Circular Economy of Source-Separated Organic Waste in New York City

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Abstract: New York City (NYC) generates more than one million tons of compostable organic waste annually, most of which is still landfilled, contributing to greenhouse gas emissions and resource loss. **Objective:** This review aims to examine the circular economy potential of source-separated organic waste (SSOW) in NYC, with a primary focus on the residential curbside organics program. **Method:** This study uses a systematic literature review approach by synthesizing peer-reviewed articles, government reports, program documents, and policy records related to composting, anaerobic digestion (AD), community composting, life-cycle assessment (LCA), and NYC's regulatory framework. **Findings:** The findings show that landfilling organic waste produces nearly 400 kg CO_2e per tonne, whereas composting generates net negative emissions of approximately −41 kg CO_2e per tonne and dry AD for renewable natural gas yields −36 to −2 kg CO_2e per tonne. Although NYC's mandatory curbside composting program was fully enforced in April 2025 and collected more than 30,000 tons of organics in 2024, residential capture rates remain below 5%, indicating persistent challenges in infrastructure, public education, contamination control, and multi-family building compliance. **Implications:** These results imply that an integrated system combining composting, AD, and community composting can improve resource recovery, climate performance, and social participation. **Originality:** The originality of this review lies in its integrated analysis of technical, environmental, regulatory, and community dimensions of SSOW management within a single circular economy framework, providing a policy-relevant perspective for advancing zero-waste strategies in dense metropolitan contexts.

Keywords: Circular Economy; Source-Separated Organic Waste; Composting; Anaerobic Digestion; New York City; Zero Waste

INTRODUCTION

The global waste crisis has intensified as urbanization and population growth accelerate the generation of municipal solid waste (MSW) at unprecedented rates. By 2020, total organic solid waste production worldwide was estimated at approximately 2.24 billion tonnes, a figure projected to increase by 73% by 2050 (Chaudhary et al., 2024). Within urban economies, organic waste comprising food scraps, yard trimmings, and food-soiled paper   represents a critical and largely underutilized resource stream. The linear "take-make-dispose" model of waste management, in which organic material is collected and deposited in landfills, generates potent greenhouse gases, primarily methane (CH_4), while

simultaneously destroying the economic value embedded in these materials (Ellen MacArthur, 2013).

The circular economy (CE) offers an alternative paradigm grounded in the principles of reduce, reuse, and recycle, with the explicit goal of keeping materials in productive use for as long as possible. Applied to organic waste, circular economy principles call for the source separation of biowaste at the point of generation, followed by valorization through composting, anaerobic digestion, or other biological treatment processes that return nutrients and energy to the productive economy. This approach has been widely recognized as one of the most effective strategies for simultaneously reducing landfill emissions, recovering nutrients for agriculture, and producing renewable energy (Ellacuriaga et al., 2021; Tamasiga et al., 2022). Far from being a theoretical construct, the circular valorization of organic waste is increasingly backed by rigorous life-cycle analysis demonstrating substantial climate, energy, and public health benefits over conventional landfill disposal (Nordahl et al., 2020).

New York City presents a particularly instructive case study for the circular economy potential of source-separated organic waste. As one of the world's largest and most densely populated urban centers, NYC generates approximately 3.5 million tons of residential solid waste annually, of which more than 40% consists of compostable organic material (NYC DSNY, 2023 Waste Characterization Study). This translates to over one million tons of compostable organics entering landfill and waste-to-energy (WTE) facilities each year rather than being recovered as compost, biogas, or soil amendment (MacBride, 2024). The wasting of these resources carries staggering environmental consequences: landfilling organic waste emits nearly 400 kg CO_2e per tonne, making it the most greenhouse gas-intensive waste management option available (Nordahl et al., 2020). For a city committed to reducing greenhouse gas emissions by 80% by 2050 under its OneNYC sustainability plan, this represents a major, unresolved challenge.

