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Preliminary Study of Life Cycle Assessment on Food Surplus Redistribution Compared to Food Waste Management in Surabaya

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Food waste accounts for approximately 40% of total waste generation in Indonesia and contributes significantly to national greenhouse gas (GHG) emissions. While most food waste is still disposed of in landfills, food surplus redistribution through food banks has emerged as a potential mitigation strategy. This study evaluates the environmental performance of food surplus redistribution compared to conventional food waste management options using a life cycle assessment (LCA) approach. The analysis was conducted at Garda Pangan, Surabaya, with a functional unit of 1 ton of food surplus and assessed three scenarios: (1) landfill disposal, (2) composting and anaerobic digestion, and (3) food surplus redistribution. The assessment applied the CML IA Baseline method and focused on Global Warming Potential (GWP), using SimaPro 9.0 and the Ecoinvent 3 database. The results show that landfill disposal has the highest GWP at 1,920 kg CO_2-eq per ton of food waste, driven primarily by methane emissions from anaerobic decomposition. Composting and anaerobic digestion result in lower impacts, at 1,503 and 1,730 kg CO_2-eq per ton, respectively. In contrast, food surplus redistribution shows a markedly lower GWP of 1.24 kg CO_2-eq per ton of food surplus, as emissions are dominated by transportation activities within a simplified gate-to-gate system boundary. This preliminary analysis relied on secondary inventory data and excluded potential avoided food production impacts; therefore, the estimated GWP for redistribution may underestimate or overestimate actual emissions. These findings highlight the importance of prioritizing food waste prevention and the benefits of food surplus redistribution within integrated waste management strategies to reduce GHG emissions while delivering social co-benefits.

Keywords: Food Surplus, Food Waste, Waste Management, Life Cycle Assessment

INTRODUCTION

In 2024, total waste generation in Indonesia reached 33.5 million tons, equivalent to 91,893 tons per day. Waste in Indonesia is dominated by food waste (39.37%), followed by plastic waste (19.56%) and wood or garden waste (12.71%) (Sistem Informasi Pengelolaan Sampah Nasional (SIPSN), 2025). Food waste is divided into two main categories: food loss and food waste. Food loss refers to food that is lost or discarded during the stages of production, processing, storage, and distribution before reaching the consumption stage. Meanwhile, food waste refers to food that is still fit for consumption but is discarded after the consumption stage, such as uneaten leftovers (Liao et al., 2019; Thamagasorn & Pharino, 2019). Based on data from the National Waste Management Information System *(Sistem Informasi Pengelolaan Sampah Nasional/SIPSN)*, the sectors contributing the largest shares of food waste in Indonesia include households (50.08%), markets (16.68%), areas or estates (11.3%), and commercial activities (11%). More specifically, sectors that also generate substantial food waste, besides households, include restaurants or food service providers and institutional sectors such as hospitals, hotels, and schools (Wu et al., 2021). In 2024, the waste handling rate reached 43.21%, while waste reduction accounted for only 9.44%. This indicates that most food waste still ends up in landfills. The current condition remains far below the 2025 targets of 70% waste handling and 30% waste reduction.

Overall, food waste contributes 7.29% of Indonesia's annual greenhouse gas emissions (Low Carbon Development Indonesia (LCDI), 2021). In addition, although the volume of food loss is higher (56%), the average emissions generated per ton of food waste are approximately 4.3 times higher than those from one ton of food loss. This indicates that food waste, particularly when not properly managed, has a significant environmental impact (Hong et al., 2024; Sundin et al., 2022; Thiel et al., 2021). The waste sector in Indonesia ranks as the fourth-largest contributor to national GHG emissions; however, it is the primary source of methane (CH_4) emissions (Our World in Data, 2024). The government has set ambitious targets to reduce food waste by 50% by 2030 and 75% by 2045, with surplus food redistribution identified as one of the key strategies to achieve these goals. Food redistribution has been shown to generate positive environmental impacts, with a higher potential for carbon emission savings compared to anaerobic decomposition in conventional waste management systems (Sundin et al., 2022; Thiel et al., 2021; Vázquez-Rowe et al., 2021).

