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Review

Review of personal protective equipment and their associated wastes, life-cycle and effective management during the Covid-19 pandemic in developing nations

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Abstract: Plastics have become vital assets for humanity; these materials are used widely in pharmaceuticals, healthcare systems, and many other applications. The rising demand and uses of articles made wholly or partly from synthetic polymers, coupled with their non-biodegradability, contributes to the massive volume of plastic wastes across cities in most developing nations. Thistrend has become an issue of significant environmental concern. However, the fight against COVID-19 would look almost impossible without personal protective equipment (PPE) primarily made from various plastics which in turn, contribute enormously to the volume of waste streams. To circumvent this present challenge, research has been recommending solutions. The existing literature primarily focuses on the most developed countries, emphasising Asian countries with less attention to other developing countries like Nigeria and African countries. This study, therefore, reviewed the personal protective equipment used in healthcare, plastic types employed for their production, and the appropriate technology for managing their associated wastes. The application of proper disposal methods can reduce the toxic effects of discarded plastics on human health and the environment. In this review, the SWOT analysis approach was employed to unveil the benefits, limitations, opportunities, and threats associated with respective waste management approaches. As the coronavirus pandemic continues to intensifier, its adverse impacts on human health and the economy are increasing; authorities are encouraged to address waste management, including medical, household, and other hazardous waste, as an urgent and critical public service to minimize potential secondary health and environmental impacts.

Keywords: COVID-19; single-use plastics; waste; used personal protective equipment; environment

1. Introduction

In the last decades, there has been a global call for the ban of plastics, especially single-use plastic items [1–3]. Despite the fact that these calls are good intentions for the environment and humanity, it might not be the best positive approach to managing waste from these materials, considering the significant advances in modern technology made possible by plastics. About a year ago, the world witnessed an outbreak of a disease that has become a global pandemic called Corona Virus or COVID-19 [1]. Effective management procedures adopted in handling the pandemic have attracted plastic-made personal protective equipment (PPE). Unfortunately, most of the PPEs are considered single-use plastic equipment. The necessity to prevent coronavirus spread means tonnes of medical and domestic plastic waste are generated worldwide. For example, hospitals and related facilities have been advised to employ extra care on clinical waste from COVID-19 patients. While this is a necessary measure, it adds to the plastic waste problem. Therefore, converting these wastes to an energy source and viable raw materials for emerging industries would be a more realistic approach to a better future [4].

In an environment of understandable health and hygiene concerns during the pandemic, the problem of disposable plastics has not been given the adequate attention it deserves. The need and demand for products packaged in non-biodegradable plastics or manufactured in whole or in part with synthetic plastics such as disposable wipes, cleaning products, hand sanitisers, disposable gloves and masks are increasing now more than ever. Unfortunately, they are also thrown into the environment rather than adequately disposed of.

The COVID-19 pandemic has taken lives, causing inconveniences and negatively impacting the global economy. In the same measure, it also contributes to plastic pollution in cities worldwide. Countless surgical and N95 respirator masks and non-surgical masks that local people use to protect themselves from the virus are discarded improperly. This trend implies that vast volumes of these masks end up on water bodies, waterways and unmanaged dumpsites. Once there, they further threaten aquatic animals that may mistake them for food or get entangled in them, destroy soil structure and even pollute the atmosphere if eventually burnt. As people do their best to protect themselves and adhere to government policies and advice of health organizations against the corona virus, the volume of waste is expected to continuously grow due to using and discarding disposable face masks and other used PPE.

Furthermore, during such an outbreak, many types of additional medical and hazardous waste are generated, including infected gloves, masks, and other protective equipment, together with a higher volume of non-infected items of the exact nature. Improperly managed waste could have unintended impacts on human health and the environment. Therefore, the safe handling and final disposal of such waste are vital for effective emergency response.

Safe management of domestic waste is also essential in this time more than ever before. Medical waste such as contaminated masks, gloves, expired medicines, and other items can easily be mixed with domestic garbage. Still, it should be treated as hazardous waste and disposed of separately. Such waste must be stored separately from other domestic waste streams and collected by municipal specialists or waste management operators. Literature survey has revealed that wrong or ineffective management of these medical wastes have the potential of causing transmitting disease since they contain different kinds of pathogens or organisms that are carriers of specific bacterial, viral, parasitic or fungal-based infections [5–7]. Other potential negative impacts that negligence of effective waste management could also result in the pollution of our water sources via leaching of active components from the medical material. They can attract scavenging animals, including bats and others [6–8].

Among other related previous works that also looked into the management of PPE wastes and their disposal in various communities across the globe includes Hantoko et al. [9], whose report attempted to explore the challenges and measures deployed by communities with emphasis on the Asian countries in the management and disposal of wastes amidst the COVID-19 pandemic crisis. The authors adapted their data from published research articles, government reports and other media reports in rating the volume of wastes generated during the period. The study reveals a significant rise in food and plastic waste (which essentially entails the PPE related materials) during the pandemic. The existing waste management system across the Asian countries considered in their studies was overwhelmed. Recommendations were on the need to treat the waste prior to disposal. Vanapalli et al. [10] report also indicated that the COVID-19 pandemic significantly increased our reliance on plastics for safety and hygiene. The report further promotes the need to consider the transition towards a more environmentally friendly material like bioplastics and harbour new sustainable technologies that would be crucial and effective in fighting future pandemics.

Furthermore, Yousefi et al. [11] further emphasize the epidemic's impact on the management of solid municipal waste across communities via a systematic literature review to identify the impact of the COVID-19 crisis on the volume of waste generated and its management practice. A similar approach deployed by Hantoko et al. [9] in sourcing data was also used in Mahmood et al. [12] report using existing reported literature for years 2019–2021. Findings from their study reveal that COVID-19 caused the municipal solid wastes quantity variation and their composition change. The authors also indicated that COVID-19 has significantly affected waste recycling, management, quantity, and composition. This report has unfolded the need to design a better municipal solid waste management plan that would be more efficient and reduce disease risk via waste. Similar studies were also investigated by Fan et al. [13], looking at the effect of COVID-19 on waste management, indicating the suspension of the practice of manual sorting and recycling of wastes due to the risk of infectious diseases. Fan et al. [13] studies indicated that cities like Shanghai reported a significant decrease of 23% in municipal solid waste (MSW).

In comparison, Singapore was a 3% increase; likewise, Brno recorded a 1% increase in MSW, majorly from household and small-scale business and a 40% decrease for significant business and industrial wastes. Moreover, Singh et al. [14] share the opinion of the need for the world and research works to look into the development of PPE that would facilitate easy management of its wastes. The volume of such wastes would continue to rise during the pandemic and post-pandemic era.

Most existing reports emphasize the situations reported for developed nations like China, Singapore, and many other nations. With insignificant report on the situation of the developing nations' pandemic impact on the municipal waste management, especially the medical waste primarily made up of the PPEs like a face mask, face shield, coverall, gown, hand gloves, and many other materials. The quest to identify possible alternatives to effectively manage wastes in developing nations like Nigeria, emphasising the management of personal protective equipment wastes during the COVID-19 pandemic period, has become a subject of attention as the current management practice deployed is poor and ineffective.