The policy landscape in NYC has undergone rapid evolution in recent years. After a decade of faltering voluntary programs, the New York City Council passed landmark legislation in June 2023 establishing a mandatory citywide curbside organics collection program, with phased borough-by-borough rollout from late 2022 through 2024. By October 2024, participation became mandatory for all residential buildings, and as of April 2025, enforcement of non-compliance fines began citywide (New York City Department of, 2025). This regulatory shift represents the most significant structural change to NYC's

organic waste management in decades. However, the success of this transition measured in meaningful diversion of organics from landfills will depend not only on collection infrastructure but on achieving high participation rates, maintaining low contamination levels in separated organics, and ensuring adequate processing capacity across the city's five boroughs.

This review aims to comprehensively examine the circular economy potential of source-separated organic waste in New York City. Specifically, it addresses the following questions: (1) What is the quantitative resource potential of NYC's organic waste stream? (2) What valorization pathways composting, anaerobic digestion, and community composting offer the greatest environmental and economic returns? (3) What are the environmental trade-offs of alternative organic waste management strategies as revealed by life-cycle assessment? (4) What are the key challenges and opportunities facing NYC's current organics programs? (5) What policy and operational recommendations can move NYC closer to a genuine circular economy for organic waste? The article proceeds from method to results and discussion, concluding with recommendations for policy and research.

RESEARCH METHOD

This review adopts a systematic literature review approach, integrating findings from peer-reviewed academic publications, government reports, and program data from NYC's Department of Sanitation (DSNY), the New York City Economic Development Corporation (NYCEDC), and allied organizations. Literature was sourced using multiple academic databases including Semantic Scholar, PubMed, and Google Scholar, using search terms including "circular economy," "source-separated organic waste," "composting," "anaerobic digestion," "New York City waste management," "food waste valorization," "greenhouse gas emissions organic waste," and combinations thereof. Priority was given to studies published between 2019 and 2026 to ensure relevance to contemporary conditions, although foundational studies of significance were also included.

Inclusion criteria for academic papers required that studies address at least one of the following: (a) life-cycle assessment of organic waste management alternatives; (b) technical performance of composting or anaerobic digestion systems applied to municipal organic waste; (c) source separation programs for organic waste in urban settings; (d) circular economy frameworks applied to urban waste; or (e) community composting

initiatives with documented social and environmental outcomes. Studies were excluded if they focused exclusively on non-organic waste streams (e.g., plastics, construction debris) without addressing organic fractions. Gray literature, including DSNY annual reports, NYC Council legislative records, and analysis published by organizations such as BioCycle and Columbia University's School of Professional Studies, was incorporated to capture program-specific performance data not yet available in peer-reviewed form.

A total of over 60 relevant sources were identified and reviewed. Quantitative data on waste generation, capture rates, greenhouse gas emissions, and processing outputs were extracted and cross-referenced across sources to ensure consistency. The review was structured thematically around: (1) the nature and scale of NYC's organic waste stream; (2) valorization pathways and their technical characteristics; (3) environmental performance assessed via LCA; (4) community composting as a social-ecological innovation; (5) regulatory and policy context; and (6) challenges and opportunities for program improvement. Where data from multiple sources diverged, variation is explicitly noted and attributed to methodological differences or contextual factors. The analysis synthesizes these themes to assess the overall circular economy potential of SSOW in NYC and identify priority areas for intervention.

To ensure clarity in synthesizing life-cycle assessment (LCA) findings across studies, this review adopts a standardized functional unit of one metric tonne (1 Mg) of SSOW generated at the household level and managed through alternative end-of-life pathways. Reported greenhouse gas (GHG) emissions values (e.g., kg CO_2e per tonne) are normalized to this functional unit to allow direct comparison between landfill, composting, and anaerobic digestion systems.

