INCINERATION AS A POTENTIAL SOLUTION TO AFRICA'S PLASTIC WASTE CHALLENGES? A NARRATIVE REVIEW

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Abstract

Africa is considered the second most polluted continent and it will contribute the highest amount of waste into the world's oceans by 2035. A paltry 4% of the total municipal solid waste (MSW) generated in Africa is recycled and yet 70-80% of the MSW is recyclable. In addition, 90% of the waste that is generated is dumped at uncontrolled landfills while 10% is illegally burnt. Africa has accumulated over 130 million tonnes of plastic waste on its landfills. The poor recycling statistics of the continent means that Africa is missing out on the benefits that plastic waste can yield such as job creation and energy generation; both which are lacking in Africa. The objectives of this review are therefore to assess whether incineration can be considered in the management of plastic waste in Africa based on past life cycle assessment studies; to determine the risks associated with incineration as well as evaluate threats to its success. Data was sourced using keywords and phrases in academic databases and grey literature. The results show that opportunities exist for Africa to manage its plastic waste sustainably and therefore, landfilling of plastic wastes is not the solution due to the risk of spontaneous fires that release harmful toxins. In conclusion, as the continent navigates the path to "zero waste to landfills" in line with circular economy principles; it is time for waste to energy technologies such as incineration to be considered in waste management systems. Life cycle assessments (LCAs) within the African context need to be carried out as they are lacking, in order to determine how incineration or other treatment methods such as pyrolysis and use of plastic wastes in cement kilns and blast furnaces can be successfully implemented without increasing eco-toxicological and human toxicological impacts.

Keywords: Incineration, Life Cycle Assessment, Plastic waste, Risks

1 INTRODUCTION

For so many years, plastic has been the preferred choice of material owing to its robustness [1][2] and to date this trend has not changed as we will continue to use plastic in our daily living. However, the mismanagement of this valuable material has resulted in significant environmental pollution and is also now a part of our food chain [3] [4], with single use plastics being the most problematic [2][5]. According to McKinsey & Company, if plastic waste pollution is not curtailed then it will continue to increase sharply [6]. From its study the company found out that the bulk of marine litter (above 80%) is contributed by land-based sources. As much as 75% of that waste is generated from waste that is not collected and the balance, from leakages along the waste management chain [6]. In 2013, a 300% increase in plastic production globally was predicted for 2050 [7], while in 2014 Eriksen et al [8] reported that the sea's surface contained a minimum of about 5.25 trillion plastic particles with an approximate equivalent weight of 268 940 tonnes.

Of the total marine debris, 80% is attributed to plastic and without any intervention methods in place, it is postulated that in 5 years' time, our seas will contain a ratio of 1 tonne of plastics:3 tonnes of fish while in 30 years, the amount of plastic in the oceans will exceed the number of fish [4]. It is also estimated that an equivalent of emptying a 14 tonne garbage truck almost every minute into the ocean is how much plastic waste enters the oceans yearly and this is postulated to increase to 2 and 4 trucks per minute in 2030 and 2050, respectively.

The waste hierarchy shown in Figure 1, has been used around the globe as a "rule of thumb" when grading waste management methods from the least preferred to the most preferred method in the management of plastic waste.

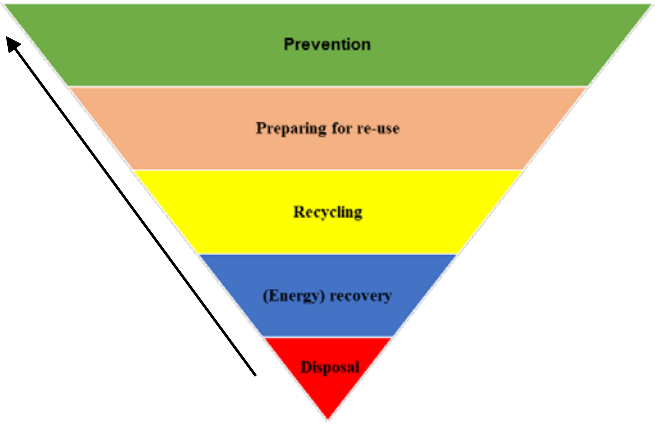

Figure 1. Waste Hierarchy (arrow points to most preferred option)

