Special Issue: Comparative assessment of compositing and anaerobic digestion of municipal biodegradable waste in Harare, Zimbabwe

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Abstract

Composting and AD of biodegradable waste were assessed for their benefits from literature and environmental impacts using the life cycle impact assessment procedure. Literature review findings indicate an overall edge for AD over composting largely due to its renewable energy production capabilities, reduced exhaust emissions and cost effectiveness considering the entire MSW life cycle. LCIA results show that both AD and composting leads to increases across the four impact categories considered namely, global warming, human health, eutrophication and acidification. AD however showed lower contributions than composting to global warming, human health and acidification. Composting only showed lower contribution than AD in regards to eutrophication. Overall study results indicate an edge for AD over composting in treating and managing biodegradable fraction of MSW generated in Harare and its surrounding urban and peri urban environments of Chitungwiza, Epworth, Norton and Ruwa.

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Novelty or Significance

The biodegradable waste fraction of MSW generated in Harare City and its surrounding urban environments is estimated at 196,267 tons per annum. Only 60% is indiscriminately collected and dumped at non-engineered and unsanitary dumpsites. The uncollected 40% is illegally dumped in undesignated areas. Therefore environmental and human health challenges prevail manifesting themselves in eutrophication, greenhouse gas emissions and acidification together with the outbreak of water borne diseases such as Cholera and Typhoid. Simapro based LCA findings will aid and inform the design and development of future sustainable and integrated biodegradable waste management in Zimbabwe and other regions experiencing similar municipal biodegradable waste management challenges considering the universal and reliability nature of Simapro results capable for regionalization and expansion.

Keywords

Life Cycle Assessment, sustainable, compost, biogas, digestate

1. Introduction

Globally, biodegradable waste landfilling has been getting attention and increasingly becoming a concern [1]. Composting and Anaerobic Digestion (AD) have largely been identified to be viable and sustainable alternative biodegradable waste management and treatment methods. The annual Municipal Solid Waste (MSW) generation rate for Harare is estimated at over 460,000 tons per annum [2-5]. Despite the global concern on biodegradable waste landfilling, currently an estimated 60% of the MSW generated in Harare, Zimbabwe, is indiscriminately collected and dumped at Pomona dumpsite and 42% of this is biodegradable waste amounting to over 100,000 tons/annum [6-9]. The remaining 40% is dumped illegally threatening the environment and health of residents. The life span of Pomona dumpsite on the other hand is expected to reach its end in 2020.

Composting entails the aerobic degradation of biodegradable waste to produce compost. The compost is used as a growing media component and biofertiliser or soil enhancer. Composting has received interest over the past two decades as a solution to current challenges in regards to the management of biodegradable waste fraction of MSW [10-13]. Such challenges include but not limited to increased amounts of wastes (volume and weight) sent to landfills threatening land availability and greenhouse gas emissions especially methane from degradation of biodegradable waste fuelling global warming or climate change. Three composting methods exist namely windrow with turning, in vessel and aerated static pile [14].

AD or biomethanisation is the anaerobic degradation (in the absence of oxygen) of biodegradable waste to produce biogas (45-80% methane) and digestate (biofertiliser). It combines a series of four steps namely hydrolysis, acidogenesis, acetogenesis and methanogenesis where microorganisms anaerobically digest biodegradable matter hence its appropriateness use for domestic and industrial scale biodegradable waste treatment and or energy and biofertiliser production. AD is classified under three categories namely; single stage continuous systems (low-solids or wet and high solid or dry), multi stage continuous systems (dry-Wet and Wet-Wet) and batch systems (one stage and two stage). The AD operation temperature range, either mesophilic or thermophilic, is the determinant parameter for reactor type selection.

AD technologies have largely been applied in wastewater treatment plants and its potential use for commercial level treatment of biodegradable fraction of MSW due to its potential in producing renewable energy (biogas) and reducing the volume of MSW to be landfilled has been investigated and found to be technically and perfectly (economically, socially and environmentally) feasible. Fagerström et al [15] described AD as a multiple purpose system that combines renewable energy production, biowaste management and treatment, Greenhouse Gases (GHG) emission reduction process, a surface and groundwater quality conservation means and a biofertiliser production method through nutrient mineralization. The International Energy Agency [16] reported that there were over 150 operational AD plants whose principal feedstock were biodegradable fraction of MSW or industrial waste.