The significance of giving better attention to the effective management of biomedical and health—care wastes cannot be overemphasized, especially in developing nations like Nigeria, where the waste management is not given the adequate attention that it requires in these communities. The significance of advocating for the need for government to take adequate measures in design systems for identifying, collecting, classifying or separating (into different categories), storing, transporting, treating, and disposing of waste in the surrounding cannot be underrated. This present study, therefore, attempted to review the various personal protective equipment (PPE) used in managing the COVID-19 pandemic, the materials used in their production, current management of their wastes and evaluation of modern alternative facilities that could be deployed in the management of the wastes in developing nations like Nigeria. Recommendations were made on the approach that would best aid waste disposal for the safety of humanity and the environment in communities.

2. PPE and specific plastic types used

Knowing the nature and type of plastic used in making a PPE is essential for laboratory safety. It will sufficiently reduce exposure to hazards and serve as a helpful guide to the best disposal method after usage. This effort surely helps lower environmental pollution and toxicity due to plastic waste.

2.1. Face and eye protection

The use of eye and nose protecting gadgets is crucial during laboratory procedures. However, the eye, nose, and mouth can be further protected by using specific PPE. Eye protection is provided through the use of glasses specially designed to reduce the risk of exposure to chemical splashes, laser radiation and debris. There are four primary types of eye protection, each of which has its limitations, including general safety glasses, laser safety glasses, chemical splash goggles, and impact goggles. Good practices and measures demand that reusable goggles and shields should be cleaned and disinfected after every use. Disposable types should be appropriately disposed of after use.

2.1.1. Goggles

Goggles are usually made of multi-components; injection-moulded lenses are made of high-purity, high impact and scratch-resistant polycarbonate, followed by frames usually made from polypropylene plastics or straps made from synthetic rubber, mainly polychloroprene. However, there are goggles with metal frames though used in laboratory applications. Most goggles used in medical procedures are vented types [15].

2.1.2. Face shields

Face shields are PPE consisting of a visor and a holder system that attaches the shield firmly to the head. The visor is a transparent, lightweight plastic usually made from polyester film or polycarbonate because of its light weight and optical clarity. Other plastics also used are propionate, acetate, polyvinyl chloride, or polyethene terephthalate glycol (PETG). Unique surface treatments such as anti-glare, anti-fog, anti-static are given to these materials to improve their optical and scratch properties. The straps are made of synthetic rubber, such as polychloroprene (Figure 1).

Figure 1. Face shield.

2.2. Nose protection

Several kinds of materials are used to protect the nose from inhaling poisonous and dangerous items. Some of the materials include a respirator and surgical mask.

2.2.1. Surgical masks

Surgical masks are flexible textile fabrics. They provide a physical barrier between the wearer's mouth and nose and potential contaminants in the immediate environment. Surgical masks are regulated under 21 CFR 878.4040 [16]. Such masks are often commonly referred to as face masks.

Surgical masks are made in different thicknesses and with different abilities to protect the wearer from contact with liquids. They provide varying levels of protection ranging from large particulate droplets, splashes, sprays, or splashes that may contain germs (viruses and bacteria) during surgical or medical procedures. However, with the outbreak of the coronavirus pandemic, the use of masks has become a new normal for humans worldwide, whether indoors or outdoors. While research has a face mask, by design, does not filter or block microscopic particles in the air that coughs, sneezes may transmit, or specific medical procedures [16], the CDC still held that it provides a certain level of protection, especially with person-to-person transmission of coronavirus disease. Surgical masks also do not offer absolute protection against germs and other contaminants due to the loose fit between the mask surface and the face [17].

2.2.1.1. Types of masks

Surgical masks are classified according to the degree of protection based on ASTM certification. It comprises four levels, including the first minimally shielded face masks (otherwise known as level 0 mask) designed for short procedures or exams that do not involve liquid, spray or aerosol. Level 1 mask often contains ear loops and are generally used for surgical and procedural applications, with a fluid resistance of 80 mmHg. They are designed for low-risk situations where neither liquid nor aerosol is present. Another is that level 2 masks with fluid resistances of 120 mmHg are a barrier to light or moderate aerosols, liquids and aerosols exposure. Lastly, the level 3 face masks protect high exposure to aerosols, liquids, and aerosols, with liquid resistances of 160 mmHg.

The material commonly used in the production of surgical masks is polypropylene by melt spinning technology. Polypropylene is one of the five most important commercial plastic resins used for various articles. Masks can also be made using polyethene and polyester. The melt-spun plastic fibres are made into fabrics of multiple layered non-woven fabrics [18]. Non-woven fabrics are generally cheaper to manufacture; hence are usually for one time use. However, the effectiveness of filtration that a mask provides depends on the fibre, fibre manufacturing process and fabric architecture (Figure 2).

Figure 2. Surgical mask.

2.2.2. Respirators

Respirators are made with melted non-woven fabric by extruding plastic fibres (usually polypropylene) one micron in diameter onto a conveyor. These layers bond as they cool to form the cloth. This fabric is laminated with an embroidered prefiltration layer of non-woven fabric, usually calendared, warm and thick enough to be moulded in the mask’s shape (Figure 3). The proper respirator selection for a particular purpose in an environment depends on the contaminants present and their concentrations [19]. N95 respirators are speciality masks with superior filtration capabilities; they are known for their complex manufacturing process.

Figure 3. Respirator.

2.3. Hand protection

Surgical and chemically protective hand gloves are among the essential PPE for minimizing skin exposure to chemicals in research laboratories and minimising possible contact or transfer of pathogens for health care workers. Gloves tend to degrade over time. Therefore, they are expected to be inspected and replaced to provide adequate protection. But for medical procedures, they are expected to be single-use PPE. Consequently, the volume of used and discarded gloves is expected to increase as the fight against the coronavirus intensifies. Hand gloves for health care systems, otherwise known as surgical/examination gloves, are made using synthetic or natural rubber. Some rubber types are nitrile rubber, natural rubber, butyl and polychloroprene.

The glove's thickness, elastic and tear-resistant determines its quality and ability to provide protection (Figure 4). Depending on the level of testing, the highest performing batches are referred to as medical gloves. In contrast, the lowest-performing batches that still pass the minimum qualifications become industrial gloves.

Figure 4. Blue and white latex gloves.

2.3.1. Colored medical gloves

Healthcare establishments often prefer a coloured nitrile glove because it allows staff to distinguish latex gloves from non-latex gloves. A shade of blue is the traditional nitrile colour of choice in medical facilities. But in recent years, other colours like grey, purple and pink have become common. Glove colour can help for easy identification of glove failure. The use of double gloves, i.e., wearing coloured gloves beneath a white one, can help reveal punctures and small tears during procedures. Many more gloves are made from other polymeric materials such as Kevlar, polyvinyl chloride, and polyvinyl alcohol. However, natural rubber and nitrile gloves are the most common medical gloves for treating patients with COVID-19.

Natural rubber (NR) obtained from *Hevea brasiliensisis* is the leading commercial feedstock for rubber materials used in hygienic and medical use [20]. Fresh NR latex comprises approximately 94% rubber hydrocarbon and 6% non-rubber components. The non-rubber components comprise proteins, phospholipids, glycolipids, fatty acids, and so on, which exist in serum and the surface of NR particles [21]. Nitrile rubbers are copolymers of butadiene and acrylonitrile, frequently referred to as Buna N. Their properties vary with the acrylonitrile content. Nitrile rubbers exhibit high resistance to attack by oils at both average and elevated temperatures. The more nitrile within the polymer, the higher its resistance to oils but the lower its flexibility. Nitrile rubber is more resistant to oils and acids than natural rubber and has superior strength but suffers from inferior flexibility.

