collected throughout several years showed that closing the incinerator greatly reduced air pollution levels in the area.[180] Similarly, a study in Seoul, Korea, observed an increased risk of asthma-related hospitalization in relation to a person's distance from an incinerator, and concluded that asthma should be considered an adverse health outcome during health impact assessments of incineration plants.[181] In this sense, it becomes clear that by reducing our reliance on these polluting practices, zero waste strategies such as waste reduction, organic waste prevention, source separation, and separate treatment alleviate the harm that incineration poses to human health and the environment.

在葡萄牙的波爾圖（Oporto）的一項研究，花了數年時間進行環境樣本的採集，其檢測分析結果顯示，關掉焚化爐可大幅降低該地區的空氣污染程度。[180]同樣地，在南韓首爾的一項研究也觀察到，因氣喘而住院治療的風險增加，和住家離焚化爐的距離有關，並總結指出在進行焚化廠的健康風險評估時，應將氣喘視為焚化爐造成的不良健康後果之一。[181]由此可清楚看出，採取可減少仰賴這些污染性的廢棄物處理技術的零廢棄策略，諸如廢棄物源頭減量、避免有機廢棄物產生、源頭分類以及分開處理，可減輕焚化對人類健康與環境生態帶來的危害。

4.2.2. Saving natural resources

4.2.2. 節約自然資源

Zero waste strategies like single-use plastic avoidance, reuse, refill, and recycling reduce demand for virgin materials. The extraction, transport, and processing of virgin materials produce high amounts of GHG emissions, consume high volumes of energy and water, deplete non-renewable resources, and destroy natural ecosystems. Recycling discarded materials such as aluminum or glass in particular provides industry with an alternative source of raw materials from which to make new products without the damage associated with virgin materials.

零廢棄策略可減少對原生物料的需求，不管是避免一次用塑膠的使用，或者是再使用、重複填充或再利用。原生物料的開採、運送與加工處理，會產生大量的溫室氣體排放，消耗大量的能源與水資源，耗用不可再生的資源，並破壞自然生態系。而廢棄物的回收再利用，特別是廢鋁和廢玻璃等物質，可提供產業替代料源，不用為了生產新產品而去使用會帶來上述危害的原生物料。

Similarly, recycling of paper and wood products reduces the demand for virgin wood fiber, thus reducing deforestation rates, which benefits the overall ecosystem. Some materials, like glass and aluminum, have relatively high recycling rates and can be recycled endlessly. [182] For this reason, it is estimated that 75% of the

[180] Coutinho, Miguel, Margaret Pereira, and Carlos Borrego. 2004. "Air Quality Impact of the Shut-down of a Hospital Waste Incinerator in the Oporto Region."

[181] Bae, Hyun-Joo, Jung Eun Kang, and Yu-Ra Lim. 2020. "Assessment of Relative Asthma Risk in Populations Living Near Incineration Facilities in Seoul, Korea." International Journal of Environmental Research and Public Health 17 (20): E7448. https://doi.org/10.3390/ijerph17207448.

[182] Wakefield, Faith. 2022. "Top 25 Recycling Facts and Statistics for 2022." World Economic Forum. June 22, 2022. https://www.weforum.org/agenda/2022/06/recycling-global-statistics-facts-plastic-paper.

total aluminum ever produced is still in use today,[183] and that the recycling of aluminum reduces emissions by over 90% compared to primary production.[184] Successful recycling of these materials directly contributes to saving natural resources.

同樣地，紙類與木製品的回收再利用，可減少對原生木纖維的需求，從而降低伐林速率，對整個生態系都有助益。某些物質，如玻璃與鋁，回收率相當高，且可不限次數地循環利用；[182]也就是這個原因，據估計所有曾經被開採、生產出來的鋁，還有75%至今仍在使用。[183]而鋁的回收再利用，相對於原生鋁的生產，可減少超過90%的排放量。[184]這些物質若能成功回收再利用，將直接對節省自然資源帶來貢獻。

4.2.3. Protection of ecosystem health

4.2.3. 保護生態系健康

Zero waste strategies have been demonstrated to achieve an important reduction of plastic waste in the environment, which significantly supports the overall health of ecosystems. In particular, plastic waste, which is often found to be the most leaked type of waste in the environment, severely contaminates biodiversity and the overall ecosystem balance.

零廢棄策略已被證實可達到一項重要的成果，就是減少環境中的廢塑膠，而能大大促進整體生態系的健康。尤其是，廢塑膠這種最容易逸散到環境中的廢棄物，對生物多樣性及整體生態系的平衡帶來了嚴重危害。

From the approximately 6,300 million tonnes of plastic waste that has been generated globally as of 2015, only around 9% has been recycled and 12% incinerated. 79% has accumulated in dumps, landfills, lands, and waterways.[185] While ocean plastic waste is most publicly prominent, further scientific research points to a wide spectrum of environmental, social, and economic impacts from plastic pollution throughout its life cycle.[186] Plastic pollution has not only been found in the marine environment but also in remote terrestrial locations, with growing evidence of plastic ingestion by organisms, including humans,[187] and contamination of the soil ecosystem. [188,189]

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[183] Martchek, Kenneth. 2006. "Modelling More Sustainable Aluminium (4 Pp)." *The International Journal of Life Cycle Assessment* 11 (1): 34–37. https://doi.org/10.1065/lca2006.01.231.

[184] Martchek, Kenneth. 1997. "Life Cycle Benefits, Challenges, and the Potential of Recycled Aluminum."

[185] Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." *Science Advances* 3 (7): e1700782. https://doi.org/10.1126/sciadv.1700782.

[186] Lau, Winnie W. Y., Yonathan Shiran, Richard M. Bailey, Ed Cook, Martin R. Stuchtey, Julia Koskella, Costas A. Velis, et al. 2020. "Evaluating Scenarios toward Zero Plastic Pollution." Science 369 (6510): 1455–61. https://doi.org/10.1126/science.aba9475.

[187] Huerta Lwanga, Esperanza, Jorge Mendoza Vega, Victor Ku Quej, Jesus de los Angeles Chi, Lucero Sanchez del Cid, Cesar Chi, Griselda Escalona Segura, et al. 2017. "Field Evidence for Transfer of Plastic Debris along a Terrestrial Food Chain." Scientific Reports 7 (1): 14071. https://doi.org/10.1038/s41598-017-14588-2.

[188] Chae, Yooeun, and Youn-joo An. 2018. "Current Research Trends on Plastic Pollution and Ecological Impacts on the Soil Ecosystem: A Review." Environmental Pollution 240 (September): 387–95. https://doi.org/10.1016/j.envpol.2018.05.008.

[189] Souza Machado, Anderson Abel de, Werner Kloas, Christiane Zarfl, Stefan Hempel, and Matthias C. Rillig. 2018. "Microplastics as an Emerging Threat to Terrestrial Ecosystems." *Global Change Biology* 24 (4): 1405–16. https://doi.org/10.1111/gcb.14020.

截至2015年，全球曾經產生的廢塑膠總量高達63億噸左右，只有大約9%曾被回收、12%被焚化，另外還有79%囤積在垃圾堆置場、掩埋場、陸域與水體。[185]雖然海洋塑膠廢棄物最受到大眾關注，更進一步的科學研究則指出，塑膠在其整個生命週期所造成的污染，對環境、社會與經濟有相當廣泛的影響。[186]不只海域可發現塑膠污染，在偏遠的陸域也可發現，且有越來越多的證據指出，塑膠被包括人類的生物給吃進去，[187]並污染了土壤生態系。[188, 189]

The plastic industry's continuing increase in plastic production and plastic waste generation is the most significant obstacle to solving the persistent problem of plastic waste.[190] Since the 1950s, global plastic production has grown by an average 9% per year, with a significantly increased production in the last two decades: half of all plastic ever manufactured has been made in the last 15 years.[191] It has been predicted that, unless the trends are reversed, production of plastic will double again over the next two decades.[192] This is why zero waste strategies that minimize plastic production and consumption, such as single-use plastic bans, reuse systems, or redesign solutions, are instrumental in reducing plastic in the environment and maintaining ecosystem health.

塑膠產業持續在增加塑膠產生量與廢棄量，是解決廢塑膠這長年沈痾的最大阻礙。[190]自1950年代起，全球塑膠產量每年成長率平均約為9%，而過去二十年來的產量更是大幅增加：曾經被生產製造出來的所有塑膠中，約有一半是在過去15年內誕生於世。[191]曾有人預測指出，除非扭轉這種趨勢，否則塑膠產量會在下個二十年再度倍增。[192]這也是為何可減少塑膠生產與消費的零廢棄策略（比如一次用塑膠禁令、再使用制度或重新設計等解決方案），對於減少環境中塑膠以及維持生態系健康方面是如此重要。

4.2.4. Improve soil quality

4.2.4. 改善土壤品質

A key pillar in zero waste systems is the recovery of organic waste, which makes up the largest fraction of municipal solid waste and can easily be turned into compost on site, at decentralized, community-scale facilities or at larger, centralized facilities depending on local capacities and needs.

零廢棄體系中的一個重要支柱是有機廢棄物的回收，而有機廢棄物在城市垃圾中佔有最大的比例，可以輕易地就地堆肥，而堆肥究竟是要在社區規模的分散式設施，或在更大型的集中式設施裡進行，則取決於在地的能力與需求。

As discussed in the Adaption chapter, finished compost sent to gardens and farms returns organic matter and nutrients to the soil, improving its quality through boosting carbon sequestration capacity, increasing

[190] Borrelle, Stephanie B., Jeremy Ringma, Kara Lavender Law, Cole C. Monnahan, Laurent Lebreton, Alexis McGivern, Erin Murphy, et al. 2020. "Predicted Growth in Plastic Waste Exceeds Efforts to Mitigate Plastic Pollution." *Science* 369 (6510): 1515–18. https://doi.org/10.1126/science.aba3656.

[191] Geyer, Roland, Jenna R. Jambeck, and Kara Lavender Law. 2017. "Production, Use, and Fate of All Plastics Ever Made." Science Advances 3 (7): e1700782. https://doi.org/10.1126/sciadv.1700782. Note: this estimate includes high rates of growth in the 1950s and 1960s. In recent decades, the growth rate is 3.5-4% per year. "The New Plastics Economy: Rethinking the Future of Plastics." 2016. World Economic Forum. https://www.weforum.org/reports/the-new-plastics-economy-rethinking-the-future-of-plastics.

[192] Ellen Macarthur Foundation. 2017. "The New Plastics Economy: Rethinking The Future of Plastics and Catalysing Action." https://www.ellenmacarthurfoundation.org/assets/downloads/publications/NPEC-Hybrid_English_22-11-17_Digital.pdf.

resistance to flood and drought, and reducing irrigation and tilling needs.[193] In this way, compost prevents desertification and land degradation, which impact mostly poor rural communities, small-scale farmers, women, youth, Indigenous peoples, and other at-risk groups.[194] When compost replaces synthetic fertilizers, the impact is even greater, saving energy and reducing emissions of nitrous oxide, a powerful GHG.[195]

如同第三章「零廢棄與調適氣候變遷」所述，熟成的堆肥送到庭院與農田使用，可讓有機質與養分回歸土壤，改善土壤品質，而能提昇土壤碳吸存能力，增加抵抗洪水與乾旱的能力，減少灌溉與翻耕需求。[193]也因此，堆肥可預防沙漠化與土地劣化，而最容易受到這些災害打擊的，大多為貧窮農村、小農、婦女、青年、原住民及其他風險族群。[194]當堆肥取代了化肥，將可節省能源、減少一氧化二氮這種強力溫室氣體的排放，效益會更大。[195]

4.3. Economic benefits

4.3.經濟紅利

A zero waste strategy holds significant alignment between economic and environmental goals. This approach not only minimizes environmental harms, but is also significantly less expensive than systems that primarily burn or bury waste. It also contributes to a just society.

零廢棄策略可讓經濟和環境目標相輔相成。零廢棄不僅降低對環境的危害，而且比起焚化或掩埋更省成本。它還有助於建立一個公正的社會。

Zero waste systems offer more desirable employment opportunities than traditional waste management jobs, as they foster skills beyond basic manual labor, provide higher wages, offer more permanent positions, and improve quality of life. They also require a much lower initial capital investment in comparison to traditional industrial facilities, leading to better fiscal sustainability. Zero waste businesses have flourished across the world, triggering innovation and sustainability simultaneously.

