

The role of informal sector solid waste management practices to climate change abatement: A focus on harare and mutare, Zimbabwe.

Steven Jerie*

Faculty of Environmental Science and Engineering, Kunming University of Science and Technology, Kunming, China

Abstract

The aim of this study was to examine the impact of waste management practices in the informal sector on climate change in Zimbabwe with particular reference to the cities of Harare and Mutare. A multi-methods research design that triangulates quantitative and qualitative approaches was employed. In Harare and Mutare, the city councils are experiencing major problems in collecting and minimizing the huge amounts of waste that could otherwise have negative impacts on local climate. Analysis of results gathered from the study, therefore, highlighted (a) the lack of recognition of the crucial role that could be played by the enterprises in reducing the amount of waste; and (b) the low rates of resource recovery and recycling in the enterprises which are vital waste minimization strategies as postulated in the principles of industrial ecology. Field investigations in the informal sector enterprises of Harare and Mutare indicated that waste minimization practices such as re-use and recycling are essential in reducing the impact of greenhouse gases on the environment. Governments of cities in African countries could be assisted in appreciating the value of informal sector solid waste management. The role of the informal sector recycling in climate change abatement should therefore not be underestimated in developing countries. All in all, in order to reduce greenhouse gas emissions from solid waste, conventional solid waste management needs to be replaced by resource management.

Keywords: Climate change, Waste management, Greenhouse gases, Informal sector, Waste minimization, Integrated waste management.

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Introduction

Greenhouse gases are generated from waste management practices and their impact on climate is influenced by the net greenhouse gases indirectly through downstream greenhouse savings. It is difficult to determine the actual impact as a result of the scarcity of data on the amounts of waste generated and its composition. Gaps exist in knowledge on the climatic impact of solid waste in developing countries and more-so with regard to informal sector enterprises [1-4]. The studies need to be extended to the impact of waste that includes products imported by developing countries for a wider scope of the impact of solid waste management practices in the informal sector enterprises [4-7]. In developing countries, the informal sector makes a significant, but typically ignored, contribution to resource recovery and greenhouse gas savings [8-11]. Waste pickers require support to form co-operatives, access better equipment, negotiate direct access to waste resources, and generally improve their safety, health, and livelihood. Governments of cities in developing countries need assistance to understand the value of the informal sector and to incorporate the sector in waste management strategies. The role of the informal sector recycling sector should not be underestimated in developing countries. The World Bank estimates that about 1% of the urban population in developing countries (approximately 15 million people) earns

their livelihood from waste picking and the informal recycling sector [3,12]. As a result of the fact that these activities are not formally organized or often sanctioned by the government, their contribution to the waste management and resource recovery (and the economy) is often not recognized. However, there is a growing appreciation of the role of 'waste pickers' in some countries. Governments in Brazil and Colombia now support the informal sector which has enabled the formation of waste picker organizations with greater respect and ability to negotiate direct source-collection contracts (or informal agreements) with businesses, industries, and neighborhood associations [12].

In the study, the major aim is to examine the potential benefits that can be obtained from the management of solid waste that is generated in the informal sector from the various economic activities that are undertaken on climate change abatement. The study thus focuses on the cities of Harare and Mutare in Harare that have been experiencing severe challenges in collecting, recycling, treating and disposing of the huge quantities of waste generated which could have impacts on the local climate. A number of safety, health, and environmental benefits could result from the effective management of waste because of the reduction in the generation of greenhouse gases. These include better quality of life, improved public health, and the prevention of the eutrophication and sustainable use of natural resources to

benefit future generations. Post-consumer waste is regarded as a renewable source of energy and thermal processes, landfill gas utilization the anaerobic gas digester can be employed in order to harness it. [13-15]. Preliminary field investigations in the informal sector enterprises of Harare and Mutare indicated that waste minimization, recycling, and re-use represent an important and increasing potential for indirect reduction of greenhouse gas emissions through the conservation of raw materials, improved energy, and resource efficiency and fossil fuel avoidance. Waste pickers and informal enterprises also require support to form co-operatives, access better equipment, negotiate direct access to waste resources, and generally improve their safety, health, and livelihoods. Governments of cities in developing countries such as Zimbabwe need assistance to understand the value of the informal sector and to incorporate the sector in waste management strategies. The role of the informal sector recycling in climate change abatement should therefore not be underestimated in developing countries. All in all, the paper proposes that in order to reduce greenhouse gas emissions from solid waste, conventional solid waste management needs to be replaced by resource management.

Literature Review

Solid waste generation

Worldwide solid waste management contributes a significant amount of greenhouse gases amounting to between 3% and 5% of the anthropogenic emissions [3,16,17]. It has been observed that despite being a minor contributor to greenhouse gases, the waste management sector could become a notable sector in reducing the release of greenhouse gases. The US EPA has estimated that 42% of total greenhouse gas emissions in the United States of America are associated with the management of materials [18]. Globally, the quantity, characteristics, and composition of solid waste are influenced by socio-economic status, spatial location, values and customs, the nature of jobs and climate of particular areas [19-22]. Characterization of waste is based on the weight generated in kilograms per person per day (kg/person/day) and density in cubic metres. There is very scanty information regarding the amounts and types of waste generated in the developing countries of the world [19,23-25]. Level of development and levels of affluence influence solid waste generation in most countries of the world [8,19,26-33]. Refuse is, and has always been a keen pointer to the socio-economic conditions of those who create it [26,34]. In developing countries, there is little data on generation and types of waste. High rates of consumption and the informal resource recovery activities by scavengers tend to reduce the amount of waste generated in developing countries; Zimbabwe included [27,33,35,36]. Urbanization, population growth, and socio-economic status have played an important role in influencing waste generation rates in India, Brazil, and Thailand [37]. However, per capita, waste generation actually decreases as economic development increases in the wealthiest countries of the world [38].

