Food Waste Treatment and The Effect of Composting on The Gambia's Carbon Footprint

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Abstract. In The Gambia, about 35\% of food is wasted, making it the most significant contributor to municipal solid waste. Food waste presents unique challenges for conventional waste treatment techniques because of its high moisture, oil content, and changeable composition. Food waste is disposed of in landfills, significantly raising the carbon footprint and producing greenhouse gases. Two treatment methods successfully utilized to treat and manage leftover food are anaerobic digestion and composting. This study provides a brief overview of the effects of composting food waste on carbon footprint in The Gambia, paving the path for future research on the benefits of composting along with other food waste treatment methods including anaerobic digestion. It determined The Gambia's altered carbon footprint due to diverting food waste using carbon calculation over lifecycle version 2 (CCaLC2) software. Food waste composting lowered The Gambia's overall carbon footprint by 2.58 and 2.53 megatons of CO\textsubscript{2} in 2019 and 2020, which were accounted for roughly 20\% and 22\% of the country's total municipal solid waste footprint respectively. The carbon footprint statistics were compared to the data from Senegal, Nigeria, Guinea, and Sierra Leone to demonstrate the significant efficacy of composting in The Gambia.

Keywords: Food waste; carbon footprint; waste treatment; composting; anaerobic digestion; municipal solid waste management.

1 Introduction

Handling, storing, processing, distributing, and consuming are all parts of a food life cycle. During these procedures, food may become partially or even entirely unusable. Food waste is the term used to refer to these inedible components which should be disposed of properly. About 30\% to 50\% of municipal solid waste in The Gambia is made up of food waste, and the Food and Agricultural Organization (FAO) estimates that about 1.8 billion tons of food waste are produced annually worldwide [1]–[3]. The increase in global population coincides with a dramatic rise in food loss over time. In the supply chain, pre-consumption of waste occurs on farms during the production or processing stage, while out-production waste emerges from food leftovers in households [4]. Pre-consumption waste produced by Gambians is 2.73 Kg/day on average, more than 15 times the amount of food production [5]. In The Gambia, food waste has a quantifiable value of over US$10 billion annually, with 31\% of the nation's total food waste reportedly coming from domestic sources (waste generated on farms, during food processing, during consumption, during delivery and transit, at lodging facilities, during retail sales, and international catering) [3],

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[5], [6]. Although there is not much food processing in The Gambia, about 40% of the food produced artificially in The Gambia is wasted [7]–[9]. When food waste decomposes, methane which is 18 times more potent than CO2 is emitted, contributing to a significant change in carbon footprint [10]. Reducing food waste globally might decrease gigatons of CO2 by 2050 according to a project created by the Kanifing Municipal Council (KMC) [11], [12], claiming that it is the best individual option for combating global warming. This costly burden could be reduced by diverting food waste to temporary storage, processing, treatment, and recovery facilities, but prevention of food waste can only be done from its source [13], [14]. The majority of un-diverted waste is made up of organic waste. However, significant differences exist from the carbon footprint, waste generated worldwide, to global variant good production and consumption trends [1]. These wastes' biodegradation releases methane, carbon dioxide, and other greenhouse gas (GHG) emissions, and causes poor sanitation and abrupt climate change [15], [16].