與傳統的廢棄物管理工作相比，零廢棄系統提供了更理想的就業機會，因為它培養的技能不只是基本勞力，還提供了更高的工資，更長久的職位，並可改善生活品質。與傳統工業設施相比，其初期資本投資低很多，在財政上更加永續。在世界各地，零廢棄企業已如雨後春筍般繁茂興旺，同時帶動創新並促進永續。

[193] Favoino, Enzo, and Dominic Hogg. 2008. "The Potential Role of Compost in Reducing Greenhouse Gases." Waste Management & Research 26 (1): 61–69. https://doi.org/10.1177/0734242X08088584.

[194] "Global Land Outlook 2nd Edition." 2022. UNCCD. April 27, 2022. https://www.unccd.int/resources/global-land-outlook/glo2.

[195] Favoino, Enzo, and Dominic Hogg. 2008. "The Potential Role of Compost in Reducing Greenhouse Gases." *Waste Management & Research* 26 (1): 61–69. https://doi.org/10.1177/0734242X08088584

4.3.1. Job creation

4.3.1. 創造就業機會

According to a recent global meta-analysis of the job creation potential of different waste management sectors,[196] zero waste strategies score highest on environmental benefits and create the most jobs of any waste management approach:

近期一份研究報告針對不同廢棄物管理部門創造就業機會的潛力進行全球性的統合分析，[196]根據該研究報告結果，零廢棄策略在環境效益上得分最高，且在所有廢棄物管理方法中創造最多的就業機會：

- Reuse creates over 200 times as many jobs as landfilling and incineration.

  再使用創造的就業機會是掩埋和焚化的 200 多倍。

- Recycling creates around 70 times as many jobs as landfilling and incineration.

  回收再利用創造的就業機會是掩埋和焚化的70倍左右。

- Remanufacturing creates almost 30 times as many jobs as landfilling and incineration.

  回收再製造創造的就業機會是掩埋和焚化的將近30倍。

The report analyzed the job growth potential of cities around the world if they were to divert 80% of recyclable and compostable waste from landfilling and incineration. The numbers were impressive: for example, **Dar Es Salaam** and Ho Chi Minh City could create over 18,000 jobs, and São Paulo could create an astonishing 36,000 new jobs.

該報告試圖分析的是，假定世界各地的城市可把80%的可回收物和可堆肥物回收，使其免於掩埋與焚化，那麼他們的就業成長潛力將會有多大？分析結果令人印象深刻：例如，三蘭港和胡志明市將能創造超過18,000個工作崗位，而聖保羅更是驚人，可以創造36,000個新工作。

The findings also discredit the common belief that waste management offers only low wages and undesirable jobs. Strong qualitative evidence of diverse, high-skill job creation through elements of zero waste programs was also observed. This evidence was reinforced by case studies that found that zero waste systems create large numbers of better-than-living wage jobs.[197]

[196] Ribeiro-Broomhead, John, and Neil Tangri. 2020. "Zero Waste and Economic Recovery: The Job Creation Potential of Zero Waste Solutions." Global Alliance for Incinerator Alternatives. http://zerowasteworld.org/zerowastejobs.

[197] "Wastepickers to Robust Entreprenuers: Creating Stories of Change." 2016. Hasiru Dala. https://hasirudala.in/wp-content/uploads/2020/09/HD_Annual_Report_2015-16-1.pdf.

該報告還駁斥了廢棄物管理只能提供低薪和不合宜工作的普遍認知。強烈的定性證據顯示，透過零廢棄計畫的各項要素，能創造多樣化、高技能的就業機會。案例研究也發現，零廢棄系統創造了大量優於維生工資的工作，進一步強化了前述證據。[197]

This remarkable correlation demonstrates the compatibility of environmental and economic goals and positions the waste management sector as an opportune social infrastructure in which investments can strengthen local and global resilience.

這顯著的關聯性證實，零廢棄策略可讓環境和經濟目標兼容並蓄，也定位了廢棄物管理部門是個切合時宜的社會基礎設施，在這方面的投資可以增強在地和全球的韌性。

For example, in San Francisco, the unionized and worker-owned waste management company Recology, which has achieved an 80% recovery rate,[198] offers a starting wage to waste collection drivers of USD 40 per hour, compared to the average California waste collection driver's income of USD 16 per hour.[199]

例如，在舊金山，一家由員工擁有且所有員工都加入工會的廢棄物管理公司Recology，達到了80%的廢棄物回收率，[198]能提供廢棄物清運司機每小時40美元的起薪；相對地，加州廢棄物清運司機的平均時薪只有16 美元。[199]

4.3.2. Improved economic performance

4.3.2.改善經濟表現

By switching to a zero waste strategy, municipalities can immediately begin reducing the costs of their waste management. A zero waste strategy is, essentially, good value for money.[200]

改採零廢棄策略，市政當局馬上就可以降低廢棄物管理成本。零廢棄策略本質上是物超所值的。[200]

If a city is paying for a waste management service that only includes waste collection and disposal in a centralized facility like a landfill or incinerator, a switch to a zero waste system can be very beneficial. It avoids costs associated with transport, operating transfer stations, maintenance of sophisticated vehicles, leasing landfill space, and gate fees at the landfill or incinerator. In contrast to disposal facilities, there are potential revenues that can accrue from the sale of recyclables and compost.

如果一個城市付費取得的廢棄物管理服務只包括了廢棄物收集以及集中處理(比如在掩埋場或焚化爐等集中式設施)，那麼轉換至零廢棄系統對這城市將帶來極大效益。它可省下運輸費用、轉運

[198] "San Francisco Annual Rate Report." 2021. Recology Sunset Scavenger, Recology Golden Gate, Recology San Francisco. https://www.sfpublicworks.org/sites/default/files/RY2021%2004%20Report%20%2006132022.pdf.

[199] "Cleaning Up Waste and Recycling Management and Securing the Benefits: A Blueprint for Cities." 2015. The Los Angeles Alliance for a New Economy. http://laane.org/wp-content/uploads/2017/06/Cleaning-Up-Waste-1.pdf.

[200] Moon, Doun. 2021. "Zero Waste Systems: Small Investment, Big Payoff." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/beyondrecovery.

站操作成本、車輛維護成本、掩埋場地租金以及掩埋或焚化處理費用等相關成本。相對於廢棄物處理設施，零廢棄策略有可能從回收物和堆肥的出售而獲取收益。

For instance, the city of Parma,[201] Italy (population 196,518), has seen a €450,000 reduction in overall annual costs for waste management after introducing a zero waste system. In northern Italy, the cost of managing residual waste in 50 municipalities oriented to a zero waste strategy is €178.9 per household/year, compared to the average cost in Italy of €245.6 per household/year, representing 27% cost savings through zero waste.[202]

例如，義大利帕爾馬市（居民196,518人）在引進零廢棄系統後，每年廢棄物管理成本減少了 450,000 歐元。[201]在義大利北部，有五十個採取零廢棄策略的城市，其殘餘廢棄物處理成本平均為每年每戶178.9歐元，而義大利全國平均成本為每年每戶245.6歐元，表示這五十個城市透過零廢棄策略而省下了27%的成本。[202]

The city of San Fernando (population 306,659) in the Philippines has reduced the annual waste management budget by Php 36 million (594,745 EUR) after transitioning into a decentralized zero waste system.[203] The Philippine city of Tacloban (population 242,089), in turn, saved Php 21.6 million (348,065 EUR) in their annual budget after transitioning into zero waste, representing 27% cost reduction.[204]

菲律賓聖費爾南多市（居民306,659人）在漸進導入去中心化零廢棄系統後，年度廢棄物管理預算減少了3,600萬菲律賓比索（相當594,745歐元）。[203]菲律賓塔克洛班市（居民242,089人）在改採零廢棄系統後，其年度預算節省了2,160萬菲律賓比索（相當348,065 歐元），相當於節省27%的成本。[204]

In cities that have centralized and technology-driven waste management systems in place, one of the potential financial barriers to transitioning into a zero waste system is paying for the initial costs. Once set up, zero waste will be much more affordable than the conventional system, but overpaying for current waste management systems leaves cities without the resources needed to invest in new approaches. The Zero Waste Cities savings calculator[205] has been designed by GAIA member Ekologi brez meja[206] to help visualize and understand the financial benefits that adopting zero waste policies can bring to a local area.

對於擁有集中式的、以技術為導向的廢棄物管理系統的城市，改採零廢棄系統可能面臨的財務障礙之一，就是必須支付初始成本。但一旦建立起來後，零廢棄管理系統將比傳統的廢棄物管理系統更省開銷；然而現行廢棄物管理系統過重的財務負擔，常讓其城市沒有足夠資源轉移到新的方法上。由 GAIA 會員團體「無國界生態學家協會」（Ekologi brez meja）[206]設計的「零廢棄城市省錢計算器」（Zero Waste Cities savings calculator）[205]，是個以視覺化方式呈現計算結果的工具，可幫助人們理解採取零廢棄政策為在地帶來的財務效益。

[201] Rosa, Ferran. 2016. "The Story of Parma." Zero Waste Europe. https://zerowasteeurope.eu/library/the-story-of-parma.
[202] Simon, Joan Marc. 2015. "The Story of Contarina." Zero Waste Europe. https://zerowasteeurope.eu/library/the-story-of-contarina.
[203] Dayrit, Felicia, Anne Larracas, and Gigie Cruz. 2019. "Picking Up the Baton: Political Will Key to Zero Waste." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/wp-content/uploads/San-Fernando-1107.pdf.
[204] Liamzon, Catherine. 2019. "Sunshine After the Storm: A Typhoon-Ravaged City Rises to Become Zero Waste." Zero Waste Cities Asia. Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/wp-content/uploads/Tacloban.pdf.
[205] "Zero Waste Cities savings calculator." Zero Waste Europe. https://zerowastecities.eu/academy/savings-calculator.
[206] "Ekologi Brez Meja." Zero Waste Europe. https://zerowasteeurope.eu/member/ekologi-brez-meja.

4.3.3. Fiscal sustainability

4.3.3. 財政永續

Conventional waste management approaches are often expensive propositions that are generally directly or indirectly funded by the public. Often, waste management is the single greatest line-item in many municipal budgets, despite much of the world's municipal waste remaining uncollected. Incinerators and engineered landfills require large investments to be built and maintained, often pushing municipalities into significant debt.

傳統的廢棄物管理方法通常花費高昂，且常由大眾直接或間接買單。儘管世界上仍有許多城市廢棄物未被回收，廢棄物管理通常是許多城市的市政預算中最大筆項目。焚化爐和經過專業規劃設計的掩埋場，其建設和維護需要龐大資金，往往會使市政當局背負巨額債務。

Waste-to-energy incineration is the most expensive waste management approach, three times the costs of landfills and up to five times the cost of recycling and composting.[207] A comprehensive study of the industry in the U.S., from its rise in the 1980's to today, concluded that incinerators are a bad investment for cities.[208] Construction and maintenance costs are significant and more capital-intensive compared to other forms of waste disposal. When an MSW incinerator has reached or is close to reaching its life expectancy, it requires another round of capital investment, often at the expense and risk of local taxpayers. Incineration revenue streams are volatile, dependent on competitive tipping fees and access to the renewable energy markets. Although larger plants provide economies of scale that may make profitability more secure, these oversize facilities require hauling and importing waste from a larger area, sometimes even different countries.[209]

廢棄物焚化發電是最昂貴的廢棄物處理方式，其成本是掩埋的三倍，是回收和堆肥的五倍。[207] 有一份報告針對美國廢棄物焚化處理業從 1980 年代興起到今天的情形進行全面性的研究，報告結論指出，焚化爐對城市來說是一項糟糕的投資。[208]與其他廢棄物處理方式相比，焚化爐需要龐大的建設成本和維護成本，是資本更為密集的設施。當焚化爐達到或接近其預期壽命時，它需要進行另一輪資本投資，而其所需經費與所生風險，通常由在地納稅人承擔。焚化爐的收益並不穩定，取決於須與他廠競價的的處理費，還有所發電力是否可賣到再生能源市場。儘管較大的焚化廠因為具有經濟規模，獲利較穩定，但卻需要從較大的區域（有時甚至是不同國家）收運和進口廢棄物，才能餵飽這些過大的設施。[209]

[borrow a chart from Beyond Recovery pub]

[207] Moon, Doun. 2021. "The High Cost of Waste Incineration." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/beyondrecovery.