The composting and anaerobic digestion of biodegradable MSW fraction as compared to landfilling leads to reduced GHG emissions and amount (weight and volume) of MSW landfilled. The reduction in GHG emissions emanates from avoided landfill emissions, reduced use of water, synthetic fertilisers and herbicides. Composting is capable of handling different organic waste materials namely, food waste, tree branches, leaves, wood waste, grass and AD digestate depending on compost facility design and its associated applied technology. However for growing media and soil enhancer or biofertiliser production, source separated biodegradable fractions of MSW (kitchen and/or garden and park waste) and materials separation during the entire composting is required to limit compost contamination with glass, plastic, heavy metals and organic pollutants to minimum levels [17].

Until recently source or mechanically separated biodegradable fraction of MSW could be used as feedstock for AD of MSW because AD has been a single substrate and purpose biodegradable waste treatment technology [18]. The increased understanding and knowledge of the limits and capabilities of AD has standardized the simultaneous AD of a homogenous mixture of two or more biodegradable waste types. Therefore source or mechanically separated biodegradable fraction of MSW could be co-digested with other biodegradable waste from other waste streams such as sewage, animal manure and plants. Co-digestion improves the balance of nutrients from various substrates thereby helping maintaining reliable and stable AD performance guaranteeing the production of a digestate of good organic fertilizer quality. It also provides for the optimization of the rheological qualities of biodegradable wastes of poor fluid dynamics (aggregates, particulate, bulk materials and floating wastes) to be digested easily post homogenization with watery substrate like liquid manure or sewage sludge. Co-digestion increase biogas yields of AD of manure when mixed with co-substrates of high methane potential since manure has relatively low biogas yield potential making its biogas production economically not feasible considering the prevailing prices of fossil fuels (Braun and Wellinger, 2003). However the AD plant objective determines the nature and quality of the biodegradable feedstock. As mentioned earlier if the plant objective is to maximize biogas production then co-digestion of mixed biodegradable waste streams becomes appropriate. On the other hand if plant objective is the production of a high quality digestate, the quality and purity of the biodegradable waste feedstock becomes crucial.

Composting produces compost while AD produces biogas, digestate and liquid fertiliser. The compost is used for landscaping purposes, for agricultural and horticultural applications as a biofertiliser and for soil improvement. Digestate can be in the form of the entire AD sludge or separated semi-solid and liquid phase that has been sanitized and aerobically stabilized post AD. The digestate could also be composted properly not by mere aerobic maturation to produce compost depending on its intended use. The liquid product from an AD process is predominantly recycled within the process and any extra could be used as liquid fertiliser if its quality is deemed fit for purpose or use. The digestate from AD and compost from composting and AD have almost similar uses largely in the agricultural sector as organic fertilisers. Therefore composting and AD are appropriate in Zimbabwe considering its agro based economic status. The biogas is burnt in generators to produce renewable electricity and or heat. Renewable electricity and heat is concurrently produced when the biogas is burnt in combined heat and power (CHP) generators. The production of electricity from MSW will be a welcome development considering the energy challenges facing Zimbabwe and its urban environments. The biogas may be further refined into methane to fuel vehicles.

The increasing concern on biodegradable waste landfilling and interest in the development of Low Emission Development strategies (LEDs) together with the imminent closure of Pomona dumpsite calls for the need to redesign future management and treatment options for biodegradable waste fraction of MSW generated in Harare city and surrounding per urban and urban environments. This entails the identification of opportunities together with potential sustainable solutions for managing and treating the biodegradable waste fraction that is being currently indiscriminately dumped at Pomona as well as that which is part of the 40% that remain uncollected and illegally dumped. The identification of the best sustainable biodegradable waste management and treatment method between AD and composting is vital in contributing to the development and implementation of LEDs in light of Zimbabwe‘s National Determined Contributions (NDCs) commitment regarding greenhouse gas emission reduction. This study thus is a literature review and Life Cycle Assessment (LCA) based comparative assessment of the sustainability of composting and AD of biodegradable waste fraction of MSW generated in Harare.