An important way of reducing the amount of waste disposed of is by ensuring that waste is separated at the source of its generation into its constituents and hence it can be managed through re-use, recycling, and energy recovery [20,39]. Efficient

separation is essential so as to ensure convenience between the waste generators and disposers [40,41].

Approaches to solid waste management

Several approaches have been identified in the literature in relation to sustainable solid waste management. Traditionally, the local authorities have been responsible for all aspects of the waste collection, transport, and disposal. However, this approach has not been economically viable [3]. Since waste management seeks to dispose of waste in the safest and most cost-effective manner possible, the best approach to deal with waste problems has been identified in the literature as planning ahead and managing all the waste and processes that generate it as a system [3,26]. An appropriate approach in this regard is integrated solid waste management which ensures waste minimization in all waste management activities from the point of generation to the point of disposal hence minimal generation of greenhouse gases [42]. It draws much from the waste management hierarchy, which is a widely accepted list of preferred waste management options, gives priority to waste minimization, which includes changing processes to prevent waste and the related downstream impacts such as greenhouse gas generation [26,42]. The waste management pyramid intends to illustrate that ideally, one should build up the waste management strategy primarily using prevention measures and secondarily, relying on recovery and disposal methods are used sparingly. The European Topic Centre on Waste (ETC/W) of the European Environmental Agency defined waste minimization measures to include waste prevention, internal recycling of production waste, and source-oriented improvement of waste quality and re-use of products for the same purpose. Other waste management measures include external recycling, sorting of waste, re-use for another purpose and energy recovery [43]. Waste regulation at virtually every level gives priority to prevention; however, the definition of waste suggests its role to be mere to get rid of existing waste. The Guideline for Life-Environment demonstration projects also places emphasis on prevention and encourages waste management research toward prevention, re-use, recovery, and recycling of waste.

The waste management hierarchy is thus a basic tool which is employed to make solid waste management as environmentally friendly as possible. It revolves around the 3R approach (Reduce-Reuse-Recycle) which is basically a precautionary principle that prioritises the prevention and reduction of waste, then it's reuse and recycling, and lastly the optimization of its final disposal. The waste management hierarchy is vital in that waste should be handled differently based on its characteristics. The waste management hierarchy is thus an essential and established framework that deals with two fundamental requirements i.e. first, produce less waste and then implement an effective system for managing the waste that is still produced.

The doctrine of sustainability provides a mechanism for development to occur in harmony with environmental protection and enhancement. It presents a challenge to technologists to manage construction and manufacturing processes so as not to cause environmental harm from greenhouse gases, and to preserve environmental resources for future generations [43]. There is growing demand from legislators, shareholders, investors and environmental groups for the industry to demonstrate

environmental responsibility as conceptualized in integrated resources management. This implies that waste management has to be tackled holistically by integrating it into the activities of an enterprise so as to avoid pollution that contributes to climate change. In integrated resources management, economic value can be derived from naturally produced resources and this has the advantage of taking into consideration the importance of ecological, economic, technological and social implications of recovery, recycling and reintegration technologies [5,26,44,45]. Minimizing the amount of waste generated in the informal sector enterprises of Harare and Mutare thus plays a vital part in resource use optimization and this concept can be extrapolated to the field of integrated resources management.

Another doctrine vital in conceptualizing solid waste management in the informal sector is that of industrial ecology. Industrial ecology involves the design of industrial processes and products from the dual perspectives of product competitiveness and environmental interactions. This systems-oriented approach is also premised on the idea that production processes interlink with each other and their environs forming forward and backward linkages and aim at the minimal use or wastage of raw materials, money and power (energy) right from the initial production phase to the final product. In this regard, nothing is regarded as waste in industrial ecology and operates in a manner that simulates a biological system in which waste is a raw material for another production process or activity. An important goal of an industrial ecological system is that every material that enters the process leaves the process as a marketable product. This is because there is no product that has no purpose in leaving the process and will always have an owner. In an industrial ecology loop, every product is designed so that it can be used to create useful products after the end of its lifecycle. Hence after the product has fulfilled its purpose, or does not perform in accordance with its purpose, it would be assigned another purpose. Therefore, any waste product or object has to serve a purpose and be created as such and should also serve another purpose after fulfilling the first and therefore be useful to another owner. Industrial ecology is a paradigm that could possibly lead toward sustainability. Waste management needs to be connected with the paradigm of industrial ecology in order to be sustainable [42,46]. The principles of industrial ecology need to guide individuals, private firms and other organizations in developing an infrastructure for sustainable waste management practices and methodologies.

Methodology

The methodological philosophy for this research bases its investigative framework on mixed methods and uses systems analysis to evaluate the causal relationships observed in the survey. This study uses qualitative methodological approaches and quantitative surveys and measurements in a combined effort to arrive at a deeper understanding of solid waste management in its current state, to assess the current efforts to ameliorate the situation and devise viable solutions toward the implementation of a sustainable solid waste management system in the informal sector enterprises of Harare and Mutare. Solid waste management-climate change investigations have a very broad outlook overlapping several academic disciplines from the social sciences [47,48]. For this reason, this research adopts aspects of

both quantitative and qualitative approaches. The quantitative approach involves the physical characterization of solid waste by way of analyzing waste samples and questionnaire surveys as aids in understanding the nature of solid waste management practices in the informal sector. The qualitative approach involves interviews, open-ended questionnaires, focus group discussions and participant observations in order to generate other useful supporting data, especially from human subjects so as to strengthen the quantitative evidence.

