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REVIEW PAPER

# Applicability of the Life Cycle Assessment Model in Solid Waste Management in Zimbabwe

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## Abstract

Solid waste increase is inevitable globally due to anthropogenic activities. This adds burden to waste management systems in developing countries including Zimbabwe. Currently, life cycle assessment (LCA) model is used to achieve sustainability and circular economy (CE) in solid waste management. Therefore, the main goal of this paper was to unearth LCA model applicability in solid waste management in Zimbabwe. Data sources were retrieved from databases like Scopus, ScienceDirect and Springer, although government documents were also used. In Zimbabwe, organic and inorganic solid waste is generated from various sources, namely industries, institutions and households. Solid waste management in Zimbabwe is based on traditional linear approach where waste is collected and disposed through landfilling, burning, incineration, burying, open pits or illegally. Most disposal approaches occupy base of waste management pyramid, hence posing detrimental impacts to human health, terrestrial, aquatic and atmospheric ecosystems. Management approaches are far from Agenda 21, Sustainable Development Goals (SDGs), Zimbabwe Vision 2030 and National Development Strategy 1 demands. Literature revealed that LCA model can be utilised to achieve sustainable solid waste management in countries like Zimbabwe. LCA model is essential in management of solid waste in Zimbabwe, since it assists decision makers in selecting management approaches with less environmental health impacts. Moreover, LCA enables application of waste material reuse, recycle, repairing and recovery, thus narrowing the gap to achieve CE and economic growth in Zimbabwe. Owing to LCA model implementation of waste management legislation and policies which support energy recovery and circular economy became easier in Zimbabwe.

**Keywords** Life cycle assessment · Solid waste · Solid waste management · Zimbabwe · Environmental impacts · Circular economy · All authors have read · Understood

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## Introduction

Generation of solid waste is an unavoidable natural consequence of anthropogenic activities worldwide [35, 111]. This implies that production and increase of solid waste is driven by human existence. Godfrey et al. [30] and Cudjoe and Acquah [21] opined that African countries are facing solid waste management crisis translating to various environmental health problems. In Africa, constraints in management of solid waste are ascribed to socio-economic and political problems [21, 35]. Consequently, Zimbabwe is also facing numerous problems in management of solid waste, since it is not spared by regional problems. According to Mandevere and Jerie [66] and Chikowore [15], solid waste management is among problematic issues confronting Zimbabwe. Therefore, it needs to be dealt with considering economic, social, environmental and political aspects to achieve sustainability. In the Zimbabwean context, increase of solid waste is attributed to urbanisation, population increase, disease outbreaks and better living standards [55, 66]. However, in the Zimbabwean context, solid waste increase is exerting pressure to humanity and already fragile environment.

In Zimbabwe, solid waste is generated from institutions, manufacturing and construction industries, supermarkets, households and streets among other sources [55, 109]. This revealed that various types of solid waste which may include hazardous and non-hazardous waste are produced in Zimbabwe and hence need attention. Existence of several waste types facilitates disposal of solid waste using numerous approaches, namely incineration, landfilling, open dumpsites, burning and open pits [40, 41, 58]. However, most of the approaches used occupy the base of the waste management hierarchy and hence have potential to cause environmental problems. In a view upheld by Makarichi et al. [62] and Nhubu and Muzenda [83], Zimbabwe's mismanagement of solid waste is associated with water, air and land pollution while threatening human life. Henceforth, it is clear that solid waste management standards in Zimbabwe are far from reaching requirements of Agenda 21, Chapter 21 and current Sustainable Development Goals. Management of solid waste particularly disposal of waste is emerging as a problem due to solid waste increase and Not In My Backyard Syndrome in Zimbabwe [44, 103]. Jerie and Tevera [44] highlighted that public resistance is ascribed to their awareness that solid waste management stages to cause health risks and soil, air, water and land contamination. This means Zimbabwean municipalities must move away from linear traditional waste management approaches which focuses on collection to disposal.

In order to achieve sustainable waste management in Zimbabwe, solid waste must be managed following most desired approaches on the waste management hierarchy which prioritises prevention, recycle and recovery [64, 65],Mahamba, 2015). Consequently, the country must adopt solid waste management hierarchy philosophy's apex which put much emphasis on waste prevention to safeguard the environment and human health. According to Yadav and Samadder [113] and Yadav and Samadder [115], in order to adopt most desired approaches of waste management hierarchy, a number of techniques may be utilised. Therefore, evaluation of solid waste management options is required to unearth performance towards the environment. Evaluation and determination of the most sustainable strategy of solid waste management system can be carried out through life cycle assessment model (LCA) [5, 71, 116]. LCA model presented to be effective in implementing appropriate solid waste management in nations such as Brazil [19]. LCA supports circular economy which insists the issue of waste reduction and redesigning of solid waste materials and therefore facilitates sustainable waste management in Asian countries [3] and Romania [29]. As a result, LCA model facilitates assessment of environmental health impacts associated with utilised solid waste management elements and makes it possible to simulate solid waste management scenarios to achieve sustainability. Yadav and Samadder [113] and Aldhafeeri and Alhazmi [3] that LCA enable decision makers to choose appropriate waste management approaches which safeguard the environment while supporting CE.