An essential method of managing municipal solid waste is landfilling [17]. Unfortunately, this procedure harms the environment by depleting the land. It also contributes to greenhouse gas emissions and water source contamination from landfill leachate [15], [18]. The anaerobic breakdown of food waste in landfills produces methane (CH4). Methane is a greenhouse gas 25 times more potent than carbon dioxide when it is discharged into the atmosphere [19], [20]. The release of GHGs has significantly impacted the carbon footprint in terms of food waste footprint. Sub-Saharan African nations emit the most significant amount of CO2 compared to other African countries. North-American nations also produce a significant amount of CO2 in the world counted for 860 kg per capita per year [21], [22]. It is projected that The Gambia's initiative to cut the GHGs emitted in 2018 by at least 20% in 2050, which landfills generally produce, should be supported by decomposing organic waste [23]–[25]. Unconsumed food waste that is thrown away is classified as organic waste, as are non-edible scraps, biosolids, leaf and yard waste (sometimes referred to as "green rubbish") which includes grass clippings, yard, and garden debris, agricultural waste such as manure, and remnants of food [8], [26]. The overall volume of organic waste processed in The Gambia over the period of 5 years from 2017 to 2022 according to the national environment agency was 1.08 million tons while having a capacity of 2.18 million tons [3], [27]. Food waste prevention is one of the most effective methods for minimizing food loss and its negative environmental impact [28]. Using a food waste flow hierarchy, waste can be prevented, reduced, and disposed of in the most efficient and environmentally friendly manner possible [12], [29]. The Sustainable Development Goals (SDG) number 12 emphasizes waste avoidance which aims at diminishing food waste at the retail and consumer levels by 2030 and preventing resources (energy, nutrients, water, labour, etc.) from being used in food processing [3]. According to current studies, consumers' behaviour should be the focus of education initiatives concentrating on sustainable consumption and healthy lives [30], [31]. It is thought that eliminating food supports would yield a favourable impact on waste avoidance because along with prosperity and accessibility, food waste typically increases [20], [32]. However, this could severely impact the most vulnerable members of society. Following prevention are reduction and disposal which are the least preferred choices. Reduction in food waste is crucial for guaranteeing food security and decreasing environmental challenges. Bulk of food waste reduction initiatives relies on knowledge and communication to influence behaviour. Meanwhile, behaviour tactic measures like the elimination of food subsidies are being discussed [33]. These tactics include rapid, low-cost, and easy-to-deploy activities like round tables and information portals [33], [34].

Landfilling, composting, anaerobic digestion, heat moisture reaction, and incineration are some of the most frequently used techniques to manage food waste. The previous paragraph already describes landfilling. Incineration, also known as waste-to-energy (WTE)
conversion, can be applied for medical waste as well. It is particularly effective in reducing the volume of garbage from 85% to 90% and creates heat and energy that can be used to produce power [35]. Despite these benefits, food waste is less desirable for incineration due to its high moisture content, the release of toxic gases containing dioxins and heavy metals, as well as a hefty initial installation cost of the incinerator [31], [36]. In most African countries and Europe, around half of garbage is burnt [37] compared to about 10% in The Gambia [5]. Energy and nutrition recovery from food waste remain essential [14], [38]. For the treatment of food waste, there are numerous solutions for trash diversion and treatment including the 3R (reduce, reuse and recycle), composting, and waste banks [38]–[40]. The biological waste treatment process known as anaerobic digestion (AD) yields methane gas and digestate. Food waste contains organic and eco-friendly elements, making AD a superior option for treating it and producing power through minimal greenhouse gas discharges [41]. According to reports, AD can have 367 m³ of biogas per ton of food waste daily, yielding about 5.25kwh/m³ of biogas and 528 terra-watt hours of electricity [10], [42]. In nations like Germany, Canada, England, Denmark, and Austria, the number of biogas plants has increased by 20–30% as a result of these benefits [26], [37], [43]. On the other hand, high initial cost and drawn-out digestion process prevent its widespread application. Another easy and efficient way to address food waste is to compost it. Composting methods like windrow and tunnel are popular worldwide [44], [45]. Additionally, nutrients recovered by composting food waste can be applied to agricultural areas as fertilizer [23]. When organic waste (food waste) is composted, microbes break it down and turn it into valuable organic fertilizer [46], [47]. Composting food waste is becoming more popular in The Gambia. For instance, in 2018, more than 60% of Gambian households participated in this waste management method [7]. In addition to preventing and reducing GHG emissions, composting is more appealing due to its lower capital cost per ton of trash than AD and WTE [48].