[208] Baptista, Ana Isabel, and Adrienne Perovich. 2019. "U.S. Municipal Solid Waste Incinerators: An Industry in Decline." The New School Tishman Environment and Design Center. https://www.no-burn.org/u-s-municipal-solid-waste-incinerators-an-industry-in-decline.

[209] Jofra Sora, Marta. 2013. "Incineration Overcapacity and Waste Shipping in Europe: The End of the Proximity Principle?" Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/Overcapacity_report_2013.pdf.

Well-known examples of city bankruptcy due to investments in incinerators are the Harrisburg (Pennsylvania, USA) Incinerator,[210] and the Detroit incinerator (Michigan, USA).[211] Both were an ongoing source of contention due to toxic air emissions and unforeseen costs, which greatly contributed to the bankruptcy of these cities. The economic "lock-in effect" is caused by the fiscal debt incurred by the municipality to set up and run an incinerator, creating waste management systems locked into providing large amounts of waste as feedstock to incinerators that prevent development of sustainable policies, and essentially punish attempts to be less wasteful. This dynamic has also been reported in locations around the world, like Göteborg, Sweden,[212]; Honolulu, USA[213] and the UK,[214] amongst others.

因投資焚化爐而破產的城市，知名例子有美國賓州的哈里斯堡[210]和密西根州的底特律[211]。有毒氣體排放和未能預見的成本，是這兩個城市破產並陷入持續性爭議的主因。市政府因焚化爐的設置及操作所背負的債務，引發經濟上的「鎖定效應」，讓其廢棄物管理系統不得不提供大量廢棄物以餵養焚化爐，從而阻礙了永續政策的進展，根本不利於任何試圖減少廢棄物的嘗試。這樣的情形在世界其他地方也曾被報導過，比如瑞典的哥德堡[212]，美國檀香山[213]和英國[214]等地。

In contrast, this lock-in effect does not exist in zero waste systems, which, particularly in the Global South, tend to be decentralized and rely on local community-led collection, sorting, recycling, and composting infrastructure. Ideally, these systems are reinforced with waste reduction policies, although this is not widespread.

相對之下，這種鎖定效應在零廢棄系統中並不存在。零廢棄系統，尤其在全球南方，常常是去中心化的，仰賴在地社區主導的收集、分類、回收和堆肥設施。理想上，這樣的系統會因為廢棄物減量政策的推動而強化，儘管這情形並不普遍。

By implementing a better collection and recycling/composting system, municipalities can, on average, reduce waste management costs per tonne of waste by 70%.[215] Organics represent the largest component of global waste streams.[216] Organic waste prevention and source separation, therefore, can greatly reduce the volume of material sent to landfills or incinerators. This in turn avoids the costly construction of new disposal infrastructure. When it comes to alternative treatment options, composting is cost-effective, has low start-up

[210] Cooper, Michael. 2010. "Lost Bet on Incinerator Leaves Harrisburg in the Red." The New York Times, May 20, 2010. https://www.nytimes.com/2010/05/21/us/21harrisburg.html.

[211] "Detroit's Waste Incinerator, USA." Environmental Justice Atlas. https://www.ejatlas.org/print/detroits-waste-incinerator-usa

[212] Corvellec, Hervé, María José Zapata Campos, and Patrik Zapata. 2013. "Infrastructures, Lock-in, and Sustainable Urban Development: The Case of Waste Incineration in the Göteborg Metropolitan Area." Journal of Cleaner Production, Special Issue: Advancing sustainable urban transformation, 50 (July): 32–39. https://doi.org/10.1016/j.jclepro.2012.12.009.

[213] "Community Tools for Anti-Incineration Organizing." 2021. Global Alliance for Incinerator Alternatives. https://www.no-burn.org/wp-content/uploads/2021/12/AI-Toolkit_v5.pdf.

[214] "Why Oppose Incineration." United Kingdom without Incineration Network. https://ukwin.org.uk/oppose-incineration.

[215] Moon, Doun. 2021. "The High Cost of Waste Incineration." Global Alliance for Incinerator Alternatives. https://zerowasteworld.org/beyondrecovery.

[216] Kaza, Silpa, Lisa C. Yao, Perinaz Bhada-Tata, and Frank Van Woerden. 2018. *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. Washington, DC: World Bank. https://doi.org/10.1596/978-1-4648-1329-0. https://openknowledge.worldbank.org/bitstream/handle/10986/30317/211329ov.pdf

costs, and requires less land area than landfills.[217] In countries where governments are expanding waste services, the low cost of composting can free up funds for expanded waste collection coverage. Finished compost can also be sold to defray operational costs. Decentralized treatment can save further resources spent on collection, transportation fuel, and large infrastructure.[218]

藉由實行更好的垃圾收集、資源回收及堆肥系統，市政府平均可將每噸廢棄物的廢棄物管理成本降低 70%。[215]有機物是全球廢棄物流中最主要的成分；[216]因此，避免有機廢棄物的產生和源頭分類，可大大減少送往掩埋場或焚化爐的垃圾量，從而免於增建昂貴的廢棄物處理設施。至於可取代焚化與掩埋的其他處理方式中，堆肥是最具成本效益的，其興設成本較低，用地面積較掩埋場為小。[217]堆肥的低成本，對於那些持續擴展廢棄物管理服務的政府而言，可省下用於擴大廢棄物收運服務範圍的費用。堆肥成品也可出售以支付營運成本。去中心化的處理系統，也可省下用於收集、運輸燃料和大型處理設施的花費。[218]

4.3.4. Innovative business development

4.3.4 創新的商業發展

Zero waste business models have emerged in recent years, as businesses increasingly align their production and consumption models with the principles of waste avoidance and minimization. In particulr, businesses that have replaced single-use packaging items and packaging in general have flourished, tapping into demand from a consumer base increasingly aware of the impacts of plastic waste.

近年來，隨著越來越多企業將廢棄物避免與減量原則融入其生產和消費模式中，零廢棄物商業模式陸續出現。特別是，由於意識到塑膠廢棄物負面衝擊的消費族群日漸擴大，為回應其訴求而放棄使用一次用包裝或所有包裝的企業也跟著蓬勃發展。

Bans on **wasteful products and packaging** such as SUPs should therefore not be seen as detrimental to business because they create conditions conducive to new businesses. As opposed to multinationals, which depend heavily on plastic packaging, these new businesses are more likely to be local and to keep economic activity local as well.

禁止浪費資源的產品和包裝（例如一次用包裝）不應被視為妨害商業發展的政策，因為它們創造了有利於新商業模式的條件。與嚴重依賴塑膠包裝的跨國公司相反，新興企業更趨於在地化，並更能維持經濟活動在地化。

[217] Ravishankara, A. R., Johan C. I. Kuylenstierna, Eleni Michalopoulou, Lena Höglund-Isaksson, Yuqiang Zhang, Karl Seltzer, Muye Ru, et al. 2021. Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions. Nairobi: United Nations Environment Programme.

[218] "Ministry of Environment, Forest and Climate Change notification." 2016. Government of India Ministry of Environment, Forest and Climate Change. https://cpcb.nic.in/uploads/MSW/SWM_2016.pdf

In Europe, the packaging-free shop sector is growing rapidly, with an increasing number of shops, jobs, and sales turnover over the past 5-10 years. Long-term forecasts present a mid-estimate EU market for bulk goods of €1.2 billion in 2030, with its best-case potential being significantly greater.[219]
在歐洲，無包裝商店行業發展迅速，在過去 5-10 年中，相關商店數量、工作機會和銷售額持續成長。長期預測顯示，到2030年，歐盟大宗商品市場的中值估計為12億歐元，而在最佳情境下的估值更是多上許多。[219]

This overlaps with characteristics and trends observed in circular economy businesses.[220] In both cases, they are defined in opposition to linear businesses, which are based on the paradigm of **"take-make-waste."**
這與在循環經濟企業中觀察到的特徵和趨勢相符。[220]零廢棄與循環經濟的企業，其商業模式皆與基於「開採-製造-廢棄」模式的線性企業背道而馳。

BOX - Innovative ZW businesses - what do they look like?[221]
創新的零廢棄企業——它們是長什麼樣的？[221]

1. **A zero waste business** is organized to recover high-quality materials post-consumption i.e. used products and packaging like reusable cups or electronics. While linear businesses are not concerned with a product after it is sold, a zero waste business is designed to track it, so that the product can be easily taken back for reuse or to serve as feedstock in the production process. In this way, companies are also motivated to ensure the delivery of high-quality, long-lasting products designed for durability and reparability. Ensuring that the product can be repaired, upgraded, refurbished, remanufactured, or remarketed is an essential added-value. Examples of this model involve deposit return schemes (DRS) or leasing.
零廢棄企業的設立目的，是提供高品質的物品並將其於消費後回收；物品包括產品與包裝，如可重複使用的杯子或電子產品。線性企業在產品售出後就不管其下場，但零廢棄企業的運作設計，則是要持續追蹤產品流向，以便將產品回收再使用或作為製程原料。通過這種方式，企業也會有動力去確保產出高品質、具耐用性、可修復性、使用壽命長的產品。確保產品可維修、升級、翻新、再製或再銷售，是一項重要的附加價值。這種模式的例子包括押金回收計畫（deposit return schemes；DRS）或租賃。

   barePack: reusable containers for food meal deliveries in Singapore
   barePack：新加坡使用循環餐盒的美食外送服務

   barePack facilitates the purchase of food from restaurants in reusable containers through an app. It's a membership-based service that works across several delivery platforms like

[219] Eunomia. 2020. "Packaging Free Shops in Europe. An Initial Report." Zero Waste Europe and Reseau Vrac. https://zerowasteeurope.eu/wp-content/uploads/2020/06/2020_06_30_zwe_pfs_executive_study.pdf.
[220] Ellen Macarthur Foundation. 2017. "The New Plastics Economy: Rethinking The Future of Plastics and Catalysing Action." https://www.ellenmacarthurfoundation.org/assets/downloads/publications/NPEC-Hybrid_English_22-11-17_Digital.pdf.
[221] Vilella, M. (2021). New Business Models Cutting Back Plastic Waste. Sustainable Consumption Institute, University of Manchester, UK.

Foodpanda, Deliveroo, and Grab. The app shows restaurants that are enrolled in the network and reusable container options. Customers return the used containers to the restaurants, where they are cleaned and made ready to be used again.
barePack這家公司，透過app讓消費者向餐館訂購以循環餐盒（可重複使用容器）盛裝的餐食。這是一個會員制的服務，且其運作跨越了數個美食外送平台，如Foodpanda、Deliveroo和Grab。barePack app會顯示已登錄其網絡的餐廳，並提供循環餐盒的選項。消費者將使用過的餐盒送回餐廳，由餐廳清洗後再次使用。

2. Zero waste businesses are made possible through collaboration along the supply chain: while linear businesses are based on downstream cost-reduction and competitive relationships with suppliers, a zero waste business benefits from the joint work of all the actors along the supply chain, because the added value is the joint process of assembling and disassembling, delivering, and recovering. This is especially important for **reusable packaging systems**: collaboration amongst customers, businesses, staff, logistics providers, and the cities is key to success .[222] For example, **online refillable/reusable delivery models** offer an alternative to take-out SUP dining and operate in a closed-loop system of reuse and redistribution. Customers utilize these services by downloading sustainable apps to directly order food delivery, or to locate take-out restaurants that have sustainable container reuse and return models in place.
零廢棄企業透過供應鏈上下游的協力合作而實現其夢想：線性企業是建立在下游的成本削減及與供應商之間的競爭關係，但零廢棄企業是藉由供應鏈上所有角色的整合運作而獲利，因為其附加價值是來自於組裝和拆卸、交付和回收等過程的整合。這對於可重複使用包裝系統特別重要，因為這系統需要客戶、企業、員工、物流供應商和城市之間互相合作，才能成功。[222]例如，可重複填充/可重複使用服務的線上交付模式，為外帶美食的一次性包裝提供了替代方案，而且是在重複使用和重複配送的閉環系統中運作。客戶可以透過下載app享受這類服務，可以直接下單叫外送，或尋找有提供循環餐盒租還服務的外帶餐廳。

Refillables Hoi An: a packaging-free shop in Vietnam
Refillables Hoi An：越南的裸賣商店

Refillables Hoi An is the first refillable concept shop in Central Vietnam, founded by Alison Batchelor, a zero waste lifestyle practitioner who moved from Canada to Vietnam and missed the option of shopping in packaging-free shops in her new locale. The shop proposes an affordable packaging-free experience, targeting low-income families.
Refillables Hoi An 是中越第一家以可重複填充為經營理念的商店，由 Alison Batchelor 創立。Alison Batchelor是一位零廢棄生活方式實踐者，她從加拿大搬到沒有裸賣商店的越

[222] Closed Loop and Ideo. 2021. "Bringing Reusable Packaging Systems to Life Lessons Learned from Testing Reusable Cups." https://www.closedlooppartners.com/wp-content/uploads/2021/01/CLP_Bringing-Reusable-Packaging-Systems-to-Life.pdf.