Yadav and Samadder [114] and Nhubu et al. [86] indicated that LCA model is among the widely accepted strategies for quantification and evaluating environmental problems associated with waste management options. This means LCA can be used as a breakthrough to minimise detrimental impacts associated with solid waste. LCA presents to be applicable in Turkey [116], Italy [20], Malaysia [97], China [13], Singapore [2] and Thailand [105]. Considering this, LCA is able to bear fruits in both developed and developing regions in terms of solid waste management,hence, Zimbabwe can also test and apply the model. A number of LCA studies reported that conversion of solid waste to energy, biological treatment and recycling of solid waste is regarded as sustainable compared to landfilling and thermal treatment like incineration [114],Dastjerdi et al., 2019; Mukherjee et al., 2020). Consequently, LCA minimise the quantity of solid waste destined in disposal sites through using recovery, recycling and reuse, thus upholding CE concept. However, in the Zimbabwean context, landfilling and incineration are mostly applied [42, 83]. Hence, their effectiveness can be assessed through LCA model in order to achieve sustainability using landfills and incinerators which allow energy recovery. The reason being LCA model can be used to carry out precise comparison and figure out environmentally friendly solid waste management approaches [5, 49]. In order to overcome prevailing challenges in solid waste management, countries like Zimbabwe are supposed to adopt LCA model which supports CE.

Ciambrone [18] and Khandelwal et al. [49] indicate that life cycle assessment (LCA) is a tool used to assess environmental problems and benefits associated with the product throughout its life cycle, that is, from raw material acquisition and down to disposal. LCA systems include cradle to grave, cradle to gate and cradle to cradle. LCA was formulated around the 1970s [25]. Its primary objective was for packaging analysis considering environmental aspects such as resource conservation and energy use. Coca-Cola was among the first companies to carryout internal LCA to determine containers with lower negative impacts to the environment comparing glass and plastic beverage containers [8, 25]. LCA facilitates comparison of different products or waste management systems, therefore making a good platform for environmental improvement [8]. LCA techniques will not guarantee that one can choose an environmentally superior waste management system since actual environmental effects of waste depend on when, where and how they are released into the environment [48, 106],Khandelwal et al., 2018). Consequently, the application of LCA model in solid waste management remains general and almost subjective. LCA model is more limited since it does not consider available waste management processes and challenges and does not include course of action to deal with the problem [22, 48] and requires adequate resources, experts and waste management data (Gallego and Tarpani, 2019). Therefore, it may be difficult for countries experiencing a myriad of challenges to adopt LCA model in solid waste management owing to its loopholes and demands.

Moreover, the LCA model proved to be effective in developed countries such as Canada [57], Sweden and Italy (Laurent et al., 2014a). This may be attributed to availability of resources, namely finance, experts, waste treatment and disposal facilities and solid waste data in terms of quality and quantity. Additionally, life cycle assessment presents to be effective in management of solid waste globally, as shown by various studies carried out across the globe (Table 1). However, the studies are surrounded by various gaps (Table 1) for instance focusing on single type of solid waste or disposal strategies as well as putting much emphasis on developed nations but in one city or town. Therefore, to address the gap, the current review paper takes into account aspects related to solid waste of different nature, management techniques and life cycle assessment to attain sustainability and circular economy. In developing regions like Africa, specifically Southern Africa, studies related to application of LCA model in solid waste management are limited [83, 114]. Similarly, like other African countries, application of LCA model in solid waste is still evolving in Zimbabwe, since it is usually not spared by regional problems. In the Zimbabwean context, studies related to solid waste put much emphasis on nature of solid waste, management approaches and associated environmental risks. As a result, the researches neglect studies directed to management of solid waste applying various models including LCA model. In addition, the abovementioned information denotes that there is spatiotemporal variation in effectiveness and applicability of LCA model in solid waste management. Therefore, applicability of LCA is surrounded by skepticism due to its weaknesses; however, they are outweighed by its strengths. Also, major studies carried out in Zimbabwe demonstrated limited literature which focuses on Zimbabwe as a whole since they put much emphasis on single cities particularly Harare (Table 2). In order to address this gap, this paper offers a comprehensive review with wider scope considering local and international literature. Existence of few secondary sources emphasizing on solid waste and LCA in Zimbabwe in Table 2 is supported by Fig. 1 developed using data from Scopus. Therefore, this review intends to focus on applicability of LCA model in solid waste management in the context of Zimbabwe. The major aim is to figure out potential and ability of LCA model to facilitate attainment of sustainable solid waste management and CE in Zimbabwe.

## Description of the Study Area

The study focused on Zimbabwe, a landlocked country located in Southern part of Africa. The country covers approximately 390.757 square kilometre of Africa. The country shares geographical and political boundaries with South Africa, Mozambique, Botswana and Zambia. Zimbabwe experience sub-tropical climate consisting of two major season, namely hot wet summer and cool dry winter. The country's yearly average rainfall is 670 mm received between November and March while average temperature is between 15 degree Celsius and 25 degree Celsius. Zimbabwe is divided into 5 agro-ecological zones considering precipitation and temperature with 1st region experiencing high rainfall while 5th region received lest rainfall. According to ZIMSTAT [121], Zimbabwe's population is around 15.1 million. Zimbabweans reside in both rural areas and urban areas. The country's single city/town areas have potential to generate approximately 467,303 tonnes of solid waste annually [83]. In Zimbabwe, about 38.6% are urban dwellers [121],therefore, urbanisation is also adding substantive quantity of solid waste to the country's total waste. Mandevere and Jerie [66] revealed that approximately, 90 percent of solid waste generated in Zimbabwean cities is disposed, while 10 percent is either converted through processes like reuse and recycling. This revealed that in Zimbabwe, management of solid waste is through traditional linear approach which focuses on collection and disposal. This strategy is known to be associated with various environmental health problems. Hence, Zimbabwe must adopt a LCA model which assesses existing solid waste management approaches to minimise environmental health impacts.