2.4. Body protection

The use of coveralls and gowns ensures body protection in laboratories, industries, and hospitals.

2.4.1. Coveralls

Coveralls can be worn in place of gowns. They provide better protection, but they also are more uncomfortable to most healthcare workers. However, they have added insulation. Additionally, healthcare workers are often more unfamiliar with coveralls, leading to risks if coveralls are not properly removed. Coveralls are commonly made from plastic fibres. The fibres are produced by melt spinning technology and converted to fabrics by non-woven technology. High-density polyethene (HDPE) is the most common synthetic plastic material used for most coveralls intended for single-use medical purposes. Other materials also used are polypropylene and polyester. The sewing of coveralls can be the most challenging part to get right if maximum protection is achieved. Leakages are closed in seams by putting tape or paying particular attention to the armpit, zip region, cuff, and edges to prevent leakage.

2.4.2. Gowns

Gowns have been reported as the second-most-used piece of PPE, after hand gloves, in healthcare facilities [22,23]. Association for the Advancement of Medical Instrumentation (AAMI) defined Isolation gowns as the protective apparel used in the protection of health care workers (HCWs) and patients from microbial infection, mainly from body fluids from infected persons [24]. ANSI or AAMI PB70 Level 3 or 4 isolation gowns are recommended for use where medium to high risk of contamination is envisaged. Surgical gowns at levels 1–4 can be worn for all levels of exposure during medical procedures. ANSI/AAMI PB70 Level 1 or 2 gowns can be worn for activities with minimal risk during healthcare delivery [25].

Early type isolation gowns were made from cotton and polyester blend; these gowns do not provide a high level of protection from body fluid due to their relatively high absorption of water and fluid. In addition, these old type gowns are primarily reusable. So the fabric structure tends to be distorted as a result of mechanical processes during washing. They are 100% cotton or 50/50 cotton/polyester [25]. In recent times, isolation gowns have been produced from various fabrics and a wide range of fibres. They are primarily disposable/single-use. In the US, disposable isolation gowns are used more commonly [26]. Modern isolation gowns are produced from synthetic plastics such as; polypropylene, polyester and polyethene.

Generally, isolation gowns and coveralls made from these materials provide a better level of protection because of their excellent fibre bonding and increased protection from liquid penetration. Consequently, the volume of used and discarded single-used isolation gowns in health care facilities is increasing as the coronavirus pandemic intensifies its havoc worldwide. This is even more worrisome, particularly in Africa and most developing countries. Locals use this PPE during the burial of friends, relatives, and community members who died during the pandemic. After such exercise, the used gowns are seen not to be discarded safely Figure 5. Another is the case of the little kid in Figure 6 walking in the open dumpsite where wastes of different forms are widely disposed off openly without being treated, exposing her to the risk of infectious disease.

Figure 5. Man carelessly disposing of PPE by roadside caught on camera after burial exercise Nigeria source: The Africa News [27].

Figure 6. Dumpsite around Korle Lagoon close to the Volta Lake in Accra, Ghana (Isaac, [28]).

3. Wastes, its collection, and implications to our surroundings

From the above review so far, it is evident and evident that most PPE used in the management of COVID-19 are made from polymers and mostly single-use articles. Goggles, nose masks, protective gowns, sanitiser cans, and face shields are either partly or entirely made from plastics except for the hand gloves that are made with rubber. In addition, hospital waste with an increased volume of plastic components is witnessed in cities worldwide [29].

Garbage contaminated with bodily fluids or other infectious materials is becoming a more significant concern for hospitals as they brace for a surge in patients sick with COVID-19 around the world. Patients and health care workers are quickly going through medical supplies and disposable personal protective equipment, like damage shields, coveralls, and drug containers. Eventually, all this used gear piles up as medical waste that must be safely discarded. In addition, locals are also generating a large volume of used masks and sanitiser cans.

In Wuhan, where the novel coronavirus first emerged, the government had to build more health care facilities to contain the damaging consequences of the pandemic, build more health care facilities, construct the new medical waste plant, and deploy mobile waste treatment facilities. Their daily output of medical waste reached 240 metric tons at the peak of the outbreak, which is six times as much medical waste as before the crisis began [30].

Regulations on wastes management broadly vary with local laws in different countries. Unfortunately, for Africa and most developing countries where laws and legislation on waste management are weak or practically non-existence, improper disposal is often seen. But for most advanced societies, contaminated trash from health care facilities does not harm the public because they are either sterilized with steam, heat-treated or chemically disinfected and then treated asnon-hazardous waste [31].

During the coronavirus pandemic, some people with mild are recovering at home. In contrast, others choose not to present themselves for proper medical treatment in the hospital for fear of stigmatization, yet the trash they generate is contagious. Therefore, there is more to worry about than waste from medical centres. That means people may be generating volumes of virus-carrying trash, which is a potential danger for waste managers and sanitation workers, as the virus can remain active on surfaces for days [32]. But suppose garbage is properly bagged instead of kept loose and workers wear personal protective equipment, especially gloves. In that case, the risk of infection can be minimized. People handling health care waste, in particular, should wear appropriate PPE according to recommendations from the World Health Organization [33,34]. As the pandemic intensifies with different variants emerging, the associated waste would increase in volume across health care facilities and even in our environment. Managing these wastes must be sustained in communities until the crisis is overcome.

3.1. Survey of the used PPE collection

Unfortunately, most PPE items are designed for single use with a life span ranging between a few hours to 3 days. This condition implies that the volume of these PPE produced and distributed across various countries for managing this pandemic can represent the corresponding increase in the volume of waste witnessed due to the COVID-19 pandemic (Table 1).

The World Health Organization (WHO) estimated that 89 million medical masks are required for the COVID-19 response each month, along with 76 million examination gloves and 1.6 million medical goggles [35]. Moreover, WHO reported having shipped nearly half a million sets of personal protective equipment to 47 countries worldwide; expectedly, supplies are depleting rapidly as the disease intensifies even with new mutations. Therefore to meet the rising global demand for PPE, WHO estimates that industry must increase manufacturing by 40% and urges governments and authorities to act quickly to boost supply. If the values presented in Table 1 are increased by 40% to meet the increasing demand for the PPE monthly, the volume of the corresponding plastic waste generated across major cities around the world would obviously be so large that the environment could be overwhelmed if we do not shift from the old traditional ways of waste management. This is even more worrisome for developing countries, especially in Africa.

Table 1. Global monthly requirement of PPE for managing Covid-19 pandemic.

S/No	Item	Monthly requirement (million)	Polymers/plastics used in the production	The expected volume of wastes after use
1	Isolation masks	89	High-density polyethylene, spun polyester	89
2	Examination gloves	76	Natural rubber, nitrile rubber, and polychloroprene	76
3	Gowns and coveralls	50	Non-woven polypropylene, polyester, and polyamides	50
4	Goggles	1.6	Silicone, neoprene, and polycarbonate	1.6
5	Face shields	1.6	Polycarbonate, propionate, acetate, polyvinyl chloride, and polyethene terephthalate glycol	1.6
6	N95 masks	60	Melt-blown polypropylene	60
7	Hand sanitisers and liquid soap	Over 100 million plastic bottled	Polyethene, polyethylene terephthalate	Over 100 million plastic bottles

Source: WHO [35].

