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Understanding the Plastic Flow and Circularity in Nairobi City, Kenya

Ian Karani Mwai*, Takeshi Fujiwara

Graduate School of Environmental, Life, Natural Science and Technology, 3 Chome-1-1 Tsushimanaka, Kita Ward, Okayama, 700-8530
iankarani@hotmail.com

Accurate material flow models of plastic waste and recycling streams are crucial in intervening plastic waste's negative environmental impact while enhancing circular lifestyles. Nairobi generates roughly 500 t of plastic waste daily, with about 70 % to 75 % collected by the responsible actors. 93 % of collections go to landfills with a small fraction recovered by informal waste pickers, collection or transfer stations and landfill scavengers. This study tracks importation, manufacturing, export, consumption, and disposal of PET (Polyethylene Terephthalate), HDPE (High Density Polyethylene), LDPE (Low Density Polyethylene), and PP (Polypropylene) plastics in Nairobi City applying Material Flow Analysis based on the mass balance model. Annually, approximately 385,000 t of plastics are imported into Nairobi for both B2B and B2C enterprises. Around 214,000 t of semi-refined materials move from one B2B to other B2B entities, and about 87,000 t to B2C companies, highlighting significant internal business dynamics. This novel study of interactions between B2B and B2C companies provides crucial insights into previously overlooked flows, enabling targeted policy interventions. Studying these dynamics is particularly important in growing economies like Nairobi, where rapid urbanization and economic expansion significantly influence plastic consumption and disposal patterns. Export activities including extra-boundary sales account for roughly 273,000 t annually, while local consumption reaches about 0.035 t per capita. Consumer-generated waste totals nearly 170,000 t annually, with a minimal fraction stored. Recyclers receive about 101,000 t annually, with an output efficiency of roughly 60 %, accumulating a stockpile of nearly 42,000 t. These figures indicate existing recycling infrastructure inefficiencies, underlining significant opportunities to enhance a circular economy. Policymakers can utilize these findings to strategically boost waste recovery efforts, optimize recycling operations, promoting sustainable plastic management.

1. Introduction

Globally and regionally, it is well recognized that plastic pollution brings about detrimental, environmental and health challenges (Geyer et al., 2017). Resource depleting production and high consumption of plastics can be linked to the generation of large quantities of plastic waste, over burdening waste management systems. These two factors have been identified as a significant ecological challenge, leading to substantial plastic waste accumulation within ecosystems (Ošlovnik et al., 2024).

As this trend continues overtime, landfills overfill, some waste leaks to rivers and other critical water bodies, increasing risks to aquatic life and harming key economic sectors such as tourism, shipping, and fisheries (Mora et al., 2021). Countries and cities with high environmental awareness have already reduced one-way plastic products, including plastic containers and packaging. Recently, the circular economy is highlighted as a model of an independent recycling society and would be useful in reducing plastic waste. (Chidepatil et al., 2021). Also, the circular economy might lead to job creation in the plastic recycling business. Nairobi, the capital city of Kenya, hosts numerous industries, making it the richest county in Kenya (KNBS, 2025). The city is facing a stark reality of population increase, rapid urbanization, high consumption and high waste generation (Kloettschen et al., 2024). Unfortunately, the waste management of Nairobi could not catch up with the urbanization. Indeed, it features numerous and mainly unregulated landfills, with the largest and still growing in East Africa, the Dandora landfill (Kloettschen et al., 2024).

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As seen in Table 1 below, institutions have tried to estimate waste generation, collection and leakage within Nairobi, though with some margins. UN Habitat's Wise Cities Tool and Kenya National Bureau of Statistics, a societal and economic statistics Kenyan government body has been doing the same over the years. According to these institutions, between 2019 and 2023, plastic waste generated is between 142 and 474 t/d and collections are between 65 % to 86 % on average. This means the city has about 20 t to 165 t of uncollected plastic waste lying around on any given day.

In Kenya, plastic waste generation in t per day was estimated by Eunomia (2018) and fell in the range of 1,378 to 2,646 t, by UN-Habitat (2019) as 3,654 t and JICA (2010) as 2,216 t, verified from published reports. Most of these quantities arise from Nairobi, given its huge population and income activities. After the famous plastic ban on single use plastics in 2017, the ban extended to single-use plastics in protected natural areas like parks and forests in 2020. The Sustainable Waste Management Act of 2022 further reiterates environmental concerns and gives specific responsibilities to Counties like Nairobi.