**Table 1** Major global articles which focus on life cycle assessment and solid waste management

| Author's name | Year | What the study was focusing on | Contributions of the current review paper |
|---|---|---|---|
| Ahamed et al | 2021 | The research was focusing on life cycle assessment of plastic grocery bags in Singapore | The research paper focuses on different types of solid waste including electronic, food, metals, textile and construction and demolition waste |
| Gallego-Schmid and Tarpani | 2019 | The main goal of the paper was on wastewater treatment and life cycle assessment in less developed nations | The current review paper put much emphasis on solid waste of different characteristics using developing country as a case study |
| Aung et al | 2019 | The involve life cycle assessment and management of medical solid waste in Myanmar | The review paper encompasses life cycle assessment and solid waste from different sources, namely households, industries, commercial building and educational institutions |
| Chen et al | 2019 | The paper's main objective was "Environmental benefits of secondary copper from primary copper based on life cycle assessment in China | Current paper major benefits of pinning life cycle assessment of different types of solid waste. The benefits included are recycling, reuse and recovery to achieve the concept of circular economy |
| Ghinea and Gavrilescu | 2019 | Pointed out management of solid waste using approaches which facilitate attainment of circular economy in Lasi Country Romania. However, was addressing general solid waste more as compared to hazardous solid waste | In this paper adequate attention was given to general solid waste for instance domestic waste from households as well as hazardous solid waste exemplified by waste from hospitals, industries and electronic waste |
| Coelho and Lange | 2018 | Focuses on how application of life cycle assessment can enhance sustainable solid waste management in Brazil | In order to cover knowledge gap of the paper, the recent research take account of ability of life cycle assessment to support environmentally acceptable solid waste management policies and legislations |
| Khandelwal et al | 2019 | Addressing life cycle assessment and solid waste management at global level. Nevertheless, the critical review gives more attention to developed countries | Accordingly, to narrow the gap between developed and developing countries regarding application of life cycle assessment in solid waste management, this review paper focuses on Zimbabwe as one of the world's developing countries |
| Colangelo et al | 2018 | The study put much emphasis on life cycle assessment relating to recycled concretes | Similarly, to cover gap of the existing paper, the current paper include aspects linked various categories of waste such as medical solid waste which is currently increasing |

**Table 2** Major articles which focus on life cycle assessment and solid waste management in Zimbabwe

| Author name | Year | What the study was focusing on | Contributions of the current review paper |
|---|---|---|---|
| Nhubu et al | 2022 | Focusing on impacts associated with various solid waste management options in Harare | The current review paper focuses on Zimbabwe as a whole not a single city. This was driven by the fact that solid waste is a nationwide problem |
| Nhubu et al | 2020 | Comparative assessment of composting and anaerobic digestion of municipal biodegradable waste in Harare city | This study covers other treatment and disposal strategies which were omitted by the previous study |
| Nhubu et al | 2019 | In this study life cycle assessment was only focusing on conveyance of solid waste | This review paper addressed the issue of solid waste from generation to treatment and disposal. The study also involves issues related to solid waste reduction alternatives, namely recycle and reuse which support CE |
| Nhubu and Muzenda | 2019 | Life cycle assessment was used to determine solid waste disposal approaches with less detrimental impacts to the environment | This review paper focuses on strategies which support circular economy, thus focusing on strategies which minimise quantity of disposed solid waste |
| Nyakudya et al | 2022 | The paper put much emphasis on waste management policies in Zimbabwe, life cycle assessment and circular economy | The current paper considers the concept of highlighting potential environmental, social and economic benefits of pinning LCA to solid waste management. This is broad comparing to focusing on solid waste management policies only |

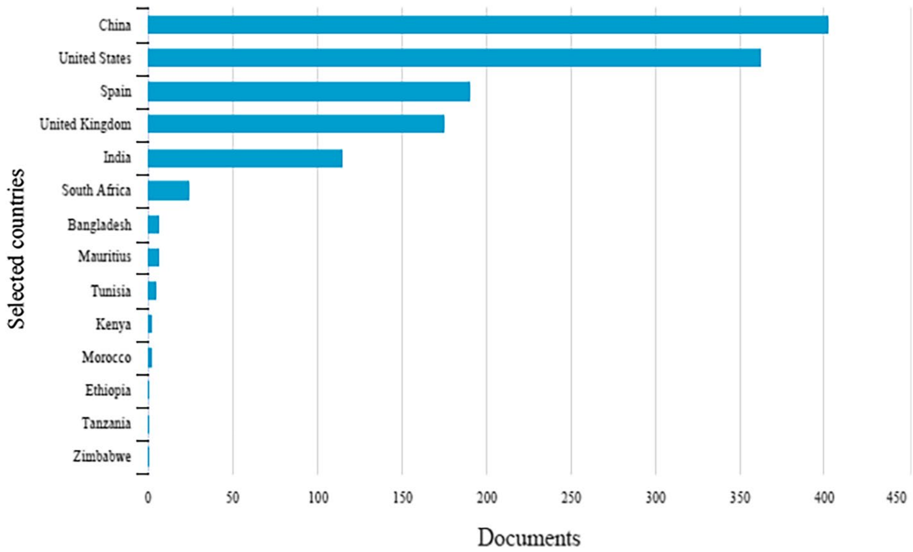


**Fig. 1** Number of LCA and solid waste documents published under Scopus. Source: Authors

## Methodology

The study sought to review applicability of life cycle assessment model in solid waste management in Zimbabwe. In order to accomplish the review, already published literature related to Zimbabwe was used. Nevertheless, solid waste literature from other countries was reviewed for comparison and benchmarking with Zimbabwean literature. Already existing literature was searched applying direct search approaches and key words. The review process put much emphasis on articles and books published in peer-reviewed scientific journals, although governments' reports and documents were considered. Secondary data sources were retrieved from Google Scholar, Scopus, ScienceDirect, Sage Publications, PubMed, Elsevier and Springer as well as government websites. In order to meet requirements of the review paper, literature written in English and published from 2012 to 2023 were considered. Reliability as well as validity was guaranteed through in-text and end-text referencing. Major key words used during the search include life cycle assessment, solid waste, solid waste management, Zimbabwe, environmental impacts and circular economy. However, searching of literature was carried out using phrases such as solid waste, hospital solid waste, electronic waste, construction and demolition waste, institutional waste and municipal solid waste. In order to review relevant literature which addresses potential benefits of utilising LCA model issues and management of solid waste, only secondary sources from 2012 to current dates were used.

