

Review

A Perspective on Four Emerging Threats to Sustainability and Sustainable Development

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Abstract: Plastics are a precious, versatile set of materials. The accumulation of plastic waste threatens the environment. Recycling plastic waste can produce many new products. The many opportunities for using plastic waste create pressure for a strategy to develop or improve current waste management systems to reduce the negative impact on humans, fauna and flora. The objective of this review paper is to consider an opportunity to recycle plastic; to convert plastic waste into plastic sand bricks. This would reduce the impact of the four emerging crises (plastic pollution, unemployment, the shortage of affordable housing and climate change) identified in South Africa as a threat to sustainability. This paper reviews studies utilising plastic waste to manufacture materials for the construction industry. The feasibility of using plastic waste to manufacture bricks revealed high compressive strength, low water absorption and weighed considerably lower compared to traditional bricks. Plastic sand bricks, therefore, can provide a solution that can be used to curb the four emerging crises and contribute to sustainability.

Keywords: crises; green engineering; recycling methods; plastic sand brick; eco-friendly building material; sustainability; pollution; housing; unemployment; climate change



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1. Introduction

To think of a world without the use of plastics is simply unimaginable [1]. Plastic is used in various products, from consumer goods to packaging, medical devices, automotive, and construction [2]. Plastic pollution is growing relentlessly, and the accumulation and disposal of plastic waste is a significant problem [3]. Plastic waste somehow escapes the waste management system and makes its way into the environment, inadvertently or through illegal practices. It eventually fragments into smaller pieces that severely threaten the health of humans, plants, animals, birds and marine life [4]. If no action is taken, the yearly flow of plastic into the ocean will triple by 2040, amounting to 29 million metric tonnes annually. This is equivalent to 50 kg of plastic waste per metre of coastline globally [5].

The high demand for plastic products has drastically increased the production of single-use plastic, and its end life harms ecosystems and causes environmental pollution. The harmful effect of plastic materials' end life has become a global challenge [6]. Wilcox et al. [7] warned that plastic pollution has become a worldwide problem and poses a severe environmental hazard. There have been several studies [8–12], which emphasise that plastic materials are the most common type of debris that make their way into the world's oceans, causing enormous problems for marine animals and bird life. Allsopp et al. [13] and Ostle et al. [14] stated that many seals, fish, dolphins, porpoises, whales, and turtles suffer or die due to entanglement in fishing gear, such as nets and strapping bands from bait boxes and ropes. These types of debris cause bodily harm, suffocation, starvation and other injuries. Derraik [8] and Nelms et al. [15] stated that marine animals, including fish, have suffered due to the ingestion of marine debris. Napper and Thompson [16]

highlighted that plastic waste includes beads, foams, fibres, films, flakes from plastic bags, plastic pellets and plastic fragments from more oversized broken plastic items. Most of these ingested particles consist of 84% fibres, while the remaining 16% are broken plastic fragments. Eating these items causes digestive tract blockage, starvation and death.

According to [17], another challenge was the illegal dumping of plastic waste materials on the West African Coast. This contributes significantly to the demise of marine life. The beaches show a definite decline in their aesthetics and beauty, with plastic trash thrown all over the beaches.

Lebreton et al. [18] contended that between 1.15 and 2.41 million tonnes of plastic waste currently enters the ocean annually from rivers. Jang et al. [19] stated that the amount of plastic debris along shorelines hurts tourism. For example, the total tourism revenue of Geje Island was lost due to the marine waste flowing from the Nakdong River in July 2011. Considerable revenue loss was estimated to be USD29–37 million.

An additional environmental challenge posed by plastic waste is the production of greenhouse gas (GHGs). The projected output of GHGs from 2030 to 2050 is increasing at an alarming rate. It is expected to reach approximately 225 million tonnes of CO₂ soon. Hence, GHGs are predicted to cause untold damage in the future [20]. The past trends show that South Africa was the highest emitter of CO₂ gas emissions in 1990 and 2017, reflecting a total of 243.8 metric tonnes (Mt) CO₂ and 421.7 Mt CO₂, respectively [21].

Therefore, the urgent need for recycling plastic to provide a solution for reducing plastic pollution, unemployment, dealing with the shortage of affordable housing and climate change has been identified in South Africa as a threat to sustainability in the country. There have been many technological advancements to produce eco-friendly biological building materials from plastic waste and other waste materials. Suresh et al. [22] proposed using straw and clay for their many advantages, such as it being cheap, durable, and having good insulation properties. Similarly, fly ash produced as a waste product by coal-powered plants is now being used to develop environmentally friendly products [23]. Various studies have found that fly ash, which was found to be strong and has relatively high compressive strength could be used as a substitute for clay-based bricks [24]. A supplementary study found that as the content of fly ash is increased, the compressive strength increased, the water absorption test did not surpass 20% of the bricks' weight, according to the testing standard [25]. Another material identified for brick production is rice husk. Rice husk is a by-product of the milling process when harvesting rice grains and is available in large quantities [26]. It found that adding rice husk in specific ratios improved building products and concrete properties. Despite these raw materials' availability and cost effectiveness, these resources would not be sufficient to address the increased demand for bricks in the construction industry. In this regard, the number of propositions and shifts towards the green economy to analyse end-of-life disposal methods in many forms of waste are increasing daily [27,28]. The amount of plastic waste is widely available and can be sourced at a low-cost. Hence, it is proposed to be used as an alternative binding material for buildings and other products [29]. Including plastic waste in construction may serve two primary purposes: firstly, providing eco-friendly brick-making materials and secondly, extracting plastic waste from the environment [30], resulting in a waste-to-profit movement. Therefore, the objective of this review paper is to consider the feasibility of using only plastic waste in plastic brick manufacturing in South Africa, while simultaneously reducing the negative impact of the four emerging crises.

This solution will not take place naturally, but the current focus on incorporating waste pickers into the formal industry in South Africa will have far-reaching implications, as discussed in the case analysis. Godfrey [6] estimated the projected number of waste pickers to be around 215,000 in 2017, which is still growing. Government, industry, and other stakeholders identified the beneficial role waste pickers play in the diversion of valuable waste products away from landfills; thereby reducing waste pollution and redirecting it towards recycling and reuse [31].

Several studies argued for the inclusion of waste pickers into an integrated waste management system with proper regulatory frameworks since they currently face many challenges such as discrimination, working under poor conditions, compromised health and safety regulations, being overworked, workers receiving low salaries when they worked for other agents and receiving little cash for the resale of their waste products. Velis [32] proposed that it is essential to upgrade waste pickers from the informal recycling system towards a formal or structured waste management system and link them to the recycling value chain.

It is also argued that the framework must build into the system a pre-condition to ensure the transformation of the informal industry through the organisation and empowerment of the informal waste pickers. Samson [33] stated that waste pickers play a critical role in substantially contributing to the recycling industry. She believes that a coordinated and integrated approach of waste pickers into a regulated framework is compulsory since all other methods will fail.

The informal sector in Pakistan implements the recycling of waste. Masood and Barlow [34] argued that it is advantageous to integrate this informal industry with the formal sector. Hence, this forward-thinking led to the designing of a framework that offered explanations as to how to integrate the informal and formal waste management sectors in such a way as to exert a positive impact on the economic, environmental and social spheres. They also believed the integration would benefit the government, municipalities, the general public, and the informal waste sector.

Dias [35] presented a brief overview of the legal framework regarding the integration of informal waste collectors (waste pickers) in solid waste management (SWM) in Brazil. Recently, Brazil favoured the enactment of laws to include waste pickers. The new legislation gives waste pickers much more visibility and recognition for their economic contribution. Due to the inclusive way in which they integrated waste pickers into their national policies, Brazil has become one of the leading countries worldwide.

Drawing on the experience of Brazil and other countries, South Africa followed a similar path. In her speech, Molewa [36], the previous Minister of the Environment, placed an increase in plastic waste recycling rates on record. She supported the role played by waste pickers in diverting waste from landfills, thus making a huge contribution to the recycling economy in South Africa. She stressed that there must be strategic interventions to publicise economic prospects by promoting entrepreneurial activities that integrate waste pickers into a controlled and supportive environment.

The researcher stated [31] that the intervention of the South African government, industry, and civil society was necessary to formally integrate waste pickers by designing guidelines to recognise their essential role of salvaging valued resources from landfills and redirecting them towards reuse and recycling in a structured and coordinated way. This evidence-based guideline was necessary to introduce policy measures to maximise the achievement of this growing sector. Mazhandu et al. [37] highlighted that the government and various stakeholders outlined the roadmap for future actions in plastic waste management in South Africa, where all waste pickers will be formally registered by 2022, and after that, there will be a drive towards zero waste products sent to landfills by 2030. This will result in several benefits for all industries, which is projected for the future of South Africa.