Despite its potential, research on the environmental impacts of surplus food redistribution, particularly its effects on greenhouse gas emissions, remains limited. Food redistribution has not yet been widely implemented and is predominantly practiced in developed countries, while existing studies mostly focus on formal waste treatment technologies such as landfill diversion, composting, and anaerobic digestion (Patel et al., 2021). Life cycle assessment studies evaluating food surplus redistribution as a waste prevention strategy in developing country contexts remain scarce. In Indonesia, where food redistribution initiatives have only recently emerged and are largely managed by non-profit organizations, there is a lack of quantitative evidence comparing greenhouse gas emissions from food surplus redistribution with those from conventional food waste management systems. Moreover, previous studies rarely assess redistribution alongside multiple local treatment scenarios within an LCA framework, limiting their relevance for urban waste management planning and policy development.

To address these gaps, this study applies a life cycle assessment approach to compare the global warming potential of food surplus redistribution with food waste management scenarios in Surabaya. Specifically, this study aims to quantitatively compare the GWP of three food waste management scenarios, including surplus food redistribution and existing treatment options; identify the dominant emission sources across the life cycle stages of each scenario; and analyze the policy implications of food surplus redistribution as a waste prevention strategy. This assessment is intended as an initial or preliminary evaluation, focusing on waste management-related emissions under simplified system boundaries and excluding avoided food production impacts due to data limitations.

METHOD

Goal and Scope Definition

A life cycle assessment was conducted to evaluate the environmental impacts of food surplus redistribution compared to conventional waste management practices in Surabaya. The goal of this analysis is to quantify and compare global warming potential, while other environmental impact categories are excluded at this preliminary stage. The environmental impacts of each management option were evaluated using SimaPro 9.0 software, with background data sourced from the Ecoinvent 3 database.

The analysis is based on food surplus quantities recorded by Garda Pangan in 2024. The functional unit (FU) of this study is defined as 1 tonne of food surplus and is applied consistently across all three management scenarios. The same tonnage and assumed food composition were used for each scenario to ensure comparability among alternative treatment options. The food types included ready-to-eat food, bread, cakes, vegetables, and fruits. This composition reflects typical surplus food generated from hotels, restaurants, catering services, and bakeries.

This study is considered preliminary because it relies on secondary data, applies simplified system boundaries, and excludes avoided food production emissions as well as sensitivity analyses for key parameters such as landfill methane capture. These methodological choices were made to support an initial comparison of management pathways under data and time constraints.

System Boundary and Scenarios

The system boundary of this study is defined as gate-to-gate and is applied consistently across all scenarios (Figure 1). The boundary includes processes from the point at which food surplus is collected from hotels, restaurants, catering services, and bakeries to the point of final treatment or consumption, depending on the scenario.