南。她開的這家商店，是以低收入家庭為客群，提供他們負擔得起的無包裝消費體驗。

Its engagement with the community on increased waste prevention is also part of its value proposition: the founder has observed that suppliers are seeing increased patronage from startups; there are three different spots in Da Nang that are doing refills; and newly opened shops take their cue from Refillables Hoi An in terms of their product offer. Refillables Hoi An has a very strong alliance with suppliers, a critical collaboration to ensure both the minimization of plastic waste and affordable prices. Some of the suppliers have provided discounts on wholesale prices, which are facilitated by bulk purchases.
與社區一起努力推動廢棄物預防，也是其價值主張的一部分：創始人觀察到其供應商得到越來越多新創公司的訂單，目前峴港有三個提供重複充填服務的點；新開的商店在產品供應方面則借鑒Refillables Hoi An的理念與作法。Refillables Hoi An 與供應商建立了非常強大的連結，這樣的合作對於確保減少塑膠廢棄物產生和提供可負擔得起的銷售價格非常重要。一些供應商對於大宗採購，則提供了更優惠的批發價。

3. Often, zero waste businesses sell a service rather than a product. This development is also known as 'servitization' – providing access to products to satisfy user needs without needing to own physical products. These types of services are often run through local networks of similar businesses on a subscription or membership basis. Many companies have developed mobile apps or website maps to help customers identify participating businesses.
通常，零廢棄企業銷售的是服務而不是產品。這樣的發展模式也稱為「服務化」，也就是提供消費者使用產品的服務以滿足其需求，而無需擁有實體產品。這些類型的服務通常以訂閱制或會員制為基礎，在以類似企業組成的地方型網絡上運作。許多公司開發了手機app或網站地圖，協助客戶找到有參與該服務網絡的店家。

The Lavanda project by Eta Beta, Bologna (Italy)
The project provides a collection and washing service of used cloth diapers to the local community, in addition to delivering clean ones in return. Currently, the project works with public administrations, organizations, and cooperatives that manage nurseries. In the future, Lavanda wants to gradually open its services to families.
Lavanda：義大利波隆那Eta Beta合作社推動的專案
薰衣草（Lavanda）專案為當地社區提供尿布收集和清洗服務，且在收集同時提供乾淨尿布。目前，此專案與經營幼兒園的公家機關、團體及合作社合作。未來，薰衣草專案要逐步向家庭開放其服務。

4. Zero waste businesses are based on ecological and social values that complement overall business culture and philosophy. Zero waste businesses are regenerative and restorative by design, keeping

resources in use at their highest value for as long as possible; they also ensure social-economical returns with better inclusive livelihoods, giving priority to local economies. These businesses seek to replace the linear economy based on a take-make-throw away model, which assumes our planet has infinite resources. In this sense, the value proposition of a zero waste business model is a direct engagement in improving the sustainability of the overall system, going beyond the conventional eco-consumerism.

零廢棄企業是建立在生態和社會的價值上，而這些價值可補整體企業文化和理念之不足。零廢棄企業在設計上是可再生和可回復的，盡可能讓使用中資源長時間維持在最高價值狀態下；並藉由提供更具包容性的生計以及採取在地經濟優先的原則，確保社會經濟效益。這些企業尋求取代以「開採-製造-廢棄」模式為基礎、假設地球擁有無限資源的線性經濟模式。從這個意義上說，零廢棄商業模式的價值主張可直接提昇整體系統的永續性，超越傳統的綠色消費主義。

Hasiru Dala in India: integration of waste pickers

Hasiru Dala works with a vision to integrate a generation of waste pickers into the mainstream circular economy. They aim to create better livelihoods for waste pickers through inclusive businesses that have an environmental impact. Their current services include the organization and provision of zero waste events where all SUP is replaced by compostable or recyclable options. They also provide brand owners with Extended Producer Responsibility (EPR) compliance.

Hasiru Dala：印度整合拾荒者的綠色力量

綠色力量（Hasiru Dala）這個團體的願景，是將拾荒族群整合到主流的循環經濟體中。他們的目標，是透過具包容性、有正面環境影響的事業，為拾荒者創造更好的生計。他們目前的服務包括籌辦零廢棄活動，活動中以可堆肥或可回收的選項取代所有一次性包裝。他們還為品牌商提供盡到生產者延伸責任的機會。

4.4. Social benefits

4.4.社會紅利

4.4.1. Enhanced energy access and security

4.4.1. 促進能源的取得與安全

Within a zero waste system, the use of anaerobic digestion can offer an accessible source of energy when developed and implemented in a decentralized and community-led manner, improving energy security for local communities. Biogas derived from anaerobic digestion is a substitute for natural gas, providing a renewable energy source that can be deployed in sectors that are difficult to electrify. Yet caution should be given to implementation of AD, as explained in section 2.2.2.2.

在零廢棄系統中，若以去中心化和社區主導的方式來規劃推動厭氧醱酵的使用，則可提供能源的來源，也可改善當地社區的能源安全。由厭氧醱酵產生的沼氣是天然氣的替代品，為難以電氣化的行業提供再生能源來源。然而，應謹慎推動厭氧醱酵，原因如第 2.2.2.2 節所述。

Anaerobic digestion is a biological process wherein diverse groups of microorganisms convert complex organic matter into simple and stable end-products in the absence of oxygen. This process, which takes place in sealed vessels (anaerobic digesters), collects methane until it is burned as fuel, converting it into biogenic CO_2. In this sense, anaerobic digestion can be very attractive because it yields biogas, a mixture of methane and carbon dioxide that can be used as energy resources. Biogas can also be stored for timely conversion to electricity, which is useful in balancing fluctuating supply from intermittent renewables.[223]

厭氧醱酵是一種生物過程，其藉由各種不同的微生物群在缺氧條件下將複雜的有機物質轉化為簡單而穩定的最終產物。這個發生在密封槽體（厭氧消化槽）中的過程，可將所產生甲烷收集起來，做為燃料燃燒轉化為生物源 CO2。這也表示厭氧醱酵可能非常有吸引力，因為它會產生沼氣，沼氣是甲烷和二氧化碳的混合物，可用作能源。沼氣也可儲存起來以便及時轉化為電力，這有助於平衡間歇性再生能源供電的波動性。[223]

AD of the organic fraction of municipal solid waste (OFMSW) is used in different regions worldwide to reduce the amount of material being landfilled, stabilize organic material before disposal in order to reduce future environmental impacts from air and water emissions, and recover energy. Advances and adoption of the technology are rapidly gaining momentum. Several research groups have developed anaerobic digestion processes using different organic substrates. Cheap, small-scale anaerobic digestion units have been employed with great success in remote communities with less-reliable access to energy grids in countries such as Bangladesh, India, and China.[224] In Kerala, where 70% of the waste is compostable organics, anaerobic digestion is an attractive option for energy generation from the putrescible fraction of MSW as well as for reducing the region's disposal problem.

全球已有許多地方採用厭氧醱酵法處理城市垃圾中的有機成份，除了可減少垃圾掩埋量，還能在處置前將有機物質穩定化，以減少未來造成空污與水污等環境衝擊，同時還可回收能源。此技術的發展與應用正突飛猛進，一些研究團隊採用不同的有機物做為基質來開發厭氧醱酵流程；便宜、小規模的厭氧醱酵設施，已在孟加拉、印度與中國等國的一些電網較不穩定的偏遠地區出現，且運作相當順利。[224]在印度的喀拉拉邦，廢棄物中有70%是可堆肥的有機質，因此厭氧醱酵是相

[223] Thrän, Daniela, Martin Dotzauer, Volker Lenz, Jan Liebetrau, and Andreas Ortwein. 2015. "Flexible Bioenergy Supply for Balancing Fluctuating Renewables in the Heat and Power Sector—a Review of Technologies and Concepts." Energy, Sustainability and Society 5 (1): 35. https://doi.org/10.1186/s13705-015-0062-8; "Using Quality Anaerobic Digestate to Benefit Crops." 2012. Waste & Resources Action Programme. https://www.nutrientmanagement.org/using-quality-digestate-to-benefit-crops.

[224] "Converting Waste into Cooking Gas in Low-Income Communities." 2021. Community Partners International. 2021. https://www.cpintl.org/field-notes—updates/converting-waste-into-cooking-gas-in-low-income-communities.

當具吸引力的產能選項，可從城市垃圾中的會腐敗成份來提供能源，還可減少該地區的廢棄物處理問題。

4.4.2. Reduction of poverty and inequality through the inclusion of waste pickers

4.4.2. 融合拾荒者以減少貧窮與不平等

Despite the critical role the informal sector plays in waste management, waste pickers are often marginalized and live in extreme poverty.[225] Waste picking is poorly remunerated, dirty, and often demeaning work. Governments often ignore or actively discourage waste pickers' services, neglecting a potential route to increasing the reuse and recycling of waste.[226] As a result, many waste pickers face health risks and lack access to health care and other social protection.[227]

儘管非正式部門在廢棄物管理系統中扮演重要的角色，拾荒者卻常常被邊緣化，生活極度貧窮。[225]撿拾垃圾這項工作的報酬極低，又骯髒，且常常遭到貶低。政府常常忽視拾荒者提供的服務，甚至大力阻擾其工作，忽略這條可增加廢棄物再使用與再利用的潛在管道。[226]因此，許多拾荒者不但面臨健康風險，還難以取得醫療照護及其他社會保護。[227]

The inclusion of waste pickers is a fundamental pillar within zero waste systems, improving livelihoods and therefore reducing poverty and inequality, particularly amongst vulnerable women. An analysis of 45 recent papers covering case studies on waste pickers from 27 different countries demonstrated that the integration of waste pickers into the formal sector can alleviate poverty by securing the livelihood of waste pickers and their families.[228] It also brings other societal benefits such as reducing child labor and gender inequality, as well as removing the stigma attached to this line of work. Other studies also recognize the importance of formal inclusion to generate income for waste pickers and economically empower women waste pickers; it can also contribute to the achievement of Sustainable Development Goals on eradicating poverty (SDG 1) and improving gender equality (SDG 5).[229]

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[225] Samson, Melanie. 2010. "Reclaiming Reusable and Recyclable Materials in Africa - A Critical Review of English Language Literature." WIEGO Working Paper (Urban Policies) No. 16. Women in Informal Employment: Globalizing and Organizing. https://www.wiego.org/publications/reclaiming-reusable-and-recyclable-materials-africa-critical-review-english-language-li.

[226] Mpanang'ombe, Wrixon, Adrian Mallory, and Elizabeth Tilley. 2021. "Poverty, Politics and Plastic: Organic Waste Sorting in Blantyre's Public Markets." Journal of Urban Management 10 (3): 192–204. https://doi.org/10.1016/j.jum.2021.05.001; Kasinja, Cidrick, and Elizabeth Tilley. 2018. "Formalization of Informal Waste Pickers' Cooperatives in Blantyre, Malawi: A Feasibility Assessment." Sustainability 10 (April): 1149. https://doi.org/10.3390/su10041149; Oteng-Ababio, Martin. 2012. "The Role of the Informal Sector in Solid Waste Management in the Gama, Ghana: Challenges and Opportunities." Tijdschrift Voor Economische En Sociale Geografie 103 (September). https://doi.org/10.1111/j.1467-9663.2011.00690.x; Scheinberg, A., S. Spies, M. H. Simpson, and A. P. J. Mol. 2011. "Assessing Urban Recycling in Low- and Middle-Income Countries: Building on Modernised Mixtures." Habitat International 35 (2): 188–98. https://doi.org/10.1016/j.habitatint.2010.08.004.

