

Environmental Life Cycle Assessment of Food Waste Management Using OpenLCA

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Case Report

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Comparative environmental performance of landfilling and in-vessel composting

RESOURCE
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FUTURE

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ARTICLE TYPE
Technical paper

METHOD
Comparative LCA using openLCA

STUDY CONTEXT
Food waste management

GRAPHICAL ABSTRACT



KEY ACHIEVEMENTS

- 81.9% reduction** in Global Warming Potential compared to landfilling.
- Ten environmental** impact categories were comparatively assessed.
- Assessed approximately **98.3 t** of food waste using openLCA.
- Composting showed lower environmental impacts than landfilling across the reported categories.
- Supports **circular economy** principles through nutrient recovery and reduced landfill dependency.
- Contributes to the United Nations Sustainable Development Goals and Saudi Vision 2030 objectives.

Keywords: Life cycle assessment; openLCA; food waste; composting; landfill; circular economy

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SUSTAINABLE WASTE MANAGEMENT
HEALTHIER COMMUNITIES | BRIGHTER TOMORROW

SAUDI VISION
2030

Abstract

Food waste is a significant global environmental challenge due to its contribution to greenhouse gas (GHG) emissions and resource depletion. This study presents a comparative Life Cycle Assessment (LCA) using OpenLCA software to evaluate two food waste management methods: landfilling and composting, utilizing Food Composter. We analyzed four key impact categories: global warming, acidification, eutrophication, and resource depletion. Results indicate that composting reduces GHG emissions by 81.9% and lowers marine and freshwater ecotoxicity by over 83%, demonstrating composting's role in promoting circular economy principles through nutrient recovery and reduced landfill dependency. The study confirms composting as a sustainable waste management strategy aligned with the United Nations Sustainable Development Goals.

1. Introduction

Food waste contributes significantly to greenhouse gas emissions and resource depletion. Traditional disposal methods such as landfilling emit methane and prevent resource recovery. Composting offers a sustainable alternative that converts organic waste into nutrient-rich compost, reducing landfill dependency and improving soil quality. This study conducts a comparative Life Cycle Assessment (LCA) using OpenLCA software to evaluate the environmental impacts of food waste treatment via landfilling and composting with Food Composter. The research supports sustainable waste management practices consistent with Saudi Vision 2030 objectives.

2. Literature review

Studies about food waste management have established its critical nature as a global problem because of significant environmental, economic and societal impacts. Previous research revealed that worldwide food production generates more than one-third of waste that leads to major resource depletion and land pollution and Green House Gas (GHG) emissions. The practice of landfilling together with incineration as waste disposal methods produces methane emissions and leads to groundwater contamination while wasting resources poorly. In response to these challenges, composting has emerged as a sustainable alternative that enhances waste valorization, reduces emissions, and supports circular economy principles (Makan and Fadili 2020).

2.1. Life Cycle Assessment (LCA) in Food Waste Management

A thorough comparison of various disposal techniques is made possible by the widespread use of Life Cycle Assessment (LCA) to measure the environmental impact of waste management systems (ISO 14040, 2006). Several LCA studies have demonstrated that composting food waste significantly reduces environmental burdens compared to traditional disposal methods. For example, (Boldrin, Andersen et al. 2009) found that composting minimizes GHG emissions,

reduces soil and water pollution, and enhances carbon sequestration. Similarly, found that composting reduces the acidification and eutrophication potential associated with landfilling and incineration.

2.2. Environmental Benefits of Composting

Composting is recognized as an effective organic waste treatment method, transforming leftover food into a valuable soil amendment while mitigating ecological impacts. Studies indicate that composting can reduce methane emissions by up to 98% compared to landfill disposal. Additionally, compost applications improve soil fertility, enhance microbial activity, and reduce the need for synthetic fertilizers. By keeping organic carbon in the soil, composting also helps with carbon sequestration, which slows down climate change (Awasthi, Sarsaiya et al. 2020).

2.3. Food Waste Composting Technologies

Several composting technologies have been developed to optimize the process, including windrow composting, in-vessel composting, and accelerated composting systems. In-vessel composters offer a controlled, efficient, and odor-free method for composting food waste. The Food Composter is specifically designed to accelerate organic matter decomposition, reducing composting time while ensuring high-quality compost production. Research indicates that such advanced composting systems significantly reduce energy consumption, optimize nutrient retention, and improve overall environmental performance compared to traditional composting methods (Mu, Horowitz et al. 2017).

2.4. Comparative LCA of Food Waste Disposal and Composting

Composting performs better than landfilling and incineration in terms of energy use, resource recovery, and potential for global warming, according to comparative life cycle assessment (LCA) research. For instance, (Yaman, Anil et al. 2020) found that composting reduces GHG emissions by up to 60% compared to landfill disposal. Similarly, found that composting lowers the ecotoxicity and acidification potential, making it a more environmentally friendly alternative.