This paper is divided into eight sections. The first section commences with an introduction. The second section deals with the method of literature retrieval from various sources. The third section overviews the four emerging threats to sustainability and sustainable development. These threats are discussed in a national, continental and global context. This section also provides a diagram which offers a perspective on understanding the positive implications of recycling plastic waste into plastic sand bricks. This will eventually promote sustainability, as well as reduce the four emerging crises; namely, plastic pollution, unemployment, shortage of affordable housing and climate change. Possible solutions have also been included with each threat to sustainable development. The fourth section explains the feasibility of using plastic waste in manufacturing plastic sand bricks and the

types of plastic waste used. The fifth section ends with a conclusion. The sixth section highlights research gaps in the literature that was reviewed. The seventh section explains the limitations of the review paper. The last section ends with possibilities for future research.

2. Method

The background readings on the themes “sustainability” and “sustainable development” were completed in-depth first. It all started from having a sustainable environmental, social and economic focus at a national, continental and global level, which was discussed.

Then, an extensive literature search was conducted using Google Scholar. Using the operators “AND” and “OR”, the documents were then screened for refining words (see Figure 1) for the categories “plastic pollution”, “unemployment”, “affordable housing”, and “climate change”.

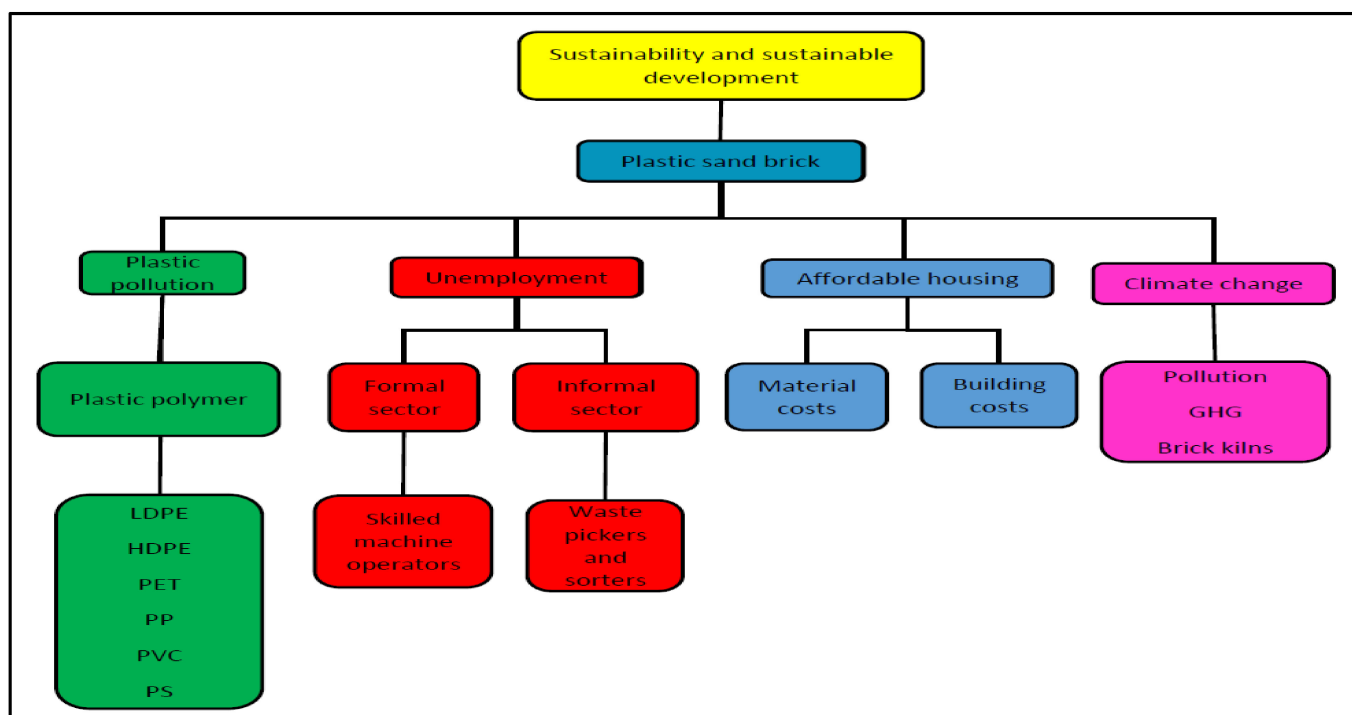


Figure 1. Flowchart of the literature.

Generally, the selection of relevant studies did not follow a specific pattern or scheme because of the broad scope of the study. Instead, the screening of the literature focuses on the four emerging crises.

- Plastic pollution and its impact on the environment;
- Lack of affordable housing;
- Unemployment; and
- Climate change.

A deeper analysis of the four emerging crises was conducted at a national, continental and global level. It was also important to elicit information from government institutions such as Statistics South Africa. It was also necessary to study the references of the other publications to find more appropriate and suitable articles.

3. An Emerging Global Crisis—A Threat to Sustainability

We live in unprecedented times, and the world has been forced to react to many significant threats such as pollution, unemployment, shortage of affordable housing, climate change, poverty, diseases, global warming, and political, religious and food security [38]. These global threats have led to lower living standards for most people. However, gaining

a better understanding of the four global crises also affecting South Africa, as indicated in Figure 2, requires taking immediate action, and that only by taking action now with the utmost priority can we secure our future [39–43].

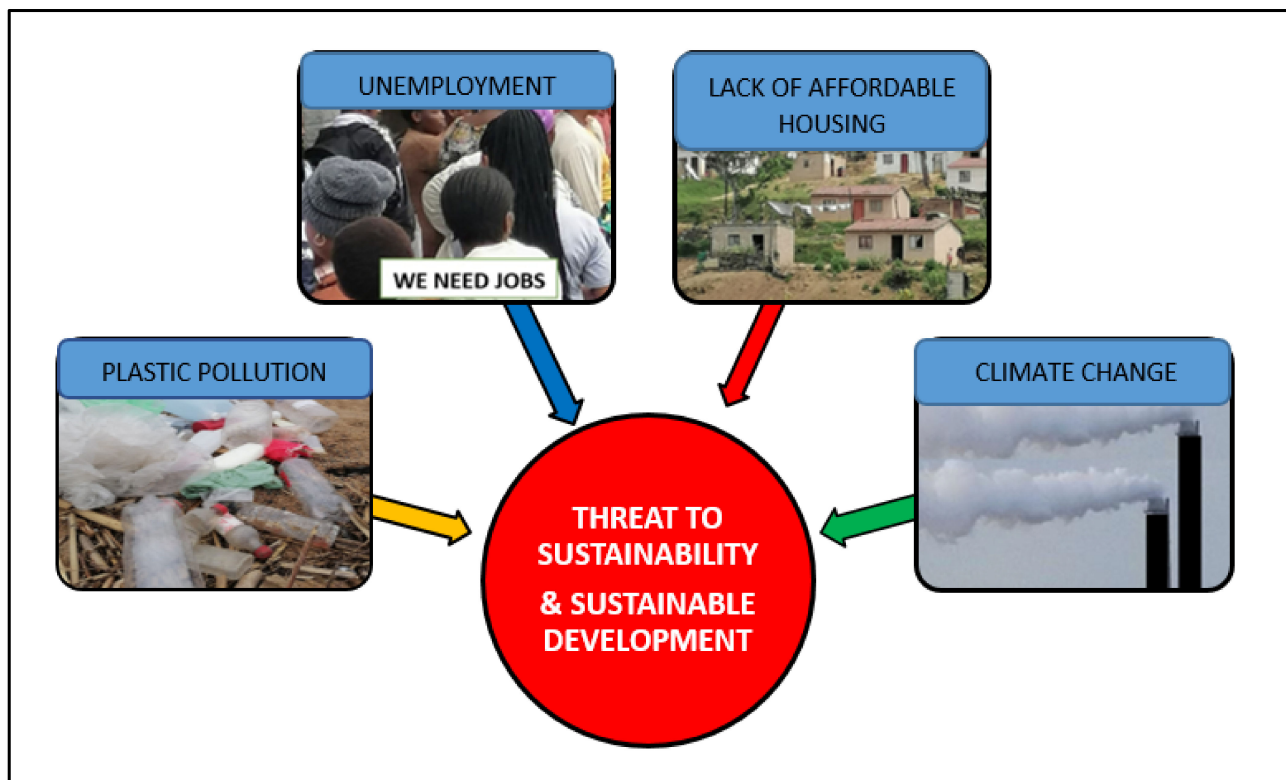


Figure 2. Four emerging global crises.

Four emerging crises have been identified that need to be addressed as a matter of urgency; failure to do so will have a ripple effect, leading to an explosion of crises. It has been highlighted worldwide that unimaginable damage to our planet will occur if these emerging global crises are not given sufficient attention [28]. Sadan and de Kock [44] stated that: “the amount of unmanaged plastic waste entering the environment, particularly the ocean, has reached crisis level”. The expansion rate of plastic doubles every subsequent decade. Our environment is becoming more polluted due to current development, urbanisation, population growth and changes in peoples’ lifestyles [3]. Page [45] alerts us by saying that “the growing population of more educated and urbanized youth who are hampered by finding few jobs is a crisis in the making”. Rodríguez-Caballero and J. E. Vera-Valdés [46] stated that as the number of unemployed individuals increases and the longer they are outside the labour force, the more difficult it will become for them to be employed. Therefore, it has become imperative for the Federal Reserve to increase employment opportunities by introducing various programmes and strategies. Henley [47] flagged the housing challenge and stated that: “the problem of inadequate or non-existent housing has reached crisis proportions globally”. Lastly, climate change and its consequences that arise around the world have become one of the biggest challenges to date, which will be addressed in this paper [48]. Climate change has been identified as one of the biggest threats to sustainability in the 21st century. Extreme climate changes have led to significant disasters. These observations showed that weather patterns pose a huge challenge to disaster risk management, which calls for increased efforts from all stakeholders [49,50].