[227] "Informal economy." 2020. Women in Informal Employment: Globalizing and Organizing. https:// www.wiego.org/informal-economy

[228] Morais, Jandira, Glen Corder, Artem Golev, Lynda Lawson, and Saleem Ali. 2022. "Global Review of Human Waste-Picking and Its Contribution to Poverty Alleviation and a Circular Economy." *Environmental Research Letters* 17 (6): 063002. https://doi.org/10.1088/1748-9326/ac6b49

[229] Morais, Jandira, Glen Corder, Artem Golev, Lynda Lawson, and Saleem Ali. 2022. "Global Review of Human Waste-Picking and Its Contribution to Poverty Alleviation and a Circular Economy." *Environmental Research Letters* 17 (6): 063002.

融合拾荒者是零廢棄體系的基本支柱之一，其可改善生計，進而減少貧困與不平等，尤其是對於弱勢婦女而言。有一項統合分析彙整了45篇近期的文獻，這些文獻涵蓋了27個不同國家的拾荒者案例研究，結果證實若能把拾荒者納入正式部門，將能確保拾荒者及其家庭的生計，進而減輕貧窮。[228]此外，還有其他社會利益，比如減少童工及性別不平等，同時除去對拾荒這一行的污名化。其他研究也肯定把拾荒者納入正式部門的重要性，因為可為拾荒者帶來收入，同時提昇女性拾荒者的經濟能力；這對於達成永續發展目標也有貢獻，包括消除貧窮（第一項目標）及提昇性別平等（第五項目標）。[229]

The inclusion of waste pickers can help address these issues by offering formal recognition, involvement in municipal waste management decision-making processes, and access to facilities, which can provide dignity, personal safety, and increased earnings.

融合拾荒者，包括提供他們正式肯定，讓他們參與城市廢棄物管理的決策過程，取得場所設施，如此他們將更有尊嚴、更有安全感，且能增加收入，這將有助於解決許多問題。

BOX - Successful integration of waste pickers

成功融合拾荒者的例子

- In India, the integration of waste pickers into the formal system has proved invaluable to the sector. Hasiru Dala, an organization based in Bangalore, for example, worked with the local authority to issue formal identification cards to waste pickers. With the IDs, women were able to open bank accounts, hundreds of youth were able to get education loans, and families were able to access health insurance.
- 在印度，將拾荒者納入正式體系的作法，已證實對該部門極有助益。比如，綠色力量（Hasiru Dala）這個位於班加羅爾的團體，和在地政府合作，核發正式的身份卡給拾荒者；有了這張身份卡，婦女得以開銀行帳戶，許多年輕學子們得以取得助學貸款，而其家人則得以取得健康保險。
- In the Philippines, the waste workers who used to pick waste from the streets have been officially integrated into the zero waste program as formalized waste workers. This has allowed them to earn better wages under better working conditions.
- 在菲律賓，過去在街道上撿拾廢棄物的拾荒者已被官方納入零廢棄計畫，成為正式的廢棄物工作者。這改善了他們的工作條件，同時提昇了他們的薪資。
- Malabon City, a highly-urbanized and densely populated city in Metro Manila, Philippines, implemented a city-wide zero waste program starting in 2017 to all the barangays (neighborhoods) in the city, many of which are now in advanced implementation. Waste pickers in Potrero, Malabon City used to earn about USD 20-40 a month from selling recyclable materials to junk shops; now

https://doi.org/10.1088/1748-9326/ac6b49; Singh, Dr Richa. "Integration of Informal Sector in Solid Waste Management: Strategies and Approaches." Centre for Science and Environment. https://cdn.cseindia.org/attachments/0.89670700_1626944339_integration-of-the-informal-sector-richa.pdf.

they receive a monthly salary of USD 60 as a village waste worker, on top of what they earn selling recyclables collected from households.[230]

- 在菲律賓馬尼拉大都會，有個高度都市化、人口密集的城市：馬拉翁（Malabon）；這個城市在2017年全面實施了一個零廢棄計畫，範圍涵蓋了城市中所有社區，這些社區許多都已有不錯進展。在馬拉翁市的泊伽洛（Potrero），拾荒者過去將回收物變賣給古物商的所得約為每月20-40美元；現在他們成為村里的廢棄物工作者，每月薪資60美元，此外還有把從家家戶戶收來的回收物拿去變賣的所得。[230]

4.4.3. Food and water security

4.4.3. 糧食與用水安全

Both compost and biodigestate (an output from anaerobic digestion) have a beneficial impact for waste management and agriculture: by providing nutrients for soil, they increase soil fertility and its capacity to hold water, thus supporting food and water ecosystems.

堆肥及沼渣液（厭氧醱酵的產出物）對於廢棄物管理與農業都有好處：可提供土壤養分，增加土壤肥力以及保水能力，因此有利於與糧食及用水有關的生態系。

Research shows that agroecological practices — like farm diversification, agroforestry, and organic agriculture — can make a significant contribution to helping low- and middle-income countries meet their climate adaptation and mitigation targets through their food systems;[231] the zero waste system can be a great ally to agroecology. The application of compost or biodigestate to soils supports urban and periurban agriculture, which in turn helps reduce the risk of flooding and the severity of drought, especially beneficial for small farmers and self-sufficient families.

研究顯示，生態農業的作法，比如農業多樣化、農林業與有機農業，可大大幫助中低收入國家透過其糧食體系達成其調適與減緩氣候變遷的目標。[231]零廢棄系統和生態農業是相得益彰。將堆肥與沼渣液施用於土壤，有助於城市及其周邊地區的農業，進而能降低洪水與嚴重乾旱的風險，這對於小農與自給自足的農戶而言特別有幫助。

The fact that, in many parts of the world, waste is primarily organic (over 50%) and that compost can play a major role in supporting the farming that feeds the world should lead to a market for compost. Challenges that currently prohibit this market are lack of support at the city level, reliance on government-subsidized

[230] Salazar, Marlet. 2019. "Route to Zero Waste: A Flood-Prone City Shows How It's Done." Zero Waste Cities Asia. Global Alliance for Incinerator Alternatives.

[231] Jones, Sarah K., Nadia Bergamini, Francesca Beggi, Didier Lesueur, Barbara Vinceti, Arwen Bailey, Fabrice A. DeClerck, et al. 2022. "Research Strategies to Catalyze Agroecological Transitions in Low- and Middle-Income Countries." Sustainability Science, June. https://doi.org/10.1007/s11625-022-01163-6.

fertilizer,[232] and lack of public awareness. Subsidies to enable composting and the use of organic waste in agriculture would be an effective measure to increase acceptance and demand.[233]

在世上許多地方，廢棄物的主要成份是有機質（超過50%），而堆肥可扮演支持農業的重要角色，而農業是全球糧食來源，這些事實按理皆能形成有利於堆肥的市場環境。然而由於缺乏城市層級的政府支持、農民仰賴政府補貼的肥料[232]以及大眾對這議題的認識不足，而妨礙了這種市場的形成。透過補貼推廣堆肥以及鼓勵農民使用有機廢棄物，會是提昇堆肥接受度與需求的有效策略。[233]

BOX – success story from São Paulo

聖保羅的成功故事

São Paulo is a great example of a city taking steps towards building bridges across zero waste, agroecology and sustainable food systems, while addressing inclusion and equity issues. The project Connect the Dots, an initiative from São Paulo's City Hall that won the grand prize of Bloomberg Philanthropies' 2016 Mayors Challenge in Latin America and the Caribbean, aims at creating a circular economy for food by supporting local and peri urban farmers to transition to organic agriculture. São Paulo municipality seeks to buy 30% of produce from small farmers for school meals to incentivise the transition.[234] In turn, organic farmers receive compost from a pilot composting facility in Lapa, which receives organic waste collected from around 50 street markets as well as garden waste. The composting facility can treat up to 60 tonnes of organic waste per week and produce approximately 900 tonnes of compost each year.[235] São Paulo also has a network of more than 50 local civil society organizations promoting the São Paulo Composta, Cultiva Campaign, asking the the São Paulo City Hall and City Council to increase its commitment to public policies for source separation and recycling of organic waste, and the promotion of agroecology in the municipality.[236] The local think-tank Institute Polis has put forward a comprehensive proposal to implement a segregated collection of organic waste and a community composting program prioritizing the participation of organizations of waste pickers.[237]

巴西聖保羅（São Paulo）透過計畫採取步驟，縫合零廢棄、生態農業與永續糧食體系，同時處理包容性與平等議題，在這方面是相當成功的模範城市。聖保羅市政府提出的計畫「串連節點」（

[232] Mpanang'ombe, Wrixon, Adrian Mallory, and Elizabeth Tilley. 2021. "Poverty, Politics and Plastic: Organic Waste Sorting in Blantyre's Public Markets." Journal of Urban Management 10 (3): 192–204. https://doi.org/10.1016/j.jum.2021.05.001.

[233] Barré, Juliette. 2015. "Waste market in urban Malawi." Second cycle, A2E. Uppsala: SLU, Dept. of Urban and Rural Development. January 7, 2015. https://stud.epsilon.slu.se/7550; Dijk, Meine van. 2008. "Urban Management and Institutional Change: An Integrated Approach to Achieving Ecological Cities," January.

[234] "Regenerative Agriculture around São Paulo: Connect the Dots." https://ellenmacarthurfoundation.org/circular-examples/connect-the-dots.

[235] "São Paulo Tackles Organic Waste | Climate & Clean Air Coalition." 2019. April 12, 2019. https://www.ccacoalition.org/en/news/s%C3%A3o-paulo-tackles-organic-waste.

[236] "São Paulo composta e cultiva." Instituto Pólis. https://polis.org.br/projeto/sp-composta-cultiva.

[237] "São paulo composta e cultiva." Instituto Pólis. https://polis.org.br/projeto/sp-composta-cultiva.

Connect the Dots)，曾贏得彭博慈善基金會(Bloomberg Philanthropies)2016年拉丁美洲和加勒比地區市長挑戰賽的大獎。該計畫目標是藉由支持市區與市郊農民轉型至有機農業，創造食物的循環經濟。聖保羅市政府的算盤是，透過向小農採購30%的農產品做為學校餐點食材，以鼓勵農民轉型至有機農業。[234]接著，有機農民可從拉帕(Lapa)區的一個堆肥試辦場取得堆肥成品；而該堆肥場的料源則是來自於從大約50個街市收來的果菜殘渣，另外還有庭園廢棄物。該堆肥場每周可處理高達60噸的有機廢棄物，每年產出大約900噸的堆肥。[235]聖保羅還有個公民網絡，由50個在地公民團體發起，叫做「聖保羅堆肥與農耕運動」(São Paulo Composta, Cultiva Campaign)，該網絡要求聖保羅市政府與市議會強化其公共政策承諾，包括推動有機廢棄物的源頭分類與再利用，以及擴展該城市的生態農業。[236]在地智庫Institute Polis已提出一個縝密的提案，提案內容包括實施有機廢棄物的分類收集，還有一個以拾荒者組織參與為優先的社區堆肥計畫。[237]

4.4.4. Better health outcomes

4.4.4. 改善健康狀態

Because disposable items cause pollution throughout their lifecycle, a zero waste system will inevitably cut pollution and improve community health, especially for those living closer to these facilities. This has been comprehensively presented in point 4.2.1, under reduction of air pollution and toxic residues.
由於一次用製品的整個生命週期都會造成污染，因此零廢棄系統必然可削減污染，改善社區健康，尤其是對於那些住在處理設施附近的民眾而言，更是如此。這已在4.2.1「減少空氣污染與有毒廢棄物」一節中詳述。

The widespread leakage of plastic in the environment and its persistence in the form of microplastics (<5 mm) has infiltrated the human food system, with increasing evidence that humans are eating plastic through food.[238,239] The prevalence of toxics from plastic packaging and plastic waste in the food supply is leading to increased toxicity in our bodies and surrounding environment: recent studies have found these toxics in human blood and everywhere on the planet.
塑膠流落環境的現象相當普遍，並會以微塑膠(<5mm)的形式長久存在環境中，其已滲入到人類的食物系統，有越來越多證據顯示，人類透過食物把塑膠吃下肚。[238, 239]來自塑膠包裝與廢塑膠的毒性物質跑到食物鏈中的普遍現象，導致我們的身體與周遭環境的毒性增加：近期研究發現，這些毒性物質已跑到人體血液中，並存在於世界各地。

There are thousands of chemicals in "food contact materials (FCM) that can potentially migrate into our food or drink, and eventually end up in our body. In Europe alone, some 8,000 chemicals can be used in food packaging