The key informants pertaining to the impact of solid waste management practices on climate change were drawn from the Ministry of Local Government and the Harare and Mutare City Councils (the physical planning section, the Amenities Division Managers, the Senior Environmental Health Officers, the Cleansing Supervisors, and the city chemists). Other key informants included officials from the Environmental Management Agency (EMA) as well as the National Social Security Authority (NSSA) and the Chairpersons of the informal sector enterprises in all the geographical locations with the intention of gathering data pertaining to types of waste generated, collection, minimization practices and final disposal as well as the occupational safety and health problems associated with solid waste disposal emanating from the emission of greenhouse gases from the waste. Questionnaire surveys were targeted at all the 396 informal sector enterprises in Harare's high-density suburb of Mbare and 112 in Mutare's high-density suburb of Sakubva. The questionnaire followed guidelines provided by Oppenheim [49-51] in order to increase the level of validity and reliability. It hence focused on generation, collection, and minimization practices such as re-use and recycling and the impact on the climate of improper waste disposal.

A number of data sets were obtained from waste composition analysis and the questionnaire survey. The waste composition data and the questionnaire response data were analyzed using Microsoft Excel for Windows and SPSS. Data from the questionnaire survey that was nominal and ordinal in nature were analyzed using descriptive statistics and non-parametric statistical tests, namely Chi-Squared tests. Samples of subjects in terms of variables or combination of variables were described using descriptive statistics. The descriptive statistical analysis involved the use of frequencies, percentages, and measures of central tendency. These techniques were used to analyze data relating to the characteristics and amounts of waste generated in the enterprises. The graphical techniques that were used for presenting the results from the analyses included cross-tables.

Results and Discussion

Characteristics of waste generated in the informal sector enterprises

A waste management system which includes generation, collection, separation, treatment, transfer, and disposal is associated with the generation of greenhouse gases at different levels. In the case of Harare and Mutare, the solid waste characterization was based on solid waste sampling, measurements, and questionnaire responses. Waste characterization is hence based on the rates of generation, the composition and biodegradability rates. According to the most dominant type of waste generated in the enterprises includes

food and vegetable waste (Table 1). The food and vegetable waste dominates in market areas in both Harare and Mutare. High percentages of food waste are a result of the activities that dominate in these areas which are associated with retailing in vegetables and food hence generating large quantities of waste that include rotten vegetables and fruits as well as left-over foodstuffs from food preparation and retailing.

Source: Field Survey (2015).

Food waste is highly biodegradable as a result requires to be collected most frequently so as to reduce the levels of decomposition and the generation of greenhouse gases. Any organic material that is allowed to reach the landfill including garden trimmings, wood, paper, and the food is acted upon by upon by the microbes under anaerobic conditions and the result is the generation of methane, carbon dioxide and trace amounts of gaseous compounds. Methane and carbon dioxide constitute the greenhouse gases that contribute to global warming and climate change. Scientists have noted that methane gas is a dangerous greenhouse gas that has the global potential of which is 25 times that of carbon dioxide considering a time horizon of 100 years.

Waste collection and disposal

The aim of any solid waste collection system should be to reduce environmental pollution and this includes the generation of greenhouse gases. An effective waste collection system aims to collect as much waste as possible within the given amount of labor, capital and time. In the informal enterprises that generate relatively large quantities of solid waste and skips are used as temporary waste disposal and storage sites. There are, however, many factors that needed to be considered in the location of the skips. Firstly, the surrounding community should have been consulted to curtail any negative impacts of waste manifested themselves and agreements should be made on how to deal with the impacts. There were no consultations made with the neighboring residential areas regarding the potential impacts of the solid waste. Questionnaire surveys in the enterprises revealed problems such as odors from rotting waste, smoke from burning waste and rodents as potential health hazards. Another problem with skips is that they are not monitored for any illegal dumping. Some enterprise operators were observed throwing waste on the ground outside the skips and were only concerned about removing waste from their premises and not what happened to the waste thereafter. Each enterprise has the

Table 1. Average composition of waste generated in Harare and Mutare (% by weight).

Waste category	Harare market areas	Harare industrial areas	Mutare market areas	Mutare industrial areas
Food	6.4	10.7	31.6	10.7
Paper	6.0	6.4	10.7	6.4
Cardboard	4.3	4.0	7.9	4.0
Plastics	5.7	5.0	6.4	5.0
Glass	5.0	3.5	3.3	3.5
Metals	39.6	30.6	5.0	30.6
Wood	12.1	10.4	17.0	10.4
Textiles	1.0	9.0	4.0	9.0
Rubber	3.0	5.0	5.6	5.0
WEEE	2.0	2.7	1.4	2.7
Builder's rubble	13.9	8.7	2.6	8.7
Miscellaneous	1.0	4.0	4.5	4.0
Total	100	100	100	100

task of carrying waste from its premises using cardboard boxes, sacks, plastic bags, dishes, small carts or for big items such as car shells, four or more men lift the car shells for dumping in or outside the skips. Most of the enterprises indicated that they dumped their waste inside the skips although observations indicated that some illegal dumping was taking place in the backyards and the open spaces around the informal enterprises. Wood shavings, paper, cardboard boxes, plastics, and tyres were also seen burning with huge amounts of smoke emanating from the area.