Figure 3 provides a holistic view of these four disturbing scenarios that are snowballing rapidly. These four crises are intentionally dealt with separately to present a deeper and more comprehensive understanding of each one. However, it must be understood that all four concerns exist concurrently and simultaneously, affecting sustainability as

one common challenge, see Figure 3a. The four emerging crises, namely, plastic pollution, unemployment, shortage of affordable housing and climate change, are integrated and directly linked to the three pillars of sustainability, viz. pollution (environmental), housing (social) and employment (economic), see Figure 3b [51–54]. Several studies [55–57] indicated that recycling (see Figure 3c) presents excellent opportunities and innovations for individuals, companies and governments to convert plastic waste into other valuable products. While plastic waste harms human health, it can be used for business and wealth creation [58]. Covenant University engaged in a waste-to-wealth scheme, which focused on managing and processing used plastic materials to create other reusable products [56]. This review study shows that recycling plastic waste converted into plastic sand bricks can reduce the impact of the four emerging crises.

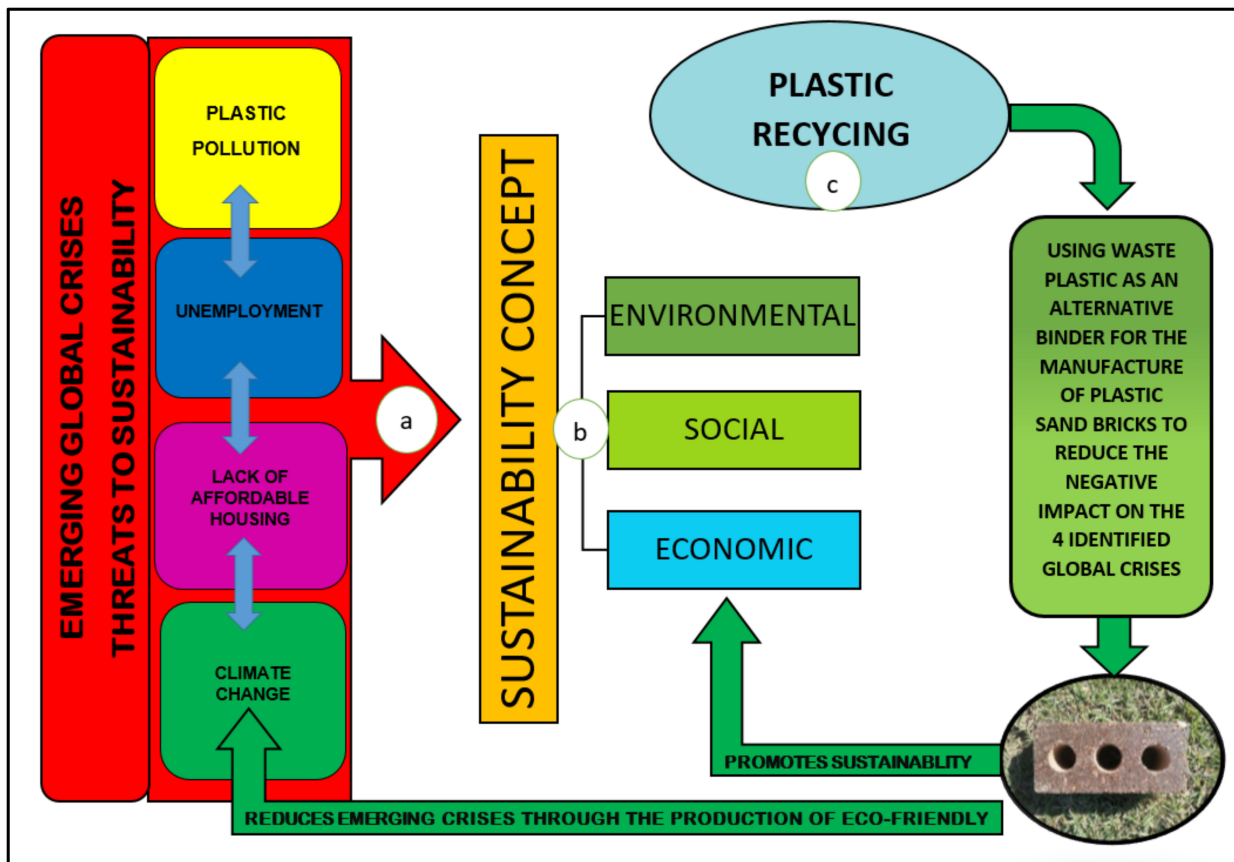


Figure 3. Plastic recycling as a solution to reducing emerging global crises.

3.1. Plastic Pollution as an Emerging Crisis

Plastic pollution has become one of the most unrelenting environmental issues locally and abroad. South Africa is facing a rapid increase in plastic pollution, and poor waste disposable methods make it difficult for communities to manage the crisis. Plastic, a common material, is widely used by everybody in daily life, e.g., for containers, bottles, and food packaging materials [28,59]. The disposal of plastic waste is a huge problem nowadays. Although plastic products are compact in shape, light weight and have various advantages, the problem is that their daily use increases at an alarming rate and they become a hazard by damaging human and animal life. Victory [60] emphasised that plastic disposal has become a waste pollution crisis over the last decade and collaborative effort will be needed to determine its future effects on the planet and its inhabitants. Plastic pollution is becoming extremely dangerous to the environment due to its enormous production and usage, which has harmful environmental effects [61]. Additionally, plastic

waste on land and water has harmful effects on all living species in the marine ecosystem of our planet [62].

3.1.1. The Extent of Plastic Pollution in South Africa, Plastic Pollution in Five Urban Estuaries of KwaZulu-Natal, Durban

Naidoo et al. [12] stressed that the quantitative records of plastic pollution surface little in literature reviews. Little to no data is published in accredited journals on marine plastic pollution, although there are problems in 73 estuaries in the province of KwaZulu-Natal alone. Only five of the estuaries were sampled for plastic pollution. A study was conducted in the following areas: Mdloti Estuary, Umgeni Estuary, Durban Bay, Isipingo Estuary and Ilovu Estuary. Samples were obtained from three sections of the estuary at spring low tides: head, middle and mouth. Some of the following results are recorded. Plastic pieces were found in five estuaries. A total number of 13,680 pieces were found. There were differences in the mean plastic concentration among the five estuaries. Durban Harbour had the highest mean concentration of plastic (159.9 ± 271.2 particles per 500 mL), followed by Umgeni and Isipingo estuaries, respectively. Mdloti and Ilovu recorded the lowest concentration of plastic particles, some distance from Durban Harbour.

Therefore, it was paramount to include these findings in [63]. The Litterboom Project, was published in the National Business Day, on 12 January 2022, by Suthentira Govender to present a more accurate picture of plastic pollution in and around Durban. Waste was revealed as coming from nearby communities and industries. Much of the waste material was removed before it reached the ocean. The Project leader, Josh Redman, announced that his team had removed more than 300 tonnes of plastic from the rivers in KwaZulu-Natal and the Western Cape before it ended up in the sea.

3.1.2. Extent of Plastic Pollution in Africa, West African Perspective

Adam et al. [64] presented an overview of West Africa as a sub-region of Africa, which is made up of the following 16 countries: Benin, Burkina Faso, Cape Verde, Ghana, Guinea, Guinea Bissau, Ivory Coast, Liberia, Nigeria, Niger, Mali, Mauritania, Senegal, Sierra Leone, Gambia and Togo. About 47.3% of West Africa's population lives in urban areas with rapid population growth, and there has been a significant increase in urbanisation and steady growth of the middle class. Hence, there is a corresponding increase in the use of plastic material. Plastic waste has various harmful effects on the environment and society in general. It causes water pollution, blockages in stormwater drains, severe risks to marine life and damage to fishing and tourism activities. It is sad to note that much plastic waste is mismanaged due to a lack of or no plastic waste management system, which leads to marine pollution [28]. The status of plastic pollution in these 16 countries signals a major ongoing problem of disposing of and managing plastic waste.

3.1.3. Plastic Problem in Central Africa and Surrounding States

Bashir [17] pointed out that most of the 48 million plastic bags produced in Kenya end up in their immediate environment, which causes problems such as blocked sewer pipes, spreading of diseases, livestock deaths and damage to the tourist industry. The non-governmental organisations (NGOs) in Botswana have raised concerns about the widespread use of and disposal methods of plastic. The Republic of Congo has taken a strong stance against environmental pollution by banning the manufacture, import, sale and use of plastic bags. Congo has experienced significant environmental pollution due to plastic bags, which cause serious problems such as blocked drainage systems, resulting in areas being continuously flooded.