## Composition of Solid Waste Generated in Zimbabwe

Solid waste produced in Zimbabwe mirrors solid waste generated in most developing countries particularly those in Sub-Saharan Africa [62]. This reveals that generated solid waste consists of organic, non-organic, recyclables, non-recyclables, combustible and non-combustible waste. As a result, sources of solid waste in Zimbabwe vary; hence, composition of solid waste varies (Table 3). In Zimbabwean cities, 84% of solid waste consist of recyclables such as papers, cardboard, glass bottles and jars, plastics products, metal containers and food waste, while 16% is not recyclable for instance absorbent hygienic products, namely diapers and sanitary pads [120]. Consequently, a large quantity of solid waste in Zimbabwe can be used as a resource in formal and informal industries. According to Makarichi et al. [62] and Maqhuzu et al. [68], proportion of solid waste encompasses textiles, plastics, paper, leather, glass, wood, rubber, metals, among others. This diversity of solid waste needs different management techniques particularly disposal and treatment approaches which lead to recycling, recover and reuse, thus paving route for energy recovery and circular economy in the Zimbabwean context.

Currently, quantity of electronic, food and wood waste is adding substantial quantity of solid waste due to changes in living standards and technology in Zimbabwe [66],Tongesai et al., 2018). This denotes that solid waste in Zimbabwe may consist of hazardous and non-hazardous from various sources. In the Zimbabwean context, institutions like (schools, hospitals) industries and households have potential to generate hazardous waste such as sharps, infectious waste, radioactive waste, cytotoxic, electronic waste, pharmaceutical waste and metal waste [41],Tongesai et al., 2018; [14]. This suggests that attention and conformity to solid waste segregation is vital to lessen burden and challenges in management of solid waste with different characteristics. This congruence with Ramachandra et al. [95] and Jerie and Musasa [42] that data regarding solid waste composition and segregation is essential in developing waste collection, conveyance, treatment and disposal strategies. Therefore, considering various types of solid waste in Zimbabwe (Table 3), no single technique can manage different types of waste effectively. Henceforth, various management strategies may be applied to overcome constraints faced in management of waste of different fraction. In a view upheld by Yadav and Samadder [115] and Khandelwal et al. [49], management of various types of waste requires numerous approaches since none of the existing strategy suits all waste.

## Solid Waste Management Approaches in Zimbabwe

Solid waste management is described as collection, transportation and recovery as well as solid waste disposal, including monitoring of the operations involved and caring of disposal areas [44]. This implies that management strategies encompass various processes which need attention to avert environmental problems. In the Zimbabwean context, municipalities are accountable for management of solid waste, as stipulated by Urban Council Act Chapter 29:15 (Jerie and Mandevere, 2018; [12]. As a result, generators of solid waste including households and institutions remain mere participants while the municipalities shoulder the burden of solid waste management. Additionally, only urbanites are beneficiaries of the Act as stipulated by its name,hence, rural areas are neglected. In Zimbabwe, collection of solid waste from households and institutions is done by municipalities using dump trucks through kerbside or block (communal) collection approach [62, 83]. However, collection of solid waste is termed inefficient due to shortage of fuel, labour, trucks and improper planning during dispatching of waste trucks since solid waste may last for a week without being collected [55, 109]. Although this contradicts with climatic conditions (Subtropical climate) which promote rapid decomposition of solid waste, hence it should be collected at least twice per week [66]. In the Zimbabwean context, 70% of municipality's waste budget is used for waste collection [55, 88]. This demonstrated that Zimbabwe as a country focuses on waste collection while giving less attention to waste reduction alternatives,therefore, large volume of waste is collected and disposed.

**Table 3** Sources, nature and description of solid waste generated in Zimbabwe

| Sources of solid waste | Nature of solid waste | Description of solid waste | References |
|---|---|---|---|
| Households (multifamily or single) | Construction and demolition waste | Builders' rubble, stones of various sizes, broken bricks, pieces of metals and glasses and piles of sand | Hobwana et al. [34] |
| Institutions (schools, prisons, barracks, hospitals, air ports and government buildings) | Papers | Flyers, books, book covers, newspapers, stickers, package containers, card boxes and files | Chatira-Muchopa et al. [12] |
| Industries (light, heavy and construction industries) | Textile waste | Tattered clothes, fabrics and pieces of cloth | Rugedhla et al. (2020) |
| Commercial buildings (markets, stores, restaurants and hotels) | Wood | Pieces of timber, trusses, broken and old doors, broken furniture such as chairs, tables and pencils | Charis et al. [11]<br>Nyemba et al. [93] |
| Municipal services such as street sweeping | Electronic and electric waste | Computers, printers, old cell phones, appliances such as electric jars and iron, televisions, radios, air conditioners, refrigerators, batteries and electric (plugs, adaptors, cables, lamps) | Maphosa and Maphosa [67]<br>Madanhire et al. (2020) |
| | Medical waste | General waste, pathological, sharps, pharmaceuticals, chemical waste, infectious and radioactive | Jerie and Musasa [42]<br>Shabani and Jerie (2023) |
| | Rubber | Tyre pieces, old door mates, shoes, bags and belts | Chihiya et al. [14]<br>Shabani and Jerie (2022) |
| | Glass | Window pens and old and broken glass, bottles, jars, cups and bottles | Zikali et al. [120]<br>Chihiya et al. [14] |
| | Food waste | Remains of fruits, sadza, vegetables, rice, bones, meat, maize cobs among other food stuffs | Makarichi et al. [62]<br>Kwenda et al. [55] |
| | Plastics | Containers of (cosmetics, disinfectants, lotions, chemicals), beverage containers, broken kitchen utensils (cups, plates), food takeaways, food wrappers, book covers, plastic pipes, compact disks and other packaging materials | Mazhandu et al. (2020)<br>Shumba et al. [98] |
| | Metals | Scrap metal, sharpeners, car shells and empty containers of oil, paint, polish, thinners, disinfectants and chemicals | Shabani and Jerie (2022)<br>Magidi [59] |