Table 2 shows the most common waste disposal methods in the informal sector enterprises of Harare and Mutare.

The data in Table 2 reveals that there are five main methods for solid waste disposal used in the informal sector enterprises because of inadequate and inefficient collection and these are open dumping, burning, open dumping and burning, incineration and landfilling. The most common method used to dispose of the waste is through open dumping of waste by 65% out of the total of 508 enterprises and burning of waste is the second most popular method of disposing of the waste as reported by 22% of the enterprises. The factors that were cited as influencing open dumping of solid waste include the lack of solid waste disposal facilities (50% of the enterprises), the non-existence of penalties for dumping (lack of enforcement of legal deterrents by way of penalties (25% of the enterprises), inadequate information on waste disposal and management in general (22% of the enterprises) and the desire to save on disposal costs. A total of 50% respondents identified the absence of municipal solid waste management facilities as the key factor responsible for the open dumping of waste in the informal sector enterprises. The enterprises that reported that lack of facilities promoted open dumping of waste included the service sector (63% operators), the retail sector (50%), the repair sector (49% operators), manufacturing (45% operators) and the construction sector (39% operators). There was significant association $P < 0.05$ significance level (with a Pearson Chi-Square P value of 0.032 and a likelihood ratio of 0.026) between enterprise type and propensity to dump waste. In confirming the problems associated with the collection and disposal of solid waste generated in the informal sector enterprises the Education and Publicity Officer in the Environmental Management Agency noted that:

A total of 25% of the respondents reported that the City Councils lacked the will to enforce penalties for the open dumping of solid waste as stipulated by the Harare and Mutare City By-Laws. 22% of the respondents were of the view that the main reason for the open dumping of waste in the informal sector enterprises was the absence of timely information on sustainable disposal options and a small number (3%) of the respondents attributed

Table 2. Methods of waste disposal in the informal sector of Harare and Mutare.

	Open dumping	Burning	Open dumping and burning	Landfilling	Incineration	Other	Total
Retail	69	22	4	3	1	1	100
Service	48	35	9	2	2	4	100
Repair	68	18	7	0	1	6	100
Manufacturing	56	29	4	0	2	9	100
Construction	76	7	10	1	0	5	100

Source: Field survey (2015)

waste dumping to the need to maximize profits by saving on costs. These factors have resulted in the undesired dumping of solid waste.

Climate change impacts of waste management practices in the informal sector enterprises

Waste minimization behavior: Waste prevention is considered the most important step in the waste management hierarchy and it results in the highest climate benefits. Within waste prevention there exists a raft of mechanisms that can deliver climate benefit such as cleaner production, extended producer responsibility and sustainable consumption and production. The extent, to which solid wastes can be reduced, recovered and recycled needs to be an integral part of any solid waste management system. The first step needs to be the reduction of waste at the point of generation. Included here are returnable bottle deposits and containers such as glass, metal and plastic and not food jars, plastic and paper cups, liquor bottles etc. In the informal enterprises of Harare and Mutare significantly more enterprises ($P < 0.05$) [Pearson's Chi-Square value of 0.000 and likelihood Ratio of 0.000] reported recycling as the most friendly method of managing solid waste with waste minimization (waste prevention/source reduction) (waste prevention/source reduction) as the second most preferred option (Table 3).

In the informal sector enterprises, 32% respondents indicated they would source-reduce waste and 50% would prefer to recycle waste and hence a total of 82% respondents were considered the potential 'reducers-recyclers' in the informal sector enterprises of Harare and Mutare. Waste minimization is the most dominantly preferred in the service sector (57%) and it is the second most dominant way of managing waste in the retail enterprises (35%), the repair (20%), the manufacturing (26%) and the construction (25%) enterprises. On the other hand, recycling dominates as a preferred method of waste management in construction (70%), repair (68%) manufacturing and retail enterprises (45%). The most common methods for the source reduction of solid waste unknowingly employed by the informal operators were the re-use of waste materials (as well as the repair and re-use of things that had been damaged). The other methods involved in source reduction take into account the attitudes of the enterprise operators in their decision whether to buy particular raw materials. The most important aspects considered include the durability of the raw materials, whether the products' package can be re-used, possibilities for re-using the products, amount of packaging included with the raw materials, and whether the raw materials are from renewable resources. With the exception of the third, fourth and fifth methods discussed above, percentages of enterprise operators for all other methods differed significantly among the enterprises.

In terms of climate change impact, the benefits of waste

Table 3. Environmentally friendly methods of managing waste in enterprises (%).

Enterprise	Waste minimization	Recycling	Energy generation	Landfilling	Other	Total
Retail	35	44	5	14	2	100
Service	57	20	3	15	5	100
Repair	20	68	2	10	0	100
Manufacturing	26	55	4	14	1	100
Construction	25	70	0	5	0	100
Total	32.4	50.3	4.1	12.7	0.5	100

Source: Field survey (2015).

prevention generally outweigh benefits derived from any other waste management practice- not only are net greenhouse gas emissions avoided from treatment and disposal of the waste, but there is also a noteworthy benefit in avoided greenhouse gas emissions from less raw resource extraction and manufacturing. A US EPA study found that, generally, the net greenhouse gas emissions for a given material are lowest for source reduction and highest landfilling [52]. This is especially true for prevention of paper waste where GHG savings are attributed to carbon sequestration (i.e. less use of virgin forest materials to produce paper products equates to less deforestation).

