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Creating a Healthy Community Through the Use of Biodigesters' (An Impact Assessment Case Study in Prisons and Boarding Schools in Zambia)

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Abstract

The challenge of waste management should be finding a way not to produce waste; and to rethink waste management to a point where the processes, methods, techniques and solutions to the problem of waste do not themselves produce waste. The circular economy is arguably the closest solution we can get to a future without waste. Solid and liquid waste pose significant problems and challenges in disposal and both negatively impact the ecological systems critical to the wellbeing of the environment and humanity's survival. We must harness the power of science to be able to find solutions firstly to not producing waste and secondly to handle the already produced waste in a manner that can benefit the environment and help fix the environment. There must be a shift to regard waste as a resource, to promote a waste hierarchy of recovery of waste, where prevention, reduction, reuse, recycling and composting are of primary consideration followed by other means of recovery such as energy recovery and lastly disposal. This will translate to the development and promotion of public health by observing solid waste safeguards that uphold key social and health determinants. It is important to emphasize that proper waste management is crucial for maintaining hygiene and for economic and social reasons, as waste can serve as a source of low-cost raw materials for bio-energy and valuable bio-products with high potential.

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1.1 Introduction

Electricity is Zambia's primary source of energy, and the supply of electricity is mainly hydroelectricity with a few exceptions. Zambia produces hydroelectricity from the Kafue Gorge Power Station, Kariba North Bank Power Station, Lunsemfwa Hydropower Station and Itezhi Tezhi Hydropower Station. In 2022, the Zambia's Ministry of Energy (2022) stated that "Electricity remains a major source of energy in our country. The Electricity Supply Industry (ESI) in Zambia comprises power generation plants owned and operated by ZESCO Limited, the national electricity utility company and power generation plants owned and operated by Independent Power Producers." Apart from these, there is one thermal power plant, Maamba Collieries. Another power plant is the Ndola Energy Company Limited, which is a Heavy Fuel Oil (HFO) power plant. Together these power plants make up the electricity supply of the nation.

In the recent past, the hydro power plants have been unable to keep up with electricity demand (Government of Zambia Ministry of Energy, 2016). And in recent times the situation has worsened (Government of Zambia Ministry of Energy, 2019; Government of Zambia Ministry of Energy, 2022). The Policy Monitoring and Research Centre (2015) categorically stated that "Power demand has outstripped supply" and that "electricity demand in Zambia outweighs supply, especially during peak hours". Similarly, Mukumba and Mukuka (2016) observed and stated that "Zambia is in the middle of a crippling energy crisis as the country grapples with a huge power deficit... the situation is likely to worsen as the demand for electricity continues to grow by an estimated 200MW annually."

The above means that Zambia is either unable to or is struggling to sustainably and efficiently supply hydroelectricity electricity to the nation. The consequence has

been power rationing called load shedding (Government of Zambia Ministry of Energy, 2016; Government of Zambia Ministry of Energy, 2022; Government of Zambia Ministry of Energy, 2019).

Load shedding is defined as “a deliberate shutdown of electric power (electricity) in a part or parts of a power-distribution system, generally to prevent the failure of the entire system when the demand strains the capacity of the system” (Policy Monitoring and Research Centre, 2015). Load shedding is a preventive measure to prevent damage to the national grid as well as an economic and social safeguard to prevent critical industries and institutions from halting operations and services.

During power rationing or load shedding, power supply in selected areas is for predetermined hours on either fixed days or random days disconnected by the national power utility company called the Zambia Electricity Supply Corporation; ZESCO for short (Government of Zambia Ministry of Energy, 2016; Government of Zambia Ministry of Energy, 2022; Government of Zambia Ministry of Energy, 2019).

ZESCO is a state owned or para state monopoly; it has been and remains the only hydroelectricity power utility company supplying and selling hydroelectricity to the entire country. According to the Ministry of Energy (2022), of the actual available electricity generation; about 3,000 MW as of that year, ZESCO produces 80 per cent and the other 20 per cent is from Independent Power Producers (IPPs). ZESCO maintains its monopoly over electricity supply largely because of the unattractive tariffs, and this has consequently led to what, as has been already been stated, electricity supply in Zambia being mainly dominated by ZESCO through a single buyer model (Policy Monitoring and Research Centre, 2015). ZESCO's monopoly is also because of “insufficient incentives for private sector investments in the energy sector due to lack of renewable energy feed-in-tariff and prevailing non-cost-reflective electricity tariffs” (Policy Monitoring and Research Centre, 2015).

Alternative sources of energy in Zambia remain prohibitively expensive for most Zambians and investors; “There are insufficient incentives for private sector investments in the energy sector due to lack of renewable energy feed-in-tariff and prevailing non-cost-reflective electricity tariffs” (Policy Monitoring and Research Centre, 2015). The cost to purchase, set up, run and maintain alternative sources of energy remains costly.

As a result, the only real option and alternative to hydroelectricity are charcoal and fire wood for most Zambians to the extent that we can rationally argue and make an educated assumption that the staple energy source for Zambia is charcoal or at least firewood, and this what the Ministry of Energy (2016; 2019; 2022) and the Ministry of Green Economy and Environment (2021) alluded to.

According to the Ministry of Energy (2022), the primary energy consumption by the residential sector accounts for 63 of the overall primary energy consumption. Of that, approximately 90% of the energy used for cooking in homes comes from either firewood in rural areas and charcoal in urban areas. The reason for this is charcoal and firewood are affordable, either free or relatively very cheap and with less or no barriers to access.