**Table 3** (continued)

| Sources of solid waste | Nature of solid waste | Description of solid waste | References |
|---|---|---|---|
| | Mining waste | Piles of soil, rocks and temporary stockpile of ore, empty cyanide containers, cadmium fluid tins, used crucibles, empty bags of crude sulphur and carbon | Njini and Mapira [89] Mutsvanga et al. [75] |
| | Absorbent Hygienic Products (AHP) | Diapers (disposable or washable) and sanitary pads | Nyamayedenga and Tsvere [91] |

Moreover, application of recycling, reuse and reduction approaches is still evolving in Zimbabwe. A scenario demonstrated that ninety percent (90% of generated solid waste in Zimbabwe is disposed through legal and illegal strategies [65],Jerie and Mandevere, 2018) while 10% is recycled, composting and reused [50]. This revealed that solid waste is considered a useless product of no value, yet it can be used as a resource to achieve green economy as well as economic growth. Additionally, by recycling and reusing approximately 10% of solid waste means the issue of CE is neglected in Zimbabwe.

Disposal and treatment of solid waste is done through open pits, open burning, incineration, landfilling and open dumpsites [41, 81, 92], while burying is practised but at lower rate [58]. This articulates that the country put much emphasis on waste management hierarchy's secondary approaches while giving less attention to primary strategies, namely recycle, reuse and prevention.

In Zimbabwe, solid waste is disposed in improperly engineered landfills without leachate control or collection systems [82, 83],this is exemplified by Pomona dumpsite [50]. This opines that landfills in Zimbabwe are operated as dumpsites where solid waste is disposed, not compacted and left uncovered. According to Chanza et al. [9], urban areas notably Bulawayo, Harare, Beitbridge, Gweru, Mutare and Bindura are still dumping solid waste on unsanitary landfills without leachate control systems. As a result, dissolved acids, ions and solids from landfills have potential to affect ground and surface water quality negatively. Currently, cropping of illegal dumpsites is rampant in Zimbabwe since piles of solid waste are now a common sight along road edges, open spaces and drains [81, 103]. Mushrooming of illegal dumpsites is an end product of inefficiency waste management approaches specifically collection. Emerging of illegal dumpsites is ascribed to inefficiency waste collection [62],however, the city fathers owed it to ignorance and resistance of residents [65, 99]. Hence, due to unawareness, residents eliminate piles of uncollected solid waste through illegal solid waste disposal approaches including backyard burning. Makarichi et al. [62] and Nhubu et al. [85] coincide that 37.6% of solid waste generated in Zimbabwe is disposed through open burning. Adoption of open burning may be attributed to its ability to reduce volume of solid waste at generation source and disposal sites. However, incineration of solid is highly practised to minimise quantity and toxicity of solid waste specifically medical solid waste [42]. Nevertheless, from an environmental perspective, these combustion processes are harmful since they release toxic gases exemplified by carbon dioxide, monoxide, sulphur dioxide and nitrous oxide with potential to contaminate the atmosphere. To worsen the scenario, most of the incinerators used in Zimbabwe are substandard (Shabani and Jerie, 2023); hence, they are failing to meet requirements of CE, namely energy recovery from incinerators. Management of solid waste in Zimbabwe is guided by legislation for instance Environmental Management Act 20:27 and Public Health Act [39]. However, problems associated with solid waste remain a challenge in Zimbabwe due to lack of law enforcement, citizens' resistance and unawareness. In order to address the gaps hindering ability of existing solid waste legal frameworks in Zimbabwe, a combination of various aspects including utilisation of LCA model is required (Nyakudya et al., 2022).

## Environmental Health Problems Associated with Solid Waste Management Approaches

Inappropriate handling and management of solid waste result in a number of social, economic and environmental problems [15, 66]. This suggests that contaminants from solid waste have potential to hinder economic progress while causing environmental deterioration. In the Zimbabwean context, improperly disposed waste results in land pollution [15, 92], therefore compromising land aesthetic value [65]. As a result, poorly disposed solid waste can affect activities such as tourism which generates income for Zimbabwe, hence fuelling economic deterioration. This assertion is supported by Tevera (1991) and Jerie (2006) that normally people are not comfortable with areas with solid waste; hence tourists are not exempted. Decline in tourist inflow means income from tourism is reduced while most of the employees in the tourism sector lost their jobs. Furthermore, light solid waste, namely plastics and papers from landfills, can be transported by wind and deposited in water sources as well as residents' yards.