2. Materials and methods

Literature review and LCA based comparative aassessments of composting and AD of the biodegradable fraction of MSW generated within the urban and peri urban environments of Harare metropolitan province namely Harare city, Chitungwiza, Ruwa, Norton and Epworth were carried out. Data for population and municipal biodegradable waste (daily per capita generation and biodegradable waste composition) was taken from literature sources.

2.1. Population and MSW data

Population data gathered indicated that these urban and peri urban environments have an estimated population of 2,133,802 people [19]. Data from six literature sources gathered [2,4,5,20-22] was used to estimate the average daily per capita MSW generation of 0.6 kg as shown in Table 1. Therefore with a daily per capita MSW generation rate of 0.6kg, 467,303 tons of MSW are generated per annum within the study area. An average composition of biodegradable waste of 42% was estimated based on figures observed and reported from five studies and data sources [7-9,23,24] shown in Table 1. Therefore 196,267 tons of biodegradable waste is projected to be generated in the study area per annum.

2.2. LCA of composting and AD

LCA is a tool that could be used in the design and development of innovative strategies with appropriate and sustainable MSW management methods. Sustainable MSW management entails efficiency in environmental protection, economic viability and social acceptability. LCA methodology is crucial in identifying MSW management strategy with the least environmental impacts potential thereby guaranteeing sustainability in regards to efficiency in environmental protection.

LCA was carried out to compare and analyse the environmental impacts of AD and composting biodegradable waste fraction of MSW generated in Harare and its surrounding urban and peri urban environments of Chitungwiza, Epworth, Norton and Ruwa in Zimbabwe. The environmental impacts analysed were human health, acidification, eutrophication and global warming impact potentials because their effects are currently being experienced in the study area.

The LCA was performed using version 8.5.2 of SimaPro software analyst and update852 database with Ecoinvent 3 database (2018) providing the environmental loads for waste collection and transportation, composting and AD materials and processes. Simapro was used because it has been applied widely for LCA studies, it is standardized making results universal and reliable and capable for analyzing complex waste management scenarios due to parameterized modeling, weak point and interactive results analysis utilizing process tree [25,26]. ReCiPe 2016 v1.02 endpoint method, Hierarchist version the default ReCiPe endpoint method was used for Life Cycle Impact Assessment (LCIA) for all the materials and processes under waste collection and transportation, composting and AD of biodegradable waste fraction of MSW. The ReCiPe 2016 method is the latest version of ReCiPe 2008 created by RIVM, Radboud University, Norwegian University of Science and Technology and PRé Consultants [27,28].

All the materials and processes involved in the composting and anaerobic digestion of biodegradable waste together with composting and AD products treatment formed part of the LCA system boundary. The collection and transportation of biodegradable waste generated in Harare and its domitory towns managed by or on behalf of the respective local authorizes was also part of the LCA system boundary under a source separation basis. The annual biodegradable waste generation for Harare and its dormitory towns was considered the LCA functional unit as having been applied by Cherubini et al [29] and Fernández-Nava et al [30] in their studies.

Waste transportation was modelled for 5,887,980 tkm (tons-kilometres) for municipal waste collection service by 21 ton lorry. MSW anaerobic digestion and composting were modelled for 196,267 tons of biodegradable waste per annum. For AD an average biogas yield of 115m^3/ton [31] of biodegradable waste digested was assumed resulting in 22,570,590m^3 of biogas produced per annum. Both processes included process energy demand, emissions and needed plant infrastructure. The composting and AD inventories applied data from the Ecoinvent 3 database with a true together with transparent assessment of its data quality modelled under Simapro 8.5 for the rest of the world.

3. Results and discussion

The comparative advantages and disadvantages of composting and AD from literature are illustrated in Tables 2 and 3 respectively.