Therefore, most Zambians consider charcoal and firewood the most convenient fuel, especially for those living in rural areas. The propelling reason is limited access to electricity coupled with load shedding measures. This situation makes charcoal and firewood attractive and necessary. The Ministry of Green

Economy and Environment (2021) stated that while “forests are one of the most important natural resources from which citizens enhance their livelihoods through the provision of various products such as wood fuel...within the legal bounds of the law”, it observed what it stated as “the increased and illegal cutting down of trees for charcoal production”. The noted increase and illegal cutting down of trees for charcoal production can be attributed to the efforts to meet the surging demand for charcoal as Zambia goes through high connection fees to the grid, load shedding and no other largely available options for energy that a renewable and environmentally friendly.

The Policy Monitoring and Research Centre (2015) observed and discovered that charcoal and firewood, as of 2015; a situation that has not so much changed to date, accounts for 61-70% of the total energy in Zambia with electricity only accounting for 20-25%. The estimated demand for charcoal and firewood has severe implications for Zambia's forests, and consequently ecosystems and the environment. This is regrettable as “forests provide several ecological benefits that are cardinal to our attainment of sustainable socio-economic development” (Government of Zambia Ministry of Green Economy and Environment, 2021).

The other problem Zambia faces is a problem of a lack of effective, efficient and environmentally friendly waste management. The country largely has no substantive and substantial industries that can recycle, reuse and remanufacture waste products. This means that most of the waste produced in Zambia remains unprocessed. In the country, this means that solid waste management has not been carried out in a sufficient and proper manner in terms of collection, transportation, disposal, dumping or recycling (Government of Zambia Ministry of Health, 2023; Government of Zambia Ministry of Health, 2017; Government of Zambia Ministry of Local Government, 2017).

Therefore, the environmental and sanitary conditions have become and will continue to become more serious through the years affecting both the health of the environment as well as that of the public; of Zambians.

The Ministry of Local Government (Government of Zambia Ministry of Energy, 2016) stated that “Increasing waste generation and complexity of waste streams associated with urbanization, economic growth and increased affluence. This requires more investment in the sector for Local Authorities to manage waste efficiently,” the ministry further stated that “inadequate waste management equipment and infrastructure such as engineered sanitary landfills for final disposal and treatment of solid waste” are some of the challenges and hurdles faced in Zambia in solid waste management. The situation described, for example, has led to either illegal dump sites or indiscriminate dumping.

The problem is further worsened by a lack of enforcement of the law on waste management. Then Minister of Local Government Hon. Vincent Mwale, MP stated that the problem of poor solid waste management can be attributed to “Inadequate enforcement of statutes that govern the implementation of solid waste management” (Government of Zambia Ministry of Local Government, 2017).

Lusaka City is a prime example of the problem of waste in Zambia (Jesuit Centre for Theological Reflection, 2024). A poignant example of the problem of solid waste management in Lusaka is the repeated annual cycle of the cholera epidemic in the city that can be arguably described and defined as being related to the problem of waste management in the city

(Government of Zambia Ministry of Health, 2017; Government of Zambia Ministry of Health, 2023; Jesuit Centre for Theological Reflection, 2024). Therefore, the logical question to ask is, with the lack of industries to process and manage waste, what happens to the pile of waste already existing, and which continues to grow in the country? The problem of electricity has created the demand for charcoal and firewood. This has environmental impacts. The problem of waste recorded poses a threat to environmental health and public health. Zambia in the recent past has both felt the impacts and consequences of the lack of alternative energy, deforestation and pollution by waste.

The above would not be a problem if the world were not dependent on fossil fuel. It is estimated that up to 80% of the world population depends on fossil fuels for its total primary energy demand and that from 1990 to 2010 global energy demand as well as the utilization of fossil fuels increased by 45% (Surendra, *et al.*, 2014). The problem is this is 13 years later (2023). Problematically, of the total 80% of the world population that depends on fossil fuels for its total primary energy demand, combustion of those fossil fuels represents more than 50% of global anthropogenic emissions of greenhouse gases affecting the climate and contributing to global warming (Surendra, *et al.*, 2014).

1.2 Problem Statement

Traditionally, Zambia has been using biomass fuels; primarily charcoal, and wood and in some areas cow dung or similar fuel types, as a staple fuel. This has led to deforestation of worrying proportions. The problem is further compounded by traditional farming methods that clear forests and wooded areas for subsistence agriculture. Alone charcoal and wood fuels account for the majority among the reasons for Zambia's disappearing forests. The reliance on these fuels is sustained by expensive hydroelectricity bills, high pump prices for diesel, petrol and kerosene and expensive solar energy prices in terms of set-up and maintenance costs. Therefore, we need a solution that simultaneously solves the problem of environmental degradation due to the loss of forests and foliage cover and offers a feasible alternative to Zambia's reliance on biomass fuel and energy crisis.

The other related problem comes from Zambia's ever-increasing population. The fact that Zambia's population has increased and continues to grow at a faster rate, means there are more and more Zambians relying on biomass fuels. Inevitably, and progressively the demand will exceed the supply. This situation will create and result in a continued and sustained pattern of environmental degradation leading eventually to an unhealthy environment, and human habitat and continued destruction to the environment. To prevent this, we must find a solution that to supply energy that will eliminate the reliance on biomass fuels and if not eliminate the reliance on hydroelectricity, at least be a substitute for hydroelectricity.

The second issue is that the lack of viable alternative energy sources apart from biomass fuel means Zambians will continually rely on biomass fuel. This in turn means there is no end in sight for deforestation, and its negative ripple effects and the loss of a healthy green habitat for Zambians.