Inorganic and organic contaminants from non-lined disposal sites result in deterioration of water quality chemical and physical parameters, namely temperature, PH, hardness, electrical conductivity and total dissolved solids [63, 104]. Similarly, in Zimbabwe, pollutants from dumpsites affect aquatic life by causing eutrophication that facilitates emerging of water hyacinth [65],Jerie and Mandevere, 2018). Hence, besides increasing water scarcity, solid waste pollutants affect creatures living in water, for instance fish yet humans consume them. Additionally, pathogens from decomposing solid waste can result in cropping of waterborne ailments notably typhoid, dysentery, cholera as well as diarrhoea in Zimbabwe [16, 80]. Henceforth, mismanaged solid waste is affecting the surrounding environment and human lives are not spared. Incineration as well as open burning generates toxic gases (nitrous oxide, carbon dioxide, carbon monoxide, sulphur dioxide), thus causing air pollution (Mangizvo and Chinamasa, 2008; Chatira-Muchopa, 2019). Hence, need for LCA model is unavoidable since Nhubu et al. [87] indicated that comparison of impacts associated with disposal approaches can be achieved through applying LCA. According to Muchandiona [72] and Chapungu et al. [10], landfills devoid of gas outlets release odour and methane into the atmosphere. Considering this, inappropriately disposed solid waste produce trace gases, greenhouse gases and particulate matter with potential to pose global warming and acid rain. Nhubu and Muzenda [83] and Shabani and Jerie (2023) lament that emissions from landfills and incomplete combustion of solid waste accelerate climate change which is already felt globally.

Jerie and Zulu [45] and EPA [26] coincide that environmental attributes located near dumpsites specifically less than 500 m are vulnerable to pollutants. Therefore, toxic gases from incineration and decomposing solid waste may cause eye, nose and skin irritation among people in proximity to the dumpsites or waste treatment sites. Exposure to furans, heavy metals, dioxins and radiation from incomplete combustion and incineration causes health problems to people since they are known to be mutagenic and carcinogenic [41],Zubar and Andrees, 2019; [110]. Therefore, one may argue that waste workers responsible for solid waste incineration and burning are vulnerable to skin burns and cancer unknowingly. Incomplete combustion of solid waste such as electronic waste and medical equipment such as clinical thermometers and sphygmomanometer generate heavy metals like mercury, nickel, lead, zinc, cadmium, among others [41, 107]. However, burning of electronic and medical waste is rampant in Zimbabwe,hence, various metals are released into the environment. Nevertheless, metals have potential to impact reproductive systems and pregnant mothers and facilitate occurrence of genetic disorder among unborn babies [32, 52, 107]. This means females are more vulnerable since their foetuses' weight, genetic chromosome and neurodevelopment are affected negatively, thus ruining lives of future generation. This goes in line with Ncube et al. (2017b), Munyai and Nunu [74] and Muzvondiwa [76] that females are more vulnerable to pollutants from solid waste since they are involved in waste management at various institutions and households.

Inappropriately managed solid waste open pits, dumpsites, landfills and illegal dumpsites are mostly used by mosquitoes, houseflies (*Musca domestica*), false stable flies (*Muscina stabulans*), stable flies (*Stomoxys calcitrans*), cockroaches, rats and rodents as breeding grounds [41, 44, 109]. Nevertheless, flies as well as cockroaches may move from dumpsites to nearest households freely and therefore have potential to spread pathogens which affect human health. Similarly, unrestricted movement of mosquitoes can lead to spread of malaria to citizens yet according to Muchena et al. [73] and Mbunge et al. [69] that malaria is among major health problems confronting Zimbabwe. Hence, proper monitoring and assessment of waste disposal strategies is essential since it can contribute to reduction of malaria outbreak. Moreover, partially secured and non-secured dumpsites in Zimbabwe are accessed by children, waste scavengers, birds and animals (Mangizvo, 2010, [51, 82]. This suggests that human beings including children are vulnerable to respiratory diseases due to dust from waste and cuts as well as pricks due to contact with sharp waste. As a result, human beings can be exposed to HIV and AIDS, hepatitis B and C, COVID 19 and tetanus due to solid waste (sharp) injuries. In the African context, particularly Sub-Saharan Africa, 30% (hepatitis B and C) and 2.5% (HIV) new infections are attributed to injuries from solid waste annually [1].

To worsen the scenario, loading as well as offloading of solid waste during transportation and disposal processes is associated with musculoskeletal problems and pains [38, 41]. This entails that glissile and sessile dislocations of elbows, fingers, back and shoulder bones are inevitable among Zimbabwean waste workers since waste management processes are done manually.

Furthermore, marauding scavenging animals and scattered solid waste piles create an eyesore environment and nuisance to Zimbabwe [99],Kwenda et al*.,* 202). As a result, if solid waste is mismanaged, it can affect the health of Zimbabweans particularly mental health of those near to dumpsite who are already stigmatised. Dumpsites accommodate materials with high potential of explosion, reaction and to ignite [41], therefore creating favourable sites for fire outbreak. An issue which is associated with most of the dumpsites in Zimbabwe, as exhibited by fire outbreak at dumpsites such as Pomona in 2013 and Golden Quarry in 2000 in Zimbabwe [10, 50, 81]. This asserts that dumpsites may act as sources of fire resulting in biodiversity loss, air contamination and property loss as well as loss of lives, thus affecting the country's socio-economic and environmental aspects. Consequently, solid waste management approaches affect the environment negatively, while posing detrimental impacts to human health thus contradicting the requirements of the global sustainable development goals. Hence, a clearly structured assessment and evaluation of management approaches including disposal strategies is essential to narrow the gap to reach sustainable development as well as Zimbabwe National Development Strategy 1 objectives. Potential environmental health effects associated with solid waste management techniques can be assessed through life cycle assessment [117],Nabavi-Pelesaraei, 2022). This entails that quantifying of environmental health risks that emanate from solid waste can be minimised through utilisation of life cycle assessment model. This presents to be effective in countries such as Korea [53]. In a view upheld by Aung et al. [6] and Zhang et al. [117], life cycle assessment is regarded as a unique comprehensive approach to examine environmental problems that emanate from solid waste management processes, due to its ability to compare various methods. Therefore, life cycle assessment model can be applied in order to improve existing solid waste monitoring techniques in Zimbabwe.