The role of recycling of solid waste

After waste prevention, recycling has been shown to result in the highest climate benefit compared to other waste management approaches. This is the case not only in developed countries but also in developing countries [52,53]. The greenhouse gas benefits of recycling specific materials such as metals, plastics, and glass and paper products are well documented in the literature and vary with material recovery rates and the type of fossil fuel avoided. The most common reasons for enterprises recycling waste were perceived to be saving resources in Harare (66% of the operators respectively) followed by the desire to reduce costs of waste collection and disposal since the municipalities would charge for any waste more than could be held by the standard bins or skips provided. In Mutare, on the other hand, the major reason that was perceived important for recycling was the desire to avoid waste and saving resources was the second reason for choosing to recycle as a method of managing waste. However, improving the appearance of the areas was the least important reason for choosing to recycle in four of the five spatial areas indicating that recycling was mainly viewed in terms of converting waste into valuable materials rather than in terms of environmental aesthetics.

Most of the enterprise operator's revealed lack of adequate room within their premises to store materials and the lack of time and zeal to sort, save and transport materials as the reasons why they would not recycle waste. Some of the important reasons indicated for not recycling included not having buyers for the waste and the absence of recycling programmes. These responses would really be expected from such enterprises where the bulk of solid waste generated is a vegetable and food waste that could not be easily recycled or composted due to the lack of a composting culture in the enterprises. Enterprise operators in repairs such as mechanics suggested elimination of old car bodies as a major method of improving the aesthetic value of the landscape. The other common waste reduction methods included removal of litter, debris, and illegal dumps as well as public education to reduce waste.

Out of all the enterprise operators who preferred recycle solid waste, 63% indicated that they have been doing so for more than 12 months, 22% for 6 months to a year, 8% for 1 to 6 months and 7% did not remember the length of time they have been recycling materials. However, the length of time of recycling differed significantly among the spatial areas ($P < 0.01$) with the enterprise operators in the industrial areas being the leading recyclers and those in the market areas being the least recyclers. The most commonly recycled materials in the industrial areas include ferrous metal from tin cans and scrap metal from old

vehicles and non-ferrous metals such as aluminum, copper, and lead. Heavy metals such as zinc, mercury, and silver are also recovered from the vehicle and household batteries while automobile and truck tyres and road building materials are recovered from tyres for recycling. Recyclable construction and demolition wastes in the industrial areas have been a source of soil, asphalt, concrete, wood, drywall, shingles and metals for builders and have in some cases constituted up to 25% of the building and construction material. The materials recovered from recycling differ significantly between the enterprises mainly involved with manufacturing and construction.

The methods of disposal of e-waste generated in the informal enterprises were influenced by the objective factors that included both the characteristics of the waste such as the type of waste stream and the different types of recycling channels. Methods of disposal of large household e-waste items such as televisions, refrigerators, washing machines, air conditioners and computers and small items such as cell phones were quite different. Selling to scrap merchants is the main way of discarding e-waste in Harare and Mutare. It was established that 46% of the enterprise operators chose this method, while trade-in or selling directly to companies accounted for another 19% of the disposals. The major reasons for disposing of the larger appliances included the inconvenience of storing such large items within the not-so-large enterprise premises as well as the economic benefit of recouping some salvage value. Indeed 16% of the discarded appliances had not completely lost their original function and hence could be sold as second-hand products (hence could serve the same purpose). Some of the discarded appliances could also enter the secondary market after being repaired i.e. a change of state after structure reformation and hence performance is improved to serve the same or sometimes different purpose.

In the manufacturing and construction enterprises, the most commonly recovered materials for recycling from open dumping and other disposal receptacles are plastics, paper, and cardboard, glass, aluminum, food and vegetable waste, textiles and wood. The paper that is recovered for recycling comprises packaging material, old newspapers, corrugated cardboard in the form of bulk packaging paper (which is a major source of paper for recycling) and mixed paper derived from various mixtures of white ledger paper including newsprint, magazines and white colored long fiber paper. The plastic recovered for recycling includes polyethylene terephthalate (PETE/1) and is recovered by scavengers and sold by those who process it to produce soft drink bottles, salad dressing, and vegetable oil bottles as well as photographic film. High-density polyethylene (HDPE/2) is recyclable material that is derived from water containers, milk jugs, detergent, and cooking oil bottles. Another common type of plastic that is recovered from recycling is low-density polyethylene (LDPE/4). This comprises thin film packaging wrap that is discarded by customers who purchase items from the markets and nearby shops. In the enterprises located in the high-density areas, closures and labels of bottles and containers as well as cereal box liners are sources of Polypropylene (PP/5) when recycled. Polystyrene (PS/6) is derived from packaging for electronics and electronic components, foam cups, fast food containers, tableware, and microwave plates. In the market areas, the organic component of the solid waste is dominant and is derived from food and vegetable waste. Some of the

organic waste is recovered by farmers prepare compost for soil enrichment.