3. Materials and methods

We recognized the structured waste management approach, emphasizing the importance of segregation at source through dedicated waste bins for different waste streams and repurposing organic waste into compost for sustainable agricultural practices process flow is illustrate below.



Figure 1: Stages of Food Waste Composting – Collection, Processing and Application

4. Functional unit

The functional unit forms the basis for comparing the environmental impacts of food waste disposal through Landfilling (Case 1) and Composting (Case 2). It measures the total amount of food waste generated during the study, including chicken, mutton, beef, rice, vegetables, fruits, fish, and bread- kept identical for both cases. In **Case 1**, food waste is managed through conventional disposal, while in **Case 2**, the same quantity is processed using the Food Composter. Electricity use for composting is also considered to ensure a fair and complete environmental assessment. This approach allows for a balanced and transparent comparison between both waste-management scenarios.

4.1. System Boundaries

The research adopts a cradle-to-grave evaluation technique. A complete lifecycle environmental evaluation of food waste and food composting operations is ensured through this analytical method. The Centrum Voor Milieukunde Leiden (CML) impact assessment approach determines environmental loads through its focus on resource depletion and eutrophication and acidification and global warming potential assessment.

4.2. Inventory Data

The life cycle inventory summarizes the material flows and energy use for both scenarios—landfilling (**Case 1**) and composting (**Case 2**). Equal amounts of food waste, including meat, rice, vegetables, and other organics, were used to ensure a fair comparison under the same

functional unit. The main differences are in transport distance and electricity use: composting requires 14,742 kWh of electricity for processing, while landfilling involves a longer transport distance of 20,160 km. These variations significantly influence the overall environmental impacts assessed in the next step

Table 1: Inventory Data

Material	Case 1: Food Waste Landfilling	Case 2: Food Waste Composting
Chicken (kg)	20868	20868
Mutton	15250	15250
Beef	14721	14721
Rice (kg)	27850	27850
Vegetable (kg)	1825	1825
Fruits (kg)	9150	9150
Fish	7316	7316
Bread	1280	1280
Transportation (km)	20160	14616
Electricity (KWh)	-	14742

4.3. Model Graphs Comparison

The life cycle inventory for **Case 1: Food Waste Landfilling** is illustrated in the OpenLCA process flow diagram. Each arrow represents an input flow of food waste—such as rice, meat, vegetables, fruits, and bread—fed into the Landfill Disposal process. Transportation contributes 20,200 km, representing the distance covered by freight lorries. Input quantities (e.g., 2.09E4 kg chicken, 1.47E4 kg beef) show the total waste processed, while the output flow equals 9.83E4 kg of waste disposed in the landfill. This model helps visualize material flows and quantify the environmental load of food waste landfilling.

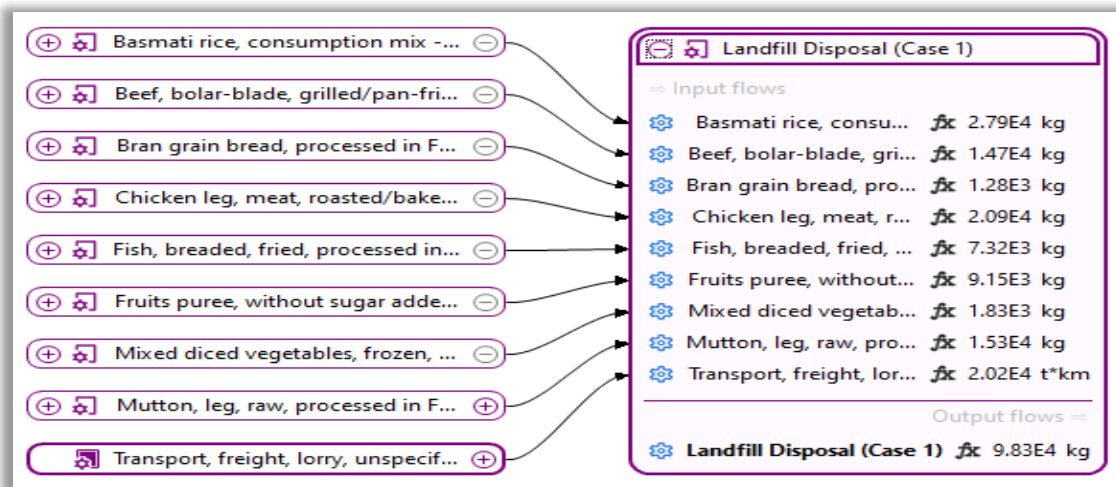


Figure 2: Model Graph for Food Waste Disposal in a Landfill (Case 1)

The life cycle inventory for **Case 2: Food Waste Composting** in OpenLCA shows similar inputs to the landfill case—rice, meats, vegetables, fruits, and bread—ensuring consistent

comparison. An additional electricity input of 14,742 kWh represents the energy used during composting, distinguishing it from landfilling. The transport distance is reduced to 14,642 km, reflecting improved logistics. The total output of 2.47E4 kg of compost highlights the material recovery benefit of this method. The model demonstrates that composting not only diverts waste from landfills but also returns valuable organic matter to the environment.