1.1 Plastic Waste Management Methods

As shown by the waste hierarchy, currently, the order of preference of handling post-consumer plastic wastes is as follows: mechanical recycling in which the structure of the material is maintained; thermal recycling' which is the incineration of plastic wastes for energy recovery and chemical/feedstock recycling, a process by which plastic wastes are broken down into their monomers or different chemicals and used as fuel in the transport sector or in petrochemical industries [9] [10] and landfilling. However, the prevalence of plastic pollution as a result of poor waste management systems [11] led to the rise of the "closing the loop concept "or circular economy [12], Figure 2 in order to close the tap on plastic waste leakage. The scope of a circular economy covers reuse, recycle, redesign, remanufacture, reduce and recover [13] [14].

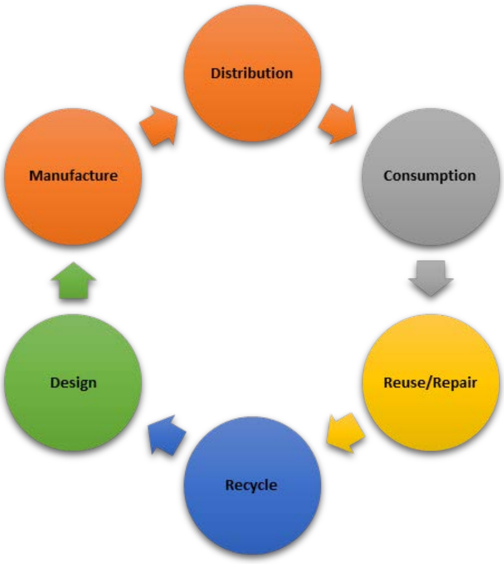

Figure 2. European strategy for plastics

Countries in Europe, across Australasia [15] and North America [16] have started implementing the concept of a circular economy to their environmental policies where waste is regarded as a valuable resource; a marked change from the "take-make-waste" model, Figure 3 [12] [13] [14] [17]. In Africa the concept is on the continent's agenda and still in its infancy [18].

Figure 3. Take, Make, Waste Model
Concept adopted from: [17]

1.2 Review of waste management practices in Africa.

In developing countries, over 90% of solid waste is not collected through formal channels and as a result it is either illegally dumped or burnt thus contributing to, eco- and human toxicological impacts [19] unlike in developed countries. This is especially true in poor urban settings [20]. According to the African Marine Waste Network, Africa is the second most polluted continent, and by 2035, it will contribute the highest amount of waste into the world's oceans [21]. A paltry 4% of the total of municipal solid waste (MSW) generated in Africa is recycled and yet 70-80% of the MSW is recyclable [22]. Even more concerning is the fact that, 90% of waste that is generated is in uncontrolled landfills. The poor recycling statistics of the continent means that Africa is missing out on the benefits that plastic waste can yield; among which are job creation and energy generation both of which are lacking in Africa. If current trends continue, by 2025, Africa would have lost an opportunity to create about 172 500 jobs. With the proportion of plastic waste in MSW at around 13% [22], this means that Africa has potentially accumulated about 130 million tonnes of plastic waste on its landfills. This is a conservative figure as we have assumed that 125 million tonnes of waste have been produced yearly since 2012. The 2012 waste statistic was reported by [22] in their 2018 report. Continuous dumping of MSW can also lead to waste landslides not to mention shortage of much needed land and this is made worse by the fact that plastics have a high specific volume [10] and as a result landfill airspace is rapidly reduced.

With this in mind, and the increasing population and its associated demand for residential land, it is crucial to divert waste from landfills and create useful resources out of it through effective mechanical, thermal and feedstock recycling.