Observations in the manufacturing and construction enterprises revealed that scrap metal recovered from the solid waste is used in the production of poultry feeding trays, pots, dishes, metal buckets, window and door frames, dustbins and scotch carts. The waste materials derived from carpentry enterprises such as planks and chipped wood are used in the production of lounge suites, kitchen chairs, stools, benches and tables, and bed mattresses. The waste rubber material is derived from conveyor belts and old tyres and this is an important input for the shoemaking and repair enterprises and is used in the production of sandals and shoes. These products are affordable and hence their market not only comprises residents of the high-density suburbs in which they are located but also customers from other parts of the two cities where such products cannot be readily obtained. Informal activities involving the retailing of spare parts, tyre tubes, bolts, and fasteners were also observed selling reused mended second-hand tyre tubes, damaged tubes, car bearings, bolts, nuts, washers, empty cardboard boxes that were used as table mats, waste timber planks used as flooring or working area.

The amounts of greenhouse gas savings as a result of these recycling activities are generally based on the fact that recycled materials replace an almost equal quantity of virgin materials in a closed-loop recycling system (where the material is reprocessed back into the same or similar product) [53]. The greenhouse benefits of recycling specific materials such as metals, plastics, glass, and paper products are well documented [5-7,16,52,54,55] and vary with material, recovery rates and the type of fossil fuel avoided. Table 4 shows a qualitative summary of the direct and indirect greenhouse emissions and savings associated with the recycling process.

It has been revealed by the UK Waste and Resources Action Programme (WRAP) of 55 LCA studies that ‘across the board, most studies show that recycling offers more environmental benefits and lower environmental impacts than other waste management options [55]. The production of paper followed by incineration with energy recovery consumes twice as much energy as paper recycling. The closed loop recycling of glass results in net climate benefits when compared to incineration. There are also environmental gains made where plastic is recycled when compared to incineration such that for every kilogram of plastic recycled, around 1.5-2 kg CO₂-e is saved. The production of virgin steel needs up to twice as much energy

Table 4. Direct and indirect greenhouse emissions and savings from recycling processes.

Upstream (indirect)	Direct (operating)	Downstream(indirect)
CO ₂ , CH ₄ and N ₂ O emissions from: production of fuel used in facilities (i.e. material recycling facilities and reprocessing plants), heat and electricity consumption, and infrastructure	CO ₂ , CH ₄ , N ₂ O, trace CO and NMVOC from fuel combustion in equipment	Recovery of materials substitutes raw materials: avoided greenhouse emissions from material production. Recovery of paper avoids the use of harvested wood: wood biomass replaces fossil fuel as energy source or wood sequesters carbon

Adapted: Scheutz *et al.* (2009) UNEP (2010)

as the production of steel from recycled scrap and hence there are climatic benefits realized in the recycling of steel.

Solid waste management and the legal framework

In Zimbabwe, there is no overall national waste management policy and hence the crisis in waste management in the informal sectors enterprises of Harare and Gweru as well as other towns and cities of the country. There are no clear policy directives requiring local authorities to implement waste management programmes in particular ways [56]. This has resulted in the haphazard implementation of waste management programs resulting in the lack of promotion of environmentally sound management strategies. Despite these shortcomings, there are a number of policy documents that recognize the importance of developing efficient waste management systems in order to safeguard peoples' safety, health, and the environment. The major weakness of the national policies is in outlining the actual practical steps that are needed in dealing with the environmental problems in the informal sector that include waste management. A comprehensive legal framework in Zimbabwe, however, guides environmental management in both urban and rural areas. The central role of legislation is to monitor waste management activities, prescribing conditions by its regulations to avoid contamination of the environment. The legislation is thus a meta-level activity, which monitors the base level activity and sets targets for activities upon waste. Even though Zimbabwe does not have a policy on waste management there are a number of Acts and by-laws that guide environmental management and also refer to waste management. A number of Acts of Parliament and regulations deal directly and indirectly with environmental pollution in general and waste management in particular and these could apply to the informal sector enterprises of Harare and Mutare. A number of ministries are involved in the administration of the Acts, but the Ministry of Environment and Natural Resources takes overall responsibility and accountability. In addition to the Acts of Parliament and policies on waste management, most local authorities have by-laws which they employ to effectively regulate activities in the areas under their jurisdiction. The results of the survey undertaken in the informal sector enterprises revealed that the majority of the operators felt that the pieces of legislation felt short in addressing fully the problem of waste management.

The Environmental Management Act Chapter 20:27 of Zimbabwe provides for the formulation of waste standards in section 69 (1), prohibition against discharge of wastes (section 70), minimization of waste through treatment, reclamation and recycling in section 70 (3), classification of hazardous waste in section 70 (1-2) and prohibition against littering in section 83 (1-4). The other pieces of legislation are silent on the issue of solid waste management standards; however, the major problem with the Environmental Management Act is in the enforcement of the standards for the informal sector enterprises. The other problem is that while section 70 (3) of the Act encourages sustainable waste management practices, it does not mention the crucial role of other methods such as re-using, reduction and composting that are vital methods in sustainable waste management practice.