With the Act now comes the Extended Producer Responsibility regulations of 2024, aiming to promote environmentally sound management of products throughout their life cycle (Kenya MoE&F, 2022). The city's administration has promoted the plastic waste reduction but still Nairobi and Kenya lack an updated, comprehensive database on plastic input and output flows, rendering current statistics outdated or imprecise. Until now, there lacks a comprehensive, updated database showcasing plastic input and output flows. There is also no research that has explained business-to-business (B2B) and business-to-consumer (B2C) plastic dynamics in Nairobi and in Kenya, and the quantitative role of transfer stations in waste management remains unexamined, limiting the understanding of waste circulation and leakage.

Thus, this study figured out all the plastic flow in Nairobi through questionnaire surveys about the input and output of plastic to stakeholders: plastic manufacturers, consumers, recyclers, landfill site, and collection centres. B2B (Business-to-Business) in reference to manufacturers or suppliers selling bulk plastic materials, components, or packaging directly to other businesses while B2C (Business-to-Consumer) in plastic products involves selling finished plastic goods directly to end-users (Swapan et al., 2014).

In the analysis, the plastic manufacturers were divided into: B2B- plastic container and packaging manufacturer and B2C - final plastic product manufacturer or retailer, to quantify the plastic flow between them.

This study aims to bridge this existing gap by understanding plastic flows through a Material Flow Analysis (MFA) and to investigate circularity by calculating system metrics including recycling and recovery rates. Its novelty lies in illuminating how B2B and B2C companies influence plastic movement within Nairobi's boundaries, introducing circularity systems of measurement that can inform evidence-based policymaking, thereby enhancing a robust framework for waste management strategies.

Table 1: Nairobi Waste Data in t/d

Institution	Years	MSW Generated	MSW Collected	MSW Uncollected	Plastic Waste Generated	Plastic Waste Collected	Plastic Waste Uncollected
UN-Habitat	2019	3,085.0	2,013.0	1,072.0	370.2	241.56	128.64
	2023	3,953.0	2,580.0	1,373.0	474.36	309.6	164.76
KNBS	2019	1,653.0	1,242.8	410.2	198.36	149.14	49.22
	2023	1,191.5	1,025.2	166.3	142.98	123.02	19.96

2. Methodology

2.1 Study Site

The administrative boundary of Nairobi County has a population of about 5.7 million people in 2025 and rising roughly by 4.08 % annually (World Population Review, 2025). In this city, the average plastic waste consumption per capita was 0.0961 kg/d and output was 0.0958 kg/d.

The city contains different income groups as indicated by (KNBS, 2025). Lower, lower-middle and middle-income groups make up the major population in the city.

2.2 Material flow model

Mass flow models and material flow analyses are an exceptionally well-suited tool because of the systematic approach that the method takes (Ghannadzadeh et al., 2022). Figure 1 shows the schematic representation of the survey process and Mass Flows in this study. The outline of the material flow description is as follows: The first is the upper stream flow before the consumption. The plastic manufacturer (M) imports plastic raw materials such as LDPE, HDPE, PET, and PP from outside of Nairobi to make the final plastic product (FP) and the plastic container and packaging product (CP). Some FP and CP are exported [ME], others flow to the plastic user manufacturer (U) as [MU] and B2C companies (S) as [MS] and thereafter to consumers (C). The unusable plastic waste in the internal production process from the manufacturer is disposed to landfill (L) as [ML]. The user manufacturer (U) also uses the (CP) imported from outside the boundary [IU].

As part of its operations, the user manufacturer (U) exports its products [UE], a part of the (CP) that goes out from Nairobi [UE], and the remaining CP goes to the B2C companies (S) as [US], highlighting massive movement between B2B and B2C companies. The imported FP from outside [IS] ends up as a consumer input. The second scene is the consumer's behavior of waste discharge. The consumers pass waste to the collection center (Y) as [CY] and informal waste collector (X) as [CX] or disposes them for landfilling [CL]. The informal plastic waste collector deals with not only the consumers waste [CX], but also the plastic waste from extra boundary sources [WX]. They form a significant team in the collection activity, receiving orders from buyers who pay them according to the kg collected, bringing fierce competition amongst informal pickers. The consumer waste recycling ratio, calculated in equation (1), where SC is total consumer input, indicates the proportion diverted from landfill. At the landfill site, some recyclable plastic waste [LR] is picked up by the scavengers (another informal collector) who deliver this waste to the recycler (R).