Successful implementation can only be achieved from the establishment of effective waste management policies and the collaboration between governments, various stakeholders and the public during implementation of these policies.

1.3 Objectives

The objectives of this review are to assess whether incineration can be considered in the management of plastic wastes in the African context based on past life cycle assessment studies and to determine the likely risks associated with this process as well as threats to its success if any.

1.4 Data Sources

Peer reviewed studies used in this narrative review were found through Google scholar, Elsevier, Springerlink, and Wiley Online Digital Library as well as grey literature. Several key words and phrases were used which included; plastic waste incineration, plastic waste management methods, life cycle assessment for plastic waste management and risks associated with plastic waste incineration.

2 INCINERATION

The incineration of plastic waste is already commonly practiced in many countries in Europe as shown in Figure 4. In 2019, 42.6% of post-consumer plastic was incinerated for energy while 32.5% and 24.9% where recycled and landfilled, respectively [23].

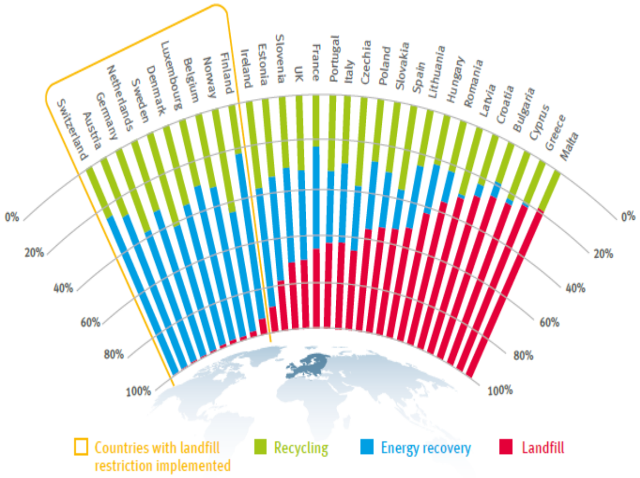

Figure 4: Recycling, Landfilling and Energy Recovery rates in Europe, 2016 [24]
Source: Conversio Market & Strategy GmbH, Germany

2.1 What is Incineration

Incineration is a dry oxidation process that occurs at high temperatures reducing organic, combustible matter to inorganic and non-combustible matter. During incineration, there is a significant reduction in the volume and weight of the waste. Incineration results in the production of gaseous emissions such as carbon dioxide, poisonous carbon monoxide (from incomplete combustion if conditions in the incinerator are poorly controlled), steam, nitrogen and sulphur dioxides, volatile heavy metals such as mercury, halogenic acids such as hydrochloric acid, dioxins and furans which are toxic [25] [26] as well as particulate matter and solid waste in the form of ash, Figure 5.

Ash and any wastewater produced during the incineration process also require further treatment to remove any toxins in order to protect people and the environment [26].

Incinerators may or may not have energy recovery systems. Steam or hot water generated from incinerators may be used as a heating source in cold areas while in warmer climates, the steam can be used for electricity generation [26]. The heat generated from incineration can also be used to preheat the incoming waste [26].

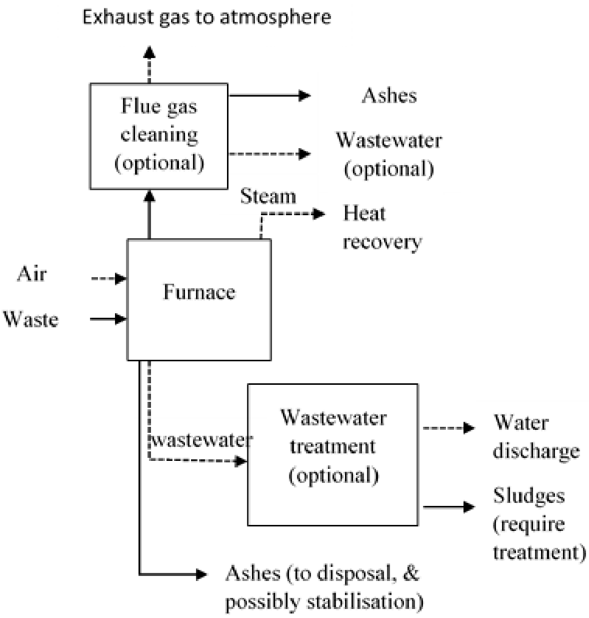

Figure 5. Simplified diagram of an incinerator. source: [26]