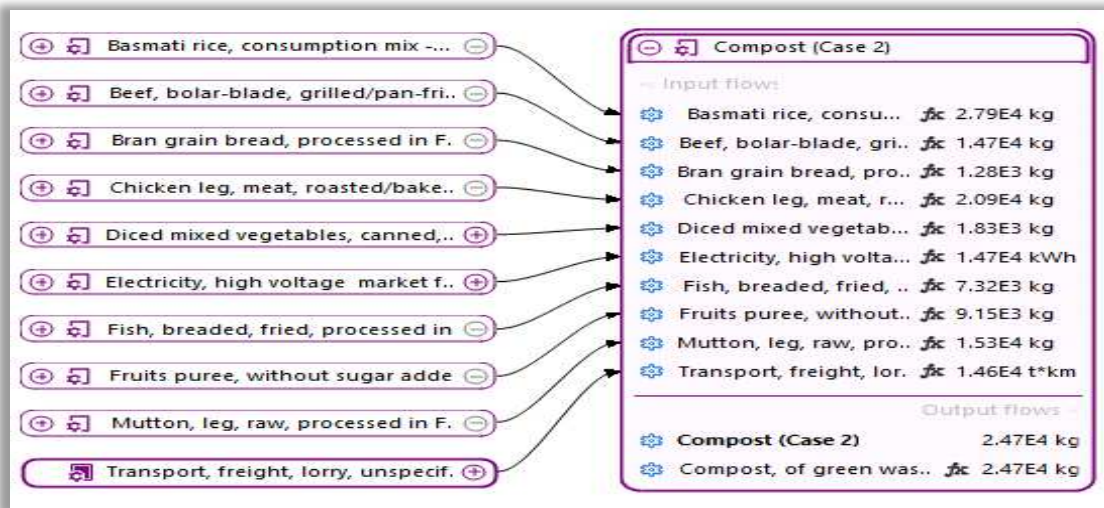


Figure 3: Model Graph for Food Compost (Case 2)

5. Analysis and Discussion of Results

This part gives a critical examination of life cycle assessment results of both landfilling food waste and composting situations. Through the consideration of important environmental impact areas, the findings show that there is a large gap between the two waste management methods. The discussion is concerned with the key contributors of impacts, finding out the underlying causes and assessing the environmental benefits of composting in relation to landfilling. This understanding is vital in making meaningful conclusions and sustaining the decision-making process.

5.1. Overall Environmental Impacts

The graphs were generated in Microsoft excel Table 2 using the formula $(\text{Individual Case Value} / (\text{Case 1} + \text{Case 2})) \times 100$ to show each case percentage share of the total environmental impact. This visualization highlights the contribution of landfilling and composting to the overall environmental burden. The percentage reduction formula $((\text{Case 2} - \text{Case 1}) / \text{Case 1}) \times 100$ was applied to quantify the environmental benefits of composting compared to landfilling. This method, consistent with standard LCA practices, clearly illustrates the relative decrease in environmental impacts and supports transparent comparison between the two scenarios.

Table 2: Overall Environmental Impacts

Impact category	Case 1: Landfill disposal	Case 2: Compost	Total Impact (Case 1+Case 2)	Percentage Reduction of Impact by Compost (Case 2-Case1)/Case1 x 100
Abiotic Depletion (kg Sb eq)	2.440000336	0.394147361	2.834147696	-84.9%
Acidification (kg SO ₂ eq)	11626.2066	1756.431681	13382.63828	-80.6%
Eutrophication (kg PO ₄ - eq)	4663.36583	906.0173796	5569.38321	-78.0%
Fresh Water Aquatic Ecotox. (kg 1,4-DB eq)	134698.0303	29684.38638	164382.4166	-87.5%
Global Warming Potential (kg CO ₂ eq)	1284202.047	160773.4011	1444975.448	-81.9%
Human Toxicity (kg 1,4-DB eq)	226596.6871	40829.3548	267426.0419	-79.1%
Marine Aquatic Ecotoxicity (kg 1,4-DB eq)	366136037.1	76694268.74	442830305.9	-91.6%
Ozone Layer Depletion (kg CFC-11 eq)	0.035698687	0.003035527	0.038734214	-87.3%
Photochemical Oxidation (kg C ₂ H ₄ eq)	330.7567221	42.1611702	372.9178923	-78.0%
Terrestrial Ecotoxicity (kg 1,4-DB eq)	12248.48579	2692.065008	14940.5508	-84.9%

Comparing the two scenarios—composting (Case 2) and landfilling (Case 1)—shows that composting significantly improves environmental performance. The results confirm that composting is a more sustainable method of managing food waste, greatly reducing impacts across multiple environmental categories.