## Relevance of Life Cycle Assessment (LCA) Model to Management of Solid Waste in Zimbabwe

LCA model is made up of four major stages [37, 47], namely goal and scope definition, life cycle inventory analysis, life cycle impact assessment and interpretation of results [96],Nabavi-Pelesaraei, 2022). Taking this into account, LCA model presents to be effective in planning, implementation, evaluating and designing of ecologically acceptable material disposal approaches and processes. This congruence with Aung et al. [6] and Nabavi-Pelesaraei et al. [77] that LCA model considers socio-economic as well as environmental aspects when dealing with solid waste management issues. This asserts that LCA model can create low hanging fruits for Zimbabwe to achieve sustainability in terms of waste management. Güereca et al. [31] noted that LCA model was applied in solid waste management since year 1995. As a result, LCA model was pinned in solid waste management strategies and processes almost two and half decades ago. Differences in sources, volumes and characteristics of solid waste as well as various disposal and treatment strategies enable LCA model to emerge as an appropriate assessment model (Mendes et al., 2004; [24, 77]. This revealed that application of LCA model enables countries to determine solid waste management approaches, processes and techniques with least impacts to natural ecosystem and human beings. ISO 14040 indicated that LCA model for waste management from generation to treatment or disposal and processing includes goal and scope, life cycle inventory [46, 119] and life cycle impact assessment as well as result interpretation [101].

LCA model presents to be essential in improving solid waste management in both developing and developed countries (Yadav et al., 2018; [24]. This suggests that LCA model can be applied in Zimbabwe to accelerate adoption of appropriate solid waste management approaches. In Zimbabwe, different types of solid waste is generated from various sources [41, 44, 109]. As a result numerous materials which the initial users regard useless need to go through life cycle assessment to know the best processing strategies to achieve circular economy. This is because LCA model is considered a comprehensive tool in terms of comparing environmental impacts associated with products and management systems [23, 77]. In this view, LCA model may pave route for Zimbabwe to adopt waste management hierarchy's highly recommended waste management approaches notably recycling and reuse which upholds CE.

Moreover, through assessment of products' life cycle, waste management authorities are able to differentiate solid waste into materials which can be used as resources [17]. In the Zimbabwean context, LCA model is essential to choose solid waste which can be processed to produce energy since energy is scarce. Considering solid waste as source of energy, few quantity of solid waste is destined in dumpsites, hence minimising pressure of solid waste to the environment. Generation of energy from solid waste means waste is regarded as source of energy and is no longer disposed. Acquiring of energy from waste means solid waste provides energy for economic growth. Minimisation of disposed solid waste increases the life span of landfills as well as dumpsites, hence reducing burden of creating and locating new disposal sites to municipalities. This is particularly vital to Zimbabwe since locating of dumpsites is currently problematic owing to Not In My Backyard philosophy [44, 83, 103], where humans are not willing to be in close proximity to waste sites. LCA of solid waste management techniques enables selection of disposal approaches with less emissions [17]. In view of this, Zimbabwe may reduce reliance on management approaches such as combustion and incineration which release greenhouse gases by adopting LCA model. As a result, LCA model is relevant in management of solid waste in order to minimise rate of climate change in Zimbabwe, since Jerie and Mandevere (2018) and Nhubu et al. (2019a, b, c coincide that emissions such as carbon monoxide, nitrous oxide, sulphur dioxide, methane and carbon dioxide from poorly managed solid waste cause global warming as well as climate change. Arushanyan et al. [4] and Christensen et al. [17] argued that LCA model exhibits to bear fruits in terms of waste management regulations and policy evaluation in Sweden. This implies that in order for Zimbabwe to strengthen its solid waste monitoring legal framework as well as policies, LCA model should come into play. This is critical since in Zimbabwe improper management of solid waste is also ascribed to legal framework loopholes and policy gaps [39, 61, 76]. LCA model paved way for disposal of food waste with processes which facilitate conversion of food waste for instance composting [101], thus facilitating adoption of CE. This postulates that by applying LCA, people may benefit from biogas from composting alongside manure which can be used as fertilizer, thus promoting attainment of Sustainable Development Goal 2 (Zero hunger) in Zimbabwe.

LCA model phase 1 (*Goal and Scope*) is set to compare waste management options considering product recovery, cost, transport and energy consumption [46, 101]. Hence, application of LCA model may enable Zimbabwe to utilise waste management strategies which are economically feasible in terms of cost and economic development. Saber et al. [96] and Nabavi-Pelesaraei et al. [77] concur that the second phase (*Life Cycle Inventory*) is where waste management data regarding required labour, nature and quantity of pollutants is collected, through research. Therefore, LCA model will stimulate carrying out of qualitative and quantitative researches related to solid waste in the Zimbabwean context. The researches will create a room for the country to implement management approaches which tallies with requirements of sustainability pillars, namely social, environmental and economic aspects. This revealed that LCA model is relevant in Zimbabwe since existing data concerning source, quantity and quality of solid waste is less reliable [55, 83], yet adequate data is essential during planning. *Life Cycle Impact Assessment* referred to as phase 3 involves categorising of waste management techniques according to effects they cause to the environment [46, 96]. Henceforth, LCA model provides Zimbabwe the opportunity to use alternatives with minimum impacts to aquatic, terrestrial and atmospheric ecosystem as well as humans, thus narrowing the gap to reach demands of National Development Strategy 1 goals such as environmental protection and natural resource management. According to Damgaard et al. [23] and Christensen et al. [17], the final LCA model stage (phase 4) put much emphasis on *interpretation of results* in order to assess if the adopted management strategies match phase 1 stipulated goals as well as scope. Hence, LCA phase 4 enables the country to evaluate and re-evaluate already existing and developed waste management. Considering this, potential benefits associated with LCA model, it is clear that Zimbabwe may create low hanging fruits to achieve sustainable development goals at national and international level. Therefore, Zimbabwe must apply LCA model in order to develop comprehensive waste management approaches which maintain environmental integrity as well as achieving CE. Relevance, benefits and applicability of LCA model in solid waste management in the Zimbabwean context are summarised in Fig. 2.