The other problem is solid waste; especially human solid waste. The problem is precisely that bad management of solid waste causes a series of environmental problems such as greenhouse gas emissions and surface and ground water contamination, for example, leading to threats against human life. A disturbing reminder, as we have already stated, is the

cholera epidemic in Lusaka City, Zambia (Government of Zambia Ministry of Health, 2023; Government of Zambia Ministry of Health, 2017). A robust solution needs to be implemented that will utilize solid waste and make it a resource thereby solving one challenge while creating an opportunity; let us say produce energy from waste for domestic use, thereby making domestic house partners in waste management.

Climate change and environmental impact have urged scientific research and novel technical solutions to the problems of waste and green alternatives of energy, for example. There have been advances in scientific and technological approaches to green environmentally friendly and sustainable technologies. While a focus lies on energy and power supply, can Zambia and Zambians find a real green option to the problem of energy and power supply. The answer lies in biogas using biodigesters which are economical, eco-friendly and green.

1.3 Research Objectives

The prime objective is to prove that biodigesters can be used both as a solution to the problem of waste, and that this would consequently and effectually contribute to the general improvement of environmental health and public health and to prove that while using biodigesters to solve the problem of waste, we can simultaneous use with this one solution to solve the problem of reliance on hydroelectricity, charcoal and fire wood at least for domestic use, and to demonstrate that this too would contribute to environmental health and public health by conducting research on how prisons and boarding schools across Zambia can benefit from this technology.

1.3.1 General Objective

This study aims to advocate for a comprehensive strategy to enhance waste management practices by analysing the efficacy of biodigesters in both waste processing and energy generation. It will also examine the obstacles encountered by correctional facilities and residential educational institutions in achieving sustainable solid waste management and meeting their energy requirements. Furthermore, the research seeks to enrich the broader discourse on environmental conservation, sustainability, and the diversification of energy sources

1.3.2 Specific Objectives

1. To understand how renewable resources can have a positive impact on society.
2. To access the current practice of bio digester use in Zambia.
3. To determine how effective and less harmful biodigesters can be.
4. To promote renewable energy through the promotion of bio digesters.
5. To recommend best practices to relevant stakeholders

1.4 Research Questions

It would not bare careful examination to state that Zambia needs energy to function, industrially and domestically; that is, at a micro level and at a macro level. This is because energy powers all sectors of life and society especially economic and social life.

In the same vein, since Zambia is an industrial and agricultural state it produces waste daily from activities related it to economic and social life. The waste produced could either be solid waste or liquid waste or industrial or domestic waste, for example.

However, the current state of Zambia's energy sector especially the production and distribution of electricity, which is almost wholly centralized, to its reliance on charcoal and firewood is detrimental to Zambia: the communities of people, the environment and ecological systems. This coupled with the fact that our total national access to electricity is about 33%, that almost 90% of Zambians use traditional wood fuels; charcoal and firewood, which are responsible for large-scale public and environmental health problems. Further, Zambia virtually does have widespread robust recycling and waste management systems, so that it would not be far-fetched to suppose and deduce that Zambia is facing a serious problem with waste.

1.5 Literature Review

The International Day of Zero Waste, starting from 2023, was officially established by the United Nations General Assembly on 14 December 2022, affirming the crucial value of zero-waste initiatives. This annual observance on 30th March serves as a global recognition of the importance of minimizing waste and promoting sustainable practices (UN Environment Programme, 2023).

According to the United Nations (UN Office for Sustainable Development, 2023), annually an estimated 2.24 billion tons of municipal solid waste is produced globally. Further, the United Nations projects that if the current pattern and situation persists or continue along the current trajectory, the rate of waste generation could surge by over 73% by the year 2050, further compounding the already dire environmental challenges we face and problems related to public health.

In a report, the United Nations (UNEP, 2024), calculated that the generation of municipal solid waste in the year 2020 had a direct cost associated with waste management on a global scale around USD 252 billion. However, when the hidden costs related to pollution, adverse health effects, and the impact of poor waste disposal practices on climate change is considered, the total cost escalates to USD 361 billion.

The United Nations Environment Programme (UNEP, 2018, p. 3) categorically stated that "the management of waste in Africa is a major challenge that needs serious attention" in a chapter that it corresponding titled 'Waste Management as a Priority in Africa'.

The main causes of inadequate waste management in Africa according to the Southern African Development Community (SADC) for its member countries, that is, those countries in Southern Africa, include: a rise in waste production, insufficient infrastructure to handle large quantities of waste, the high expenses associated with waste management, a lack of suitable treatment technologies and disposal methods, a shortage of trained personnel and equipment, and ineffective waste management practices. Consequently, the indiscriminate dumping of both household and industrial waste has become increasingly prevalent (UN Environment Programme, 2023).

The major causes of poor waste management in African countries to SADC (Southern African Development Community), for Southern African countries particularly, include the increasing rate of waste generation, limited capabilities to handle the high volumes of waste, the high costs involved in the management of waste, a lack of proper disposal technologies and methodologies, inadequate manpower and equipment and poor enforcement of waste management. Consequently, because of these factors, open dumping of domestic and industrial waste is rampant.

The East African Community (EAC) identified several factors contributing to inadequate waste management in East African nations. These factors encompass insufficient legislation, inadequate financial resources and services for handling municipal waste, a general lack of emphasis on the management of solid waste, inadequate laws, limited financial resources and a general neglect of solid waste management are contributing to challenges in effectively addressing waste disposal (UNEP, 2018).

The UN Environment Programme in 2015 made a statement on waste using the language of social justice, declaring that "waste management underpins society in the twenty-first century" (Jones, 2021, p. 1). Underlining social justice, the UN Environment Programme stated that solid waste management lines up with shelter, potable water, energy, food, transport and communications; all of which are essential to society and to the economy of a community, society or nation as a whole (Jones, 2021).