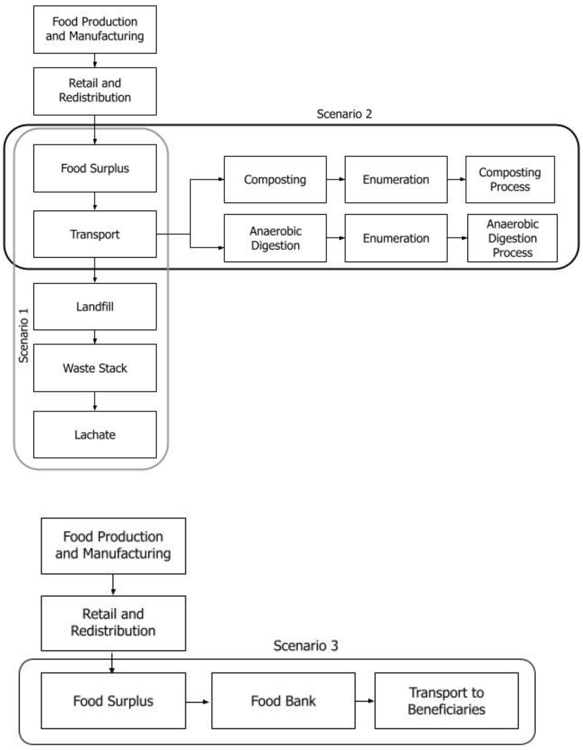

Figure 1. System boundaries and scenarios of the LCA

For Scenario 1 (landfill disposal), the system boundary includes the collection and transportation of food surplus from the source to the landfill site. Upstream food production and downstream landfill infrastructure construction are excluded. For Scenario 2 (TPST/TPS3R treatment), the boundary includes the collection and transportation of food surplus to TPST/TPS3R facilities and treatment processes through composting and anaerobic digestion; residue treatment from these processes is excluded. For Scenario 3 (food surplus redistribution), the boundary includes the collection and transportation of food surplus from donors to redistribution facilities, as well as distribution to beneficiaries. The consumption phase is represented as waste prevention, as the food surplus is assumed to be fully consumed, thereby avoiding disposal and treatment processes. Food preparation, cooking, and consumer-level waste generation after redistribution are excluded from the system boundary.

Global warming potential is calculated using IPCC characterization factors with a 100-year time horizon (Bergström et al., 2020). Avoided emissions associated with food production and upstream supply chains are deliberately excluded from this assessment to maintain a consistent waste management system boundary. Food surplus redistribution is therefore modelled as a waste prevention option within the waste management system.

Inventory Data

In this study, life cycle inventory (LCI) data for Scenarios 1 and 2 were compiled from a combination of literature sources to represent material and energy inputs. For Scenario 3, an average distribution distance of 6.83 km was calculated based on recorded routes from food banks to beneficiaries. Redistribution activities were conducted using a pick-up fleet with an average fuel efficiency of 13 km/L. Fuel consumption was converted into CO_2 emissions using the IPCC 2006 default emission factor for gasoline (69.3 t CO_2/TJ). The resulting emissions were normalized to the functional unit of 1 tonne of food surplus, as presented in Table 1.

In Scenario 3, emissions associated with downstream waste treatment processes are not generated, as the redistributed food is assumed to be consumed by beneficiaries and therefore does not enter the waste management system.

Table 1
Inventory of Treatment Processes

Input/Emission	Material and Substances	Landfilling	Composting	Anaerobic Digestion	Food Redistribution
Input Material	Diesel	8 L/t	7.7 L /t	5.5 L/t	0.525 L/t
	Water	-	38.9 L/t	1.45 L/t	-
	Electricity	-	1.33 kWh	1.33 kWh	
	EM4	-	2 L	-	-
Emission to Air	CO_2	65 kg/t	26.7 kg/t	-	1,24
	CO	185 kg/t	1.5 kg/t	1,5	0.22
	CH_4	61.29 kg/t	8.93 kg/t	61.35 kg/t	6.4
	NOx	0.753419 kg/t	0.753419 kg/t	-	0.27
	N_2O	0.00728 kg/t	0.00728 kg/t	0,00728 kg/t	-
	Pm_{10}	-	-	-	0.5
	SOX	-	-	-	0.063
	N	-	-	0.4743 kg/t	-
	Ammonia	-	-	0.3953 kg/t	-
Emission to Water	COD	37 mg/L	-	-	-
	BOD	2717 mg/L	-	-	-
	Pb	1395 mg/L	-	-	-
	Cd	1.05 mg/L	-	-	-
	TSS	0.862 mg/L	-	-	-

Source: Landfilling and Composting (Qadar et al., 2024), Anaerobic Digestion (Ula et al., 2021), Food Redistribution (IPCC, 2006)

RESULTS AND DISCUSSION

Comparative Analysis of Global Warming Potential Across Scenarios

The comparative analysis reveals clear differences in the climate impacts of the three scenarios, consistent with the waste hierarchy principle. Landfill disposal shows the highest global warming potential, amounting to 1,920 kg CO_2-eq per ton of food waste. This impact is primarily driven by uncontrolled methane emissions from anaerobic decomposition. Methane is a potent greenhouse gas with a global warming potential 28 times that of CO_2 over a 100-year time horizon, and in landfill systems it is often released directly into the atmosphere without utilization (Meegoda et al., 2025; Setiawan et al., 2025). In addition to gaseous emissions, open dumping generates leachate containing pollutants such as BOD_5, COD, and nitrates, posing further risks to surrounding environmental systems (Anasstasia & Azis, 2020).