The trash on the beaches in Namibia is a direct cause of marine plastic pollution, which affect tourism and marine life. Curtis [65] confirmed in his thesis entitled "Investigating the impact of plastic pollution in seals in Namibia", 2020, that the presence of plastic in the oceans is an old concept, which resulted in plastic being damaging to the marine environment by entangling larger marine mammals such as whales and dolphins. Other

countries such as Sudan, Chad, Eritrea, Ethiopia, Central Republic of Africa, Burkina Faso, Rwanda, Tanzania, Uganda, Somaliland, Tanzania, Ghana, Ethiopia, Sudan, Gadarif, Gezira, and Lesotho have directly experienced challenges regarding the use, accumulation and disposal of plastic bags within their countries.

3.1.4. Global Plastic Problem

Plastic pollution has now become a serious global challenge, resulting in our planet gasping for breath due to the accumulation of plastic waste and microplastics. Plastic waste, as indicated in Figure 4, has increased over 60 years from 1955 to 2015. There has been a steady increase in plastic waste to over 300 million tonnes in 2015 [66]. A large amount of plastic waste appears in all municipal waste and contaminates all areas of life. Plastics can take between 400 and 500 years to decompose in the environment [67]. Due to their composition, plastics are not fully degradable in the natural environment and are a critical environmental hazard [68], and more imaginative ground-breaking strategies and techniques for disposing of and utilising them are urgently required [69].

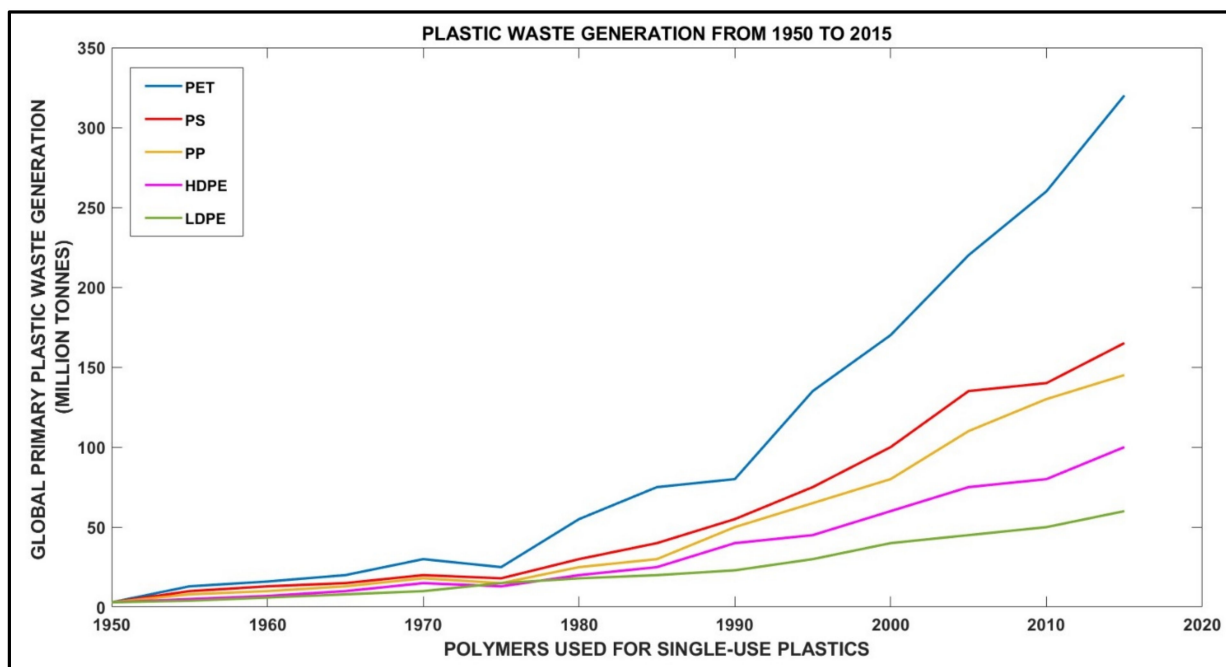


Figure 4. Global primary plastic waste generation, 1950–2015 (Adapted with permission from Reference [66]. 16 July 2022, Ibrahim Almeshal, Bassam A Tayeh, Rayed Alyousef, Hisham Alabduljabbar, Abdeliazim Mustafa Mohamed, Abdulaziz Alaskar).

Among the long list of recyclable materials, plastics have one of the lowest rates of recycling and yet contribute mainly to the growing problem of pollution [70]. More solutions and innovation are needed to overcome the global plastic pollution crisis. Emphasis must be placed on revitalised consumer action, policies and increased understanding, to educate the public about pollution and the beneficial acts of recycling waste into other products [28].

3.1.5. Problems of Plastic Pollution, Long Term Food Security

Zhang et al. [71] stated that long-term food security is visible in aquatic and terrestrial environments due to the use of plastic mulch. This has called for urgent actions to ensure the recovery of plastic film mulch and reduce the damage it is causing to croplands. The use of single-use plastics and improper disposal methods has led to the contamination of the soil and its nutrients. This has negatively impacted the agricultural production, including

animals. Plastic waste accumulation on land impedes water usage and prohibits average uptake of nutrients for plant growth [28].

3.1.6. Marine Life

Wegner et al. [72] identified the marine environment and stated that the different living organisms are constantly exposed to the effects of plastic waste contamination. The harmful effects on birds, fish and other sea creatures were noted with much concern. The study by Vegter et al. [11] also substantiated that plastic pollution has made its way into oceans and coastal environments, causing challenges to marine life. Clearly, plastic has emerged as a global crisis, reaching a threshold level that will surely lead to a disaster in the future.

3.1.7. Environmental & Health

Adeniran and Shakantu [73] concluded that plastic waste had been confirmed as a severe environmental and health concern, resulting in waste pollution and causing various health issues in humans. Saiprasad [74] argued that plastic waste has become a common material used in households, yet clear concerns are raised around its disposal methods. Additionally, its accumulation in landfills and in natural environments within communities is seen as an immediate local problem. However, the problems affecting sea life, wildlife, leaching of chemicals from the plastic products, tourism, growth of vegetation and the health and welfare of humans are becoming a public challenge.

3.1.8. Opportunities of Recycling Plastic

To combat the above problems, recycling is proposed as a strategy to convert waste materials into new products. This process protects the environment [75] and assists in the atmosphere, as well as using the waste as a valuable material [3]. The properties of plastics enable their use in various applications. Hence, the recycling of plastic waste is now looked upon as a substitute for alternative materials that reduce building material costs such as lightweight fittings, windows, door frames, interiors, and extended fixtures, (see applications and societal benefits of plastics) [76].

Through the process of recycling [55], substantial quantities of plastic waste have been recycled, which has presented many economic advantages in architecture, clothing, arts, design and construction. While plastic waste disposal is challenging to manage, it has demonstrated the potential to be converted into various kinds of fabrics, which are later turned into garments [77].

Recycling can convert plastic waste into fuel, which is an alternative energy source [78]. Fuels extracted from plastic waste sources are gaining increasing interest due to their ability to reduce the problem of plastic waste. Thus, the massive amount of plastic waste can be converted into fossil fuel substitution [79].

Bajracharya et al. [80] pointed out that recycled plastic waste has already been used in several civil engineering materials. New materials such as plastic lumber, which have been previously proposed, are now used in the construction industry. Plastic lumber items are used to make fencing and park benches. Baishya et al. [57] noted that converting plastic waste into plastic lumber is a useful solution to the plastic pollution problem. Plastic lumber can be made from recycled plastic, such as high-density polyethylene (HDPE), polyvinyl chloride (PVC), polypropylene (PP) and polystyrene (PS). Plastic lumber can be used as a substitute for timber which can also be used for making several other products such as garden furniture, exterior doors, decking, bed side tables, plastic coasters, plastic hand fans and building structures. The expanded polystyrene (EPS) components extracted from plastic waste are environmentally friendly and are recommended for prefabricated building structures such as wall panels, floor blocks and fascias [81].

Hence, the discovery of an alternative binding material from plastic waste for the construction industry will assist with the immediate decrease in plastic waste material that causes so many short- as well as long-term consequences to sustainability.

3.1.9. Case Analysis—The Value of Recycling 2 Tonnes of Plastic Waste

Based on the available literature, we have decided to include a practical model to explain the economic value of how plastic recycling waste can present opportunities to manufacture alternative products such as plastic sand bricks. This model, currently being developed, is used to demonstrate how the conversion of plastic waste to plastic sand bricks is a solution that would contribute positively to reducing the negative impacts of the emerging crises. This would also generate the economic benefits that are needed in South Africa. Figure 5 briefly explains the benefits of recycling 2 tonnes of plastic from the environment and its advantages in reducing plastic pollution [1,3,55,57], creating job opportunities [82], developing affordable eco-friendly housing [55] and reducing climate change [83,84].