As early as 1996, the Food and Agriculture Organization of the United Nations (1996) was discussing bio digesters. In a report it writes about biogas in 1996 on Nepal's national efforts to promote biogas through the use of bio digesters, the organization, in the preface writes, "Biogas has proved to be a viable technology in the physical and socio-economic conditions of Nepal." This proves two things: one, that it is possible to feasibly produce biogas, even at a national level and two, that there is a sense of agency to quickly find environmentally sustainable alternatives of energy as opposed to the long-standing traditional sources of energy that typically involve burning biomass.

Following up on the argument, Surendra, Takara, Hashimoto and Khanal (2014) stated that a considerable number of people across the world, particularly those who live in rural areas in developing nations, continue to meet their energy needs for cooking through traditional means by burning biomass resources which comprise firewood, crop residues and animal dung, for example in basic traditional stoves. They further underline that such practices are known to be the source of significant environmental, social, economic and public health issues. We agree with Surendra, Takara, Hashimoto and Khanal (2014).

Pichtel (2014, p. 15) defines solid waste management as that which is "concerned with the generation, on-site storage, collection, transfer, transportation, processing and recovery, and ultimate disposal of solid wastes" whose aim is to promote "an innovative and comprehensive programme for integrated waste management, that is, the utilization of technologies and management programs to achieve waste management objectives".

The motivating reason for solid waste management is what Bhaskar, Pandey, Rene, & Tsang (2020, p. Preface XXIII) stated; "Solid and liquid waste, both the generation and disposal, is a topic of major public health and environmental concern," not only this, "more often, these issues are engendered due to poor waste collection systems, lack of governmental...limited budget, weak management policies, and lack of an efficient organizational infrastructure".

Further, according to Michaelides (2012), because ecosystems are closely connected to their environment, every environmental change has ecological consequences such that when one considers the effects of solid waste pollutants on the subsurface organisms, the effects of the leaching of these solid waste pollutants in nearby ground water sources, streams, or generally sources of water and their ultimate effects on animals and human beings that drink and use the

water, breathe the air and use the land, then there is cause for great concern and an immediate sense of urgency to remedy the situation.

Similarly, the World Bank stated that at least 1.3 billion tonnes of solid waste is produced by various human activities around the world each year, and the World Bank estimates that this amount is expected to rise to 2.2 billion tonnes by 2025 (Kumar, *et al.*, 2019). By these numbers one should get the sense of agency. These numbers in themselves are astronomical, and worrying and they are also growing. It is therefore incumbent that we begin to implement waste management.

The other reason that would urgently warrant and necessitate solid waste management is the fast-paced development in our societies, economies and agriculture which produce huge quantities of biological solid waste that include, as we have already seen, organic fractions of municipal solid waste, agriculture waste and animal manure, for example, which are produced every year on end (Wang, *et al.*, 2019).

Jones (2021, p. Preface vii) concisely put it, "Waste is something we all generate; modern life seems to be impossible without it. What happens to our waste is increasingly integral to the future of life on the planet." Hong *et al* (2017) argued, an unsuitable solid waste management poses serious threats to the environment in the sense that environmental problems that include greenhouse gas emissions, heavy metal pollution of soil, contamination of surface and groundwater and the pollution of air would continually pose serious great to human beings and great harm to public health and environmental health itself.

To mitigate, reduce and eliminate the impacts of waste, the challenge is to rethink waste management to a point where the processes, methods, techniques and solutions to the problem of waste do not themselves produce waste and prove hazardous. Therefore, in order to achieve this, it is desirable that we attain a circular economy (Bhaskar, *et al.*, 2020) in our efforts to manage waste.

A circular economy is one in which products are preferentially either recycled, reused or remanufactured. In this economy, at the end of their useful and intended life, materials are converted back into useful products without discharging waste into the environment (Bhaskar, *et al.*, 2020). The principle of a circular economy is that waste could either be repaired, reused or recycled in an endless cycle; it is a principle of "from waste reduction to value creation" (Aggeri, 2020).

Traditional waste management primarily depends on landfilling and incineration. These waste management practices have numerous negative externalities. For example, emission of dangerous and harmful gases such as mercury, tritium and non-methane organic compounds. Substances like vinyl chloride, benzene, toluene, furans, carbon tetrachloride and dioxins can be produced as waste decomposes in landfills, posing potential threats to the surrounding environment and ecosystems including soil, water and air contamination. The primary gas generated is methane, which is said to have a global warming potential 28 times higher than carbon dioxide over a 100-year timeframe. Incineration of waste also has disadvantages and negative effects such as high levels of NO_x and dioxin emissions, excessive off gas flow rates. Further, there is need to find a proper disposal of leftover ash which leads to other challenges. Therefore, there is need to develop a safer and greener way to manage waste in an eco-friendly manner (Bhaskar, *et al.*, 2020).

Zambia on December 23, 2018, passed the Solid Waste Regulation and Management Act which come into effect in 2019 on the date that the Local Government Act of that year became operational. The Act was generally passed to deal with solid waste and ensure that the disposal of solid waste is not harmful to the environment and to Zambians and those living in Zambia, and their communities.

The Act was passed "to provide for the sustainable regulation and management of solid waste; general and self-service solid waste services; the incorporation of solid waste management companies and define their statutory functions." (Government of Zambia, 2018).

In October 2023, Minister of Health, Hon. Sylvia Masebo, MP gave a Ministerial Statement on the cholera outbreak situation in Zambia in which the ministry of health stated that "the risk facts in our country remain the same of what is causing cholera" (Government of Zambia Ministry of Health, 2023). The risk factors that remain the same were listed as

- a) Consumption of contaminated water
- b) Consumption of contaminated food
- c) Inadequate water and sanitation facilities
- d) Poor solid waste management
- e) Poor personal hygiene" (Government of Zambia Ministry of Health, 2023).