[238] Barboza, Luís Gabriel Antão, A. Dick Vethaak, Beatriz R. B. O. Lavorante, Anne-Katrine Lundebye, and Lúcia Guilhermino. 2018. "Marine Microplastic Debris: An Emerging Issue for Food Security, Food Safety and Human Health." Marine Pollution Bulletin 133 (August): 336–48. https://doi.org/10.1016/j.marpolbul.2018.05.047.
[239] Peixoto, Diogo, Carlos Pinheiro, João Amorim, Luís Oliva-Teles, Lúcia Guilhermino, and Maria Natividade Vieira. 2019. "Microplastic Pollution in Commercial Salt for Human Consumption: A Review." *Estuarine Coastal and Shelf Science* 219 (April): 161–68. https://doi.org/10.1016/j.ecss.2019.02.018.

and other FCM,[240] and many of the chemicals are carcinogens[241] and hormonal disruptors that are associated with higher incidences of cancer, infertility,[242] developmental disorders,[243] and immune disorders, with the costs related to neurodevelopmental disease and IQ loss reaching EUR 157 billion per year.[244] Women are exposed to higher risks of miscarriages, cancer, and further gender-related disparities, as these chemicals are commonly found in household and feminine hygiene products."[245]

在「食品接觸材料」(food contact materials；FCM)中有數千種化學物質可能遷移到我們的食物或飲料中，最終跑到我們體內。光是在歐洲，就有大約八千種化學物質可使用於食品包裝及其他食品接觸材料，[240]且其中不乏致癌物[241]與賀爾蒙干擾素；它們和癌症、不孕[242]、發育異常[243]及免疫異常的發生率提高有關，所導致的神經發育疾病及智商降低的相關成本，每年高達1,570億歐元。[244]由於它們常出現於住家與女性衛生用品中，導致女性因此而流產、罹癌的風險更高，進而惡化與性別有關的不平等。[245]

4.4.5. Reduced stressors (noise, traffic, congestion)

4.4.5. 減少壓力源(噪音、交通與壅塞)

Zero waste programs are able to reduce disamenities involved in waste disposal facilities, specially waste-to-energy incinerators. People living near incinerators and landfills complain of noise, litter, heavy vehicle traffic, odor, and air pollution. As temperatures rise in the summer, the smell often gets worse, forcing people to close their windows and avoid sitting outside. Areas with incinerators also experience greater vehicle traffic, with trucks bringing rubbish from other boroughs or counties. Operators often downplay these disamenities during the planning and permitting application stages, and when these problems do occur, these same operators will often dismiss them as inevitable or unavoidable.

零廢棄方案能夠減少廢棄物處理設施(尤其是焚化爐)帶來的嫌惡不適。住在焚化爐與掩埋場附近的民眾，會抱怨噪音、骯髒、車流量高、臭味與空氣污染。當夏天氣溫上升時，味道更加難聞，使得居民不得不緊閉窗戶，避免坐在外面。焚化爐座落的地區，也會有更多的車流量，因為會有卡車載運外縣市或鄉鎮的垃圾。焚化爐業者在規劃與申請許可階段，通常會淡化這些令人嫌惡的影響，而當這些問題真得發生時，同樣的業者將會把這些問題視為無法避免、必然會發生，而不予理會。

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[240] Simoneau, Catherine, Barbara Raffael, Simone Garbin, Eddo Hoekstra, Anja Mieth, LOPES João Filipe Alberto, and Vittorio Reina. 2017. "Non-Harmonised Food Contact Materials in the EU: Regulatory and Market Situation: Baseline study: final report." JRC Publications Repository. January 17, 2017. https://doi.org/10.2788/234276.

[241] "Impact of EDCs on Hormone-Sensitive Cancer." Endocrine Society. https://www.endocrine.org/topics/edc/what-edcs-are/common-edcs/cancer.

[242] Trivedi, Bijal P. 2021. "The Everyday Chemicals That Might Be Leading Us to Our Extinction - The New York Times." *The New York Times*, March 5, 2021. https://www.nytimes.com/2021/03/05/books/review/shanna-swan-count-down.html.

[243] Nielsen, Pia Juul. 2021. "Hormone Disrupting Chemicals May Also Harm Children's Brains – Scientists Call for Action." *CHEM Trust* (blog). May 12, 2021. https://chemtrust.org/edcs_brain_development.

[244] Trasande, Leonardo, R. Thomas Zoeller, Ulla Hass, Andreas Kortenkamp, Philippe Grandjean, John Peterson Myers, Joseph DiGangi, et al. 2015. "Estimating Burden and Disease Costs of Exposure to Endocrine-Disrupting Chemicals in the European Union." *The Journal of Clinical Endocrinology and Metabolism* 100 (4): 1245–55. https://doi.org/10.1210/jc.2014-4324.

[245] Calil, Juliano, Marce Gutiérrez-Graudiņš, Steffanie Munguía, and Christopher Chin. 2021. "Neglected– Environmental Justice Impacts of Marine Litter and Plastic Pollution." *United Nations Environment Programme.* https://www.unep.org/resources/report/neglected-environmental-justice-impacts-marine-litter-and-plastic-pollution.

BOX - Stressors from waste-to-energy incinerators[246]

來自廢棄物焚化爐的壓力源[246]

In the UK, residents in areas hosting waste facilities have raised serious complaints of noise, odor, and other types of disturbances. The cases include daily noises lasting 2-3 minutes each time and disturbing vibrations from cargo trains for waste transportation in Runcorn, which led to a protest by 100 residents in 2015[247]; and reported odors of rotting food and growing number of flies, which forced residents to keep their windows closed in Derby.[248] Residents in Detroit, U.S.A., suffered for decades from strong odors of rotten eggs and rotting garbage coming from an incinerator with over 20 odor violation records, until the facility was shut down in 2019.[249]

在英國，廢棄物處理設施所在地附近居民，對於這些設施所帶來的噪音、臭味與其他種類的干擾，大有怨言。例如，在朗科恩（Runcorn），運輸廢棄物的貨運列車每次經過時，都會帶來持續2-3分鐘的噪音還有擾人的振動，這令人不適的日常，導致2015年有100位居民站出來抗議；[247]在德比（Derby），據稱腐敗食物的臭味以及越來越多的蒼蠅，讓居民不得不緊閉窗戶。[248]在美國底特律（Detroit），來自一座焚化廠的腐敗垃圾與臭蛋的強烈味道，讓居民長年來苦不堪言，該廠因散發臭味而違規的紀錄超過20次，直到2019年關廠為止。[249]

Incinerators also depend on large, heavy-duty diesel trucks for waste hauling, which emit hazardous air pollutants and cause loud noises and traffic congestion.[250]

焚化爐也仰賴重型柴油大卡車把廢棄物托運過來，這些車輛會排放有害的空氣污染物並造成噪音與交通阻塞。[250]

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[246] "Why Oppose Incineration." *United Kingdom without Incineration Network*. https://ukwin.org.uk/oppose-incineration.

[247] Clay, Oliver. 2017. "In the Shadow of the UK's Biggest Incinerator - Part Two." Liverpool Echo, January 5, 2017. http://www.liverpoolecho.co.uk/incoming/shadow-uks-biggest-incinerator-part-12406245; Barbara. "Health Fears over Runcorn Incinerator." Runcorn and Widnes World. https://www.runcornandwidnesworld.co.uk/news/11753701.health-fears-over-runcorn-incinerator.

[248] https://www.derbytelegraph.co.uk/news/derby-news/residents-slam-controversial-waste-plant-2021845; Reid, Nick. 2018. "Residents Say Derby Incinerator That 'smells of Rotten Food' Should Be Shut." Derbyshire Live, September 19, 2018. https://www.derbytelegraph.co.uk/news/derby-news/residents-slam-controversial-waste-plant-2021845; Hawley, Zena. 2018. "Foul Smells from Sinfin Waste Plant Still Tormenting Residents after Almost a Year." Derbyshire Live, June 9, 2018. https://www.derbytelegraph.co.uk/news/derby-news/smell-sinfin-derby-waste-plant-1641728.

[249] Ellison, Garret. 2020. "Toxic Waste Fixer Rises from Incinerator Shadow as Source of Stink in Detroit." *Mlive*, September 27, 2020. https://www.mlive.com/public-interest/2020/09/toxic-waste-fixer-rises-from-incinerator-shadow-as-source-of-stink-in-detroit.html .

[250] Baptista, Ana Isabel, and Adrienne Perovich. 2019. "U.S. Municipal Solid Waste Incinerators: An Industry in Decline." *The New School Tishman Environment and Design Center*. https://www.no-burn.org/u-s-municipal-solid-waste-incinerators-an-industry-in-decline.

4.5. Political and institutional benefits: improved democratic quality of governance

4.5. 政治與制度的效益：改善治理的民主品質

Some of the most successful zero waste systems have been led by collaborations between civil society, local authorities, and governments, bringing together a wide range of stakeholders to build a political and visionary common ground that strengthens the quality of governance itself.

最成功的零廢棄系統之中，有些是由公民社會、地方主管機關與各級政府之間協力合作所發展出來的；發展過程中把各界的利害關係人召集起來，建立政治共識與共同願景，而這過程強化了治理本身的品質。

In these cases, communities took part in the design of the plan, or there was a significant initial consultation process. This paid off with better design and higher participation rates, since programs were tailored to community members' specific needs and context. Residents were therefore more active in consuming sustainably, minimizing waste, separating discards, and composting at home. They were also more active in monitoring the implementation of the programs in their community, in collaboration with the local authorities.

在這些案例中，社區能夠參與計畫的規劃設計，或者一開始時先展開大量的研商過程。這樣做計畫會比較容易順利、成功，因為計畫會依照社區成員的特殊需求與背景而量身設計，會有較好的規劃，參與程度也較高。因此居民也會更積極落實永續消費、減少廢棄物、分類回收與在家堆肥；會更積極監督他們社區的計畫落實情形，與地方主管機關合作。

For example, in Thiruvananthapuram (India), young volunteers who call themselves Green Army International have been instrumental in the implementation of the Green Protocol, a government initiative to eradicate single-use plastics from public events.

例如，在印度喀拉拉邦首府特里凡得琅（Thiruvananthapuram），自稱為「國際綠色大軍」（Green Army International）的年輕志工，在一政府計畫「綠色協定」（Green Protocol）執行過程中提供相當大的助力；「綠色協定」是當地政府為了將一次用塑膠從公共活動中消除所制定的計畫。

Inclusive zero waste systems ensure that resource recovery programs include and respect the community and all social actors involved in resource conservation, especially informal recyclers whose livelihoods depend on discarded materials. The workers who handle waste are fully integrated into the design, implementation, and monitoring processes, as it is the application of their skills and efforts that ultimately make the system function. A successful zero waste system prioritizes waste workers' safety and well-being and ensures that their interests are aligned with programmatic success. In some communities, where informal recyclers come from historically excluded populations, this may require ending long-standing discriminatory practices.
具包容性的零廢棄系統，能確保資源回收計畫能尊重並納入社區以及所有和資源節約有關的社會角色，尤其是那些非正式的回收者，他們的生計仰賴被丟棄的物質。應將這些清理廢棄物的工作者完全融入計畫的規劃設計、執行與監測過程中，因為他們的技能與努力，是讓系統運作的關鍵。成功的零廢棄系統會重視廢棄物工作者的安全與福祉，確保他們的利益與計畫的成功推行是

一致的。在某些社區中，非正式回收者是源自歷史上被排擠的族群，這會需要去終結長期以來持續不輟的歧視行為。

5. Case studies

5. 案例研究

5.1. Introduction

5.1. 簡介

5.1.1. Background

5.1.1. 背景

The case studies below offer a snapshot of what zero waste could look like, and the GHG emissions mitigation impact, in a variety of cities. While the principles of zero waste are universal, the implementation will vary widely from place to place, based on a host of local factors. The cities included in this report were selected to represent a wide range of conditions. They are megacities and small-to mid-sized communities; cities with ample waste management budgets and some that struggle to collect the waste generated; a variety of climatic conditions; cities with a robust informal sector, and those without; cities with highly centralized waste management systems, and those with many private and public actors; cities that are growing rapidly, growing slowly, and even one whose population is expected to shrink.
接下來這些案例研究讓我們得以一窺在各種不同城市中零廢棄能做到什麼樣的程度以及其減少溫室氣體排放的潛力。雖然零廢棄的原則是全世界通用的，然而實施方式還是會依據許多地方因素而設計，隨地之不同而大不相同。本報告刻意選擇各種不同類型和情況的城市作為案例研究。有些是人口眾多的巨型城市、有些大小接近小型或中型社區；有些城市有充足的廢棄物管理預算、有些城市連收集廢棄物的預算都很拮据；各城市的氣候條件也有差異；另外有些城市有強健的非正式部門、有些沒有；有些城市的廢棄物處理系統是高度集中式的，有些則是依靠許多私部門和公部門的人員；有人口快速成長的城市、也有緩慢成長的、甚至有一個城市的人口即將縮減。

One thing that all these cities have in common is the presence of an active GAIA member organization that is eager to partner with local governments to bring about a transformation in waste management. Most of them are implementing successful pilot zero waste projects that can be scaled up with government support. These organizations played a critical role in obtaining, analyzing, and translating the data that underlie the GHG analyses. The zero waste scenarios depicted in the case studies are drawn from their visions for their own cities.
這些城市有個共通點就是有在地的GAIA會員團體，他們熱切地想要與當地政府合作，以促成其廢棄物管理系統的轉型。這些團體多數已成功實踐過試驗性的零廢棄計畫，只要政府支持就能擴大計畫規模。他們還扮演了一個重要角色，就是協助我們取得、分析與翻譯其城市的資料，而這些

資料是本報告溫室氣體排放分析所不可或缺的基本資料。在案例研究中所描繪的零廢棄情境，也是援引他們對他們自己城市的想望。

5.1.2. Modeling zero waste

5.1.2. 模擬零廢棄

To calculate the GHG emissions from the waste system, we used the 'Carbon Calculator for Zero Waste Projects' developed by inédit for the Mission Zero Academy. This tool compares a baseline and an alternative scenario to determine the change in overall GHG emissions associated with the waste system. A particular feature of this tool is its ability to analyze the emissions of reducing waste generation. For more details, see the Data and Methods Appendix.