The third is plastic waste gathering and recycling. The recycler deals with both the plastic waste from informal sector [XR], collection centers [YR], and the landfill [LR]. The recycler sells the recovered plastic resources to the manufacturer (M), denoted as [RM] supplementing production input, creating value for sustainable activities, positively impacting circular lifestyles. Equation (2) measures the proportion of recycled input in manufacturing. Equation (3) assesses the informal sector's contribution to collections, while equation (4) quantifies waste escaping the system after recovery, indicating challenges with high waste quantities. Equation (5) evaluates overall circularity, reflecting the city's efforts in reintroducing recycled materials into production, closing the loop.

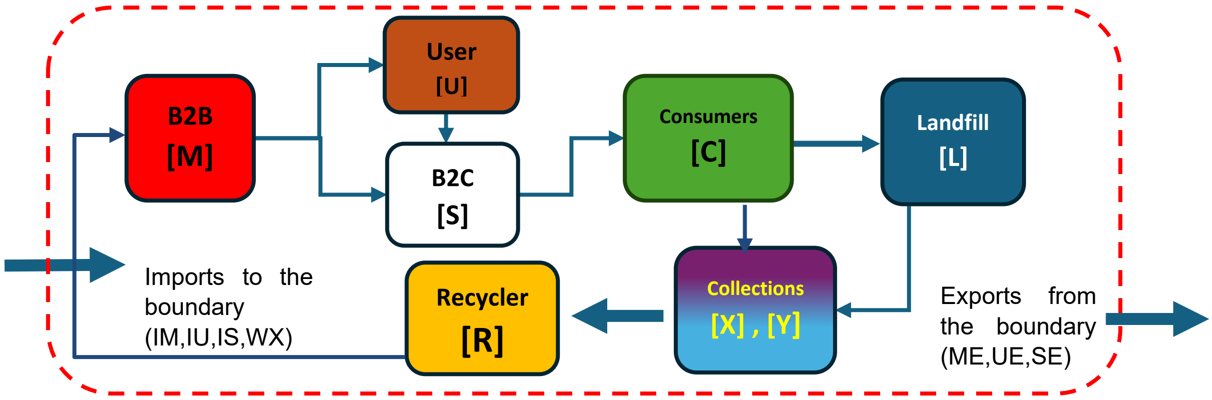

Figure 1: The Schematic Representation of the Survey Process and Mass Flows

2.2 Quantification Approach of boundary actors.

As shown below is how values for the different variables were calculated in the following plastic material flow system equations as presented in Eq (1) to (5):

$$\text{Consumers waste recycling ratio} = (CX + CY) / SC \quad (1)$$

$$\text{Recycled Plastic use ratio} = (RM) / (IM + RM) \quad (2)$$

$$\text{Informal collection ratio} = (CX) / (CX + CY) \quad (3)$$

$$\text{Net disposal ratio} = (CL + ML - LR) / (IM + IS + IU + WX - ME - UE - SE) \quad (4)$$

$$\text{System recycling ratio} = (RM) / (IM + WX + IS + IU) \quad (5)$$

Plastic flows were quantified through a combination of primary data collection, scaling techniques, and cross-referencing with secondary sources. Structured questionnaires were administered to 40 manufacturers, with 33 valid responses analysed after data cleaning. Nairobi's manufacturing imports were estimated by proportionally adjusting national data based on the city's industry representation. Transfers from manufacturers to plastic user companies (U) and B2C companies (S) were derived directly from survey responses and extrapolated accordingly. Export volumes from manufacturers (ME) and (UE) were compiled using both primary responses and complementary external data sources.

For B2Cs (S), additional imports of finished plastic goods and containers (IS) were calculated by reconciling total supply from manufacturers against exports and consumer intake, allowing indirect estimation of unrecorded imports.
Consumer flows were estimated using a three-tier income segmentation: low-income, middle-income, and high-income. Survey-derived per capita input and output values were scaled using official KNBS population figures to obtain city-wide totals.
Post-consumer flows to collection centres [CY] and informal collectors [CX] were obtained directly from surveys and validated against existing literature. Informal sector recovery (X) was recognized to include external inputs [WX] from outside the system boundary, contributing to recycler intakes but carrying higher uncertainty due to limited direct measurements.
Recycler inputs were captured as flows from collection centres [YR], informal sector collections [XR], and landfill scavenging [LR], based on recycler responses. Recycled output returning to manufacturers [RM] was also directly reported.
Limitations of this model is the following: since Nairobi has small number of the assembling factories such as the electric appliance and the automobile companies, this study only focuses on the final plastic product (FP) and the plastic container and packaging product (CP), excluding plastic components. The plastic waste from (M) is considered but the those of (U) and the recycler (R) are not considered.