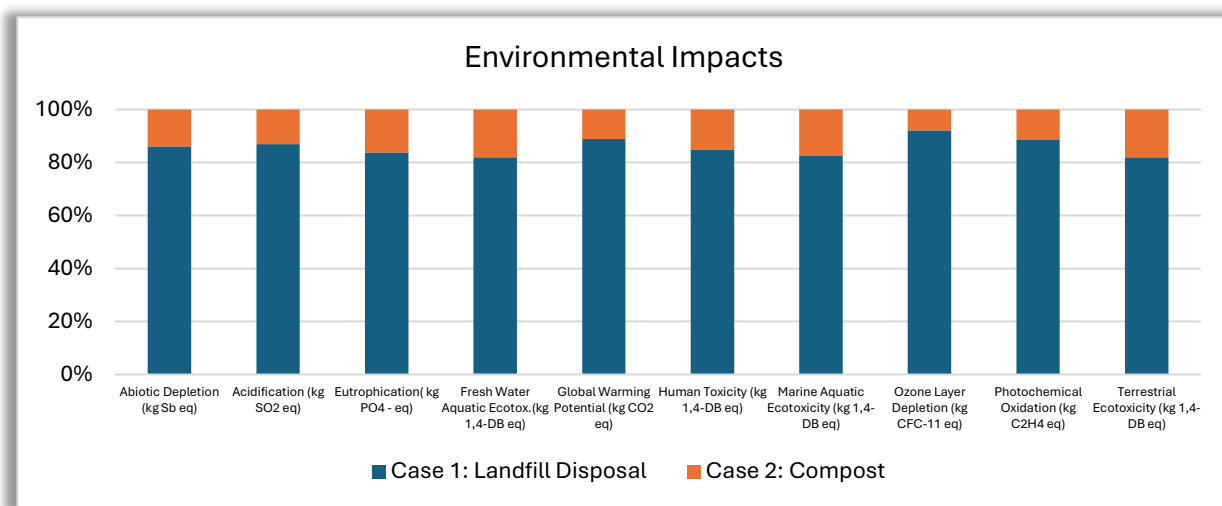


Figure 4: Overall Environmental Impacts

5.2. Abiotic Depletion

Abiotic depletion represents the use of non-renewable resources, expressed in kg Sb eq. In this study, composting (Case 2) recorded a value of 0.3941 kg Sb eq, significantly lower than landfilling (Case 1) at 2.44 kg Sb eq. This reduction indicates better resource conservation in composting, which requires less energy and raw material input than landfilling.

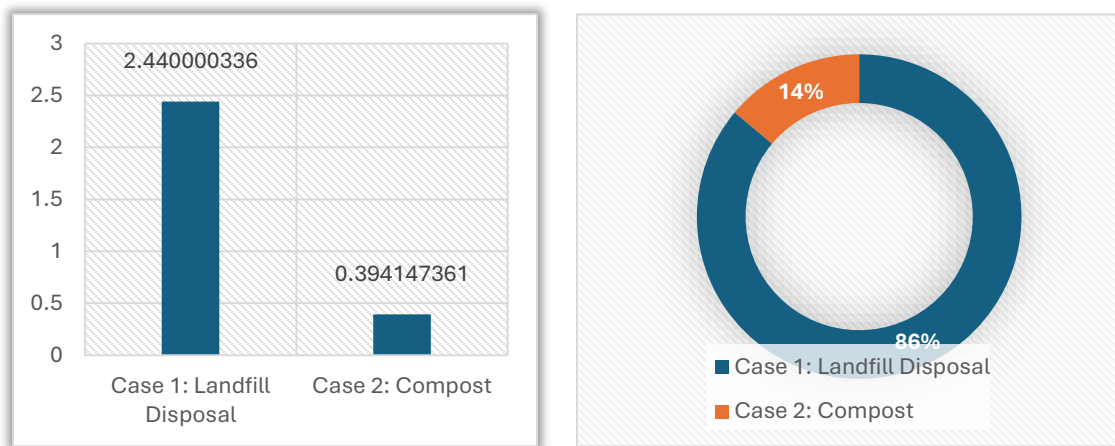


Figure 5: Abiotic Depletion (kg Sb eq)

5.3. Acidification

Acidification, expressed in kg SO₂ eq, measures the potential of air pollutants to cause acid rain and ecosystem damage. Composting recorded 1,756.43 kg SO₂ eq, much lower than landfilling at 11,626.20 kg SO₂ eq. This shows that composting emits fewer acidifying pollutants, helping reduce air quality impacts.