The Environmental Management Act falls short in that it does not consider important aspects of waste minimization and these

include sorting of waste. Separation of waste is important in reducing the amount of waste that is disposed at landfills enabling the landfills to last longer. Income generation opportunities are also created through recovery and sale of paper and other non-biodegradable materials and the sale of manure produced from the composting of biodegradable materials. The Environmental Management Act also regulates hazardous waste. The Environmental Management (Hazardous Waste Management) Regulations, 2007, Statutory Instrument 10 of 2007 have been gazetted using Section 140 of the Act and are the legal instrument used to manage hazardous waste in the country. Under these regulations, no person shall generate, store, sell, transport, use, recycle, discharge or dispose of hazardous waste to the environment except under license. Every year each generator of solid waste is required to prepare a waste management plan which includes an inventory of waste management situation by specifying the quantity of waste produced and components of such waste as well as specific goals for reducing the quantities and pollution discharges of the waste through adoption of cleaner production methods, recycling of waste, safe transportation and disposal of waste and generally the adoption of environmentally sound management of waste. Under these regulations, no hazardous waste shall be disposed of at any other place except in a licensed hazardous waste site or landfill and this is not the case obtaining in the informal sector. The Urban Councils Act regulates waste management in centers designated as urban but also falls short in waste minimization strategies in the same manner as the Environmental Management Act. In Section 218 (b) it makes provision of the council to charge for the removal of refuse where this service will have been provided. The major weaknesses of the Act are in that it is silent on key sustainable waste management practices such as the use of the three Rs—reduce, recycle and re-use. It also does not mention what the council would do with the waste collected in the informal sector enterprises and when council failed to fulfill its obligations.

The Public Health Act, Chapter 15:09 of 1996 makes reference to the collection, transportation, storage, treatment and the disposal of waste in Zimbabwe. In Section 83 of the Public Health Act, it is stated that it shall be the duty of every local authority to take all lawful, necessary and reasonably practical measures for maintaining its district at all times in a clean and sanitary condition, preventing the accumulation of refuse which may be injurious or dangerous to health. Waste producers and municipalities are also expected to take responsibility for collection, transportation, storage and the treatment of waste. The Public Health Act delegates waste management to the producers of wastes and this causes problems where no clear waste management standards and procedures exist. While the Public Health Act addresses the issue of waste by prohibiting a person from causing a nuisance on land, which he occupies, owns or controls, it does not prohibit people from causing nuisances and land over which they have no control.

Apart from the policies and Acts of Parliament dealing with waste management issues, local authorities make laws to help them control and regulate activities taking place in their areas of jurisdiction. The local authorities are empowered to make by-laws through section 227 (1) of the Urban Councils Act Chapter 29:15. Generally, by-laws are formulated from existing national legislation and as such, they complement the legislation from

which they are derived. The by-laws used to regulate waste management in cities were derived mainly from national legislation dealing with public health and environmental management. The Public Health By-laws give the municipalities the prerogative to determine the frequency of waste collection. This has resulted in the erratic collection of waste in the informal sector due to unknown frequencies of collection and as a result, waste accumulates around bins. The waste hence becomes an environmental nuisance. In the enterprises where collection frequencies are inadequate, the waste has been dumped in open spaces in backyards or pits have been dug up to deposit the waste. The By-Laws are also silent on the removal of special or hazardous wastes which may emanate from the informal sector. Part 10 Clause 60 only prohibits people from depositing explosives or burning materials or hazardous substances in any receptacle provided for storage of refuse or on any refuse disposal site. As legal instruments, the Public Health By-laws address issues of waste removal in a command and control manner. They, however, do not address the vital areas of standards of safe handling of special or hazardous waste generated in the informal sector. There are no clear objectives in terms of waste reduction, re-use, recovery, and recycling. According to the by-laws "any person who contravenes or fails to comply with any provision of the by-laws; or any certificate, permit, notice, order or another document, instruction or direction issued under these by-laws with which it is his duty to comply, shall be guilty of an offense." However, the heaps of coal ashes, yard and garden wastes and empty bottles and tins in the backyards of informal sector enterprises in Harare and Mutare provide evidence of lack of enforcement of the by-laws.

Conclusion and Recommendations

Huge quantities of solid waste are generated in the informal sector enterprises in Harare and Mutare and this is lost without resource value being extracted from them and hence these contribute to greenhouse gas emissions that exacerbate climate change impacts. The response to this problem has been in the form of erratic collections by the municipalities of Harare and Mutare as well as dumping in uncontrolled landfills as well as open dumping by the enterprise operators and the general public. Prevention of waste should be the main focus of solid waste management and this relates to resources conservation as the principal goal of in climate change abatement. Analysis of key factors that include solid waste generation rates, collection frequencies and transportation, waste minimization and reduction practices has shown that the current waste management system gives less priority to environmental protection. The study established that waste minimization practices employed in the informal sector enterprises of Harare and Mutare involved re-use, recycling, and sales as forms of waste management. Despite the fact that waste minimization is not intentionally undertaken, it has to some extent reduced the amount of waste that is eventually taken to the disposal sites. In most cases, waste minimization is a vital component of solid waste management practices. However, this principle lacks universal applicability in the informal sector enterprises of Harare and Mutare has thus lagged too far behind. The temporary waste storage facilities provided by the City Councils have not been designed to accommodate efficient resource recovery and

recycling as well as other waste minimization strategies. This is a result of the haphazard disposal of waste despite the fact that it is biodegradable or not. The amount of solid waste disposed of per enterprise far outweighs the amount of waste recycled and recycling is only undertaken by those enterprises that are willing to do so. Recycling is a strategy that is expected to consume small amounts of raw materials and less energy with minimal pollution of the environment. Source reduction has a great impact on the whole waste management hierarchy because fewer materials will be needed to be recycled or sent to landfills or even incinerated. The programs and policies that focus on source reduction include Extended Product responsibility that encourages producers to take full economic responsibility of the product from cradle to the grave. Pay as throw programs are also encouraged to force people to pay for their waste disposal and are very effective at reducing waste disposal in landfills. In order to lower waste bills enterprises reduce waste sent to landfills at the source.