System boundaries in the cited LCA studies (Nordahl et al., 2020; Rabii et al., 2024; Sanciolo et al., 2022), generally follow a cradle-to-grave waste management framework, including:

1. Collection and transport emissions
2. Pre-processing (e.g., shredding, contamination removal)
3. Biological treatment (landfill decomposition, composting, AD digestion)
4. Direct process emissions (CH_4, N_2O, NH_3, VOCs)
5. Energy recovery credits (electricity or RNG offsets)
6. Soil carbon sequestration credits (for compost land application)
7. Fertilizer displacement credits

Landfill emissions assume methane generation with partial gas capture efficiency, typically ranging between 60–85%, with fugitive methane dominating climate impacts. Composting emissions assume managed aerobic systems with carbon sequestration benefits upon land application. Anaerobic digestion scenarios assume biogas utilization either for renewable natural gas (RNG) injection or electricity generation, with avoided fossil fuel displacement credits applied accordingly.

Where studies differ in methane capture efficiency, energy offset assumptions, or soil carbon accounting methods, reported ranges are explicitly presented to reflect methodological variability.

RESULT

Characterization of NYC's Organic Waste Stream

New York City's residential refuse stream is dominated by organic material, with compostable organics including food scraps, food-soiled paper, and yard trimmings comprising approximately 40–47% of residential garbage by weight (New York City Department of, 2023)Given the city's population of approximately 8.3 million residents generating roughly 3.5 million tons of residential municipal solid waste annually, this corresponds to more than one million tons of compostable organics per year. In Queens alone, an estimated 300,000 tons of compostable organics were landfilled or sent to waste-to-energy facilities in 2023 (MacBride, 2024).

Food waste constitutes the dominant organic subfraction in NYC's waste stream. Waste characterization data from 2017 showed that food waste comprised approximately 26% of Queens' refuse by weight, alongside 9.7% compostable paper and 10.4% yard trimmings (MacBride, 2024). Source-separated organic waste from households and catering facilities typically exhibits biomethane potential values in the range of 384–426 m³/Mg volatile solids, with methane shares of 52–61% (Lelicińska-Serafin et al., 2023). Collection efficiency in well-managed source-separated systems has been reported at 92–97%, although impurity variability remains high (CV = 56–87%) (Lelicińska-Serafin et al., 2023). (Jalalipour et al., 2020), reported that composting of source-separated municipal organic waste can produce compost meeting international quality standards for pH, moisture content, nutrient levels, and carbon-to-nitrogen ratio, with heavy metal concentrations below German and Iranian regulatory thresholds.

Valorization Pathways: Composting and Anaerobic Digestion

Two primary biological valorization pathways are identified for source-separated organic waste in urban systems: composting and anaerobic digestion (AD). Composting is an aerobic biological process that converts organic matter into a stable soil amendment. In NYC, collected organics are currently processed through facilities such as NYC Compost Project demonstration sites and contracted commercial composters. Composting of food scraps collected from Queens residents has been carried out using aerated static pile and windrow methods, producing compost distributed to community gardens, urban farms, and green infrastructure projects (Morrow & Davies, 2022).

Anaerobic digestion involves the microbial degradation of organic matter in the absence of oxygen, producing biogas and digestate. In NYC, food scraps collected in Queens have been transported to AD facilities, where the resulting biogas is used to provide gas for homes (New York City Department of, 2023). Commercial organics regulations under Local Law 19 require large food service establishments to divert organic waste to composting, anaerobic digestion, or donation (New York City Department of, 2024). (Ellacuriaga et al., 2021) reported that operation at organic solid contents above 20%, combined with enhanced hydrolysis, could reduce reactor volume and capital costs by approximately one-third.

Community composting also forms part of the city's organic waste management system. The New York City Compost Project (NYCCP), established in 1993, includes sites such as Red Hook Community Farm in Brooklyn (225+ tons annually), BIG Reuse in Queens (650+ tons), Earth Matter on Governors Island (480+ tons), and the Lower East Side Ecology Center in Manhattan (250+ tons) (Morrow & Davies, 2022).
Anaerobic digestion systems are generally categorized as wet AD (<15% total solids) and dry AD (>20% total solids). NYC's wastewater resource recovery facilities, including Newtown Creek, primarily operate wet AD systems capable of co-digesting food waste. Dry AD systems are more suited to high-solids residential organics collected via curbside systems.