為了計算廢棄物部門排放多少溫室氣體，我們使用了「零廢棄計畫專用碳計算器」（Carbon Calculator for Zero Waste Projects），這是由inédit公司為「零廢棄任務學院」（Mission Zero Academy）開發的一套工具。這套工具會比較兩種情境，一是基準情境，一是採取一些零廢棄措施的替代情境，然後算出兩種情境中、與廢棄物部門有關的溫室氣體排放總量的差異。這套工具有個特點是能夠計算分析廢棄物減量的減排潛力。詳情請看附錄「資料與方法」。

The year 2030 has been identified by the Global Methane Assessment as an important target for rapid climate action. Past experience has shown that waste management systems can dramatically transform in this short a time. For each city, we created a baseline, or business-as-usual scenario, and a zero waste alternative scenario ('road-to-zero-waste'). Both scenarios used the same population, waste generation, and waste composition inputs. The zero waste scenario differs from the baseline in two important aspects, and the resulting changes in GHG emissions reflect only these two changes:

聯合國環境規劃署（UNEP）的《全球甲烷評估報告》（Global Methane Assessment）將2030年視為快速氣候行動的一個重要目標年。過去經驗顯示，廢棄物管理系統可以在這麼短的期間內大幅轉型。我們為每個城市設定了一個基準情境，或者說「一切照舊」情境，也設定了一個採取零廢棄措施的替代情境（稱為「邁向零廢棄」情境）。兩個情境中設定的人口、廢棄物產生量和廢棄物成份等參數都一樣。但零廢棄情境有兩個重要層面與基準情境不同，因此其計算出的溫室氣體排放減量潛力僅僅反映這兩種改變：

1) the use of waste minimization strategies to reduce the generation of targeted waste streams (particularly single-use plastic and, in the case of Bandung, food waste). These scenarios are city-specific and based upon plans or proposals that already exist in each city.

1）採取廢棄物減量措施，以減少目標廢棄物種（尤其是一次用塑膠品，以及在萬隆市案例中的食物廢棄物）的產生量。這些情境依城市之不同而有差異，基本上是根據各城市已存在的計畫或提案去設想。

2) efforts to divert waste material to beneficial uses, such as compost and recycling. We projected 80% diversion rates for easy-to-recycle material categories (organics, metals, glass, paper, cardboard, and wood), and 15% diversion rates for hard-to-recycle materials (plastic, textiles). These produced overall diversion rates between 42% and 68%.

2）將廢棄物導向有益用途的措施，如堆肥和資源回收。那些易於回收再利用的物種，如有機質、金屬、玻璃、紙張、紙板和木材，我們預期能有80%的回收率，不易回收再利用的物種，如塑膠和紡織品，則預期能有15%的回收率。如此總體的回收率約落在42%～68%之間。

Past experience has indicated that cities can reach 80% or higher rates of waste diversion within just a few years (see Section 2.1) Our modeled scenarios are thus conservative and fall well short of what is technically and economically feasible within the 2030 timeframe.
根據過往經驗，城市能在數年內將垃圾減量回收率提高到80%或更高（見2.1節）。因此我們模擬的情境是保守的，比起在2030年時程內於技術上和經濟上可達成的水準，是遠遠不及。

The zero waste scenarios modeled in this report do not represent an end point or ultimate goal for waste management; rather, they represent a conservative estimate for a waste system undergoing transformation, and a 2030 milestone along that path. Results are thus indicative of moderately ambitious programs. Deeper emissions cuts can be expected from more ambitious zero waste implementation.
本報告中所模擬的零廢棄情境不代表廢棄物管理的終點或終極目標，而是保守評估一個轉型中的廢棄物管理系統的減排潛力，以及在邁向零廢棄途中，於2030年可達成的里程碑。所以模擬結果反映的是相對保守計畫的潛力；若能實施更積極的零廢棄措施，應能達成更大的減排成效。

5.2. City-level case studies

5.2. 城市案例研究

5.3. Lessons Learned

5.3. 從案例研究中我們學到...

Several commonalities emerge from the GHG analyses of eight cities. First, zero waste policies and programs, even incompletely implemented, confer major mitigation benefits everywhere. Emissions reductions ranged from 50% to 105% against a business-as-usual scenario. These deep cuts were achieved with relatively modest system changes, as described above. Complete implementation of the zero waste model would deliver even deeper emissions cuts.

從這八個城市的溫室氣體排放分析中，我們發現的一些共通點：一、無論哪個城市，零廢棄的政策或計畫就算未完全落實，還是能對減緩氣候變遷帶來重大貢獻。相對於一切照舊情境，可減少50%到105%的排放量。如前所述，只需要對系統進行相對保守的改革，就能達成如此之多的減排成效；如果能徹底落實零廢棄模式，減排效益將更驚人。

The key to deep emissions reductions is source separated collection and treatment of organic waste. In all cities but Seoul, which already separately collects 96% of its organic waste, landfill methane is the primary source of GHG emissions in the waste system. Separate collection and treatment of organics – usually through composting – reduces these emissions by 43% to 83%, even with incomplete implementation. This approach is the only effective method to fully address these emissions.
能達成大幅減排的關鍵措施是有機廢棄物的源頭分類收集和處理。除了已把96%有機廢棄物分開收集的首爾以外，其他城市的掩埋場甲烷都是廢棄物部門最大的溫室氣體來源。將有機廢棄物分類收集並加以處理（通常是透過堆肥方式處理），就算沒有徹底執行，也能減少43%～83%的排放量。這種作法是可完全解決這部份排放的唯一有效方法。

Burning waste, whether with energy recovery or not, results in massive GHG emissions. In Dar Es Salaam, the only city in this study with wide-scale open burning, ending the practice would reduce GHG emissions almost half as much as ending landfill methane emissions (in addition to significant public health benefits). In Seoul, scenarios that continue to rely on incineration fail to achieve deep emissions reductions, because incineration is itself a major source of GHG emissions.
焚燒垃圾會產生大量的溫室氣體，不管有無回收能源。三蘭港是本報告案例城市中唯一的一座露天燃燒垃圾相當普遍的城市，如能終止這種行為，所能減少的溫室氣體排放量，幾乎等於掩埋場甲烷排放的一半，而且還能對大眾健康帶來重大利益。首爾的情況則是持續地依賴焚化爐，這將使其無法達成大幅的減排成效，因為焚化垃圾本身就是一個重大的溫室氣體排放源。

While organics are essential to emissions reductions, recycling creates the possibility of a net-negative waste sector. Increased recycling reduced emissions between 3% and 35%. In Sao Paulo and Detroit, this is sufficient to make the waste sector net negative – reducing more emissions than it produces. Recycling reduces emissions in the industrial, agricultural, forestry, and energy sectors as well as emissions from waste management. Source separation can strengthen recycling rates by reducing cross-contamination (for example, mingling food waste with paper renders the paper valueless). Current recycling rates are lower than technically possible because of a lack of financial incentives to recycle. These financial challenges affect both city-run recycling programs and the informal sector, which is the backbone of recycling in many countries. Strengthening and incorporating the informal sector can yield very high recycling rates. Although not captured in our analyses, rising levels of plastic use are a threat to high recycling rates: most plastic is not recyclable, and it tends to displace other, more recyclable materials.
對排放減量來說，有機廢棄物的回收處理方式是關鍵；而落實資源回收則有可能進一步讓廢棄物部門達到淨負排放。提高資源回收，可減少3%到35%的排放量；在聖保羅和底特律，這樣的減量效益足以讓廢棄物部門達成淨負排放——減少的溫室氣體排放量比產生的還多，因為資源回收不只減少廢棄物管理所產生的排放，也連帶減少工、農、林和能源等部門的排放。廢棄物源頭分類，可避免回收物交叉污染（舉例來說，紙類若和廚餘混在一起就會失去回收價值），進而提昇回收率。目前的回收率都未達技術可行水準，因為缺乏財務上的誘因。財務問題不只影響市政府執行的回

收計畫，也打擊了非正式部門；而在許多國家，非正式部門是資源回收的中流砥柱。強化、整合非正式部門，能大幅提昇資源回收率。有一點雖然在我們的分析結果中未能呈現，但仍值得一提的是——目前不停成長的塑膠使用量對資源回收是莫大威脅：大部分塑膠無法回收，而且這些塑膠可能會取代其他較容易回收的材質。

Generating energy from waste is not an effective mitigation measure. Cities that rely on landfill gas capture (Detroit, São Paulo, and Temuco) and incineration (Seoul) see relatively small GHG savings from displacing fossil energy sources while allowing large quantities of methane (from landfills) and fossil CO_2 (from incinerators) to escape to the atmosphere. Landfill gas collection is plagued by low capture rates and break downs. As the electric grid decarbonizes, the benefits of waste-derived energy will continue to shrink.
用廢棄物來產能並不是有效減緩氣候變遷的手段。有些城市依賴掩埋場沼氣收集來減少廢棄物部門的排放，例如底特律、聖保羅跟特木科，而首爾則是依賴焚化產能，但這些城市並沒有因此減少多少溫室氣體排放量，雖然有取代一些化石燃料，但還是有大量甲烷（來自掩埋場）與化石源二氧化碳（來自焚化爐）跑到大氣中。掩埋場沼氣收集常被人詬病收集率低、也容易故障；而且隨著電網的去碳化，廢棄物能源回收的利益也將持續萎縮。

Seoul is a unique but instructive case: it is the only city in our study that currently has a net negative waste sector, due to its successful organics diversion program and overall high recycling rate. However, its program is marred by its reliance on incineration, which produces twice as much as GHGs as replacement sources of energy. Ending incineration and improving recycling in Seoul would increase its GHG savings by an order of magnitude. Replacing existing incinerators with renewable energy would further deepen these cuts. Seoul also stands to benefit the most from source reduction of plastics, both because of its high current plastic use rate and because its plastic reduction program is more ambitious than other cities'.
首爾是個獨特且具有啟發意義的案例，其乃本研究報告中唯一的一座廢棄物部門達到淨負排放的城市，這得歸功於其成功將有機廢棄物回收，且整體的資源回收率也高。然而首爾對焚化爐的依賴，使得這項成就沾上污點，焚化爐的溫室氣體排放量是其所取代能源的兩倍。若首爾能終結焚化、改善回收，則其溫室氣體排放減量成果將提昇一個數量級（十倍）；若以再生能源取代既有的焚化爐，會更進一步擴大其減排成效。首爾也將從源頭減塑措施中大獲其利，因為該城市目前的塑膠使用率高，且制定的減塑計畫也比其它城市更積極。