With the growing market for recycling plastics, glass, metal, paper, and other materials, which are essentially part of the waste generated during this pandemic, 85% of all medical waste is burnt openly, even though only 15% of it is considered biohazardous [36]. Because the novel coronavirus is a new strain that has not been previously identified in humans, lack of efficient standard operating procedures, insufficient resources, and technical know-how to handle, manage and dispose of the possible infected wastes, and the twists around balancing patient safety, cost, and sustainability results in more materials being managed through traditional waste processes; open burning, un-controlled incineration and landfill.

3.2. Current approach of managing wastes: publics health implication in developing countries

3.2.1. Burning & uncontrolled incineration

Burning plastic wastes and uncontrolled incineration is common in most developing countries. It is considered a quick and easy solution to reduce overflowing garbage. Though the waste is reduced in terms of volume, these methods are known to release dangerous pollutants in the form of gases to the atmosphere and contaminants to the water bodies [35]. Dioxin is a significant chemical released during the burning of waste plastics; it has been associated with several respiratory diseases and even cancer [37].

3.2.2. Open dumpsite

The approach is one of the most common practices in most developing countries, otherwise known as traditional landfills. This approach has gained significant use across different communities due to less energy demand compared to burning. Using a traditional landfill promotes an unhealthy way of managing wastes in the communities' example of such a landfill is shown in Figure 6, where a kid can be seen exposing her body to some infectious materials. Several literature [38,39] have repeated discouraged the use of traditional landfills due to the risk it exposes its immediate communities through harbouring of pathogens, uncontrolled release of carcinogenic and poisonous gases like ammonia, hydrogen sulphide and a lot more.

4. Better alternatives to existing wastes management approach

Various technologies are available for recovering energy (as wealth) from solid waste like plastics and rubbers via pyrolysis, incineration, and engineered landfills. Waste-to-energy technologies generally can emit low levels of toxic pollutants such as dioxins, acid gases, and heavy metals.

4.1. Pyrolysis

A more attractive technology that is receiving attention today is pyrolysis, the thermochemical conversion of plastics into fuel and chemical feedstock. This technology can be reverting petro-plastics into constituent monomers at lower temperatures than gasification [40,41]. A significant advantage of this technology over mechanical recycling is its ability to use almost all plastic types as feed without being sorted into component plastic types. Furthermore, rubber-based articles can be co-pyrolyzed alongside plastics and even composites containing agro fillers. In addition, pyrolysis takes mixed plastic waste. It treats it at 350 °C to 800 °C in a low-oxygen environment, breaking it into shorter-chain hydrocarbons, making it suitable for managing wastes from used PPE given the different plastics and polymers used in their production.

4.1.1. Pyrolysis of hand gloves

Many researchers have investigated the transformation of hand gloves into valuable materials, where Kaminsky et al. [42] studied the pyrolysis of natural rubber from hand gloves, commonly used in health care and households. They obtained 18.2 wt% of gas, 80.6 wt% of oil and tar, and 1.2 wt% of carbon black. The gas fraction consisted mainly of methane, CO_2, ethane, and propene. Hydrogen, CO, H_2S, and other light hydrocarbons were also present. The sample of the raw pyrolysis oil was distilled, and the distillate was separated into two phases. The polar phase consisted mainly of water, but the second phase consisted of varieties of aliphatic and aromatic compounds such as isoprene, toluene, and xylene, all starting materials for the chemical industry. They also reported that the solid residue is mainly carbon black.

Another research is Jia et al. [43], which investigated fast catalytic pyrolysis of rubber wastes over acidic zeolites and the effect of SiO_2/Al_2O_3 mole ratio of USY zeolites on the formation of aromatic hydrocarbons. Experimental results indicated that alkenes and aromatic hydrocarbons were the main pyrolytic products obtained from the fast pyrolysis of rubber wastes. The pyrolysis temperature played a vital role in forming aromatics, with the highest concentration achieved at 750 °C. The product distribution of aromatic hydrocarbons obtained from fast catalytic pyrolysis of rubber wastes over USY zeolites was dominated by xylenes, alkyl benzenes, and toluene.

4.1.2. Pyrolysis of polypropylene

Most PPE, such as isolation garments, N95 masks, are made from polypropylene. Abbas-Abadi et al. [44] investigated the influence of polypropylene (PP) pyrolysis parameters on the product yield and condensed product composition. They used a semi-batch reactor at a temperature between 420 and 510 °C. They reported that the highest oil yield was 92.3 wt% at 450 °C. They noted that higher and lower temperatures caused a decrease in the liquid product. The components were cycloalkanes, alkanes, alkenes, and aromatics. The aromatics and olefins fractions increased, but paraffin fractions decreased with increasing temperature. Ahmad et al. [45] studied the pyrolysis of PP, and they obtained the highest yield, 69.82 wt% of oil at 300 °C, while Fakhr Hoseini and Dastanian [46] in a similar study, reported a yield of 82.12 wt% at 500 °C. In all of the above studies, the chemical composition of the liquid fuel was found to contain; olefins, paraffin, cycloalkanes, and aromatics in varying proportions.

4.1.3. Pyrolysis of mixed waste plastics

Eze et al. [40,47] investigated the effect of zeolite-based catalysts on the physical and chemical properties of liquid fuel respectively from the pyrolysis of commingled plastic wastes using a batch reactor and temperature range between 350 and 490 °C. The highest liquid yield for catalyzed pyrolysis was 46.7 wt% at 390 °C in 90 min. The uncatalyzed reaction gave a liquid yield of 66.9 wt% at a higher temperature of about 490 °C in 120 min. Consequently, the uncatalyzed pyrolysis sample consists of 59%, 36%, and 5% of gasoline, diesel, and fuel oil, respectively. In comparison, the catalyzed sample consists of 93% gasoline and 7% diesel fraction.

Similarly, Donaj et al. [48] carried out a study on pyrolysis of polyolefin mixed plastics consisting; 75 wt% LDPE, 30 wt% HDPE and 24 wt% PP. They conducted two sets of experiments at 650 and 730 °C by thermal pyrolysis and at 500 and 650 °C using Z–N catalyst in a fluidized quartz-bed reactor. The ratios of gas/liquid/solid mass fractions via thermal pyrolysis were: 36.9/48.4/15.7 wt% and 42.4/44.7/13.9 wt% at 650 and 730 °C while via catalytic pyrolysis were: 6.5/89.0/4.5 wt% and 54.3/41.9/3.8 wt% at 500 and 650 °C, respectively.

Pratama and Saptoadi [49] studied the pyrolysis of mixed waste plastics in two-stage batch reactors at a maximum temperature 500 °C. Waste polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) was used as raw material in the following proportion; PE waste (50 wt%), PP waste (40 wt%) and PS waste (10 wt%). They recorded 45.13 wt% liquid products as the highest yield.

A major reason pyrolysis technology is gaining attention is processing various plastics as a single feed. To this end, the huge cost and technical know-how associated with the mechanical recycling technique circumvented Eze et al. [41]. Furthermore, the co-pyrolysis technology, which allows for the pyrolysis of plastics and rubber wastes as single feed, has made this technology even more suitable for the valorization of hospital wastes.