2.2 Age of Incinerators

The "Age of incinerators" commenced in the 18th century as a result of municipal solid waste which was laden with glass, ceramics and other non-organic matter which was causing a deterioration of agricultural soils. In London and Hamburg, the rapid rise in MSW and the inability to manage these wastes also opened the door to incineration. These early generation incinerators comprised a furnace and a stack [25]. Incineration of MSW reportedly not only reduced waste volumes but also reduced the incidences of a number of waterborne diseases such as typhoid fever and cholera as this prevented dumping of waste into water bodies [25]. Therefore, it could be said that the goal of incineration then was to reduce volumes of waste as well as to prevent diseases from poor waste management and poor conversion of waste to energy. However, the health dangers that emissions posed were not considered. The resulting bottom ash was used in construction or soil conditioning although benefits of this practice are not clear.

Nowadays, incinerators are used to generate energy (thermal or electricity) from waste and are equipped with controls to reduce harmful stack emissions in line with environmental regulations. The management of residual ash is also regulated [27]. As the years progressed, legislation surrounding incineration technology also evolved and so did the design of these incinerators as people became more aware of the risks associated with emissions released. The filtration systems which were predominantly cyclones or electrostatic precipitators were then replaced by multi-stage wet and dry filtration systems which did not only remove fly ash, but also fine particulates laden with heavy metals and other persistent pollutants. Consequently, emissions were reduced by 97% from >150 mg/Nm^3 to <5 mg/Nm^3 with cadmium and lead metals reducing significantly [25].

Barjoan et al [28], conducted an investigation into risks associated with incinerators and found that people who reside in areas where there is exposure to emissions from an incineration plant were prone to cancers such as; acute myeloid leukaemia, myelodysplastic syndromes and myeloma in women and sarcomas of the soft tissue, myeloma and lung cancer in men. However, the authors also highlight that the passing of the waste incineration directive; Directive 2000/76/EC by the European Union which set the limit for dioxin emissions to less than 0,1 ng TEQ/m^3 (Toxic Equivalents) could have potentially reduced the incidences of these cancers with a lengthy latency, in the area of investigation [28].

Verma et al [29] carried out a review in which they assessed the risks associated with open burning of plastic waste. The authors also highlight the release of the afore mentioned toxins as well as Polychlorinated Biphenyls. According to Verma et al, dioxins may settle on plants and end up entering our food chain. The more toxic form of dioxins 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD), or agentorange reportedly causes cancer, may result in neurological damage, disruption of the thyroid glands and the respiratory system which can lead to asthma and emphysema. Burning polystyrene may also result in the damage of the central nervous system and cancers [29].

Other researchers that have also studied risks associated with incineration include Boudet et al [30] and Roes et al [31].

2.3 Ideal Feedstock for Incineration

For incineration to be economic and technically feasible, the heating value of the wastes should be at least 8370 kJ/kg. For mixed plastic wastes, the heating value is around 30-40 MJ/kg which makes plastic an excellent feedstock for incineration. Other characteristics of wastes destined for incineration are: at least 60% of combustible matter, at most 5% of incombustible solids, incombustible fines should be less than 20% and moisture content should be below 30%. Due to the high heating value of plastic wastes, they can be co-incinerated with lower heating value municipal wastes which improves the overall heating value of the municipal solid waste. Moreover, no additional fuel will be required in this case.