What we can see from the listed risk factors is that poor waste management is listed among the risk factors. We can also infer and deduce that contaminated water and inadequate sanitation facilities are related to poor waste management practices; for example, that have polluted surface as well as ground water.

The Zambian Government defines waste management as "a direction, measure, strategy, an administrative, a supervisory or an operational activity used for the management or control of solid waste" (Government of Zambia, 2018).

To summarize, the quantity of waste being generated locally is increasing. This situation poses a great threat to public health, and safety and the quality of the environment, and ecosystems. The situation, therefore, requires the use of effective and sustainable waste management strategies and practices to reduce the increasing negative impacts of waste on the local population and local environment. It is also important to emphasize that proper waste management is crucial not only for maintaining hygiene but also for economic and social reasons, as waste can serve as a source of low-cost raw materials for bioenergy and valuable bio-products with high potential.

The United Nations observed that while access to modern energy services has improved everywhere, it remains a challenge and problem in some developing regions, including sub-Saharan Africa (United Nations, 2015), to which Zambia is a part.

ENERGIA (2020), a gender and energy agency, statistically stated that about 3 billion people worldwide still cook with traditional cooking fuels and with most of that population still lacking access to electricity and that the number increases to 4 billion when other factors such as whether cooking energy is affordable, accessible, efficient, convenient, safe or reliable are considered. ENERGIA (ENERGIA, 2020), like the United Nations (United Nations, 2015), also noted that the problem described above is notorious in Sub-Saharan Africa and especially in its rural areas.

Similarly, Lumbrou and Piana (2006) estimated that there are more than two billion people worldwide who are unable to

obtain and access clean safe energy and fuels, and in the absence of these clean safe energy and fuels must depend on burning traditional biomass fuels such as wood, dung and crop residues.

The above is a problem because, for example, the lack of access to and the disproportionate lack of access to clean, safe and modern energy has ripple effects; because of this lack, tasks and activities like studying during the night, refrigerating food or medicines, cooking a meal in a clean environment, pumping safe clean drinking water and access to information and technologies are a problem in Sub-Saharan Africa. The lack of access to reliable and modern energy sources also perpetuates poverty and incapacity to improve the socio-economic state of most Sub-Saharan Africans.

To solve the above-mentioned problems; to offer a real sustainable solution to the problem of energy scarcity, to get rid of 'dirty' energy and to meet the growing demand for energy while preserving and protecting ecosystems, human habitats and the environment, biofuels are evolving as the next real alternative and clean fuel to replace the conventional fossil fuels and a heavy reliance on hydroelectricity (Banerji, *et al.*, 2010; Brosowski, *et al.*, 2016; Brosowski, *et al.*, 2016; Baredar, *et al.*, 2020; Deng, *et al.*, 2020; Government of Zambia Ministry of Energy, 2022).

Consequently, to construct biofuels, a technology called "waste-to-bioenergy" has emerged (Banerji, *et al.*, 2010). Production of biofuels from waste-to-bioenergy technologies is seen as being closely related to the United Nations's Sustainable Development Goals (SDGs) that the United Nations proposed in 2015 (Bhaskar, *et al.*, 2020).

The goals firstly relate to ensuring access to affordable, reliable, sustainable and modern energy for all and secondly, to making cities and human settlements inclusive, safe, resilient and sustainable (Bhaskar, *et al.*, 2020). Waste such as agricultural waste; crop residues, livestock effluents, industrial waste; sawdust and municipal waste; sewage treatment products are biomass that can be decomposed, as we will discover, under aerobic and anaerobic conditions to convert them into value-added products. In this sense, bio waste management should be seen as an economic approach that plays a central role in protecting the environment and enhancing living standards (Nkhama, *et al.*, 2022).

As such, biofuels derived from, for example, agricultural waste and biodegradable solid waste are environmentally friendly fuels. At least, at a domestic level, the successful development of biofuels is promises to provide better energy security. At a macro level, the development of biofuels is believed to benefit local and national economies by, for example, contributing to agricultural sectors and to improve local and global environments (Michaelides, 2012).

1.6 Theoretical Framework

A technology called "waste-to-bioenergy" (Banerji, *et al.*, 2010) is used in the production of biofuels from waste. The technique and technology is an epitome of the correlation between waste and energy. Now more than ever, there is need for and emphasis on effective waste management strategies and energy security. With this technique and technology, and such other techniques and technologies, we can address both problems while simultaneously securing public and environment health. Therefore, biodigesters can be used to address waste and energy crises.

Effective and efficient waste management practices and principle and energy security relate to principles, theories and the actual practice of sustainable development. That is, proper

waste management and energy security supports economic, social and environmental sustainability. The opposite is equally true. Improper waste management and energy insecurity threats and incapacitates economic, social and environmental sustainability.

Integrating and promoting the concept of a circular economy is crucial. This is because it focuses on minimizing waste generation, promoting recycling and resource recovery and reducing the reliance on finite resources. The practice of a circular economy is also crucial because with such a practice, economic and environmental needs align. In this way, for example, the already existing waste should be regarded as a resource, even an economic one while focusing ways to reduce waste generation which is good for the health of the environment and effectually the public. Therefore, as already stated, bio-waste can be used to produce bio-fuels which are sustainable and green and on a commercial scale produce and supply energy, for example biogas.

Efforts to address problems of waste and energy insecurity also include elements related to social justice, particularly in the context of waste management's impact on marginalized communities, gender equality and access to clean energy. Often problems resulting from ineffective and inefficient waste management and energy insecurity disproportionately affect marginalised communities, and people and the minorities. These bare the blunt of such problems. For example, without qualification, we can assert that waste is often socially and systematically dumped in areas surrounding the poor's communities and not in upstate communities.