4.1.4. Co-pyrolysis of waste rubber/plastics blended

The possibilities of treating wastes consisting of a mixture of rubber and plastics as single feed in pyrolysis have been reported in the literature. Houyang et al. [50] studied the pyrolysis oil and solid residue properties under various blending ratios of rubber and plastics. They reported that compared with the pyrolysis of rubber or plastics separately, the co-pyrolysis of rubber and plastics produced a higher liquid fraction with a higher heating value. The GC–MS analysis revealed that the primary components in the pyrolysis liquid fuel from the rubber and plastics blend were identified as alicyclic hydrocarbons and aromatics. In contrast, the oxygen-rich stalk additive increased the contents of alcohols, esters, and ketones.

Similarly, Zahid et al. [51], in their study on borax-catalyzed valorization of waste rubber and polyethene by pyrolysis and co-pyrolysis reactions, showed that; noncatalytic pyrolysis, the pure and co-pyrolyzed polyethene with rubber yielded maximum liquid product at 500 and 600 °C, respectively. In borax-catalyzed pyrolysis, the pure polyethene and co-pyrolyzed with rubber yielded maximum oil at 400 and 500 °C, respectively.

4.1.5. SWOT analysis of employing pyrolysis in managing wastes

The Strength, Weakness, Opportunity, and Threat (SWOT) analysis presented in Table 2 as obtained from literature clearly shows the benefit and implication of adopting pyrolysis technology for managing wastes, especially in developing countries.

Table 2. A SWOT analysis report of adopting pyrolysis technology for managing wastes during COVID-19 pandemic.

	Technical	Residents	Government
Strength	1. It does not require very high pressure 2. It is open to any kind of feedstocks 3. It does not require oxygen held in a vacuum 4. It does not harbour microbes	1. Improved hygiene and improved wellness 2. Lower negative impact on the soil 3. Lower greenhouse gas emissions	1. Engagement of specialized waste management organizations on public-private partnership 2. Compact and modular plants would improve energy self-sufficiency 3. Utilization of derived raw materials to run other industries
Weakness	1. Elevated temperature is required	1. Lack of practical knowledge for managing hazardous wastes 2. Corruption and disloyalty 3. Unrest and political instability	1. Consistent with the successive government in monitoring, managing, and funding projects 2. Once the project depends on collaboration, conflicts between the parties involved are more likely to occur 3. Execution of the project may not be efficient due to corruption 4. There are missing links between crucial players; ministries, industries, commerce, and investors
Opportunity	1. Syngas, bio-oil & biochar can be produced 2. Possibility of producing hydrocarbon and petrochemicals from syngas 3. The bio-oil can be transformed into different liquid fuels	1. Technical training and employment opportunities 2. Recovery of land for farming 3. Availability of more land for regional and rural development	1. Opportunity to create a safe and habitable environment for residents 2. Creation of jobs for residents 3. Complementing power generation source 4. Reduce total dependence on crude based fuels
Threat	1. Energy-intensive and cost implicative 2. Possibility of releasing unsafe gaseous substance	1. Consistent with successive governments in funding and monitoring the plants 2. Poor maintenance culture of government projects 3. If not properly managed can pose a threat to our environment	1. Management issues and preference for primarily profit-driven contractors 2. Sustenance of the project by the successive government is not guaranteed

Based on the above analysis, it can be seen that the adoption of the technology offers many potential benefits to both the residents and governments. The technology would open a new source of the lively hood, safer environment, and make more lands available to cultivate. On the other hand, the government would create more jobs, reduce dependency on crude base fuels for energy generation, and generate income from other derivatives that serve as raw materials for industries [52–54].

The major challenge faced in developing countries is corruption and lack of political will to invest in research and the outcome. Dhikur and Adeoye [55] noted that Nigeria's governance and political leadership had been driven by self-interest and other obsolete considerations, which are not people-oriented. The state has failed in three major areas: security of lives and properties, promotion of the rule of law, and provision of visionary leadership. Other African countries also share a similar faith in government unwillingness to develop and sustain modern technology for the advancement of their society [56,57].

Furthermore, disloyalty, unrest, and corruption threaten the populace. To this end, the government must begin to put the masses first, show transparency in governance above all, invest in scientific solutions to solving problems, and improve the financial sustainability of the waste management systems.

Finally, this technology has many potential advantages for any government willing to invest, monitor, and sustain the project. Based on preference, the government must employ sincerity of purpose in choosing the best option for running this project between public-private partnerships and contractors.

Pyrolysis represents a viable close-loop approach to the problem of environmental degradation occasioned by indiscriminate dumping and disposal of plastics Eze et al. [41]. The gas has high calorific value, the light oils can be used as gasoline additives to enhance octane, and the heavy oils can be used as a replacement for Number 6 fuel oil.

Vital strategies presented by Val [58] report that respective communities could deploy pyrolysis facility in the management of waste as presented in Table 3. The strategy for avoiding threats via the use of method's potential strength (i.e., S-T strategy), taking advantage of the opportunity that pyrolysis tends to offer (i.e., S-O strategy), and others which includes the use of the opportunity for the minimize weakness impact on the pyrolysis' facility (i.e., W-O strategy) and the use of the understanding of the pyrolysis' weakness and threat to design approach of minimizing weakness and avoidance of threat in its operations were summarised.

Table 3. Various strategies for deploying effective management of the pyrolysis facility.

	Opportunity	Threat
Strength	S-O strategy for taking advantage of the opportunity the approach offer with the help of the strength: 1. Petrochemical plants can be established within a pyrolysis plant to add value to the syngas to yield high-value products 2. Pyrolyzers established would reduce the chances of habouring microbes within our residentials places	S-T strategy for using its strength to avoid the possible threats in the facility: 1. Government can waive some custom duties to lessen the capital demand that the energy requirement would demand 2. Invest in this technology to maintain good public health
Weakness	W-O strategy for using the opportunity that incineration plants tend to offer for managing the weakness: 1. The profitability of the value-added products generated from the plants can alleviate the energy cost (from the high-temperature requirement)	W-T strategy for reducing the weakness while avoiding the possible occurrence of the threats: 1. Regular maintenance practice in the plant to avoid releasing or leaking unsafe substances to the environment 2. Regular accreditation exercises should be organized to ensure safety compliance in the operation of the incineration plants

4.2. Incineration

Incineration is the process of combusting waste at elevated temperatures until only ash is left. It ranges from sophisticated high-temperature furnaces to small hospital combustion units operating at lower temperatures. It is otherwise known as the thermal treatment of waste, which entails converting them into ash, flue gas, and heat. Gaseous emission in the combustion process is expected to be controlled to limit gaseous emissions such as carbon dioxide, nitrogen oxides, and particulate matter. More giant modern incinerators have energy-recovery facilities incorporated in them to generate steam and/or hot water in cold climates to feed urban district-heating systems or steam to run turbines for electricity [59,60]. Many countries have settled for incineration in North America, Europe, and Asia as a viable option in solid waste treatment due to the significant and continuous investment in its development. Emissions have received tremendous research to neutralize risk for human health and raise public confidence in incineration [61].