Composting is the best way to lessen the environmental impact of landfills of food waste. By diverting extra organic waste, a waste disposal site or landfill site's lifespan can be slightly increased by at least 12 to 16 years [5], [49]. The effects of composting on food waste treatment and carbon footprint management in The Gambia, which is also thought to be an efficient means of preventing food waste, are investigated in this article. Until now, no study has been conducted in The Gambia that estimates the carbon footprint resulting from composting and food waste. Therefore, the study aims at providing a brief overview on the effects of composting food waste on the carbon footprint of The Gambia. The outcomes will be evaluated and compared to other countries that produce food waste. Using CCoL2 software, it will be possible to determine how the reduction in food waste will affect The Gambia's average composting statistics. The results will help make decisions and establish new rules for effective waste management in The Gambia, reducing the nation's vulnerability to climate change.

2 Methodology

2.1. Composting and Carbon Footprint

A person's "carbon footprint", commonly expressed in equivalent tons of carbon dioxide, is the total quantity of greenhouse gases produced from human activities directly and indirectly [50]. Composting is one technique for treating food waste that can help reduce carbon footprint [51]. Decomposition to form a compost is an aerobic, biological process which converts organic materials into a substance biologically stabilized by microorganisms [5], [23]. The proper ratios of carbon, nitrogen, and water must also be present in addition to oxygen to sustain the organic action required to break down the organic material. Under ultimate circumstances, composting procedure lasts several months
and has three distinct stages. The phases are separated based on the compost's temperature and the dominant existing microorganisms. The most prevalent microorganisms in composting are bacteria, fungus, and actinobacteria or also known as actinomycetes, despite being a complex habitat with many different biological creatures [50], [52]. A crucial factor in determining the effect on the overall carbon footprint is the GHGs released during food waste treatment. Reducing GHG emissions and lowering carbon footprint are connected [30]. The calculated carbon footprint shows how various treatment procedures affect the environment. By lowering the requirement for fossil fuels and artificial fertilizers, bio-fertilizers (composting and AD), biogas recovery, and energy production potential (landfill and AD) [12], [50] further minimize the carbon footprint [53].

2.2. Baseline Data
Since 2010, 61% of Gambians has participated in composting especially in Brikama. The two most frequently used types of composting in The Gambia are household waste (lawn and kitchen waste) and municipal waste. However, this section looks into only household waste and focuses on only kitchen waste, primarily food waste. The Gambia annual reports for food security from food safety quality directorate (FSQHED) were used to construct the baseline statistics for The Gambia. Brikama Area Council’s report mentions that between 2010 and 2020, the annual total amount of disposed garbage varied between 30.7 and 35.0 metric tons. The amount of rubbish out of landfills grew from 15 to 38% over that time [5], [27]. Because less organic waste is treated using methods other than a landfill to dispose of food waste, composting has become a choice to process the out-of-landfill organic waste. Furthermore, the total quantity of food waste that was kept out of dumpsite and landfills was calculated using the average Gambian composting percentages. This data collection was a part of the Households and the Environment survey [5].

2.3. Carbon Footprint Calculation
Numerous forms of computer software have been tried and used throughout the waste lifecycle to calculate the carbon footprint. It is also calculated using several methods considering many factors including consumption decisions and energy-related activities [1], [2], [50]. The carbon footprints produced from landfilled organic waste were calculated in this study using a unique piece of a computer program known as carbon calculation over lifecycle version 2 (CCaCL2). In addition, five countries’ 2018 and 2019/20 total food waste and its associated carbon footprint were evaluated (Table 1). Food waste will be buried as it is a bio-degradable waste. The emission of carbon from burnt fossil fuel in the process of waste transportation was not considered, though, as this footprint of carbon already existed with landfilling, and waste diversion by composting does not increase or reduce CO2 emission because of transportation of waste.

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<tr>
<td>Guinea</td>
<td>2.71</td>
<td>4.10</td>
<td>6.81</td>
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The sum of carbon footprint is presented in Table 2. The software used to do the calculation allows users to enter the amount of garbage (in Kg) and choose the biodegradable waste to calculate their carbon footprint. This approach was used to calculate the carbon footprint in all kinds of food waste in The Gambia, independent of the trash composition.
Table 2. Total carbon footprint in five countries.