Another common theme is the underutilization of source reduction strategies. Upstream reductions, particularly of food and plastic, can trigger significant GHG emissions reductions throughout the supply chain, as well as in the waste sector. These programs, such as bans on plastic bags and plastic take-out containers, are largely in their infancy and should be dramatically expanded.
另一個在案例中常見的情況是源頭減量策略不足。若能在上游減量，將能促使整個產品供應鏈以及廢棄物部門的溫室氣體排放大幅減少，尤其是食物和塑膠更是如此。這類措施，例如禁止塑膠袋或是塑膠外帶容器，大多還在初期發展階段，需要大幅擴張其範疇。

6. Conclusions and recommendations

6. 結論和建議

With its potential to dramatically reduce short-term methane emissions, and even function as a "net-negative" sector, waste management can and should play an instrumental role in climate action. Zero waste systems deliver mitigation, adaptation, and additional benefits by source reduction for both organics and non-organic waste, and following the waste hierarchy as subsequent lines of action. For cities, zero waste is an opportunity to take a leadership role in climate action.
廢棄物管理在氣候行動中能夠發揮極大的作用，因為有潛力在短時間內大幅減少甲烷排放，甚至能使廢棄物部門達到「淨負排放」。透過有機或非有機廢棄物的源頭減量，以及依照廢棄物治理層級制定的一系列行動，零廢棄體系不僅可減緩、調適氣候變遷，還能帶來其他效益。對城市來說，實行零廢棄讓城市有機會站上氣候行動中的領導地位。

As this report has outlined, zero waste systems not only benefit society through climate mitigation and adaptation, they also enhance community health, environmental justice, and local economic development. Investments in waste reduction, separate collection, and material recovery increase environmental resilience, and can improve the broader economic state by creating green jobs and new business opportunities.
就如這份報告所清點出，零廢棄系統不只在減緩和調適氣候變遷方面為社會帶來好處，也有益於群體健康、促進環境正義和在地經濟發展。投資廢棄物減量、分類收集和資源回收，能夠提升環境韌性，也能創造綠領工作和新的商業機會，改善更廣泛的經濟狀態。

Previous analyses and the experience of hundreds of cities around the world show that zero waste is a practical, rapid, and affordable waste management strategy. Many cities have already achieved diversion rates above 50% within a few years of beginning implementation. Zero waste is far more economical than capital-intensive alternatives such as incineration and engineered landfills; it also generates significant economic benefits in terms of new and better jobs and new business opportunities.[251]
這些案例分析加上全世界數百個城市的經驗，在在顯示出零廢棄是個實用、快速又經濟可行的廢棄物管理策略。許多城市在開始實行零廢棄後短短數年之間，垃圾減量回收率就超過了50%。比起需要投入大量資本的設施，如焚化廠和經過專業規劃設計的掩埋場，零廢棄是更經濟的方案。零廢棄也帶來顯著的經濟利益，包括創造新的、更好的工作機會以及新商機[251]。

While the principles of zero waste remain the same everywhere, the manner of implementation is specific to each cities' economic and environmental context. With a large focus on community engagement, the implementation of zero waste systems has consistently proven to reduce overall waste generation and waste disposal rates, and to boost compliance in source separation in short periods of time. Examples can be found all around the globe (See Section 2.1.).

[251] "Beyond Recovery: A Zero Waste Future for Thriving Families and Communities." 2021. Global Alliance for Incinerator Alternatives. https://www.no-burn.org/beyondrecovery

雖然零廢棄原則是舉世通用，其實踐方式還是得根據各城市的經濟和環境狀況而定。只要過程中能注重社區參與，那麼零廢棄的落實，總是能減少整體的廢棄物產生量和廢棄處理量，也能在短時間內讓社會大眾做好源頭分類。這樣的案例在全球各地都找得到（見章節2.1）。

A resilient city is able to respond quickly and effectively to climate change, in an equitable and efficient way. When implementing zero waste systems to better withstand the impacts of climate change, considerations for marginalized groups are critical, as climate change will place unique and accentuated burdens on them. These include residents of low-income communities and informal settlements, especially women, children, the elderly and disabled, and minority populations. The work of building resilience must therefore be based upon a strong web of institutional and social relationships that can provide a safety net for vulnerable populations.
具有韌性的城市能夠以公平且有效率的方式，快速而有效地因應氣候變遷。在實施零廢棄以應對氣候變遷衝擊的同時，必須顧及到弱勢族群，因為氣候變遷對這些族群造成的影響更加嚴重。這些族群包括低收入社區和非正式聚落的居民，尤其是婦女、孩童、年長者、殘疾者和少數族群。因此提升城市韌性的工作，必須建構在強健的制度和社會關係網絡上，藉此提供弱勢族群一張安全網。

In the light of the above, this reports puts forward the following recommendations:
根據以上觀點，本報告整理出以下建議：

- Incorporate zero waste goals and policies into climate mitigation and adaptation plans.
- 將零廢棄的目標和政策融入減緩和調適氣候變遷的計畫中
    - Cities, which have the primary responsibility for waste management, should adopt comprehensive zero waste programs, with emphasis on source separation, organics treatment, and informal sector integration.
    - 城市負有廢棄物管理的主要責任，應採取全面性的零廢棄計畫，並把重點放在源頭分類、有機廢棄物的處理以及非正式部門的整合。
    - Funders and financial institutions should support city transitions to zero waste with financial and technical measures.
    - 資助者和金融機構應透過金融和技術的支援，協助城市轉型到零廢棄。
    - National governments can incorporate zero waste into their Nationally Determined Contributions (NDCs) and relevant national climate policies.
    - 各國政府可將零廢棄納入其「國家自定貢獻」（Nationally Determined Contributions）計畫及相關的國家氣候政策之中。
- Prioritize food waste prevention and single-use plastic bans.
- 首重避免食物廢棄和禁止一次用塑膠品
    - Food waste prevention requires a dedicated strategy that integrates the entire supply chain, with interventions from field to fork.
    - 要阻止食物廢棄，需要針對整個食物供應鏈對症下藥，阻斷從產地到餐桌的廢棄來源。

    - Bans on single-use products and packaging, particularly plastic, can be adopted at the local or national level.
    - 可在地方或全國層級實施禁令，禁止一次用的產品和包裝，尤其是塑膠。

- Institute separate collection and treatment of organic waste.
- 建立有機廢棄物分類收集與處理的制度

    - Cities should develop clear, easy-to-use systems with uniform signage and dedicated outreach programs to ensure high compliance rates.
    - 城市必須建立一套清晰、方便使用的分類收集制度，有一致性的標示、專門的宣導推廣計畫，以確保民眾高度配合。
    - Composting is the easiest, least expensive, and most scalable treatment option for organic waste.
    - 至於有機廢棄物的處理，堆肥是最簡單、成本最低、最容易擴大規模的處理方法。

- Invest in the waste management systems, recycling and composting capacity.
- 投資廢棄物管理系統，提昇回收和堆肥處理量能

    - Relatively small capital inputs are required for source separated collection, material recovery facilities, organics treatment, etc.
    - 需要投入資金，建構源頭分類收集、物料回收設施、有機廢棄物處理.....等等；但其所需經費相較慣行作法而言並不多。
    - Municipalities should create a plan to meet ongoing operational costs, which may be lower under zero waste.
    - 市政單位必須擬定一份計畫，提供廢棄物管理系統持續運作所需經費；而導入零廢棄策略應可降低這些成本。

- Establish appropriate institutional frameworks for zero waste including regulations, educational and outreach programs, and provide financial incentives through subsidies to recycling and composting.
- 為零廢棄量身打造一套制度架構，包括法規、教育和推廣計畫，並提供財務誘因，透過補助鼓勵回收和堆肥。

    - Regulations to set up a comprehensive zero waste system are key, with strong emphasis on aligned economic incentives that promote a virtuous system, continuously improving its waste reduction rates.
    - 透過法規建立全面性的零廢棄體系很重要，且這些法規應著重在相輔相成的經濟誘因，打造良好的體系，以持續提高廢棄物減量率。
    - Subsidies and other incentives to compost production and use are instrumental in developing these virtuous systems that can counter the heavily subsidized synthetic agrochemicals.
    - 提供補助和其他誘因以鼓勵堆肥的生產與使用，有助於建構良好的體系，對抗已接受過多補助的合成化學肥料。

    - Education, communication and outreach programs which ensure all stakeholders are included are needed for high participation and compliance rates.
    - 必須建立把所有利害關係人都納入的教育、溝通和宣導推廣計畫，以提高民眾的參與度及配合度。

- Recognize the role of waste pickers and fully integrate them into the waste management system.
- 肯認拾荒者的角色，並將他們完全整合到廢棄物管理系統中。

    - Create a consultative mechanism through which waste pickers can actively collaborate in the design of zero waste and take advantage of new opportunities, whether as employees or as entrepreneurs.
    - 建立一套諮詢機制，讓拾荒者可透過此機制，積極參與協助零廢棄體系的規劃設計，並利用新的機會找到工作或創業。
    - In cities where informal recyclers come from historically excluded populations, this may require ending long-standing discriminatory practices.
    - 在某些城市，非正式的回收者為自古以來即被排擠的族群，這會需要去終結那些根深蒂固的歧視行為。

More information on zero waste implementation, including best practices for source separation, how to finance zero waste, and step-by-step guides, is available on the GAIA website at www.no-burn.org/zw-guides.
您可以在GAIA的官方網站www.no-burn.org/zw-guides獲取更多如何實行零廢棄的資訊，包括源頭分類的最佳實務、如何為零廢棄籌措經費、以及按部就班的指引。

The urgency of climate action is greater than ever before. The scientific community has made clear that we are not doing enough to limit global warming to the crucial 1.5°C threshold. Yet we have solutions in our hands. As this report shows, we have come a long way in our ability to identify what works best for people and the planet. The challenge now is to gather the political will to implement these solutions quickly and at scale, while ensuring that all stakeholders are included and that justice is not sacrificed along the way.
如今我們需要氣候行動的急迫性更勝以往。科學家們已清楚表明，要將全球暖化程度控制在關鍵的1.5°C內，我們做的根本就不夠；但我們已掌握了解決之道。如同本報告顯示，對於怎樣做才是對人類和地球都最好，我們已經取得了很大的進展。現在的挑戰則是集結政治意願，快速且大規模將這些解決方案付諸實現，同時確保所有利害關係人都納入考量，過程中不會犧牲公平正義。

Zero waste strategies show a way forward and give us reasons to be hopeful. By starting with small steps toward separate collection of waste, and further building up zero waste systems to maximize source reduction and material recovery, cities can ameliorate the catastrophes of climate change, while reaping additional benefits in all directions. With zero waste, cities can take concrete actions toward climate mitigation and resilience in the waste sector, raising the ambition of national pledges made under the Paris Agreement and closing the emissions gap.
零廢棄策略為我們指出了一條充滿希望的道路。從一開始小步地推動廢棄物的分類收集，然後進一步建立將源頭減量和資源回收最大化的零廢棄系統，城市就能減緩氣候變遷帶來的災難衝擊，也能在許多其它方面獲益。藉由零廢棄策略，城市能在廢棄物部門的範圍內採取具體行動，以減

緩氣候變遷並提昇韌性，提高國家在巴黎協定下所做出的減排承諾，讓全球減碳的理想與現實之間的落差能夠縮減歸零。

7. References

8. Appendix: Data and methodology

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10. List of Endorsers

常用名詞中英文對照

Zero Waste	零廢棄
Waste Sector	廢棄物部門
Climate Mitigation	減緩氣候變遷
Climate Adaptation	調適氣候變遷
Global Warming Potential	全球暖化潛勢（GWP）
Bandung	萬隆（印尼）
food pantry	公益食品倉庫
waste to energy	廢物能源化
Pune	浦納
biologically active landfill cover	生物活性覆蓋層
waste hierarchy	廢棄物治理層級
Lusaka	路沙卡
Covid-19	嚴重特殊傳染性肺炎
Saint Louis	聖路易（塞內加爾）
Lagos	拉哥斯（奈及利亞）
Botswana	波札那
Accra	阿克拉
Mumbai	孟買
vector-borne diseases	蟲媒傳染病
filariasis	淋巴絲蟲病
yellow fever	黃熱病
arboviral infection	蟲媒病毒性傳染病
Kolkata	加爾各答

IPCC	聯合國政府間氣候變化專門委員會
carbon storage	碳封存
Marin County	馬林郡
United Nations Environment Assembly	聯合國環境大會
Global Methane Assessment	全球甲烷評估報告

補充資料

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