Among the waste treatment options, composting exhibits the lowest global warming impact, at 1,503 kg CO_2-eq per ton of food waste. Anaerobic digestion results in a higher impact of 1,730 kg CO_2-eq per ton, although this remains lower than landfill disposal. Anaerobic digestion tends to produce slightly higher CO_2-equivalent emissions than composting, largely due to methanerelated emissions. Composting is an aerobic biological process that primarily produces CO_2 rather than methane (CH_4) (Matlach et al., 2025). The higher impact observed for the anaerobic digestion scenario highlights a critical operational concern: without high-efficiency biogas capture and utilization, anaerobic digestion systems can remain a source of potent greenhouse gas emissions due to fugitive methane losses from digesters, storage facilities, and digestate handling (Lin et al., 2018; Matlach et al., 2025).

The food surplus redistribution scenario shows the lowest global warming impact, at 1.24 kg CO_2-eq per ton of food surplus. This reflects the limited system boundary, in which emissions are dominated by transportation activities and avoided food production impacts are not included. Unlike waste treatment pathways, food redistribution avoids biological degradation entirely, shifting emissions toward logistical activities, primarily transportation. The extremely low impact observed is therefore a direct consequence of the system boundary choice, whereby food surplus remains a usable product rather than entering a degradation pathway.

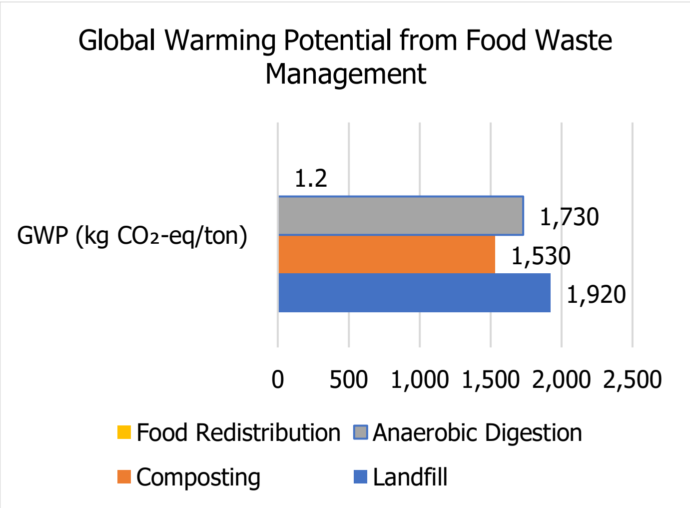

Figure 2. Representation of GWP impact from food waste management

To assess the sensitivity of the food redistribution scenario to transportation distance, a simplified sensitivity scenario was evaluated by increasing the average redistribution distance by 50%. This resulted in an increase in emissions from food redistribution from 1.24 to 2.49 kg CO_2-eq per ton of food surplus, corresponding to an increase of approximately 101%. Despite this increase, food redistribution remained the lowest-emitting option compared to landfill disposal, composting, and anaerobic digestion.

In 2024, the food bank included in this study recovered approximately 16.7 tons of food surplus, with an average redistribution distance of 6.83 km to beneficiaries. The environmental impact of food rescue therefore differs substantially from that of Scenarios 1 and 2, primarily because food rescue avoids waste disposal and its associated emissions. These findings reinforce the established food waste management hierarchy, in which prevention and surplus redistribution are consistently identified as the most environmentally beneficial strategies (Papargyropoulou et al., 2014).

Similar findings have been reported by Bergström (2019) and Sundin et al. (2022), who showed that transportation-related emissions constitute the main source of impacts in food redistribution systems, yet remain relatively small compared to avoided emissions from waste treatment. These results highlight the importance of integrating food rescue and redistribution programs into formal food waste management strategies. While composting and anaerobic digestion remain essential for managing unavoidable food waste, surplus redistribution offers a complementary approach by reducing greenhouse gas emissions while simultaneously delivering social co-benefits, including improved food security and reduced economic losses (Penalver et al., 2022).

From a policy perspective, these results reinforce the primacy of food waste prevention and surplus redistribution within integrated waste management hierarchies. Currently, the Indonesian government prioritizes waste management by focusing on waste reduction and has developed the *Peta Jalan Pengelolaan Susut dan Sisa Pangan dalam Mendukung Pencapaian Ketahanan Pangan Menuju Indonesia Emas 2045*. This roadmap emphasizes several key strategies, including source-level waste reduction, redistribution of edible food surplus, and increased recycling efforts.