3 LIFE CYCLE ASSESSMENT STUDIES

Many researchers have conducted life cycle assessment studies on the various processes that can be used in MSW management with plastic waste being a major focus. Some of these researchers include; Mølgaard [32], Song and Hyun [33], Lazarevic et al [34], Wrap [35], Aryan et al [36], Chilton et al [37], Moberg et al [19], Arena et al [38], Dodbiba et al [9], Banar [39], Foolmaun and Ramjeeawon [40], Zackrisson et al [41], Salem et al [42] and Zhao et al [43]. A few of these studies have been highlighted below in greater detail.

- **Study 1 – France and Sweden (Europe)**

Lazarevic et al [34] conducted a review of various life cycle assessments studies on plastic waste end of life options in order to determine the most preferred post-consumer plastic management method as well as assess the extent of agreement of the results with the waste hierarchy. The following options were compared in this study:

- mechanical recycling and (MSW) incineration,
- mechanical recycling and feedstock recycling,
- feedstock recycling, MSW incineration and combustion as solid recovered fuel (SRF)
- MSW incineration and landfilling.

These processes were compared across the following impact categories; assessed in more than half of the studies reviewed: abiotic resource depletion potential (ADP), global warming potential (GWP), eutrophication potential (EP), acidification potential (AP), energy use (EN) and residual solid waste destined for landfill (SW). ADP was important to analyse because of the avoided need for non-renewable (fossil) feedstock when plastic waste is recycled or used for energy recovery. The authors found that mechanical recycling was the most preferred waste management method compared to feedstock recycling and MSW incineration when the plastic waste recycled is not contaminated with organics and can replace the virgin plastics at a ratio 1:1.

However, for unrecyclable waste, feedstock recycling was more preferred than incineration, although no clear distinction could be made between feedstock recycling and combustion of plastic wastes in a cement kiln as SRF. The use of plastic waste in the blast furnace or as SRF were preferable to incineration with energy recovery, while landfilling was the least preferred management method across all impact categories except GWP.

Lazarevic et al [34] therefore emphasize the need to not only consider GWP but also other environmental impacts when selecting the most suitable form of treatment for plastic waste. The results also appeared to validate the waste hierarchy and therefore reinforcing the idea that the hierarchy still has a place in plastic waste management [34] although deviations are expected when the plastic wastes are contaminated with organics or have to be downcycled which affects the afore-mentioned 1:1 ratio. In that case, incineration with energy recovery could therefore supercede mechanical recycling [34].

- **Study 2 – United Kingdom (Europe)**

Wrap [35] conducted LCA studies on mixed plastic wastes by assessing mechanical recycling (M), incineration with energy recovery (I), pyrolysis (P), landfilling (L), conversion to solid recovered fuel in the cement kiln (SRF) and use as a redox agent (RA) in the blast furnace. Several impact categories were analysed and the results are indicated in table 1 below**.**

Table 1. LCA results [35]

Impact investigated	**Results**
Global warming potential (GWP)	M<SRF<RA<P<L<I
Photochemical ozone creation potential (POCP)	M<P≈SRF<RA<I<L
Eutrophication potential (EP)	P≈SRF<I<M≈RA<L
Acidification potential (AP)	M<SRF<P<RA<I<L
Human toxicity potentials (HTP)	P≈RA≈M<SRF<I<L
Ozone layer depletion potential (OLDP)	P<I<M≈RA<SRF<L
Abiotic depletion potential (ADP)	SRF<M≈RA<P<I<L
Solid waste arising	I<SRF<RA<M<P<L
Energy use	SRF<RA<P<I≈M<L

Incineration with energy recovery performed better than landfilling except on GWP where incineration had the highest negative impact compared to other scenarios. Incineration also had the least impact on solid waste arising due to the significant volume reduction that occurs during the process. However, the pyrolysis (P), cement kiln (SRF) and blast furnace (RA) scenarios were better than incineration in most of the impact categories investigated. Overally, mechanical recycling showed the best performance when all impact categories were considered.