Most significant, modern incinerators include energy-recovery facilities. In cold climates, steam and/or hot water from incinerators can feed urban district heating systems. In warmer climates, the steam from incinerators is used to generate electricity. The heat recovered from small hospital incinerators is used for preheating of waste to be burnt. The incineration sector is among many waste management methods but handles a wide range of waste that arises in society. These wastes may include but are not exclusive to mixed municipal waste, pretreated or selected municipal waste, hazardous waste, sewage sludge, and clinical waste. In an urgent bid to reduce emission to air, cost, and environmental performance, the sector has undergone a specific legislative and technological transformation in the last two decades. The overall target of incineration is to cut down the volume of waste, reduce the hazard they portend to the environment, energy recovery while capturing or destroying the potentially harmful substances that are, or maybe released, during the process [62].

The primary stages of the thermal incineration process involve drying and degassing; pyrolysis (degradation of organic material in the absence of oxygen); gasification (partial oxidation); and oxidation. These stages occur in parallel and are challenging to separate to a limited extent. However, using an in-furnace, the combined effect of the design, air distribution, and control engineering are optimized to achieve incineration with limited polluting emission. There are different types of thermal treatment in incineration. However, not all types of treatment are suitable for all wastes. These treatments are grate incinerators, rotary kilns, fluidized beds, pyrolysis, and gasification systems [62].

Incineration of plastic waste produces energy if conducted in controlled facilities. This waste management technology is becoming increasingly popular, as the calorific value of plastics is similar to that of fuel oil. Thus, the incineration of plastic wastes produces thermal energy of the same order of magnitude as the oil used in its manufacture [63]. A typical process scheme of the incinerator is shown in Figure 7 below.

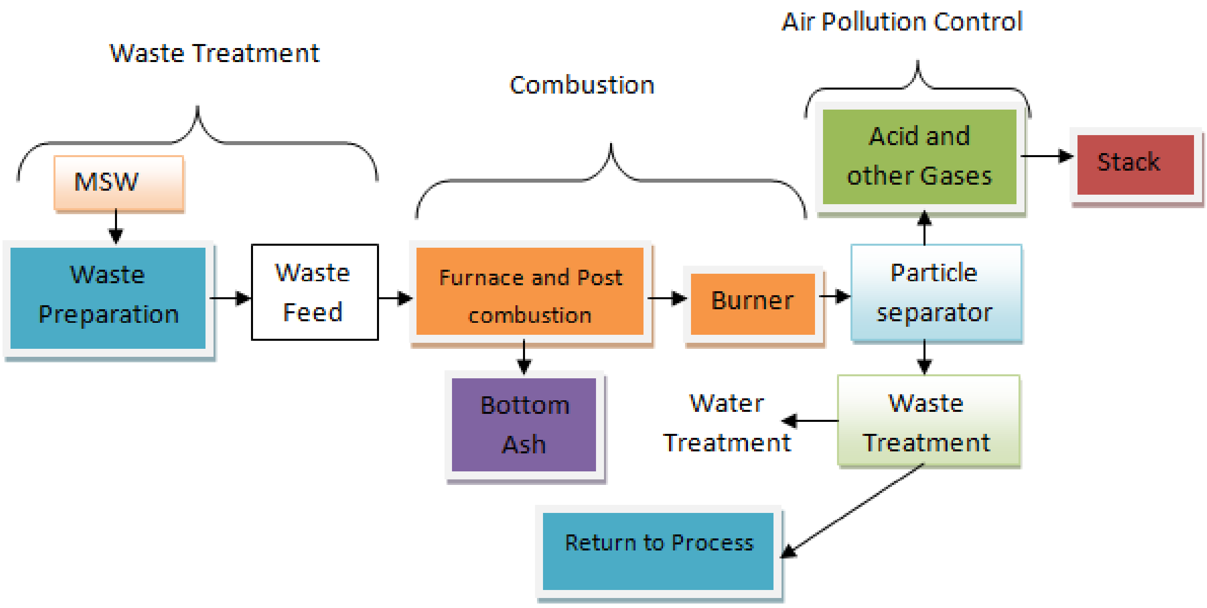

Figure 7. Block flow scheme of a municipal solid waste incinerator source: Adopted from Alonso-Torres et al. [64].

Small-scale incineration has received a share of condemnation in underdeveloped and developing countries, mainly because its environmental externalities are against sustainable development Jereme et al. [59] and its poor waste segregation practice [65]. It is observed that there is gross mismanagement of health care waste in transition countries visibly implemented through indiscriminate disposal, open dumps, and open burning. In view of the pandemic response in developing countries, waste recovery, recyclability, and management framework have set instability in the healthcare system. A systematic and multifaceted approach is needed to alleviate fears of its contagious nature [66]. However, incineration in various forms (on-site, mobile, or furnaces) has been considered potential waste management alternatives in the Covid-19 era [67].

4.2.1. SWOT analysis of incineration as a means of managing waste

A survey of the strength, weaknesses, opportunities, and threats (SWOT) of adopting the incineration method in waste management in developing countries is presented in detail in Table 4. The strength component emphasizes the residents' and government's benefits and capability in taking advantage of this method. The weakness components highlighted the limitation of employing this approach.

Table 4. Report for the SWOT analysis of incineration as a means of managing wastes.

	Technical	Residents	Government
Strength	1. Flue gas, ash, and heat are incineration output 2. Reduction of the landfill site 3. The ash can be used as fertilizers on farms 4. Bottom ash has been proven to be safe to dispose to a landfill 5. The volume of waste is reduced by 90%	1. Human resources are available 2. Significantly reduces the wide range and volume of wastes 3. Handles waste that cannot be recycled 4. Energy-recovery facilities that can feed urban district-heating systems	1. Government has the financial capability of setting up an incinerator 2. Existing government ministry or department of environment has the capability of managing unit 3. The constitutional power of the government allows them to set up rules that would facilitate wastes management 4. Continuous generation of waste and the potentials of incinerating them 5. Reduces the need for land used for landfills 6. Incinerators have a long service life 7. Solves the problem of open dumps and open burning 8. Possibility of its operation running under different weather conditions
Weakness	1. Capital investment in the flue-gas cleaning process before discharge	1. Modern designs and construction are complex, sophisticated, and expensive 2. High investment, operating, and maintenance costs 3. Encourage waste scavenging before relocation to the incinerator	1. The continuous burden of monitoring and evaluation 2. Expensive to set up an incinerator 3. Potentials of the incinerator releasing the smokes while burning wastes
Opportunity	1. Possibility of generating power 2. Waste reduction through its energy conversion 3. Heat generation 4. Opportunity to destroy the pathogens and toxins 5. It reduces the chance of greenhouse gas release from landfills	1. Provision of job opportunities 2. Save to be sited close to residential places 3. Wastes can be dumped in a short distance due to the proximity of the incinerator	1. An alternative source of energy 2. Source of revenue 3. The use of solid wastes incinerators has lessened the level of land pollution 4. The capability of decreasing waste by 95% and improves land management by reducing the dependency on landfills
Threat	1. Health risk to the resident near the incineration plant-like respiratory issues 2. Possibility of releasing acid gas, mercury, and lead to the atmosphere 3. Incomplete combustion can lead to the release of unsafe radicals and other pollutants	1. Exposure to poisonous gases if no supplementary gas collection and treatment system is incorporated 2. Leachate contaminates soil, surface, and groundwater	1. Causes other health and environmental issues, especially when poorly managed 2. Long time impact of continuous burning wastes can be a significant threat to waste reduction and recycling practice

Other components involved in the survey reported in Table 4 included the opportunities that the method tends to avail to both residents and government to improve the attitude of best waste management. In contrast, the threats involved in the method unveils the areas of concern that developing nations interested in adopting this method in their waste management could be considered depending on their capability of addressing the identified issues like the potential of exposing residents to poisonous gas in a case where the gas collection is poorly managed. Among other significant threatening issues that government has the potential to encounter is the damage to the environmental and public health of the communities if poor attention is continuously given to the management of the waste management facilities across the country.