Proper waste management principles and practices and establishing and securing energy security relate to sound policy and good governance. Policies, regulations and governance structures have a determinant, pivotal and crucial role to play in shaping effective waste management practices and promoting green and sustainable energy. The emphasis is on the need for comprehensive legal frameworks to guide waste management practices and initiatives. For example, in demanding a reduction in waste generation capacities, setting goals towards a zero-waste future, promoting recycling and reuse and championing waste-to-resource campaigns.

Technological advancements such as biodigesters are technological solutions to problems of waste and energy insecurity. They are an all-in-one solution. Biodigesters are sources of renewable energy that illustrate innovative approaches to waste management and energy production fostering safe and green practices.

1.7 Research Methodology

1.7.1 Research Design

Based on the research question, a mixed-method research approach will be used to prove the hypothesis of the paper and meet its objectives. The research methodology will use quantitative research to gather numerical data on waste management practices, energy consumption patterns, and the impact of improper waste management and electricity shortages. This will involve collecting data on waste generation, disposal methods, energy usage, and associated costs, qualitative research which will be used to gain insights into perceptions, attitudes, and experiences of institutions regarding waste management and energy security and to provide a deeper an understanding of the challenges and potential solutions to the problems of waste and energy security and field observations which will include direct observations and site visits to waste disposal sites and institutions to facilitate gathering valuable first-hand

information about the existing practices, challenges, and environmental impacts.

The research strategy will involve a systematic framework utilizing content analysis in a descriptive manner to collect information from multiple credible and reliable sources. This process will involve breaking down the information into relevant categories or factors to extract pertinent research findings.

The quantitative aspect will involve the collection of numerical data through structured surveys distributed to a sample of boarding schools, correction facilities and prisons in Zambia. This will provide statistical evidence to support the analysis. The qualitative aspect will involve semi-structured interviews and focus group discussions to gather in-depth insights and contextual information from key stakeholders. The combination of these methods will allow for a holistic understanding of the problem.

1.7.2 Research Gaps

There is little research on this topic within the context of Zambia as such an information gap exists. Also, the implementation of biodigesters is in its infancy and almost novel in Zambia. Therefore, obtaining concrete data and statistics on the implementation and impact of biodigesters on waste management and their contribution to energy security poses a significant challenge.

1.7.3 Population of Study

The population also includes the communities around the sampled prisons and schools.

To narrow our case study to feasibility, we will use Lusaka Province and Central Province as our case study samples. The reasoning is that these two provinces contain as many prisons and correction facilities as would be sufficient to draw conclusions that can be extrapolated to form a general conclusion.

1.7.4 Data Collection Tools

The data collection tools include:

I. Questionnaire

This will be the primary research tool for data collection. The questionnaire will be either mailed and filled in the absence of the researcher or hand delivered and filled in with the researcher present. This will depend on what will be attainable, feasible and practically reasonable.

II. Structured Interviews

Additionally, we will conduct interviews. Qualified personnel in our research interest, those who have implemented biodigesters and if possible, those who have done similar research will be consulted and interviewed to standardize our research and offer a more practical in-depth insight into the research.

1.7.5 Data Analysis Tools

Our primary tool for analysing our quantitative data will be STATA/MP software. We choose Stata/MP because it provides the most extensive multicore support of any statistics and data management and is easily accessible.

Our secondary tool for data analysis is Microsoft Office Excel. We will use Microsoft Office Excel because it will complement the Stata/MP software.

1.8 Data Analysis and Discussions

1. The data collected indicates that nearly 71% of the surveyed institutions engage in agriculture as a primary

means of sustenance and income generation. This agricultural activity predominantly encompasses poultry farming and animal husbandry, particularly the raising of pigs, with a minority of institutions also involved in cattle rearing. Furthermore, nearly all institutions that identified agriculture as their main income source participate in horticulture, primarily cultivating locally recognized vegetables such as Rape, Chinese and cabbage.

2. The findings suggest that a significant number of the interviewed institutions possess the necessary raw materials to implement bio digesters, which could serve as a viable source of cooking energy. This is particularly relevant given that many institutions reported substantial energy costs attributed to their reliance on electricity for cooking. The organic waste generated from poultry, cattle, and pigs is recognized as a valuable resource for biogas production. Currently, much of this agricultural waste is either discarded, left to decompose, or occasionally utilized as manure. By capitalizing on this waste, these institutions could address the challenges of energy insecurity amid ongoing load shedding while simultaneously improving their waste management practices.
3. Business activities accounted for 29% of the economic activities within the institutions. Business activities were mostly directly or indirectly linked to agricultural practices. The institutions indicated that a large portion of their agricultural production was aimed at local markets, while simultaneously functioning as a source of income, prompting many to create agricultural enterprises. An analysis of the profit margins from these ventures revealed that nearly all institutions manage to break even. However, the revenue derived from agricultural sales primarily goes towards settling electricity bills and paying outstanding electricity bills. Institutions expressed that the primary motivation for initiating agricultural projects was to achieve self-sustainability; nevertheless, they struggle to reach this goal due to the burden of electricity bills. When asked about what contributes to their high electricity bills, boarding schools identified the industrial cooking pots used for meal preparation as the principal cause, a sentiment echoed by the prisons as well.
4. The institutions surveyed exhibited inadequate waste management practices. Inquiries were made regarding the handling of waste across various types, revealing that 71% of these institutions dispose of their waste in open pits. Once these pits reach capacity, the waste is either buried or incinerated to free up space for further use. The predominant method of disposal involves burning materials such as paper, plastic, and dry organic waste, including grass and leaves, while kitchen waste is primarily deposited into these rubbish pits. A significant concern arises from the fact that these pits are open and poorly managed, leading to air pollution and unsanitary conditions within the premises.
5. During our investigative efforts, we conducted a private inspection of the waste pits and found them to be significant sources of air pollution, serving as breeding grounds for flies and mosquitoes, and generally lacking proper maintenance and oversight. Additionally, these pits were indiscriminately used for the disposal of various types of waste, highlighting a critical deficiency in their management.