Life-Cycle Environmental Assessment of Organic Waste Management Alternatives

Nordahl et al. (2020) compared landfill, composting, dry AD for renewable natural gas production, and dry AD with electricity generation using life-cycle assessment. Landfilling was identified as the most greenhouse gas-intensive option, producing nearly 400 kg CO_2e

per tonne of organic waste. Composting yielded the lowest net greenhouse gas emissions at approximately −41 kg CO_2e per tonne, while dry AD with renewable natural gas production yielded net emissions ranging from −36 to −2 kg CO_2e per tonne depending on the displaced fuel (Nordahl et al., 2020).

Rivera found that well-performing aerobic digestion with liquid output technology could reduce greenhouse gas emissions to as little as 5% of landfill emissions. Beyond greenhouse gas emissions, Nordahl identified ammonia emissions from nitrogen-rich composting as a significant human health concern (Nordahl et al., 2020). Preble in a meta-analysis of 388 emission factors from 46 studies (Nordahl et al., 2023), found that methane is the dominant contributor to global warming potential in yard waste composting, while nitrous oxide dominates for nitrogen-rich food waste and mixed organics. The study also found that anaerobic digestion prior to composting of digestate reduces N_2O, NH_3, and VOC emissions relative to composting untreated waste.

Ddiba demonstrated through material flow analysis that urban organic waste streams can generate substantial value through biogas, compost, solid fuel, and insect protein production (Ddiba et al., 2022).

Table 1. Comparative Performance of Organic Waste Management Pathways (per tonne SSOW)

Pathway	Primary Outputs	Net GHG Emissions (kg CO_2e/tonne)	Air Pollutants	Key Trade-offs
Landfill	Methane (partially captured), leachate	∼ +400	CH_4 (fugitive), VOCs	High climate impact; long-term methane liability
Composting	Compost (soil amendment)	∼ −41	NH_3, N_2O (if poorly managed)	Soil carbon benefits; potential ammonia emissions
Dry Anaerobic Digestion (RNG)	Biogas (RNG), digestate	−36 to −2	Minor CH_4 leaks; reduced NH_3 vs composting	High capital cost; energy infrastructure required
AD + Digestate Composting	RNG + stabilized compost	Net negative (system-dependent)	Lower N_2O and NH_3 than raw composting	Operational complexity

Note: Values synthesized from Nordahl et al. (2020), Preble et al. (2023), and Rivera et al. (2022).

NYC's Regulatory Framework and Program Performance

NYC's organics policy has evolved through several phases. Community composting began with the NYC Compost Project in 1993. A voluntary residential curbside organics pilot was launched in 2013, expanded to 24 community districts by 2018, and suspended in 2020 at the onset of the COVID-19 pandemic (MacBride, 2024; Morrow & Davies, 2022). A simplified curbside organics program was relaunched in Queens in fall 2022, expanded to Brooklyn in 2023, and made mandatory citywide through legislation passed in June 2023 (New York City Department of, 2023). By October 2024, organics separation became mandatory for all residential buildings, and enforcement of fines began on April 1, 2025 (New York City Department of, 2025).

In calendar year 2024, NYC residences properly separated and set out more than 30,000 tons of organics collected by DSNY and routed to composting or anaerobic digestion (New York City Department of, 2025). MacBride reported that Queens' residential curbside capture rate declined from 7.5% in 2018 to 4.3% in 2023 (MacBride, 2024). Suburban-style districts in eastern Queens recorded capture rates of 6–10% or higher, while dense apartment districts showed rates barely above 1% (MacBride, 2024).

Operational barriers reported for multi-family buildings include lack of dedicated organics storage space, absence of chute-based separation systems, limited superintendent training, high tenant turnover, language accessibility barriers, odor and pest management concerns, and contamination from improper bagging or non-compostable materials.