According to Val [58], the different relevant wastes management strategies that could facilitate the effective operation and control of the incineration plant were presented in Table 5. Different approaches like S-O, S-T, W-O, and W-T strategies were presented, indicating the ways that can help to manage the strength (S), weakness (W), opportunity (O), and threat (T) of the utilizing this approach in the management of waste in developing communities.

Table 5. Various strategies for deploying effective management of the incineration plants.

	Opportunity	Threat
Strength	S-O strategy for taking advantage of the opportunity the approach offers: 1. A significant amount of waste can be reduced quickly, and the facility can be safely sited in residential areas 2. Government can use her financial capability to set up this facility with the vast potential of combating power generation and pollution	S-T strategy for using its strength to avoid the possible threats in the incineration plant: 1. The government can invest largely in the proper maintenance of this facility to keep the surroundings clean and keep people safe from any possible danger from the facility 2. Agencies should encourage the development and adoption of continuous-emission-monitoring technology
Weakness	W-O strategy for using the opportunity that incineration plants tend to offer for managing the weakness: 1. Government should encourage private investors to invest in the sector to take advantage of its power and heat generation potentials	W-T strategy for reducing the weakness while avoiding the possible occurrence of the threats: 1. Regular accreditation exercises should be organized to ensure safety compliance in the operation of the incineration plants 2. Operators managing the plant set-up should be obligated to always obtain practice certification from a defined government regulating agency

4.3. Engineered landfills

According to Chu [68], the landfill is defined as semi-natural terrestrial ecosystems often set up on lands with a historical account of hosting waste disposal. It was further reported as a pit engineered in which different layers of solid wastes of different kinds are filled, compacted, and later covered for final disposal, often done as an award to alleviate water pollution [69]. Both authors [68,69] indicated that a thick wall often characterizes such pit to prevent leaching of the contaminant into the underground water source, which has the potential of endangering the health of the community residents in such area. Beat [69] reported that other features were that the engineered landfills have a lined ground level (i.e., the bottom), a sound leachate collection system, and the leachate treatment system unit. An engineered landfill does have units for the underground water quality assessment, gas extraction system, and cap system. The extracted gas is often largely methane-based gas mixtures and can be used in power generation, fuels, and other valuable chemicals production.

However, proper environmental risk and hazard analysis are often carried out before choosing the landfill's location and capacity [61,69]. An example of an engineered landfill is presented in Figure 8, where the principle of anaerobic digestion is employed in gas production. The engineered landfill can also be called an anaerobic bioreactor, where organic components of wastes which were collected and compacted were broken down were optimized with the addition of an external source of moisture like sewage sludge while using the extracted gas into electrical energy [70], other valuable chemicals and fuels.

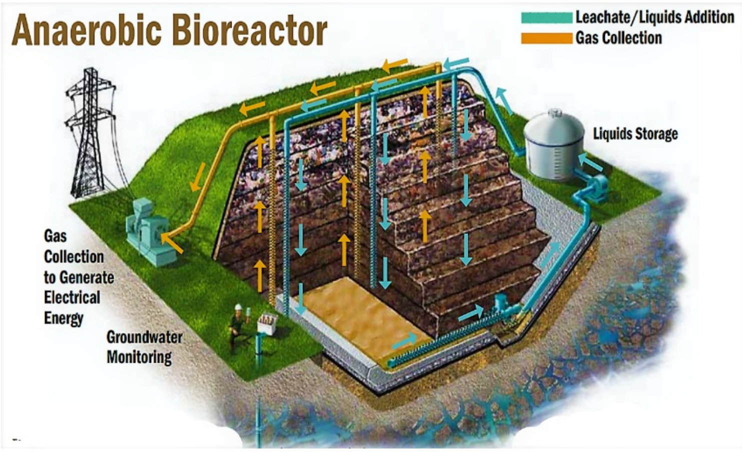

Figure 8. A graphical illustration of an engineered landfill designed for gas production via anaerobic digestion [69,70].

Moreover, the report from Chu [68] indicated that employing the traditional approach of managing our landfills can expose our community health to danger. Such an approach does take a long time of about 50 years to have the wastes decomposed. This report agrees with other literature [71–75] report also reveals that traditional dumpsites expose the public to a different form of pollution like water pollution obtainable from the leached contaminant to the underground waters, which are primarily consumed in developing nations, air pollution due to some poisonous and harmful gas like hydrogen sulphide, ammonia, methane and lot more which are often released into the environment as a result of the natural phenomena taking place on the landfills [70,72,76–79]. The report of Chu [58] further indicated that the newly closed landfills could be hospitable as they have the possibility of conserving wildlife. However, the author highlighted that closed landfills could be developed to habitat with high conservation values, proper soil management, appropriate gas control, and directed succession. Adopting engineered landfills by the governments of developing nations would further facilitate good health public care in our communities, especially when governments and communities begin to consider building a devoted engineered landfill for sanitary purposes [76,78]. This is expected to be sited within people's dwellings, adequately covered to prevent any disease-carrying animals from accessing human dwellings, and well protected to avoid any form of leaching to any contaminant to the groundwater banks.

4.3.1. The situation of landfills in developing nations

Most of the solid wastes in developing nations are poorly managed. Wastes dumpsites are primarily open and closed with the residential places. Open wastes burning is the norm approach of managing the dumpsites when they become overfilled and unbearable for the residents [74,75,80,81]. They are collected and transported to farms to serve as manures in some cases. Most importantly, the attention of the government of the concerned communities for wastes management is insufficient. Examples of some dumpsites in selected developing nations are presented in Figure 9.

The pictoral reports presented in Figure 9a–d indicated the present situation of wastes management in developing nations. As seen with the open dumpsite, some even sited close to residential places. The gravity of the health dangers these sites pose to humans cannot be overemphasized. Other dangerous hazards that the communities are exposed to aside from poor air and water quality include the risk of viral, bacterial, and fungal disease-carrying pathogens.

Figure 9. (a) A picture of Olusosun is the largest dumpsite in Nigeria (Ojuri et al., [74]). (b) A picture of drowning wastes in a scene in Accra, Ghana (WOIMA, [81]). (c) A picture of the landfill site for Karachi in Pakistan (Pakistan Today, [80]). (d) A picture of garbage at a landfill in Aleppo of Syria (Sonia, [75]).

4.3.2. SWOT analysis of engineered-landfills as a means of managing waste

With the use of Strength, Weakness, Opportunity, and Threat (SWOT) analysis, the benefit and implication of adopting the technology of establishing engineered landfills in developing nations' communities to the residents and government as survey via the use of relevant literature. The reports collected are presented in Table 6.

Table 6. A report of SWOT analysis of adopting engineered landfills in developing nations.