3. Results and Discussion

3.1 Questionnaire survey

A questionnaire survey to obtain the actual material flow data being necessary for the material balance equation system was conducted in detail from January to February in 2024. This helped the study acquire information for the full year 2023 from Nairobi city. The survey targeted the four groups of plastic manufacturers, consumers, recyclers, and waste collectors.
First, information sought was the imported resources to B2B - manufacturers [IM] and plastic user manufacturers [IU], recycled material quantity used in manufacturing [RM], the products amount going to other B2B and B2C businesses ([MU] and [MS]) respectively, the exports amount from importing manufacturers [ME] and [UE] from user manufacturers was investigated as well as waste from manufacturers to landfill [ML].
It was clear that B2C businesses played a substantial role in supplying goods to consumers. This category purchases plastic items from sources outside the boundary [IS]. The input of plastic products to consumers was identified as [SC], the output going to informal collectors [CX], to collection centres [CY] and disposed to landfill [CL] was investigated. Landfill waste [LW] is also an important parameter that was studied.
Sources and quantities from informal collectors delivered to recyclers as input [XR], the same for collection centres to recyclers [YR] were documented. Waste recovered from the Landfill to recyclers [LR] as well, was gathered. As a result, the answers from 33 manufacturers, 38 recyclers, 27 waste transfer or collection stations, and 150 households, each having an average of 3 inhabitants, were factored in.
Since [IS], [SE], [LW], [WX] and [CX] in the balance equation system are unknown parameters, reliance on proxy data and expert assumptions was considered. The resulting estimates carried inherent uncertainty. While every effort was made to apply conservative and transparent estimation methods, these uncertainties had the possibility of affecting the precision of specific flow quantities. The overall system trends and mass balance integrity remained robust for the purposes of this analysis.

3.2 MFA analysis and discussion

The results from the Material Flow Analysis (MFA) achieved using STAN software and redone here in Figure 2 for clarity purposes, provides a wide-ranging impression of plastic flows within Nairobi's waste management system, revealing critical insights into the lifecycle of plastics from importation to recovery.
Kenya being a net importer of plastics (KNBS, 2025), the analysis shows the plastic cycle begins with a significant raw material annual input quantity of 437,220 t, total exports leaving the boundary at 273,121 t with total internal stock at 164,099 t annually.
The circularity assessment highlights significant inefficiencies in material recirculation across Nairobi's plastic system. Within the manufacturing sector, only 13.63 % of total inputs consist of recycled plastic, indicating a strong dependency on virgin material streams. This low incorporation rate suggests limited market penetration for recycled polymers, potentially constrained by quality standards from old technologies, limited demand due to a resource-heavy economy that drives up costs and prices of secondary materials, or insufficient policy incentives. Expanding recycled material use could reduce primary resource extraction and enhance circularity.