On the processing side, commercial and institutional organic waste streams are generally more consistent in volume and lower in contamination than residential streams. Aldin found that anaerobic co-digestion of source-separated organic waste with thickened waste activated sludge at a 10:90 ratio improved methane yields by up to 23% and methane production kinetics by up to 58% compared with digestion of sludge alone.

Barriers and Opportunities Identified

MacBride identified five major barriers to achieving NYC's circular economy potential for source-separated organic waste: low and declining capture rates, inadequate outreach and technical assistance, insufficient processing capacity, lack of transparent disaggregated reporting, and unstable funding. The cancellation of the NYC Compost Project's community composting budget in 2023 was cited as an example of this institutional vulnerability.

At the same time, several opportunities were identified. (BioCycle, 2026) reported increasing organics tonnages under NYC's mandatory composting program and gradual improvement in enforcement. The deployment of more than 400 Smart Bins has provided a complementary collection pathway with high efficiency and low contamination (MacBride, 2024). Community composting sites have also generated substantial volunteer engagement, green jobs, and local environmental education benefits (Morrow & Davies, 2022).

DISCUSSION

The results demonstrate that NYC possesses a very large and underutilized organic waste resource base. With compostable organics accounting for 40–47% of residential waste and food waste as the dominant component, the city has strong technical potential to shift from disposal-based waste management toward circular resource recovery. The high biomethane potential reported for source-separated food waste confirms that this stream is particularly suitable for anaerobic digestion, while composting remains appropriate for fibrous fractions such as yard trimmings and food-soiled paper.

The findings also indicate that source separation quality is a decisive determinant of downstream valorization performance. Although previous studies reported high collection efficiency under well-managed systems, the large variability in impurity content suggests that program effectiveness depends heavily on operational maturity, public participation, and contamination control. This is particularly relevant for NYC, where contamination in organics bins remains a persistent concern. The compost quality findings from Morscheck reinforce that high-quality outputs are achievable, but only when input streams are adequately separated (Jalalipour et al., 2020).

In terms of treatment pathways, the results suggest that no single valorization pathway is sufficient for NYC's heterogeneous urban waste stream. Composting offers relatively low capital costs and direct production of soil amendments, whereas anaerobic digestion provides an energy recovery route through biogas and renewable natural gas. Community composting adds a decentralized and socially embedded model that contributes benefits beyond simple tonnage diversion. Thus, the most appropriate interpretation is that NYC requires a multi-pathway system, rather than reliance on one technology alone.

The life-cycle assessment evidence strongly supports diversion away from landfill. Landfilling shows the highest greenhouse gas burden, whereas composting and anaerobic

digestion both provide substantially better environmental performance. However, the discussion should not frame composting as universally superior without qualification. Although composting can achieve strong net climate benefits, its ammonia and nitrous oxide emissions may create localized environmental and health trade-offs if poorly managed. This means that the environmental superiority of composting is conditional on operational controls such as aeration, moisture management, and biofiltration. Likewise, anaerobic digestion offers major benefits for wet, high-moisture food waste, especially when integrated with digestate composting.

A key implication of the results is that integrated AD + composting configurations appear especially promising for NYC. Digesting food waste first can recover energy while reducing emissions associated with subsequent composting of residual digestate. This combined system may therefore provide a more balanced solution across greenhouse gas reduction, nutrient recovery, and local air quality performance. For a dense city such as NYC, this integrated model is particularly relevant because it can align technological efficiency with land constraints and infrastructure synergies.

The regulatory findings reveal that NYC's policy framework has advanced significantly, but actual diversion performance remains limited relative to total waste generation. The move from voluntary participation to mandatory residential separation marks an important institutional shift, yet the capture rates reported for Queens indicate that regulation alone does not guarantee high recovery. The decline in capture rate between 2018 and 2023 suggests that program visibility or symbolic scale does not necessarily translate into effective participation. Therefore, performance should be judged using capture rate, contamination rate, and participation rate, rather than total tonnage alone.