- **Study 3-India (Asia)**

Aryan et al. [36] studied the management of polyethylene terephthalate (PET) and Polyethylene (PE) wastes. Four scenarios namely; landfilling excluding energy recovery (L_{-E}), incineration without energy recovery (I_{-E}), recycling (R) and incineration including energy recovery (I_{+E}) were considered. The impact categories evaluated were; Abiotic Depletion (fossil fuels), Abiotic Depletion, Global Warming Potential (GWP100), Ozone Layer Depletion (ODP), Human Toxicity Potentials (HTP), Fresh Water Aquatic Ecotoxicity (FWAE), Marine Water Aquatic Ecotoxicity (MWAE), Terrestrial Ecotoxicity (TE), Photochemical Oxidation Potential (POP), Acidification Potential (AP), and Eutrophication Potential (EP)]. The results are summarised in table 2.

Table 2: LCA results [36]

Impacts investigated	**Results**
AD (fossil fuels)	$I_{+E}<R<L_{-E}<I_{-E}$
AD	$L_{-E}<I_{-E} = I_{+E}<R$
GWP	$R< L_{-E}< I_{+E}< I_{-E}$
ODP	$R< L_{-E}< I_{+E} = I_{-E}$
HTP	$R< L_{-E}< I_{+E}<I_{-E}$
FWAE	$R< L_{-E}< I_{+E}<I_{-E}$
MWAE	$R< L_{-E}< I_{+E}<I_{-E}$
TE	$R< L_{-E}< I_{+E}<I_{-E}$
POP	$R< L_{-E}< I_{+E}<I_{-E}$
AP	$R< I_{+E} <L_{-E}< I_{-E}$
EP	$R< L_{-E}< I_{+E}<I_{-E}$

Incineration without energy recovery had the highest environmental impact, followed by incineration with energy recovery and landfilling. This is a deviation from the findings by Wrap [35] where incineration outperformed landfilling. Incineration with energy recovery, did however have the least environmental impact when only Abiotic Depletion (fossil fuels) was considered. Overally, recycling had the least environmental impact when all impacts were considered.

- **Study 4-United Kingdom (Europe)**

Chilton et al [37] evaluated two scenarios for post-consumer PET bottles and these were; kerbside collection in conjunction with reprocessing into new drink bottles (closed loop recycling) and incineration with energy recovery of mixed wastes. The impact categories evaluated were carcinogens, respiratory organic emissions, ozone depletion, fossil fuel use, respiratory inorganic emissions, acidification/eutrophication, climate change, radiation and ecotoxicity. Chilton et al [37] found out that recycling had the least environmental impact across all the impact categories studied. However, the authors [37] also highlight that factors such as kerbside collection, cleaning and transport costs need to be taken into consideration as well before selecting closed loop recycling. Although incineration impacted negatively on climate change, there were environmental benefits realised on fossil fuel consumption, respiratory inorganic emissions and acidification.

Study 5 – Japan (Asia)

Dodbiba et al [9] evaluated mechanical and thermal recycling (incineration) across the following impact categories; ADP, GWP, AP, POCP, EP and HTP. According to [9], GWP and ADP contributed significantly to the environmental burden, with these impacts higher for incineration than for mechanical recycling. Therefore, incineration had the highest total environmental burden.

Study 6 – Sweden (Europe)

Moberg et al [19] compared mechanical recycling, incineration with energy recovery and landfilling over several impact categories for municipal solid waste, as shown in Table 3.

Table 3. LCA Results [19]

Impacts investigated	Results
Total energy	R<I<L
Non-renewable energy use	R<L<I
Global warming	R<I<L
Photo-oxidant formation	R<I<L
Nitrogen oxides (NOx)	R<I≈L
Sulphur dioxides (SOx)	R<I<L
Eco-toxicological impacts	R<I≈L

Recycling and incineration were more beneficial to the environment than landfilling in most of the impact categories analysed. However, the authors highlight that the results could also shift in favour of landfilling depending on the assumptions and system boundaries given. Moberg et al, [19] also report the uncertainties in toxicological impacts due to lack of accurate data in this area.