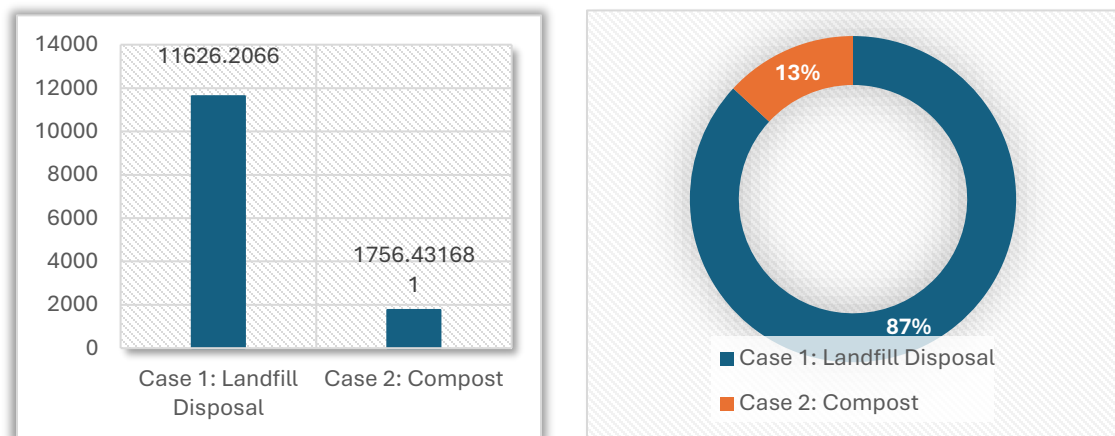


Figure 6: Acidification (kg SO₂ eq)

5.4. Eutrophication

Eutrophication refers to the excessive addition of nutrients to water bodies, causing algal blooms and oxygen depletion. The eutrophication potential for composting is 906.01 kg PO₄ eq, much lower than landfilling at 4,663.36 kg PO₄ eq. This reduction shows that composting minimizes nutrient runoff, helping protect aquatic ecosystems from pollution and imbalance.

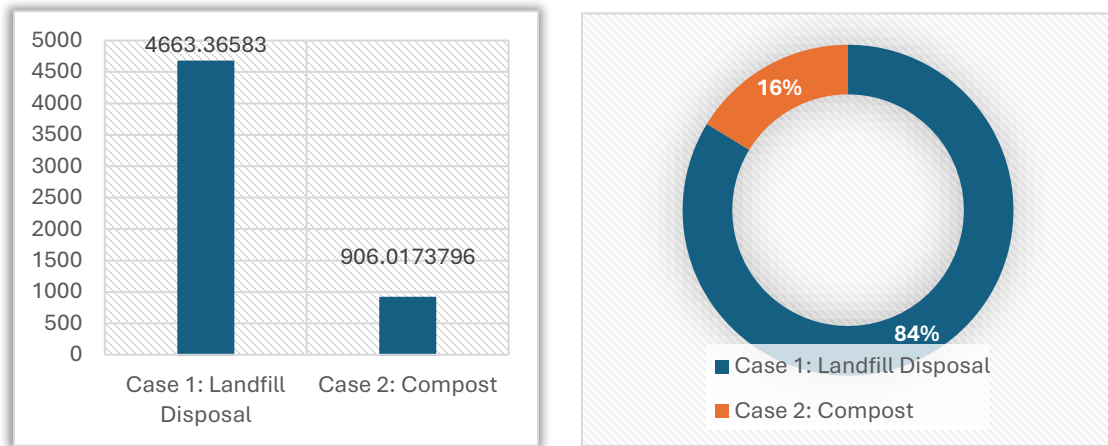


Figure 7: Eutrophication (kg PO₄ - eq)

5.5. Freshwater Aquatic Ecotoxicity

Freshwater aquatic ecotoxicity, measured in kg 1,4-DB eq, reflects the toxicity of substances to freshwater species. Composting recorded 29,684.38 kg 1,4-DB eq, significantly lower than landfilling at 134,698.03 kg 1,4-DB eq. This shows that composting reduces toxic discharges into water bodies, protecting freshwater biodiversity.