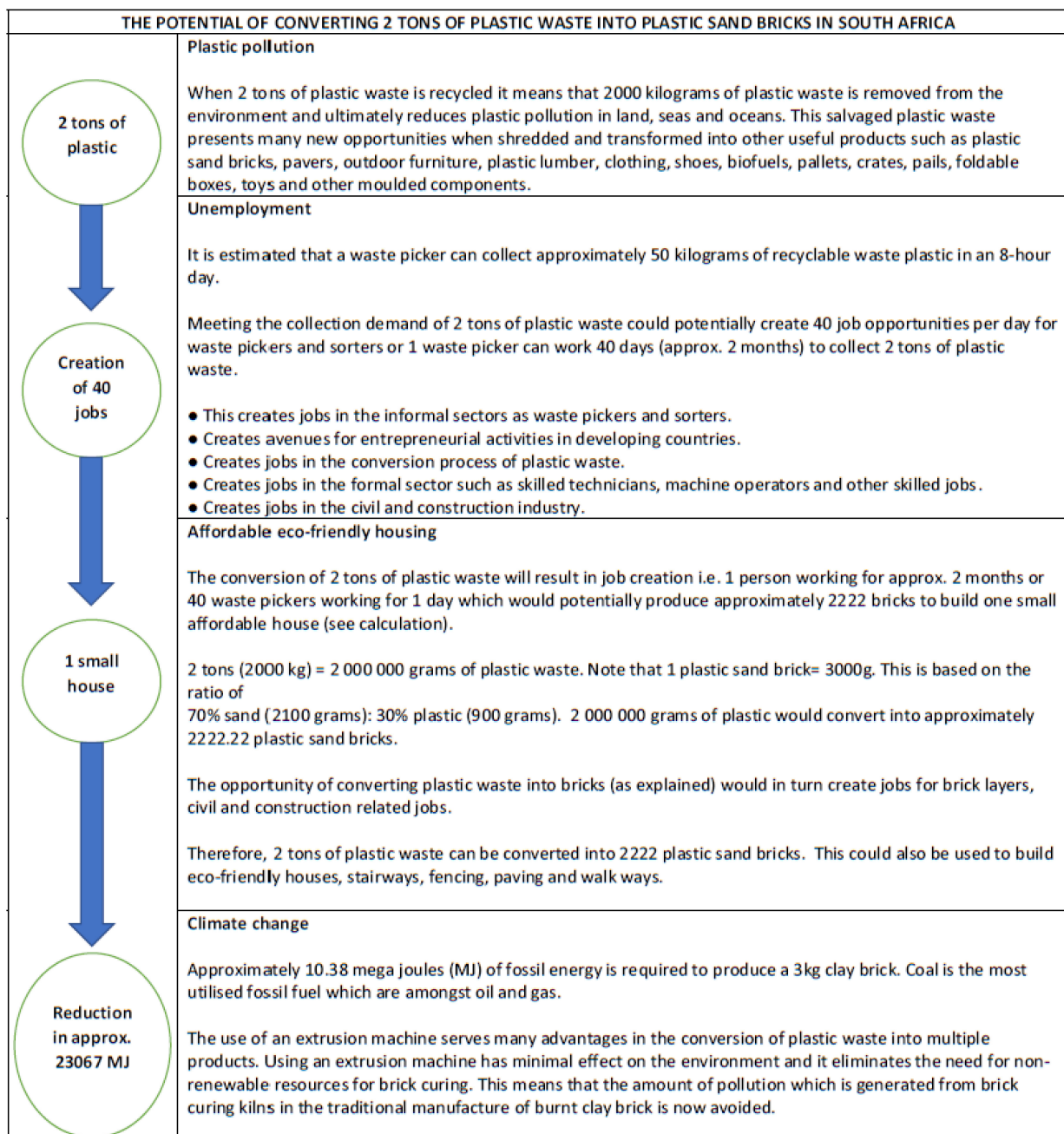


Figure 5. The opportunity of recycling 2 tonnes of plastic from the environment.

3.2. Unemployment as an Emerging Crisis

Unemployment is a massive problem faced by both developed and developing countries. In particular, youth unemployment in South Africa is escalating, despite desperate efforts and initiatives implemented by the government to reduce the very high unemployment rate. Unemployment is a “disease” faced by individuals and society that require careful and planned intervention for it to be eradicated. Statistics South Africa has revealed that the unemployment rate among the youth in South Africa is very high although they possess educational qualifications. The graduate unemployment rate is shocking for those in the various age categories, namely 15–24 at 40.3% and 15.5% among those aged 25–34 years. However, the rate among adults (aged 35–64 years) was 5.4% [85]. The presence of unemployment nationally and worldwide has many adverse effects, such as increased depression and other mental health problems, increased crime rates, overall lower economic productivity and consumption, lower rates of volunteerism, and erosion of skills. Hence, the inherent problem of unemployment needs to be urgently addressed since it affects sustainability and sustainable development [86].

3.2.1. Unemployment in South Africa

The unemployment statistics [85] presented for the first quarter of 2021 as indicated in Figure 6. The youth in the age category 15–24 years and 25–34 years recorded the highest unemployment rates of 63.3% and 41.3%, respectively. There is only an absorption rate of 7.6% and a labour participation rate of 20.6% in the 15–24 years’ category.

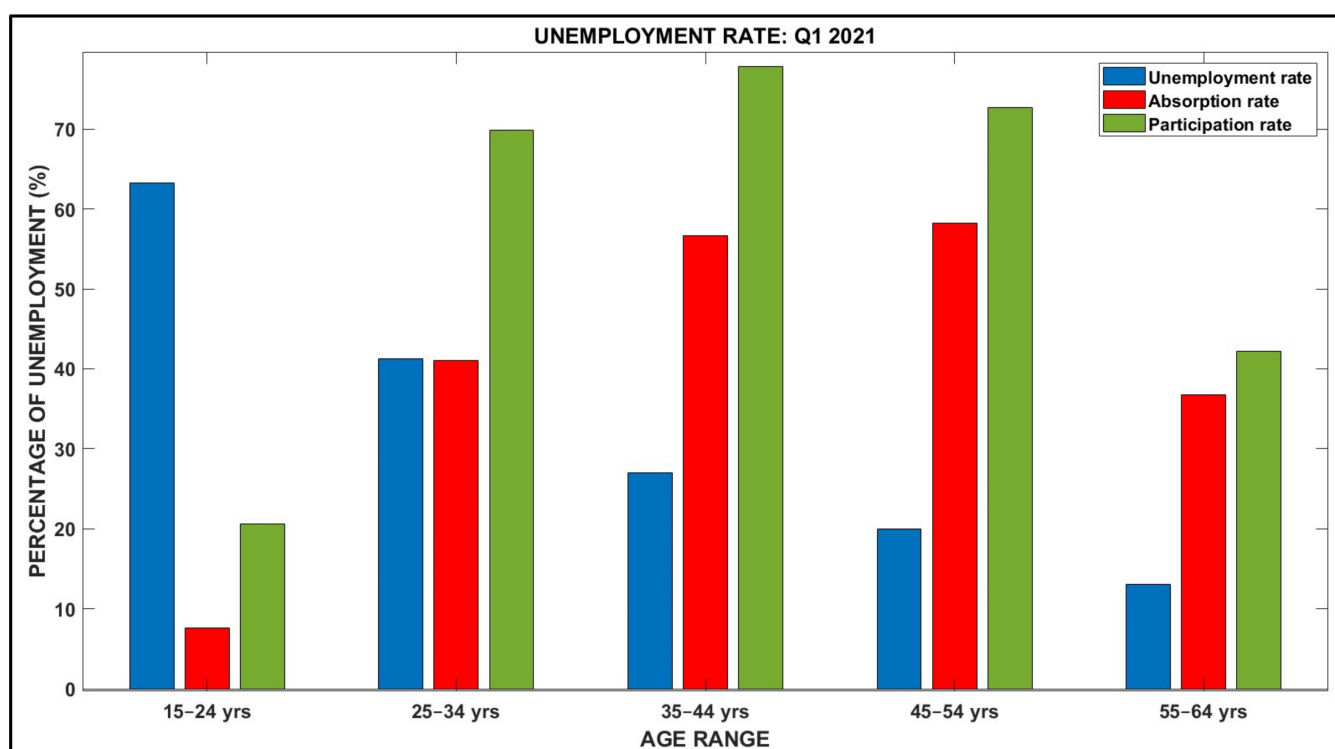


Figure 6. Unemployment rate in South Africa (Adapted with Copyright and disclaimer permission from Reference [85]. 2021, Statistics South Africa).

The unemployment rate in South Africa recently shifted to a new record high of 32.6%. This means that a huge percentage of the population does not have a job. The youth unemployment rate is more than 63% in the age group of 15 and 24 years. Hence, young people are seen to be struggling in the South African labour market. This implies that the country is vulnerable and closer to social and political unrest. As long as the unemployment

rate keeps on increasing at an alarming rate, the age-old problem of poverty and inequality will continue to escalate by leaps and bounds.