	Technical	Residents	Government
Strength	1. Lesser energy requirement 2. Both solid and liquid wastes are managed 3. It is the cheapest method of managing waste 4. It is covered to present insects and other breeding animals for spreading disease 5. Rapid wastes degradation using bioreactor	1. Safer environment for living 2. Lesser chances of falling sick 3. Makes environment cleaner 4. Promote cleaner underground water 5. Eco-friendly technology	1. Availability of human resource 2. Availability of vast land to site them 3. Improves waste management practice
Weakness	1. Accumulation of land mass 2. A large surface area is required 3. It cannot be sited close to peoples' residence	1. Poor awareness on proper waste disposal 2. Stress complying with new rules involved in the waste disposal 3. Readiness to compliance of the residents to the government directives on waters disposal procedures	1. Consistent of government in monitoring proposal waste disposal 2. Employment of suitable and capable human resources without sentiment 3. Strictness in the monitoring process 4. Proper maintenance attitude
Opportunity	1. Energy production 2. Rapid reduction of wastes 3. Production of biogas 4. Easy management of waste 5. An engineered landfill is a good wayout to waste reduction 6. Most reliable method 7. Promotion of waste disposal method if adequately managed	1. Job opportunity 2. Opportunity to learn about the better approach for disposing of domestic wastes 3. The opportunity of starting a local landfills-related business	1. Opportunity to create a safe and habitable environment for residents 2. Creation of jobs for residents 3. Opportunity to boost power generation capacity 4. It would reduce the monopoly of hydro-power 5. Keep cities and towns clean 6. Source of revenue
Threat	1. Constitute danger to public health 2. Risk of underground water contamination 3. Health risks potential if poorly managed 4. Unlike engineered landfills, basic or traditional landfills pose a significant risk threat to the communities due to their poor structure 5. Risk of leaching in failed landfills 6. Poor management can pose an environmental pollution threat	1. The consistency of government in monitoring proposal waste disposal 2. Safety of residents since methane gas is highly flammable	1. How to finance and sustain the project could be a challenge 2. Promotion of the project by the next government after the transition 3. Landfills can pose a serious challenge to public health if poorly managed via exposure to ammonia, hydrogen sulfide, and life threaten materials

Based on the results obtained from the SWOT analysis, it can be seen that the adoption of engineered landfills in our communities has many potentials to offer to both the residents and governments. Some are job creation, improvement of community health and environmental sustainability [76,78], opportunity to boost power generation capacity [74,82,83] and open another source of revenue for the government. However, the governments of these communities need to give special attention to the adequate financing and sustainability of the project, and a successive government should be mandated to continue promoting the project. The government should employ consistent and strict monitoring practices to ensure that the resident complies with the new rules on the proper disposal of wastes to be followed by all. The government should employ a proper and consistent maintenance attitude in running the plants. Also, the employment of human resources should be strictly based on competence.

Moreover, several strategies that would facilitate or promote the effective operation, management and control of the engineered landfill such that it would not end up functioning like a traditional landfill which has long been contributing nuisance to the environment via its land, water and air pollutions were explored with reference to the concept of SWOT strategies reported by Val [58] report.

Table 7. Different strategies for effective management of the engineered landfills.

	Opportunity	Threat
Strength	S-O strategy for taking advantage of the opportunity that an engineered landfill could offer: 1. The availability of advanced eco-friendly technology promotes landfills-related businesses with job creation in the community 2. Deployment of human resources through establishing a waste management agency that would employ citizens to keep the cities clean and manage the engineered landfill and the complement power generation 3. Design of structure for effective transport of both liquid and solid waste to an engineered landfill for biogas production and safer environment with lesser pathogens, unlike the open dumpsite or traditional landfills	S-T strategy for deploying the strength of an engineered landfill to prevent the occurrence of any threat in the facility: 1. Resident benefiting from the safe environment could challenge the government if they fail to give the facility the proper attention it deserves 2. The facilities can be set up as public-private joint enterprise so that the management can be more effective for having a safe environment with more significant revenue 3. The government needs to set proper policies to prevent the risk of leaching contaminants to the soil and health risk
Weakness	W-O strategy for using the opportunity that an engineered landfill can potentially offer for the management of the facility's weakness: 1. Education of the public about the significance of keeping our surroundings clean would help alleviate the attitude of improper waste disposal. And employing unemployed members of the societies to monitor and regulate compliance of the communities with the environmental laws 2. Revenue generated via this approach could motivate the government to become strict in the monitoring role and embrace good maintenance practices. It would further motivate the government to employ without being sentimental for the smooth running of the system for the high revenue generation 3. Establishment of well designed engineered landfill for maximization of land use	W-T strategy for reducing the engineered landfills' weakness while avoiding the possible occurrence of the threats during its operations: 1. Strict compliance to the new rule would have to be promoted, and proper maintenance practice must be consistently maintained 2. A rigid policy can be set up that would make it mandatory for the subsequent government to promote the smooth running of the plant 3. Stable funding of maintenance practice in the management of the engineered landfills

Report of such explorations is presented in Table 7, where strategies for preventing the release of poisonous gases and disease-carrying pathogens via the use of the facility's strength (i.e., S-T strategy). Another is the understanding of the possible threats and weaknesses attached with the employment of such facility in the management of our municipal wastes different approaches that could be used to set up policies and strategies that would minimize weaknesses and prevent threat during the operation of the facility (i.e., W-T strategy). Other strategies presented in Table 7 includes the opportunities offered by the engineered landfills used to innovate strategies, minimized the weakness (i.e., W-O strategy), and the use of the engineered landfills' strength in taking advantage of the available opportunity that the landfills could offer (i.e., S-O strategy) in the management of waste deposits in our respective communities.

5. Conclusions

Various personal protective equipment (PPE) and specific plastics used during the COVID-19, the collections of wastes, the implication of improper waste management, and different approaches to converting waste to wealth were reviewed. SWOT analysis was employed to survey the benefit, implications, potentials and possibly threats of adopting each solution: pyrolysis-controlled, incineration and engineered landfill.

Findings from the survey reveal that the continual increase in the volume of waste plastics produced by communities, health facilities, and organizations following the outbreak of the COVID-19 pandemic has raised the urgent need for developing new and better methods of wastes disposal and management.

Traditional plastic waste management methods like open burning and traditional landfilling are outdated. They should be replaced with modern, eco-friendly, effective, and easy-to-operate solutions. Plastic accumulation both on land and in the oceans is an essential issue of our time. Current trends predict that the magnitude of the issue would exponentially increase. Therefore, we must embrace modern technological solutions to decrease the rate of plastic accumulation and push toward reducing the impacts that inevitable accumulation would have. There might be no single solution to addressing these issues, so authorities must effectively combine the best solutions for its locality.

6. Recommendations

Government should encourage the production and sales of bioplastics over non-degradable plastic by subsidizing the raw materials used in bioplastic production, approving a low or zero tax on bioplastic production. This policy would promote the production and marketability of bioplastic materials in developing countries like Nigeria. The enactment of such kind of policy can promote the use of biodegradable plastic in the production of PPE for protecting our body (i.e., coverall/gown), eye (i.e., goggle), hand (i.e., hand gloves), and legs (i.e., safety boot).

Future studies can evaluate the economics involved in the design, construction, and running of these solutions in developing nations while unfolding the benefits and cost implications of adopting the technologies. Possible comparative analysis can be considered to identify the method with the best economic benefits over costs among the possible wastes management approaches (i.e., pyrolysis, engineered landfills, and incineration) reported in this survey.

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Conflict of interest

The authors declare no conflict of interest.

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