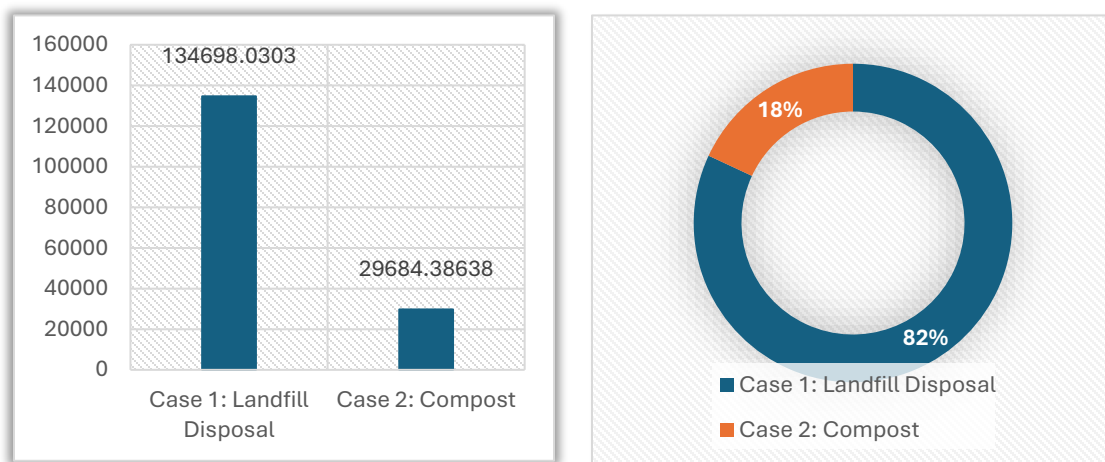


Figure 8: Fresh Water Aquatic Ecotox. (kg 1,4-DB eq)

5.6. Global Warming Potential (GWP)

Global warming potential, measured in kg CO₂ eq, represents total greenhouse gas emissions. Composting produced 160,773.40 kg CO₂ eq, far lower than landfilling at 1,284,202.04 kg CO₂ eq. This major reduction shows that composting effectively lowers greenhouse gas emissions and helps mitigate climate change.

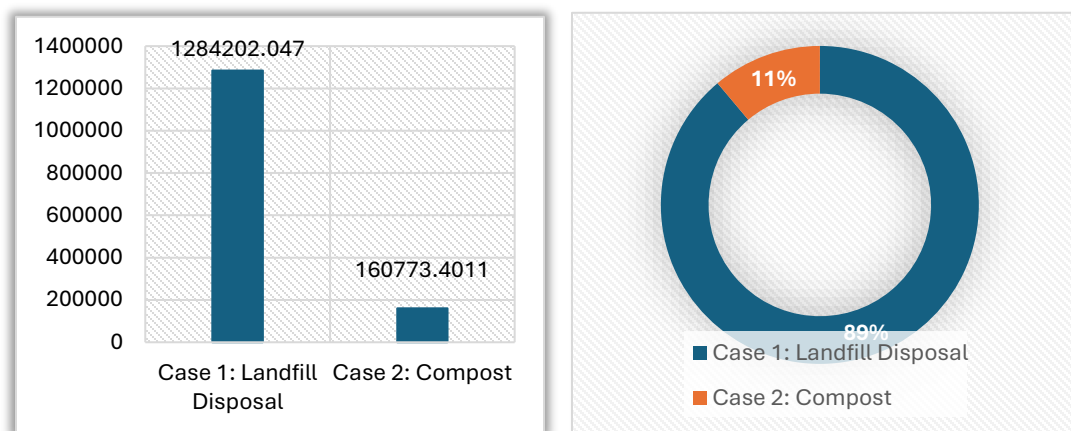


Figure 9: Global Warming Potential (kg CO₂ eq)

5.7. Human Toxicity

Human toxicity, measured in kg 1,4-DB eq, indicates potential health risks from toxic emissions. Composting recorded 40,829.35 kg 1,4-DB eq, far lower than landfilling at 226,596.68 kg 1,4-DB eq. This shows that composting releases fewer harmful compounds, creating safer conditions for human health and the environment.

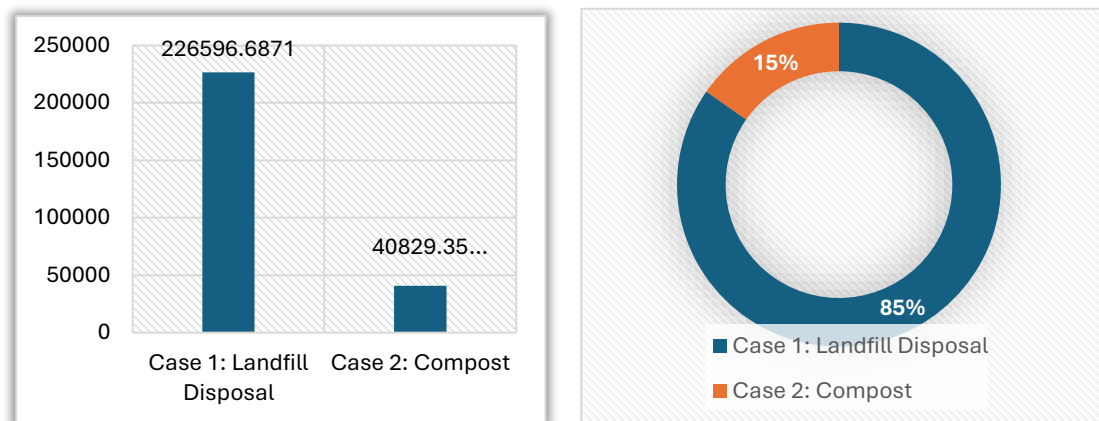


Figure 10: Human Toxicity (kg 1,4-DB eq)

5.8. Marine Aquatic Ecotoxicity

Marine aquatic ecotoxicity, measured in kg 1,4-DB eq, indicates chemical toxicity in marine environments. Composting (Case 2) recorded 36,613,603.7 kg 1,4-DB eq, markedly lower than landfilling (Case 1) at 76,694,268.74 kg 1,4-DB eq. This reduction shows that composting helps maintain cleaner oceans by limiting toxic discharges into marine habitats.