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3. Results and Discussion
3.1. The Effect of Composting on The Gambia’s Carbon Footprint

10 mega-tons of GHG or methane emissions from buried organics in The Gambia are to blame. The most significant percentage of organic waste among the Gambian provinces was found in western health region 1- Brikama and the surrounding-, making up 32% of all waste created [23]. It will be possible to reduce GHG emissions and, as a result, the carbon footprint as well if these organic materials can be kept out of landfills [43]. Composting was more prevalent in The Gambia than other waste disposal techniques. Incredibly, The Gambia treated 45% of its household waste through composting. The western region 1 composted the most kitchen trash (95%) and was closely followed by western region 2 (94%). The most significant region in terms of population was western 2, where only 62% of kitchen trash was composted [9]. From Table 3, it was discovered that lower river region created the most diminutive carbon footprint for roughly 0.000046, and western 2 produced the maximum amount which was 0.316 mega-tons in 2020. Several comparisons have highlighted the differences in operational expenses between composting and landfilling. Landfilling is more expensive than simple composting methods like backyard composting [54].

Compared to landfilling which emits powerful GHGs, composting emits minimal carbon dioxide. Composting also results in the production of beneficial compost which increases how affordable the procedure is. As a result, composting is preferable to landfilling from economic and environmental standpoints [5], [55]. However, the trash used for composting determines the type of compost produced at the end of the composting process. The quantity and ratio of carbon to nitrogen (C:N) in the soil, as well as aeration, temperature, and moisture, also affect the quality of compost and the amount of time needed to complete the composting process [17]. Similarly, several waste parameters including the amount of organic matter, the C/N ratio, the pH, and the nutrients affect the compost value [2], [10]. Additionally, if a composting process is mechanical, other elements can impact it. An automated composting process, for instance, can be affected by processing parameters like temperature difference and processing duration [56].

The effect of composting on lowering carbon footprint is clearly shown in Table 3. In The Gambia, the average amount of organic waste diverted to composting facilities decreased by 1.38x106 and 1.3x106 tons of CO2 equivalent in 2019 and 2020, respectively, roughly 20% and 18% of all the domestic solid waste disposed of throughout those years. As a result, composting decreased the overall carbon footprint according to the CCaLC2 software even without accounting for the amount of carbon emissions produced during the shipping process in 2019 and 2020 for as much as 18%-20%.

Table 3. Calculation of the carbon footprint from organic waste in The Gambia using CCaC2.

|--------------|--------------------------------|----------------------------------------|

In The Gambia, composting is utilized far more frequently than anaerobic digestion or AD. Given that The Gambia only has one AD facility, the fact that 45% of typical Gambian kitchen waste gets composted shows how reliable this method is for diverting and treating food waste likewise in Liberia and Senegal [48], [57], [58]. Referring to Table 4, The Gambia has been producing some sizable quantity of municipal solid waste within the year, and the rate has been increasing each year. Even though less food waste is produced per person each day, the amount that gets composted remains the same. Moreover, several projects including the imposition of organics disposal bans, the beginning of food donation incentives, and the imposition of additional control over the donation programs throughout The Gambia [59], [60] are lowering the total amount of food waste and help to promote composting.