## Conclusion

Solid waste management is among problems which are now beyond normal state worldwide. This is visible in resource constrained nations which are still undergoing development, urbanisation and population increase. Consequently, countries resorted to various models such as LCA model and its stages to attain sustainable solid waste management. Literature indicated high adoption, effectiveness and application of LCA model in developed countries compared to developing nations. This is visible in Zimbabwe where adoption of LCA model is still at miniature stage and evolving as demonstrated by limited LCA literature related to solid waste and solid waste management approaches which focus on collection and disposal. Less application of

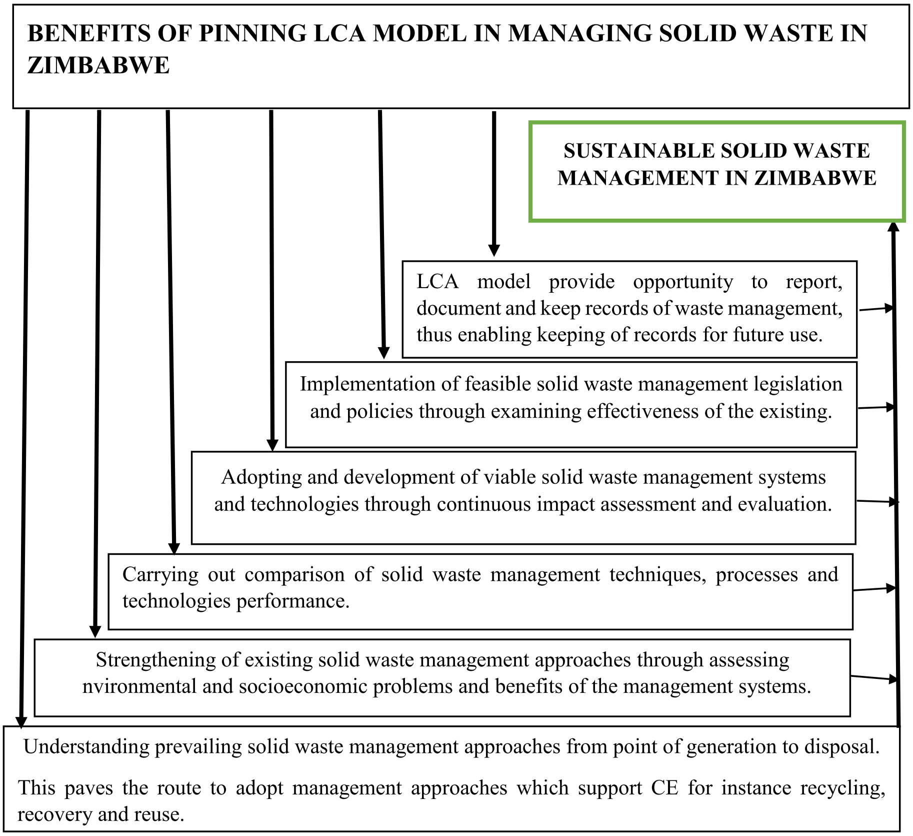


**Fig. 2** An idealised framework showing why Zimbabwe should apply LCA model in solid waste management. Source: Authors

LCA model may be ascribed to lack of resources, experts and technology. In Zimbabwe, human activities are the major drivers of solid waste generation from industries, street sweeping, institutions and commercial buildings, among others. Therefore, anthropogenic activities remain major threats to environmental integrity across the globe not sparing Zimbabwe. Reviewed literature demonstrated that co-storage and indiscriminate disposal of solid waste is common in Zimbabwe. This revealed that life cycle impact assessment of disposed products is mostly rare since solid waste is managed together regardless of source and nature. However, LCA literature pointed out that segregation assists in implementing environmentally acceptable disposal and treatment techniques such as material recovery and composting. This lead to minimisation of pollution associated with solid waste and attainment of the CE. Application of LCA model in solid waste management paves route for Zimbabwe to focus on the apex of waste management hierarchy and converts solid waste to fuel, gas and electricity. This entails that by applying LCA model, Zimbabwe narrows the gap to reach SDGs goals 11 (Sustainable Cities and Communities) and 12 (Responsible Consumption and Production), Agenda 21, Chapter 21 and Zimbabwe Vision 2030 which support waste recycling, reuse, prevention and recovery. Therefore, through LCA model, Zimbabwe may achieve the aspects of EC and green economic growth. Figure 2 denotes some of the opportunities pinning LCA model in solid waste management in Zimbabwe.

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Steven Jerie (S.J): reviewing and analysis of the review paper.
Tapiwa Shabani (T.S): compiling of documents used and writing of the original draft.

**Data Availability** The datasets generated during or analysed during the current study are available from the corresponding author on reasonable request.

### Declarations

And have complied as applicable with the statement on "Ethical responsibilities of Authors" as found in the Instructions for Authors and are aware that with minor exceptions. No changes can be made to authorship once the paper is submitted.

**Ethical Approval** Approval was granted by Midlands State University to carry out the research as well as to publish under its name. All sources were properly cited to avoid plagiarism.

**Consent to Participate** All authors participated and agreed to participate up to final revision of the manuscript.

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