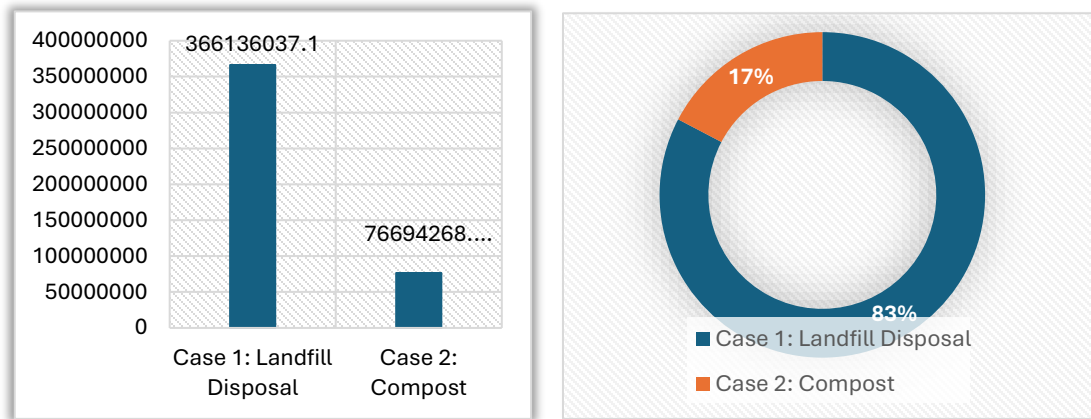


Figure 11: Marine Aquatic Ecotoxicity (kg 1,4-DB eq)

5.9. Ozone Layer Depletion

Ozone layer depletion, measured in kg CFC-11 eq, represents emissions that harm the ozone layer. Composting recorded 0.003 kg CFC-11 eq, slightly lower than landfilling at 0.035 kg CFC-11 eq. This shows that composting releases fewer ozone-depleting substances, helping preserve atmospheric integrity.

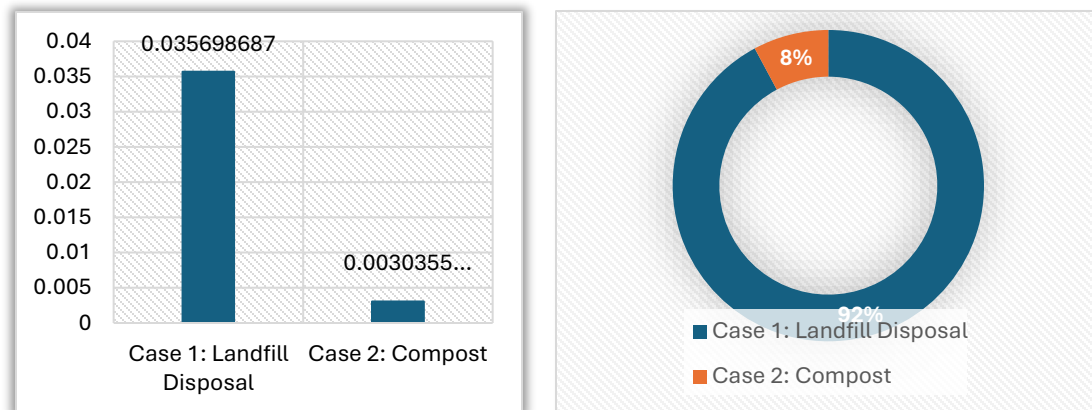


Figure 12: Ozone Layer Depletion (kg CFC-11 eq)

5.10. Photochemical Oxidation

Photochemical oxidation, or smog formation, measured in kg C₂H₄ eq, reflects emissions of NO_x and VOCs that create ground-level ozone. Composting generated 42.16 kg C₂H₄ eq, far lower than landfilling at 330.75 kg C₂H₄ eq, showing that composting effectively reduces urban air pollution.