4 DISCUSSION

The major concern surrounding incineration is to do with emissions generated during the process, which if not controlled can be harmful not only to humans but to the environment as well. Although stringent regulations have been enacted in relation to permissible emissions, findings such as those by Barjoan et al [28] and Verma et al [29]can be bothersome to residents in close proximity to areas where such initiatives may need to be implemented; and if there is no buy-in from the public due to lack of trust in the local government or municipality as is currently the case in many developed countries, then such projects may not be successfully commissioned [10]. That being said, Africa as a whole is in urgent need of sustainable measures to manage its plastic waste. Spontaneous fires burning in uncontrolled landfills, have a worse impact on the environment than controlled burning in an incinerator which is adequately equipped to reduce emissions as shown by the drop in incidences of cancers reported by Barjoan et al [28] after the passing of the Directive 2000/76/EC on permissible emissions by the European Union.

From the LCA studies that have been reviewed, it is evident that, there is no clear management method that outperforms the rest when various impact categories are separately considered. However, as explained in greater detail in another publication by the authors [2]; as much as mechanical recycling had lower environmental impacts across most categories studied, it needs to be complemented by other processes since it is not a means to the end of plastic waste [2].

There are categories where incineration outperforms mechanical recycling such as in fossil fuel depletion and solid waste arising due to the energy recovered from the process as well as the ensuing volume reduction in waste that occurs. Furthermore, incineration would be a more environmentally beneficial option when the plastic waste is contaminated with organic matter which in turn leads to downcycling (made into lower value products) [34]. Downcycling results in the manufacture of more virgin plastics which requires non-renewable resources such as crude oil and energy for production which increases the environmental burden of plastics production. This indicates that an opportunity does exist to also exploit this form of waste management method in Africa.

Pyrolysis as well as the use of plastic waste in cement kilns and blast furnaces as solid recovered fuel and a reducing agent respectively, have also proven to be quite competitive from the studies conducted when compared to mechanical recycling.

4.1 Plastic Waste Incineration Threats

There are, however threats to the success of plastic waste incineration, which if not handled can result in unintended consequences. First, if emission standards are flouted and not enforced by the responsible authorities, people may succumb to respiratory diseases or cancers. Moreover, the release of greenhouse gases into the atmosphere will increase the total burden of the process on the environment. In addition, if there is no adequate separation of waste at source, then inert wastes such as sand or ash as well as organic waste with high moisture content will enter the incinerators resulting in inefficient operation. Due to its low calorific value compared to plastic, this will result in inefficiencies of the plant. However, instituting separation at source will be beneficial in this regard. Furthermore, the high capital and operating costs required for incineration may be a limiting factor for many countries in Africa, unless they receive support from high-income countries.

5 DIRECTIONS FOR FUTURE RESEARCH

There is need for LCA studies in plastic waste management to be conducted in Africa as these are inherently lacking with most studies of such a nature having been conducted across Europe. This will also help to inform decisions on which treatment methods need to be prioritised in Africa. This has also been noted by Mazhandu et al [2].

6 CONCLUSION

Many opportunities exist for Africa to manage its plastic waste sustainably. As the continent navigates the path to “zero waste to landfills” in line with circular economy principles; it is time for waste to energy technologies to be included in waste management systems. Incineration with energy recovery has benefits that can be exploited. If countries in Europe are successfully implementing it, in the management of plastic wastes, then there is no reason why it cannot also be explored in the African context. However, this will require life cycle assessments to be carried out, together with sensitivity analysis studies which are lacking in Africa, in order to determine how this management method can be successfully implemented without increasing eco-toxicological and human toxicological impacts. Other treatment methods such as pyrolysis, use of plastic wastes in cement kilns and blast furnaces which have been shown to be beneficial in various impact categories should also be taken into consideration when drafting waste management plans.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Johannesburg and Botswana International University of Science and Technology for funding this work.

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