Sadly, the third quarter labour force survey Statistics South Africa [87] indicated a grim picture since the unemployment rate had increased to 34.9%. Therefore, South Africa and other developing countries with high levels of unemployment will continue to see high levels of poverty and inequality, which will pose a serious threat to sustainability.

3.2.2. The Unemployment Rate of South Africa Compared to 9 Other Countries

Figure 7 shows the top 20 countries according to their unemployment rate during 2022. The first three countries showed a very high unemployment rate with South Africa scoring 34.38%, Sudan 26.67% and Armenia at 18.25% compared with the rest of Africa, with Belize having an unemployment rate of 9.77%. It is seen that South Africa is leading, with the highest rate of unemployment among the 20 listed countries. The unemployment rate has a direct impact on the South African economy and the wellbeing of the people. This will eventually mean that the South African economy needs more job creation to strengthen its position [88].

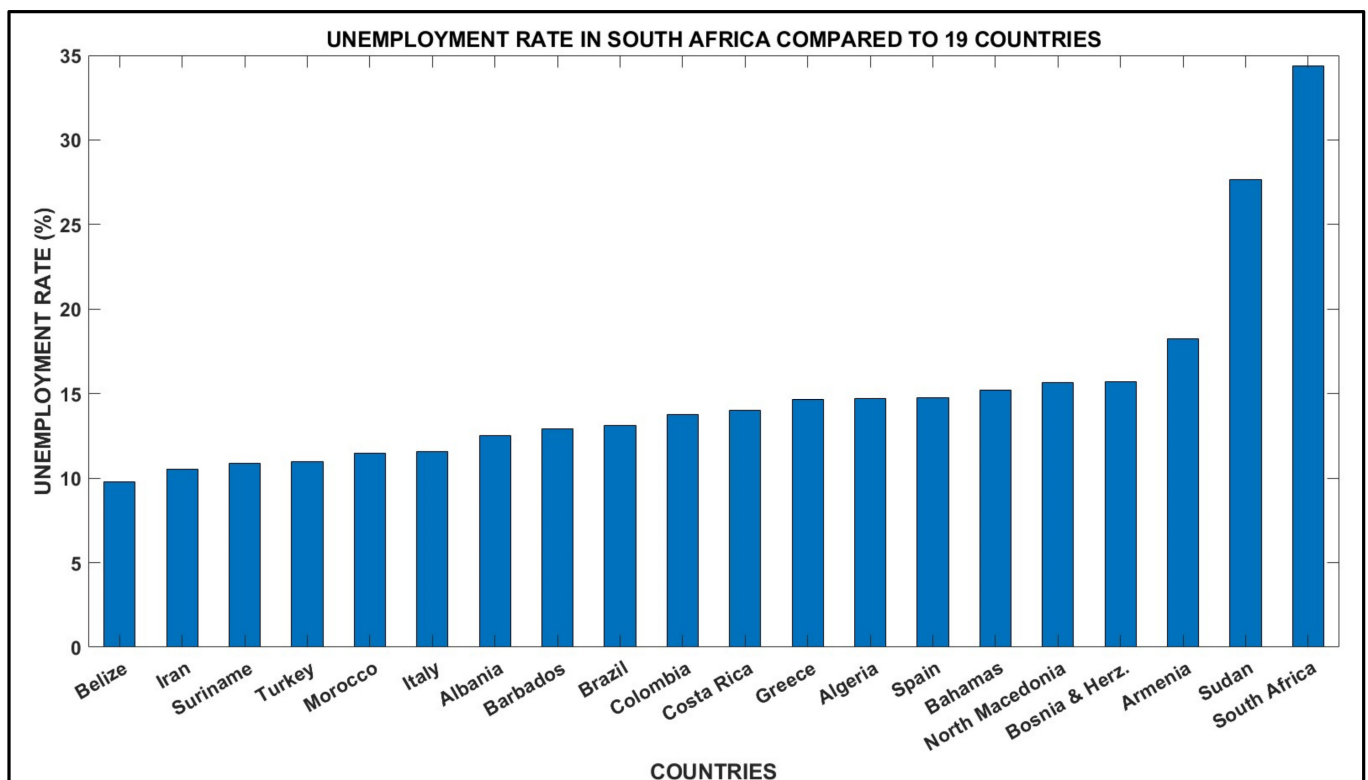


Figure 7. Unemployment rate in South Africa in comparison to other countries (adapted from [88]).

In the World Population Review [86], it is argued that high unemployment, as in South Africa, means that this results in adverse effects on people's health and welfare (increased depression and other mental health challenges), increased petty crimes and other criminal acts, decrease in economic consumption and production, erosion of skills, apathy and pessimism among people.

3.2.3. The Unemployment in Africa and Globally

The United Nations (UN) Department of Economic and Social Affairs [89] presents a scary picture of the youth population trends and sustainable development. The unemployment rate in Africa is growing exponentially. However, in 2015, 226 million of the youth were in the age category of 15–24 years and it is projected to increase to about 500 million around 2060. Countries with rapidly growing youth populations are struggling to educate

people. Hence, the rapid growth in the youth category compounds the unemployment challenge. The unemployment rate in countries such as Jordan, Iraq and Saudi Arabia is also alarming at a rate of above 30% and is expected to grow to more than 20% over the next decade and a half. Countries such as South Africa, Spain and Greece are experiencing great challenges in youth unemployment with rates above 50%.

The African Development Bank Group [90] highlighted that the majority of youth in Africa are struggling to survive in the poorer economies. There are nearly 420 million youths in Africa aged between 15 and 35 years of which 33.33% are unemployed and discouraged. Hence, there is an urgent need to provide job opportunities for the youth in Africa in the coming decades. Therefore, this paper offers possible opportunities for job creation since it investigates the possibility of using an alternative building materials, which would benefit the construction industry tremendously and job creation.

Africa tends to be the most glaring region where the vast youth category will continue to grow at an alarming rate in the foreseeable future. This scenario presents the features of an imminent time bomb if government policies to create jobs are not implemented. Unfortunately, the high poverty rate in Africa demonstrates clearly that individuals engage in low-quality jobs, and their families usually secure jobs in the informal sector [91].

3.2.4. Effect of the COVID-19 Pandemic on Unemployment

The onset of the COVID-19 pandemic caused increased unemployment in many countries globally. The coronavirus disease caused detrimental damage to the labour market worldwide, resulting in further increases in poverty, an inability to pay staff their salaries and company closures [92]. This was evident in approximately 3 months from February to April 2020, when the unemployment rate in the United States trebled from 3.5% to more than 14.7% and then later decreased in August to 8.4%. In Australia, the unemployment rate has more than doubled from 5.4% to 11.7%. Canada experienced an increase in the unemployment rate between February to May from 5.6% to 13.7% and later decreased to 10.2% in August [93]. The COVID-19 pandemic has impacted most institutions throughout the world. It has hampered the realisation of achieving the UN Sustainable development goals (SDGs) of 2030. The pursuit and implementation of the SDGs have become even more important now compared to before to improve the quality of life [94].

3.2.5. Solutions to Unemployment

Creating leadership is a solution based on government policy initiatives to curb the high unemployment rate. This initiative was designed to influence companies to create special low paying jobs, especially for younger employees. Although this policy change is not totally welcomed, it serves the purpose of job creation [95]. Another example is the Presidential Employee Youth Initiative (PEYI) [96], which has led to the employment of 280,000 youth in the education sector in South Africa. Gamede [97] encourages collaboration between the rural-based universities and tertiary institutions (government or private) within the local community to promote successful entrepreneurship. This partnership must be advocated and strengthened by members of the public. This will allow for the establishment and spread of entrepreneurial activities. Mkhize et al. [98] discovered that street vendors lacked appropriate training and education in business skills. Their survey found that street vendors played a pivotal role in generating their own employment. About three out of every ten street vendors had another assistant.

One way of finding an employment solution is to increase the demand for labour by creating new business opportunities in the market. More activities for the youth were encouraged to promote jobs [99]. In a study conducted by [41], it was recommended that it was necessary to design programmes for the youth to equip them with multiple skills which are needed in the job market. There is an urgent need for a business culture to be enhanced among the youth, especially in townships and rural areas in South Africa. This will assist them to become more economically engaged. Government spending on rural

development infrastructure and additional technical schools will adequately prepare our youth for their employment destination.

Hence, this study invariably contributes towards reducing unemployment across the country and the globe. Making plastic sand bricks requires a considerable number of waste pickers in the recycling industry for the picking and sorting of plastic waste to produce alternative binding material for the construction industry. The recycling of plastic waste for construction purposes, will create jobs in general and specifically for waste pickers, which will eventually ease the high unemployment rate in South Africa. This trend is seen worldwide where people make a living from searching, collecting and processing general waste materials that are thrown away by households and industries. Waste pickers are people working on dump sites or scavenging through rubbish and waste on the roadsides, to informal private collectors who sell items to other business enterprises so they can remanufacture them by making them into totally new products. Plastic waste from waste pickers and from industry is a necessary part of our research regarding the manufacture of plastic sand bricks.