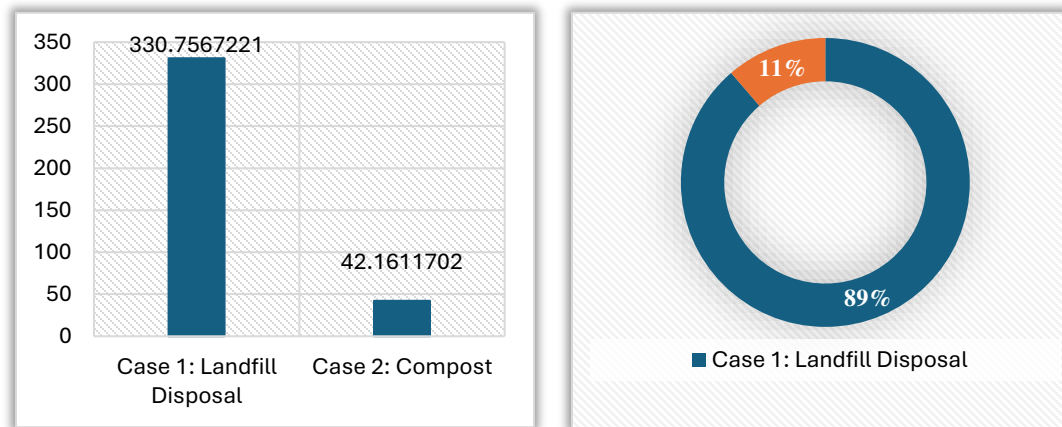


Figure 13: Photochemical Oxidation (kg C₂H₄ eq)

5.11. Terrestrial Ecotoxicity

Terrestrial ecotoxicity, measured in kg 1,4-DB eq, assesses chemical harm to soil environments. Composting generated 2,692.06 kg 1,4-DB eq, much lower than landfilling at 12,248.48 kg 1,4-DB eq. This shows that composting limits toxic releases, helping protect soil quality and terrestrial biodiversity.

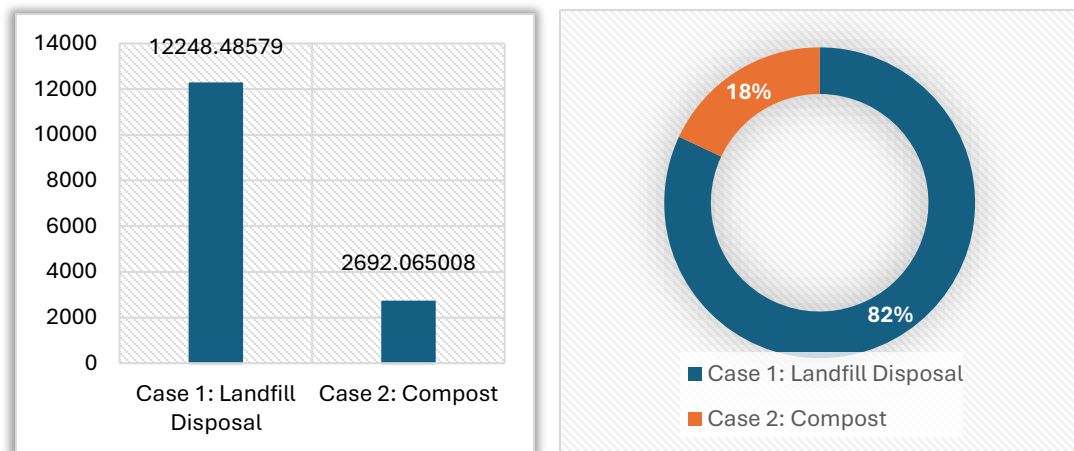


Figure 1: Terrestrial Ecotoxicity (kg 1,4-DB eq)

6. Conclusion

The analysis highlights that composting of food waste significantly reduces environmental impacts across all categories compared to dumping the food waste in a landfill. Composting not only mitigates GHG emissions and air pollution but also prevents water and soil contamination, demonstrating its environmental advantages as a sustainable waste management practice.

Beyond its environmental benefits, composting has also proven to be economically beneficial. By converting food waste into compost, save the landfill tax and waste transport trips. This

further reinforces the practicality and long-term viability of composting as an effective solution for both waste reduction and cost efficiency. The implementation of this project has yielded remarkable sustainability outcomes, including:

- 81.9% reduction in Global Warming Potential, substantially lowering carbon emissions.
- 80.6% decrease in Acidification, preventing acid rain and soil degradation.
- 78.0% drop in Eutrophication, minimizing water pollution and algal blooms.
- 87.3% decrease in Ozone Layer Depletion, helping protect atmospheric stability.
- 91.6% reduction in Marine Ecotoxicity, ensuring less contamination of aquatic ecosystems.

Furthermore, this initiative has yielded significant economic and operational benefits, such as:

- Lower landfill tax and fewer waste transport trips, improving logistical efficiency.
- Cost savings on solid waste disposal.
- Reduction in diesel consumption, cutting transportation-related emissions.
- Production of Nitrogen Phosphorous, Potassium (NPK)-enriched compost, utilized as natural fertilizer to enhance soil health.

These findings confirm that composting is not only an environmentally responsible approach but also an economically and operationally viable solution for sustainable waste management. The project has been recognized for its contribution to cost savings, resource optimization, and carbon offsetting, further reinforcing its value in promoting circular economy principles.

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