In line with the postulations of the principles of industrial ecology and integrated resources management that provided the conceptual basis of this study, there should be no waste generated in the informal sector enterprises of Harare and Mutare without a purpose. In this regard, waste could only be regarded as those things that have no purpose; or those things not able to perform with respect to their purpose. In order to minimize waste generated in the informal enterprises, there is a need to increase the proportion of non-waste emanating from the activities. Waste minimization and resources-use optimization are vital objectives of waste management and hence these concepts need to be considered in the context of industrial ecology and these concepts are inter-related. Industrial ecology is important in that it reaches far beyond the walls of an enterprise and encourages co-existence with the environment and hence creates interlocking ecosystems with other enterprises to achieve an efficient circulation of materials. As revealed in the literature review [42,57-59], resource drivers are now vital and these are revealed through the waste management hierarchy and discourage disposal and instead encourage more sustainable options such as reduction, re-use recycling, and energy recovery. Waste management in the cities of Harare and Mutare should not be regarded only as the art of how to treat waste since this is just one part of the process. Solid waste management needs to develop more or less along the lines of integrated resources management and industrial ecology. These are holistic views of materials flow in society rather than the last steps of material transformation that results in a material loss as everything becomes waste. Analysis of solid waste management in the informal sector has revealed that large amounts of waste are generated and disposed of (or lost) indicating poor material efficiency in the enterprises.

There is no mechanism that has been developed or supported by the municipalities of Harare and Mutare to promote composting of the large quantities of waste generated especially in the market areas. As noted in the literature review, composting is one of the most significant aspects of sustainable solid waste management. Composting assists in waste reduction and as a result, less waste ends up heading for the landfill. Composting assists in the production of organic fertilizer and promotes environmentally friendly practices such as reduction in the

release of landfill gas emissions, foul smell covering the dump site is greatly reduced and the composting in itself can be an excellent source of revenue generation.

Education is thus vital in raising awareness on environmental management issues, especially solid waste management. This is an area in which the Environmental Management Agency under the Ministry of Education could play a part through its education and publicity department. Public education on waste prevention and waste minimization through reduction, reuse and recycling could be directed at the informal sector enterprise operators, schools, community groups, churches, and the electronic and print. The Ministry of Education needs to ensure that Environmental Education is part and parcel of the curriculum starting from primary school, through to secondary schools, teacher colleges, poly-technical colleges, and the university. This ensures that concepts basic concepts of environmental management are inculcated in the right from the youthful stages of life.

There is need to reduce the environmental impact from a product by making the informal sector enterprise operators responsible for the entire lifecycle of the product and especially the take-back, recycling and final disposal of the product. According to the concept of extended producer responsibility a producer is considered the actor that has the most influence on the life cycle processes of the product and can be held responsible for taking the initiative for change and has the knowledge and opportunity to change both upstream and downstream processes. The goals of extended producer responsibility include source reduction (natural resource conservation/materials conservation, waste prevention, the design of more environmentally compatible products and the closure of material loops to promote sustainable development.

In order to achieve the desired course of events or line of action that favors reduction of waste outlined above the city authorities also need to affect public policies that reflect the inter-relationship of the policy stakeholders (enterprise operators), the environmental policy setting and the law enforcement environment. This setting ensures that there is scope for creating a sustainable waste management system that develops into an Environmental Management System in tandem with the goals of industrial ecology whereby nothing is considered waste and is part of a natural material cycle. The transition from the waste management system to the environmental management system is guided by the technically possible solutions to the waste management problem. However, resources are a major constraint for the Cities of Harare and Mutare in the provision of adequate waste management services for the informal sector. There is need to strengthen the municipalities of Harare and Mutare in terms of the provision of resources for financing, training, and manpower so as to enable the effective provision of an environmentally friendly solid waste management system in the informal sector. The causes of the solid waste problem in the informal sector can also be traced to the lack of a sense of urgency in dealing with the waste management problem by both the central government and the City authorities. This is mainly due to the non-existence of a waste policy that provides a framework for the planning and organization of waste management activities as well as the lackadaisical enforcement

of environmental legislation that pertains to solid waste management. The lack of will to enforce penalties as stipulated by the City By-Laws was cited by 152 (almost 25%) of the respondents as the key reason for the open dumping of waste.

All in all, the solid waste management problem in the informal sector enterprises of Harare and Mutare is related to the huge loss of resources that could be essential in the reduction of greenhouse gas emissions. The informal sector enterprises need to strive for there not to be a product or waste without a purpose and every product or waste should have an owner. There is a need to prevent creating things with no purpose by assigning a new purpose to a waste thing and this ensures an improvement of a production process of the informal activity. It becomes vital to prevent creating things that cease performing and also preventing the owner from failing to use things for their purpose through the use of legal instruments and other means. It is also important to avoid creating things that are used for just one purpose and then thrown away as waste [60-63]. The solid waste management system in the informal sector of Zimbabwe is ineffective in reducing environmental pollution and lacks proper guidelines on the 'wasting' problem. Waste minimization based on the principles of the waste management hierarchy, industrial ecology, and integrated resources management could be a useful panacea to the wasting disease and hence reduction of greenhouse gas emissions that exacerbate climate change impacts.

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***Correspondence to:**

Steven Jerie
 Department of Geography and Environmental
 Studies
 Midlands State University
 Zimbabwe
 E-mail: stevejere@msu.ac.zw