3.3. Shortage of Affordable Housing as an Emerging Crisis

The shortage of affordable housing is emerging as a significant challenge in almost all sectors of society throughout South Africa and abroad. Finding an affordable house is difficult as housing prices and rents are increasing across the country. Favilukis et al. [100] warned that: “the increasing appeal of major urban centres has brought on an unprecedented housing affordability crisis”. The UN habitat [101] links housing to a sustainable future and states that there is a continuous demand to provide decent adequate and more affordable housing to the millions of people worldwide in such a way that it guarantees a sustainable future for cities. De Villers et al. [102] argued that there are alternative ways to address this shortage of houses, in line with environmental sustainability. They also argued that despite the number of alternative building materials and systems (ABMS) that have been implemented in place at a commercial level, there is still poor or very little implementation of ABMS occurring in South Africa. The world population is growing, and there is currently a shortage of affordable housing worldwide. Furthermore, the use of clay brick becomes a question for debate and the demand for greener housing using more sustainable material is increasing.

3.3.1. Analysis of Housing Challenges in South Africa

The Constitution of the Republic of South Africa (1996) [103] ensures the right of all citizens to be given the opportunity to access adequate housing. This act makes it compulsory for the state to take reasonable steps within this legislative framework and to use all other possible measures to progressively ensure the realisation of this right to the people of South Africa. The Department of Human Settlements (DHS) is also mandated through its structures to promote sustainable housing estates by working together within all provinces and ensuring that providing institutions such as municipalities can deliver housing at a faster rate. The progressive delivery of housing is mandatory [104].

The promise of housing delivery by various sectors has turned out to be just more broken promises, while the problem continues to grow substantially. It has been noticed that on one hand, some countries experienced rapid migration of people from rural to urban areas despite challenges, which had a positive impact on the economy and even boosted the growth of some countries. However, some urban areas experienced migration deterioration in slum areas. Providing affordable houses for the billions of people migrating to urban cities is among the most immediate challenges that need to be resolved. Essentially, there are two aspects of housing challenges which are affordable housing and increased construction costs.

Ganiyu et al. [105] argued that the steady increase in the population had posed several challenges, one of which was the unavailability of affordable housing in South Africa. They indicated that this housing challenge has made it incumbent on the main stakeholders;

namely, the government and investors in real estate to provide affordable housing to lower and medium income families. Due to the shortage, these families are constantly moving to urban areas with easy access to goods and services and more job opportunities. This trend is expected to continue in the foreseeable future. This constant rise in housing demand and the shortage in housing provision signals a need to table the issue of affordable housing in South Africa for immediate action.

Phago [106] and Marutlulle [107] indicated that it is sad to note that the housing construction in South Africa (SA) appears at a sub-standard level, which has persisted since the demise of apartheid. Although many attempts have been made to improve the quality of housing in our country, the low standard of construction has remained a challenge since 1994, right until the present. The researchers argued that the continued problem of inadequate affordable housing continues to be a major political, social and economic worry for most citizens in South Africa. It has been reported that the housing challenge in South Africa is getting worse at an alarming rate, due to natural population growth in urban areas, the rural-urban migration and the flood of immigrants from neighbouring African countries. The construction of 3.3 million low-cost houses by the state housing programme has struggled to keep track of the supply and demand, due to the steady increase in population growth. Hence, the housing challenge will eventually lead to violent protest action, more informal settlements in towns and cities, health and sanitation challenges, shack fires, general criminality and, unfortunately xenophobic attacks.

3.3.2. Increasing Building Construction Costs

Windapo et al. [108] examined whether materials could be linked to the changes in the gradual increase in building construction costs. It was concluded that the cost of equipment and materials was a significant factor in increasing the building costs in South Africa. Alabi and Fapohunda [109] stated that the increase in the cost of construction was caused by increases in the cost of building materials, particularly in the Western Cape.

However, based on the above study, it was concluded that some increases in the cost of building materials for housing were due to fluctuations in the price of construction, increase in the price of building materials in the final stages and the scarcity of construction products. The use of lower-quality materials led to failures with the building process and the increased cost of building material became an added problem.

Motsie and Malematja [110] stated that the accelerated growth in the urban areas of South Africa had placed significant pressure on existing resources regarding the construction industry, due to high demand for land usage, housing, recreation and industrial activity. Dithebe et al. [111] stated that the South African construction industry is currently concerned about what is happening in the country. A factor influencing the construction industry's performance in the country is the issue of instability; combined with the escalation in the cost of materials.

It has been indicated that there has been a drastic increase in the number of houses built and delivered from post-1994 to 1999, from 60,000 to 240,000 respectively, by the South African government. There was a natural desire of the government to provide housing to its people who had been deprived of housing pre-1994. However, there seems to have been a decrease in the building and delivery of housing since 1999. There were 240,000 houses built in 1999 which decreased to approximately 90,000 in 2018. The rate of housing delivery falls considerably short in terms of the growing South African population that require housing. This paper is linked directly to housing since recycling plastic waste to produce alternative binding material will assist in the reduction of building costs in the construction industry. It will specifically assist with the building of houses through the manufacturing of eco-friendly plastic sand bricks at a cheaper cost, compared to traditional clay or cement bricks [112].

The cost of building material in South Africa has increased tremendously over the past decade, posing a huge challenge for the construction industry. Since the entire outlook of the South African construction industry remains shaky, we must find solutions to address

the high cost of building materials since the industry must grow after the outbreak of the COVID-19 pandemic.

3.3.3. The Increasing Building Construction Costs in Africa and Abroad

Akanni et al. [113] indicated that building materials played a pivotal role in the building industry in Nigeria. Building materials directly affect the quality and cost of housing from the initial step of laying the foundation to all the materials used for roofing until all finishing is done. The rise and fall of the building industry play a major role in any nation. The rising cost of building materials in Nigeria poses a huge challenge to the construction industry itself as well as those who wish to own their own houses. Some of the causes of the rise in building costs are the exchange rate of Naira, the cost of fuel and power, the cost and scarcity of raw materials, and the cost of transportation and labour.

Africa's population is growing at an average rate of 2.5% yearly [114]. This pattern of population growth is expected to continue in the future. In 2015, Africa's population was confirmed at 1.18 billion and expected to increase to 2.44 billion in 2050. In total, 60% of Africa's population are located in rural areas. However, the high rate of rural migration to urban areas will eventually lead to a catastrophe. The large percentage of housing backlog, combined with urbanisation in almost all parts of Africa is a serious problem. A delay in the provision of adequate housing will have economic consequences, as there would then be a decrease in job creation in the construction industry. The increased cost of building materials makes houses unaffordable for millions of people since the construction of houses by real estate developers is out of reach for most people.

Ebekozien et al. [115] also agreed that the high construction cost is a phenomenon currently affecting most urban areas worldwide. Malaysia is one good example. The issue of affordable housing has been a continual problem in Malaysia. The housing problem has been exacerbated due to the steady population growth and the migration of rural people to the urban areas. High construction costs are linked to the challenges faced by individuals who cannot afford housing [116]. Malaysia faces a mushrooming of low-cost housing to cater for the lower income earners. A lower income demand mismatch of housing has occurred due to the reluctance of some of the home developers to construct low-cost housing. This mismatch of high demand and insufficient supply of affordable houses has led to pockets of informal settlements across the country. It is also important to note that the cost of low-cost housing in Malaysia's capital Kuala Lumpur, has increased by more than 90% from 2003 to 2017.

The respondent in a study conducted by Chan and Lee [117] contends that there are several economic impacts of housing shortage, such as slum conditions, crowded rental premises, and increase in rentals. The study also indicated that the prices of raw material of the various types of construction materials generally used in housing construction has doubled from 15% to 30%.

3.3.4. The Global Housing Challenge

Tibaijuka [118] argued that it is essential to address the global housing backlog given the unprecedented demand. He highlights that the discourse on housing for a period of 100–150 years has taken on a new paradigm shift from one boost for economic development to a portent factor in sustainable development. Housing is now viewed as a multi-dimensional way since access to suitable and affordable housing is of paramount importance to the wellbeing of a nation. Therefore, housing should not be regarded as an ordinary activity but rather a catalyst for sound economic development.

The highlights of the study conducted by the UN Habitat [119] exemplified that more than 90% of urban growth takes place in developing countries. It is predicted that in the next 20 years the urban population of South Asia and Sub-Saharan Africa, known as the world's two poorest regions is expected to double, causing a drastic increase in the numbers of informal settlement and slum dwellers. Currently in Africa, approximately 61.7% of

people live in slum conditions. It is predicted that by 2050, Africa's urban dwellers will increase from 400 million to 1.2 billion.

3.3.5. Solutions to the Housing Challenges

Broader and more urgent solutions are needed from government, business and business players with respect to the provision of future affordable housing. Bah et al. [114] believed that political leadership, inclusive housing finance, affordable mortgages, increased access to affordable housing and industrialising the housing construction sector are solutions to the housing market dynamics in Africa.