Literature review on the comparative advantages and disadvantages of composting and AD indicate an overall edge for AD over composting biodegradable waste fractions of MSW largely due to its renewable energy production capabilities, reduced exhaust emissions and cost effectiveness considering the entire MSW life cycle. The edge of AD is attributed to its renewable energy production capabilities, reduced exhaust emissions and cost effectiveness considering the entire MSW life cycle. This is however despite its considerable smaller market share compared to composting. The interests AD is getting and its edge over composting are however anticipated to increase AD market share in the near future.

The production of organic fertilisers with potential for use in the agricultural sector could possibly transform the Zimbabwean agricultural and horticultural sector. The digestate from AD are not suitable for direct land application due to their odours, high water content and concentration of phytotoxic volatile fatty acids. Also the digestate from mesophilic AD operation is considered not sanitized unlike digestate from thermophilic AD operation which is regarded sufficiently sanitized and hygienic. Therefore either one of the following four approaches is recommended to deal with digestate sanitation issues. Operation at 55°C maintained for 24 hours daily for a minimum residence time of 20 days for thermophilic AD operation. For mesophilic AD operation substrates pre-treatment for one hour at 70°C or digestate post treatment for one hour at 70°C or composting of digestate as recommended by Walker et al [32].

LCIA results also revealed that both AD and composting leads to increases of all the four impact categories considered. AD however contributes to less increase than composting to global warming, human health and acidification with composting only contributing less than AD in regards to eutrophication as shown in Figure 1 and Table 4.

The global warming potential impact assessment results confirm findings by Rajaeifar et al [33] and Hong et all [34] that in comparison with AD, overaly composting has more global warming impact potential. Fernández-Nava et al [30] also observed that biomethanisation (AD) is better than other biowaste treatment methods as it does not require significant outside power supply largely from fossil fuels due to its capacity to generate electricity and heat from the biogas a renewable energy it produces. Evangelisti et al [35] concluded that AD emerges to be best biodegradable waste treatment option in regards to total carbon dioxide and sulphurdioxide

saved, when biogas (renewable electricity and heat) and bio-fertiliser substitute fossil fuel derived energy (electricity and heat) and inorganic fertilisers. It is however worth to note as noted by Mendes [1] that incorporating composting of biodegradable waste fraction to a MSW management strategy contributes to reductions in global warming impact potential.

In regards to human health Yay [36] observed that composting biowaste fraction of MSW has the potential of reducing the human health impact compared to its landfilling and incineration indiscriminately with other MSW. Rajaeifar et al [33] analysed the impacts of MSW incineration combined with composting and AD of biowaste fraction in Iran and found incineration combined with AD to be the most sustainable MSW management. This is therefore consistent with the findings from this study. Composting emits carbon dioxide, ammonia, nitrogen oxides, oxides of sulphur and particulate matter thereby contributing immensely to human health impact category. The contribution of the AD process to the human health impact category emanates from the Combined Heat and Power Generation engine emissions which are far less than the emissions from composting process.

Study results show that the composting of biodegradable MSW fraction leads to increased acidification potential than AD confirming findings by Mendes [1] and report by Evangelisti et al [35] that AD is a favorable option for managing biodegradable fraction of MSW. The lower contribution to eutrophication of composting than AD observed in this study confirm findings by Bernstad and la Cour Jansen [37] and Mendes [1]. Bernstad and la Cour Jansen [37] showed that AD with recovery of energy and digestate use as biofertiliser substituting inorganic fertilisers lead to a net increase in its contribution to eutrophication. Mendes [1] on the other hand noted a reduction in eutrophication impact potentials from composting biodegradable waste fraction of MSW.

4. Conclusion

The study revealed AD as the best overall treatment and management method for the biodegradable fraction of MSW generated in Harare and its surrounding urban and peri urban environments of Chitungwiza, Epworth, Norton and Ruwa. Therefore AD must be holistically considered as a waste management strategy, an avenue towards improving renewable energy supply, increasing agricultural and horticultural productivity due to biofertiliser use in the form of digestate and or compost use, reducing Greenhouse Gases (GHG) emissions in line with the National Low Emission Development strategy and conserving both surface and groundwater quality.

5. Declaration

5.1. Competing interests

No competing interests are declared by the authors.

5.2. Funding

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6. Literature Citation

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