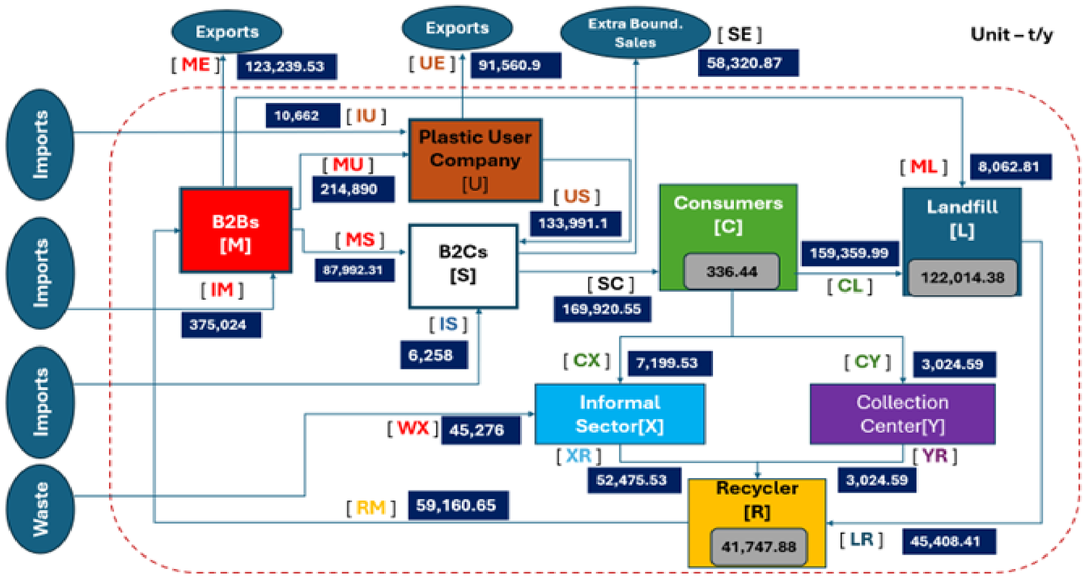

Figure 2: Outline of Nairobi Plastic movement between stakeholders for the year 2023

At the consumer level, recycling performance remains equally limited, with only 6.02 % of post-consumer waste re-entering recovery pathways. Low source segregation, contamination, inadequate collection systems, and poor public awareness contribute to this outcome. Strengthening consumer knowledge, improving segregation, and expanding collection infrastructure remain key priorities.
74.35 % of net plastic flows within the boundary are disposed of in landfills, calculated as final landfill stock relative to the balance of system inputs and outputs. This dominant landfill disposal pathway reflects a highly linear material system where significant volumes of potentially recyclable plastics are permanently removed from circulation. High landfill dependency exacerbates environmental burdens, particularly for land-scarce urban settings like Nairobi.
The informal sector demonstrates a substantial role in recovery, managing approximately 70 % of the total plastic waste collected for recycling. Informal collectors complement formal systems, especially in low-income and unprivileged neighbourhoods where municipal services are insufficient. Their contribution is instrumental in diverting recyclable materials from landfills, collections from households including extra boundary sources and supplying recyclers with feedstock.
However, the informal sector's operation remains largely unregulated, creating system vulnerabilities in terms of working conditions, material quality, and traceability. Formal integration, supported by enabling policy instruments, could stabilize and enhance recovery performance.
At the system level, the total recycling ratio — defined as the proportion of recycled material reintegrated into manufacturing relative to all material inflows, including virgin imports, in-system waste generation, and circulating product stocks — stands at 13.53 %. Recycling pathways reveal further challenges to circularity like high cost of operations- electricity, consumers conduct of non-segregation of waste leading to contamination, unpredictable tax policies that change annually and contamination arising from non-segregation of recyclable plastic waste. This aggregate figure reflects an early-stage circular economy transition, where recycling exists but is insufficient to offset high virgin material dependency and disposal rates.
According to Tsuji (2024), Japan has implemented policies in line with 3Rs and ensuring plastic circularity. For example, with the Container and Packaging Recycling Act of 2000, Resource Circulation Plastic Strategy of 2019, Plastic Resource Circulation Act of 2022, clear steps have been made to minimize environmental degradation caused by plastics. In cities and municipalities in Japan, approximately 8 million t of plastic waste was produced in 2021. Out of this, a remarkable 87 % of waste is effectively used, where 25 % is recycled to make secondary materials while 63 % is used for energy recovery. The rest of the waste -13 %- isn't utilized and heads to sanitary landfills.

4. Conclusion

Systemic inadequacies and opportunities for intervention to align with Sustainable Development Goals 11 (Sustainable Cities and Communities) and 12 (Responsible Consumption and Production) are highlighted in the study. Further, the material flow analysis of Nairobi's plastic waste management system reveals a predominantly linear structure with significant reliance on virgin plastic imports, low incorporation of recycled materials, and high landfill dependency. While manufacturers currently integrate only 13.63 % recycled content, and consumer recycling rates remain low at 6.02 %, informal waste collectors play a critical compensatory role, handling approximately 70 % of the recovered material. However, overall system circularity remains limited, with 74.35 % of plastic waste disposed of in landfills, highlighting infrastructure inefficiencies in collection and recycling. Compared to international best practices such as Japan's advanced circular economy policies, Nairobi's system reflects an early stage of circularity development, constrained by structural, economic, and policy barriers including operational costs, inconsistent regulations, contamination from poor waste segregation, and weak formal-informal sector integration. Addressing these challenges will require targeted policy interventions that incentivize recycled content use, formalize and support informal sector participation, strengthen source separation and collection systems, and establish stable policy frameworks to encourage private sector investment. Strengthening Nairobi's plastic circularity will not only reduce environmental burdens but also create economic opportunities within the emerging waste valorization sector.

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