Despite its potential, food rescue programs remain underemphasized in national and regional policy frameworks, including Presidential Regulation No. 97/2017 on the National Policy and Strategy for the Management of Household and Household-like Waste (Jakstranas). Aaron & Budiman (2025) explain that the lack of a clear legal basis for partnerships among businesses, local governments, and food banks results in large amounts of edible food being disposed of in landfills. A dedicated national regulation on food rescue is therefore needed to establish minimum standards and measurable targets, similar to those defined under Jakstranas. The absence of such regulation contributes to weak implementation across regions committed to food loss and waste reduction and limits the availability of national benchmarks for monitoring and evaluation.

Municipal waste management strategies should formally integrate food banks and redistribution organizations into the waste management system through policy instruments such as operational standards and procedures, logistical support for low-carbon transportation, and incentives for food donors. While composting and anaerobic digestion remain important for managing unavoidable food waste, upstream food surplus redistribution offers substantially higher climate mitigation potential per ton of food managed.

This study has several limitations that should be considered when interpreting the results. First, the analysis relies primarily on secondary data sourced from international databases and previous studies due to the limited availability of Indonesia-specific life cycle inventory data. Although efforts were made to adapt these data to local conditions where possible, this reliance may introduce uncertainty and affect the representativeness of the results. Second, the system boundary was deliberately simplified using a gate-to-gate approach. Upstream food production processes and downstream infrastructure-related processes were excluded. In addition, avoided emissions from food production resulting from redistribution were not accounted for in order to maintain an attributional LCA perspective. As a result, the environmental benefits of food surplus redistribution may be conservatively estimated. Third, the analysis applies a uniform food composition and emission profile per tonne of food surplus and does not differentiate emissions based on specific food types. Emissions associated with refrigeration and cold storage during handling and redistribution were also excluded due to data limitations, which may lead to an underestimation of total GHG emissions in the redistribution scenario. Finally, landfill emissions were modelled without sensitivity analysis for varying methane capture or recovery scenarios. Differences in landfill gas management practices could significantly influence the global warming potential of the landfill pathway. Future studies should incorporate sensitivity analyses to assess the effects of methane capture rates and operational conditions.

CONCLUSIONS

Food surplus redistribution exhibits the lowest global warming potential among the assessed food waste management pathways in Surabaya when compared with landfilling, composting, and anaerobic digestion within the defined system boundaries. Landfill disposal shows the highest global warming potential, reaching 1,920 kg CO_2-eq per ton of food waste, primarily due to methane emissions from anaerobic decomposition. Biological treatment options, including composting and anaerobic digestion, perform better than landfill disposal but still generate substantial greenhouse gas emissions, estimated at 1,503 kg CO_2-eq per ton and 1,730 kg CO_2-eq per ton, respectively.

These results reinforce the importance of prioritizing food waste prevention and surplus redistribution within integrated waste management hierarchies. In the Indonesian context, this aligns with the *Peta Jalan Pengelolaan Susut dan Sisa Pangan dalam Mendukung Ketahanan Pangan Menuju Indonesia Emas 2045*, which emphasizes source-level waste reduction and the redistribution of edible food surplus. However, the environmental advantages identified in this study should be interpreted with caution, as avoided food production emissions and other methodological aspects were not considered

SUGGESTION

Future research should apply dynamic life cycle assessment approaches and include avoided food production credits to better capture the full climate benefits of food surplus redistribution. In addition, variations in food types, which may significantly influence emission outcomes, were not explicitly differentiated in this preliminary assessment. Future studies are therefore encouraged to incorporate more detailed food composition data and physicochemical characteristics to improve the accuracy and robustness of emission estimates. Integrating economic and social dimensions, such as cost-effectiveness, food security outcomes, and employment impacts, would further support holistic decision-making and strengthen food waste management strategies

Waste management policies should formally integrate food banks and redistribution organizations through logistical support, low-carbon transportation solutions, and incentives for food donors. While composting and anaerobic digestion remain essential for managing unavoidable food waste, surplus redistribution offers greater climate mitigation potential per tonne of food managed and should be prioritized upstream.

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