6. The data collected indicated that 7% of the surveyed institutions completely incinerate their waste, while any residual waste that cannot be incinerated is disposed of in pits or at the nearest dumpsite, these dumpsites are usually socially recognised but illegal; that is, these dump sites are not officially sanctioned, but are generally accepted by the local community. The materials that are incinerated primarily consist of discarded paper, cardboard boxes, dry leaves collected during cleaning, plastics, and other combustible waste. When inquired about their preference for incineration as a waste management strategy, the institutions expressed that this method was the most effective means of waste disposal, particularly for plastics, as they lacked alternative methods for managing such materials. The option of dumping waste was considered feasible due to the institutions' inability to excavate open pits, which was deemed impractical, coupled with the absence of municipal services or companies to facilitate waste collection.

1.9 Suggestions and Recommendations

I. Making Waste Management a Policy Priority

To mitigate the adverse effects of mismanaged waste, it is imperative for governments and stakeholders to prioritize the establishment of formal waste management systems that adhere to environmental standards and promote sustainable practices. By investing in infrastructure for proper waste disposal, recycling initiatives, and public education campaigns, communities can work towards reducing the prevalence of open waste dumping and burning. Through collaborative efforts and proactive measures, it is possible to create a cleaner, healthier environment for all, while also protecting the well-being of those most vulnerable to the impacts of inadequate waste management.

To address the detrimental impacts of mismanaged waste, it is crucial for governments and stakeholders to give utmost importance to establishing formal waste management systems that adhere to environmental standards and promote sustainable practices. By investing in the necessary infrastructure for proper waste disposal, initiating recycling programs, and conducting public education campaigns, communities can actively work towards reducing the prevalence of open waste dumping and burning. Through collaborative efforts and proactive measures, it is possible to create a cleaner and healthier environment for all, while also protecting the well-being of those who are most vulnerable to the consequences of inadequate waste management.

Environmental pollution resulting from inadequate solid waste management is a pressing issue that demands immediate attention and decisive action. It is a problem that is intricate and multifaceted, requiring cities to prioritize the adoption of efficient waste management strategies. This includes the establishment of appropriate regulations, the development of robust infrastructure, and the implementation of effective disposal methods. By tackling these challenges head-on, cities can significantly reduce the detrimental effects of waste on both public health and the environment, leading to the creation of cleaner and healthier urban environments for generations to come.

The detrimental effects of improper solid waste management on the environment and public health cannot be underestimated. It is a multifaceted problem that requires immediate attention and concerted efforts from cities worldwide. To address this issue effectively, cities must

prioritize the implementation of robust waste management strategies. This includes the establishment of proper regulations to govern waste disposal, the development of reliable infrastructure to support waste management systems, and the adoption of effective methods for waste disposal. By taking these necessary steps, cities can significantly reduce the impact of waste on the environment and public health, leading to the creation of urban spaces that are cleaner, healthier, and more sustainable for generations to come.

It is crucial to address the shortcomings in waste management systems to mitigate health risks, protect the environment, and ensure the safety and effectiveness of recycling practices. Implementing formal waste sorting systems and regulating dump sites are essential steps towards creating a safer and more sustainable waste management infrastructure. By addressing these issues, the Government of Zambia can in partnership with the private sector and domestic sector safeguard public health, protect the environment and promote safe and efficient waste management practices (African Population and Health Research Center; Urban Africa Risk Knowledge, 2023).

II. Empowering Municipal and Local Councils

Numerous local municipalities face challenges in effectively implementing appropriate policies and strategies at both national and sub-national levels to tackle the increasing waste volumes. These challenges primarily stem from technical limitations, financial constraints, and capacity gaps within the municipalities. These factors contribute to the difficulties faced by municipalities in addressing the growing waste problem. Insufficient technical expertise, inadequate funding, and capacity limitations pose significant hurdles for local municipalities when it comes to implementing comprehensive policies and strategies to combat the rising waste volumes. These challenges are prevalent at both the national and sub-national levels, making it difficult for municipalities to effectively address the issue. Overcoming these obstacles is crucial in order to ensure proper waste management practices and mitigate the environmental and health risks associated with increasing waste volumes (UN Office for Sustainable Development, 2023).

Furthermore, evidence at hand highlights the lack of sufficient public funding, as well as a shortage of staff and equipment, pose additional institutional constraints to achieving appropriate waste management. The insufficiency of financial resources restricts the ability of authorities to invest in necessary infrastructure and technologies. Moreover, the shortage of trained personnel and essential equipment further hinders the implementation of effective waste management strategies. Addressing these institutional constraints is crucial to ensuring sustainable and efficient waste management practices (African Population and Health Research Center; Urban Africa Risk Knowledge, 2023).

III. Enforcing the Law on Waste Management

As we have discovered, there are those governing the management and production of waste both at the global level and at the local level. The problem is since these laws exist indiscriminate and disposal production of waste is rampant and continues to grow. There is virtually no policing of waste management and production. Properly funded and equipped institutions with trained personnel need to be established that would police the management of waste. The law on waste management and production need is different and rigorously enforced. The law should become punitive enough to dissuade

individuals whether private or governmental or other waste from this community managing and disposing of waste. Additionally, certain products that encourage creation of waste needs to be banned or strategies that would make such products difficult to be produced and sold should be implemented.