### 3.2. Comparing The Effectiveness of Composting in The Gambia and Other Countries

Composting and open burning have been the primary method used to handle organic waste in nations like The Gambia where landfilling is the most common way of garbage disposal [5]. Senegal, Nigeria, Guinea, and some African nations have also adopted composting (Table1). Figure 1 shows the carbon footprint calculated using information from five countries (Senegal, The Gambia, Nigeria, Liberia, and Sierra Leone). This graph shows how composting has helped The Gambia reduce its carbon footprint. In The Gambia, composting has had a higher impact on reducing carbon emissions than in the other countries mentioned. Even though the Nigeria and Senegal produce far more waste than The Gambia, most of it is landfilled rather than composted. As a result, composting has a less noticeable effect on the carbon footprint. Comparatively, carbon footprint is more highly reduced by composting in Guinea and Sierra Leone than in The Gambia. In Guinea, 16% of garbage is dumped in the ground, and 38% is burned. The fact that most of the remaining 42% of waste is recycled suggests that composting is rarely done with this waste. Similarly, only a small portion of waste is sent to a composting plant in Senegal and Nigeria. Instead, most of the trash there is treated using AD and recycling. As a result, it is shown that The Gambia has a much more significant influence on the environment than the other countries. This is primarily due to The Gambia's absence of sophisticated waste treatment techniques which other African countries, USA, Canada and other European countries commonly employ like anaerobic digestion and cremation [48], [60]–[62]. Additionally, numerous villages in provincial Gambia have promoted and started composting. Numerous studies have emphasized The Gambia's potential for collecting biogas through food waste processing. For example, Bagie et al. found that in The Gambia, 2 megatons of food waste treated using AD may produce 2.2x10³ m³ of biogas [11]. Similar to this, The Gambia's biogas collecting sources may produce 210 megawatts (MW) of power according to the Gambian Biogas Association. The agricultural industry, which generates roughly 38% of the total biogas, may be the main contributor to this electricity production. Other significant sources, at 12% and 6% respectively, are source-separated

<table>
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<th>Western Region 2</th>
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<th>North Bank West Region</th>
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<th>Central River Region</th>
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<td>16,272</td>
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**Table 4:** Municipal Solid Waste Generation in The Gambia (2021) (in megatons)
organics (SSO) from domestic sources and landfill gas or organic waste collected separately from other MSW [5], [61].

Fig. 1. Reducing carbon footprint through composting in 5 West-African countries.

3.3 Formatting of Mathematical Components
The carbon footprint in this comparison research is solely calculated using composting data. A few anaerobic digestion and incinerator units now in use in The Gambia to treat food waste are not included in the data. The entire amount of food waste generated is calculated using the amount of garbage that has been composted for as much as 45% [41]. Additionally, the carbon emissions from the vehicles utilized to transport waste from homes to temporary storage facilities, transfer stations, or segregation and treatment facilities are not considered when calculating the reduction in carbon footprint. As a result, a slightly increased estimate of carbon footprint savings is made. Additionally, the effect of the waste management and treatment techniques like anaerobic digestion and incineration should have been considered in this study. The Gambia has a higher potential for biogas production because the country has significantly more food waste, and composting has become the most prominent method in waste management. These facts were supposed to have a favourable effect on the overall greenhouse gas reduction and carbon savings.

4. Conclusion
Food waste can be directed toward various food waste treatment facilities rather than being dumped, allowing it to be transformed into usable biomethane and compost. This study evaluates how different methods of handling food waste affect carbon emissions, with composting as the central area of attention. Additionally, less waste means a smaller carbon footprint leading to a smaller and lesser effect on the environment. The results indicates that composting and open burning are the most widely and favourable waste management techniques in The Gambia which clearly take the lead in carbon footprint reduction and are potentially used as a comparison to methods used in the carbon footprint reduction in other West African nations like Nigeria, Sierra Leone, Senegal, and Guinea.

According to research on the effectiveness of compost as a substitute for chemical fertilizers, the amount of digestate or compost dramatically changes depending on the make-up of the waste source. Additionally, several studies have shown that The Gambia's biogas collecting plants have a high potential for energy generation and collection of biogases, which is favourable for further research and development. There is a significant
gap in the research on how composting affects GHG emissions though and needs to be further studied. Additionally, the widespread use of anaerobic digestion in Europe and its many benefits may persuade The Gambia to invest in anaerobic digestion facilities. This can drastically lower the formation and emission of GHGs and reduce the carbon footprint. However, the absence of national, regional, and territorial statistics makes it difficult to comprehend the current state of organic food waste in The Gambia. To accurately estimate CO2 emissions and construct a regulation or help in the decision-making process geared towards reducing The Gambia’s carbon footprint, access to relevant food waste data is necessary.

**Acknowledgment**

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