The multi-family building context emerges as the central implementation challenge. Dense apartment buildings create structural barriers to source separation, including shared bins, limited storage space, lack of accountability, and pest or odor concerns. These conditions differ fundamentally from low-density residential areas where individual household participation is easier to monitor. This means NYC's organics strategy cannot simply replicate suburban curbside models; instead, it requires building-specific system design, such as dedicated bin infrastructure, multilingual signage, superintendent training, and contamination auditing.

The discussion also highlights the importance of viewing community composting not merely as a minor diversion pathway, but as a critical institutional support mechanism for

long-term participation. Community composting sites provide education, social engagement, and localized stewardship, all of which help normalize organic waste separation behavior. Their value therefore extends beyond their processing capacity. In this sense, the reduction or suspension of community composting support may weaken the broader organics system by eroding the social infrastructure needed for sustained compliance.

Another major implication concerns environmental justice. The concentration of waste transfer infrastructure in historically overburdened neighborhoods means that an expansion of organics collection could inadvertently intensify existing inequities if truck traffic and facility siting remain spatially concentrated. This suggests that circular economy implementation must be evaluated not only in terms of material recovery and emissions reduction, but also in terms of distributive fairness. Decentralized community composting, localized processing, and more equitable siting of future facilities are therefore not peripheral considerations, but central requirements for a just organics transition.

Overall, the evidence supports a hybrid circular organics model for NYC. Wet anaerobic digestion at wastewater treatment facilities can leverage existing infrastructure for co-digestion of food waste and biosolids, while dry AD may serve high-solids residential streams. Composting remains important for yard trimmings and paper-rich fractions, and community composting should be maintained as a complementary neighborhood-scale strategy. Such a hybrid system would likely improve resilience, reduce dependence on landfill disposal, and increase the city's capacity to recover energy and nutrients from its organic waste stream.

Finally, the findings indicate that future program improvement will depend on more transparent and disaggregated reporting. Metrics such as capture rate by community district, contamination rate, per-household organics generation, pathway allocation, greenhouse gas reduction, and smart bin utilization should be published regularly. Without this level of detail, adaptive management remains difficult and public accountability is weakened.

CONCLUSION

This review confirms that New York City's source-separated organic waste stream represents a substantial yet insufficiently utilized circular economy resource. The findings show that diverting organic waste from landfill to composting and anaerobic digestion

provides clear environmental benefits, particularly through significant greenhouse gas reduction and the recovery of valuable outputs such as compost, biogas, and digestate. However, despite the implementation of mandatory curbside organics separation, actual diversion performance remains limited by low capture rates, difficulties in multi-family residential buildings, uneven processing capacity, and weak continuity in community-based support systems. These results indicate that regulatory enforcement alone is not sufficient to achieve effective circular organic waste management in a dense metropolitan setting.

Scientific Contribution. The principal contribution of this review is its integrated analysis of organic waste management from environmental, technical, regulatory, and environmental justice perspectives within a single circular economy framework. This study extends the discussion beyond treatment technologies by connecting life-cycle evidence with the institutional and spatial realities of NYC's organics system. It also offers a strategic model for urban organic waste governance based on five interrelated elements: mandatory source separation, expanded anaerobic digestion capacity, strengthened community composting, transparent performance reporting, and justice-oriented infrastructure planning. In this way, the review contributes both a synthesized evidence base and a policy-relevant conceptual direction for future metropolitan organics management.

Limitations and Future Research. This review is subject to several limitations. First, it relies primarily on pre-2025 data, as comprehensive performance evidence from the fully enforced mandatory period is not yet publicly available. Second, the lack of NYC-specific life-cycle assessment data limits the precision of environmental comparisons, requiring the use of evidence from comparable contexts. Consequently, the review cannot yet provide a fully localized assessment of long-term system performance under actual NYC operating conditions. Future research should therefore focus on updated borough- and district-level waste characterization, NYC-specific life-cycle assessment of alternative treatment pathways, intervention studies for multi-family residential participation, and longitudinal evaluation of the social and behavioral contributions of community composting. These directions are essential for developing a more robust and context-sensitive foundation for circular organic waste policy in New York City.

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