IV. Making Energy Diversification a National Priority

An overview of the present lack of an alternative electricity supply in Zambia followed by a description of the underdevelopment of the existing supply in the country and the fact that Zambia has predominantly a single source of electricity means that Zambia has not yet achieved security of energy supply, affordability and availability. Consequently, we could say that energy supply in Zambia is restrained by hydroelectricity.

The above means that Zambia has either a poor or non-existent energy mix. This continues to plague the country with energy insecurity as demonstrated by the current load shedding. As the national power company, ZESCO load sheds, most Zambians are left without power and with no option. Energy diversification will optimize the supply of energy. The current form of energy supply is insufficient, and thus unacceptable from an energy security and environmental perspective. To fill the gap, a broad range of energy sources that offer a real choice for Zambians that are also sustainable and affordable need to be available and accessible for most of the country. Thus, energy diversification prospects should depend on the available resources, costs compared with competing alternatives and environmental impacts.

V. Dismantling the Monopoly of ZESCO in Electricity Supply

Throughout its history, Zambia has heavily depended on hydroelectricity as its primary source of energy, which has been provided by a single energy company known as the Zambia Electricity Supply Corporation Limited (ZESCO Limited). However, the country's population growth, both in terms of domestic and industrial sectors, has posed significant challenges to the existing power supply chain. Compounded by the absence of a decentralized National Grid, this has further strained an aging power infrastructure, leaving limited room for viable alternatives.

The energy sector in Zambia is facing an ongoing challenge of balancing demand and supply, which has resulted in a growing demand gap. This persistent issue highlights the inadequacies of ZESCO's current strategies. An examination of energy policies emphasizes the need to address key priorities such as security of supply, affordability, and environmental sustainability. However, with Zambia's rapidly growing population, achieving these goals has become increasingly difficult for ZESCO. As the population continues to expand, it has put additional strain on the already existing energy supply and created pressure to secure sufficient energy resources. Moreover, affordability is compromised as the increasing demand naturally leads to higher prices. Additionally, sustaining the environment becomes a practical challenge when a population's energy demand surpasses its energy supply, these leads, for example, to an alarming increase in deforestation to meet the demand for biomass fuel such as charcoal as the alternative.

To overcome these challenges, Zambia needs to dismantle ZESCO's monopoly, either partially or completely; for example, establish a duopoly where the companies cannot collude. Competition will force the established energy supply

companies to reassess their strategies and compete to develop innovative solutions to keep clients. It is crucial for the energy sector to prioritize security of supply by exploring alternative sources of energy and investing in renewable energy technologies. This will not only help meet the growing demand but also contribute to environmental sustainability. This cannot, however, be accomplished by only one company; ZESCO, there is need to involve and establish other companies; clearly, the monopoly has failed.

VI. Promoting the Use of and Subsidizing Biogas

To combat the escalating demand for electricity, the Zambian Government must focus on formulating and executing effective policies and initiatives that promote biogas as a substitute for charcoal and firewood. By doing so, they can encourage a shift towards more sustainable energy practices and reduce the reliance on traditional sources that contribute to deforestation and environmental degradation. It is imperative for the government to prioritize these efforts to ensure a more sustainable future for Zambia.

Essentially, by educating Zambians about the importance of energy conservation and providing incentives for adopting energy-efficient technologies, the Zambian Government can help mitigate the impact of rising demand for electricity. Furthermore, it is essential to address the issue of deforestation by promoting sustainable practices and encouraging the use of cleaner and efficient alternative energy sources. This can be achieved through collaborations with local communities. For these reasons, the Zambian Government needs to develop and implement effective policies and initiatives for promoting biogas as an alternative to charcoal and firewood as the demand for electricity surges. Through this process of education, incentivizing and strategic partnerships with communities, the Zambian Government can pave the way for a greener and more energy-efficient nation.

Conclusion

Waste is a problem that cannot be overstated. Our findings show that waste is a worldwide problem that plagues every continent and country in the world. The problem of waste is such that it threatens the existence of life on earth. This life both includes human life as well as other forms of life such as marine life and wildlife. The problem would be simple if what is produced were wholly consumable or completely recyclable. But this is not the case. The most notorious example of such a problem is the production and use of plastic and rubber to produce consumer goods that end up being thrown away or discarded because we cannot recycle plastic and rubber at the rate that it is produced. An example of these is tyres. Mostly tires almost always end up in landfills or tyre piles or designated areas where they are stored awaiting a solution. Plastic, on the other hand, is not biodegradable, meaning that the natural forces of the environment or the earth cannot properly handle or disposal plastic in their natural capacity as biodegrading agents. In this sense, the human race races against time to find a lasting and timely solution to the problem of waste. It is of prime importance that humanity finds the solution to the problem of waste. Especially the waste that is not biodegradable and hazardous. A polluted environment is a breeding ground for diseases of pathogens. The repercussions of poorly managing waste or a poor waste management or the informal waste disposal methods are dire. The United Nations (UN Office for Sustainable Development, 2023) estimates that 400,000 individuals in developing countries succumb to diseases annually because of poorly managed waste systems. The

detrimental impact on public health cannot be overstated, as the open burning of waste not only pollutes the air but also contaminates soil and water sources, posing a significant threat to both human beings living in those areas and the local environment. Addressing systemic and social issues that promote poor waste management is important and requires a concentrated effort to implement proper waste management practices and regulations to safeguard the health of people and the environment where the problem may exist. There is also the need for collaborative initiatives to enforce appropriate waste management protocols and regulations to protect the health of vulnerable populations.

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