According to [115], several policy proposals will resolve the affordability crisis, such as waiving all forms of taxes and making companies bear construction and land costs. Governments can also provide land subsidies and aid in industrialised building schemes. However, [120] suggested that modular construction is an option since it has shown promising results in addressing the critical shortage of low-income housing. He argued that this method is capable of creating much more housing units compared to building using traditional methods.

3.4. *Climate Change as an Emerging Crisis*

Climate change is already impacting all nations of the world in myriad ways. South Africa is no exception due to frequent extreme changes in weather patterns such as heat-waves, storms and floods that have recently taken place. Climate change is a threat to millions of lives. Tsakona et al. [121] argued that “our triple planetary crisis- climate change, biodiversity loss and pollution including plastic pollution—has its greatest impacts on the world's poorest and most vulnerable populations.” Currently, there is great emphasis on the severity of the environmental crisis that threatens us, such as climate change, ozone depletion, degraded air and water quality, land contamination and global warming. The depletion of the ozone layer directly affects the quality and sustainability of human life.

Morales-Mendez [122] define the ozone layer as “a band of natural gas called ozone”. He emphasised that one of the main functions of the ozone layer is to act as a protective shield against harmful ultraviolet rays from the sun. He mentions the concern that the ozone layer is being damaged and depleted by the release of many pollutants such as carbon dioxide (CO₂), chlorofluorocarbons, water vapor, methane, and nitrous oxide gases. The National Geographic Society [123] explained that the excess heat that is accumulated in the atmosphere increases the average global temperature, which is known as global warming.

Climate change is affecting many parts of the planet, which results in today's extreme weather conditions from severe droughts to flooding and increase in sea levels. We are experiencing new weather conditions that are already negatively affecting all life on earth [124].

3.4.1. Waste Incineration in South Africa

Due to dangers posed by waste incinerators, the local environmental authorities in South Africa have rejected a proposal to build these incinerators in a low-income township near Johannesburg. The incinerators would have emitted harmful substances such as large numbers of dioxins and heavy metals. The gases that are released would have had negative effects on the health and welfare of people; such as causing cancer and other illnesses [125].

Leonard [126] highlighted that there had been various hazardous waste incineration proposals in South Africa. Previously, there was a nationwide push by many cement industries in the country to burn hazardous waste in their cement kilns. It was proposed that some types of hazardous waste would be burnt in these kilns, which included plastic and rubber waste, contaminated packaging material, plastic drums and plastic solvents. The disposal of this hazardous waste in the cement kilns would release persistent organic pollutants (POPs) and toxic emissions such as dioxins, furan and heavy metals into the atmosphere and environment. That would eventually have disastrous effects on the environment and would cause ozone depletion.

3.4.2. Gas Emission in Africa

Ayompe et al. [21] cautioned that there was an increasing trend in CO₂ gas emissions in Africa between 1990 and 2017. South Africa was the highest CO₂ emitter compared with the rest of the other countries: Egypt, Algeria and Nigeria. Africa has one of the fastest-growing rates of GHG emissions at around 2.9% annually [127]. Praise and Mbobu [128] conducted a study regarding GHG emissions in Africa and the rest of the world. The results revealed that there has been an increase in GHG emissions in both Africa and the rest of the world.

3.4.3. Global Greenhouse Gas Emission

Shen et al. [20] warned that the global projected outlook of GHG emissions with plastic packaging waste incineration and growth of plastic packaging waste paints a very dangerous picture of the atmosphere with 16 million tonnes of CO₂ produced during 2015, 84 million tonnes to be emitted in 2030 and 309 million tonnes in 2050. These figures must be viewed together with accelerated growth of plastic packaging waste produced 128 million tonnes in 2015, 219 million tonnes in 2030 and 435 million tonnes in 2050. This means that the emissions of GHGs produced from 2015 to 2030 (15 years) will total 68 million tonnes of CO₂. The projected emission of GHGs from 2030 to 2050 (20 years) is expected to be 225 million tonnes of CO₂. Plastic industries are becoming one of the fastest growing contributors to GHG emissions; hence, the damage caused by GHGs in the future would be unimaginable and catastrophic to the ozone layer.

Dabaieh [129] found that the results of their study indicate that when manufacturing fired clay bricks in comparison to sun-dried bricks, they released a relatively high amount of carbon and energy during their life cycle. Eil et al. [130] argues that brick production is posing a serious problem. It is becoming hazardous as pollutants are emitted into the atmosphere. The estimated total annual emissions of Suspended Particulate Matter (SPM), Sulphur Dioxide (SO₂), Nitrogen Oxides (NO_x), Black Carbon (BC), Particulate Matter 10 microns in diameter (PM₁₀) and Particulate Matter 2.5 microns in diameter (PM_{2.5}) from the seven main kiln technologies in Bangladesh, India, and Nepal during 2016 are having detrimental effects on the climate and on people.

Mary Lissy et al. [131] pointed out that the production of clay bricks requires large quantities of non-renewable resources that contribute to the emission of GHGs. Some of these gases include CO₂, carbon monoxide (CO), and other chemical pollutants such as SO₂ and nitrogen oxide. A very high amount of coal (approximately 24 million tonnes) is consumed annually which results in a high amount of pollutants released into the atmosphere.

3.4.4. Solutions to Climate Change

According to Mailloux et al. [132], a solution represents an immediate push to reduce all sources of GHGs, which will reduce CO₂ emissions. Fawzy et al. [43] proposed three main approaches to address climate change; namely, conventional mitigation technologies, negative emissions technologies and radiative forcing geoengineering technologies. The ocean is seen as a solution to climate change. Therefore, increasing ocean-based renewable and decarbonising ocean-based transport are some of the more powerful ways to mitigate CO₂ [133].

4. The Feasibility of Recycling Plastic Waste into Plastic Sand Bricks

This section emphasises that recycling is one of the critical activities of collecting and processing of plastic waste, into valuable materials, which would otherwise be disposed of or dumped. Instead, recycling would serve many advantages for our community, especially our environment by turning waste material into new products. This review paper proposes that recycling of plastic waste into plastic sand bricks provides a valuable opportunity to positively contribute to sustainability and address the four emerging crises that currently threaten South Africa.

There have been many studies conducted on using plastic waste for the manufacturing of bricks and other products, which indicated promising results. Kognole et al. [134] and Silviyati et al. [135] stated that there has been much awareness and debate on the topic of plastic waste as one of the major challenges facing the environment. Hence, the feasibility of using plastic waste in brick manufacturing and the construction industry has long been explored. Tiwari [136] stated that plastics have many uses and he supports the inclusion of plastic waste material in the manufacturing of bricks. This consciousness has arisen due to the huge amount of plastic waste that has devastating effects on the environment, humans and the economies. Consequently, much literature has been written on the use of different types of plastic waste, recycled rubber, bottom ash, foundry sand waste, copper slag and, crushed glass aggregate as a partial replacement for fine aggregate in concrete.

Wahid et al. [137] reminds us that recycling of plastic waste material into different products helps to prevent the plastic being dumped in landfills. The increased awareness of using plastic or plastic waste that are environmentally friendly, cheaper, compact and lightweight, as a possible construction material in the building industry. This has led to the investigation of the application of materials and how they can be used to benefit the environment and society and simultaneously, maintain sustainable development. Therefore, Jereme et al. [138] emphasised a need for urgent policy implementation, which would eventually highlight the benefits of recycling. Recycling of waste material from all other waste management systems is currently becoming accepted as a proven way of turning waste into financial capital and as one of the best methods to sustain our planet.

Aiswaria et al. [139] indicates that all stakeholders are grappling with ways to manage plastic waste. Tonnes of plastic waste are sent to landfills and there are limited opportunities to recycle and process the plastic material. Hence, large amounts of plastic are dumped or burnt daily. The accumulation of plastic waste in the environment becomes a health risk to humans, fauna and flora. Plastic waste in the form of polyethylene terephthalate (PET), HDPE, PP, low density polyethylene (LDPE) and polyethylene (PE) and all other types of plastic pose serious environmental challenges. Silviyati et al. [135] stated that the large volumes of waste material can be reused as alternative materials in the construction industry, due to their versatility and durability.

Ponraj Kumar [140] concludes that recycling of plastic waste makes it possible to use fewer natural resources and reduces pollution compared to the manufacturing of traditional burnt bricks. He added that recycling also reduces the pollution emitted from kilns during the brick manufacturing and curing process. Chauhan et al. [59] stated that manufacturing plastic sand bricks made it possible to alleviate the problem of pollution. The reduction in pollution will then assist towards achieving our SDGs.

Recycling plastic waste in the manufacturing of plastic sand bricks has been confirmed as being cost-effective. It contributes significantly towards plastic waste being removed from the environment, a reduction in GHGs emitted into the atmosphere and finally, the use of clay and cement to manufacture bricks [141,142]. Jayaram [24] in his specific use of waste alternative such as bottom ash, virgin plastic and Ground Granulated Blast-furnace Slag (GGBS) in the mix ratios found that bricks manufactured from these material proved to be less costly as compared to other types of traditional bricks.

Different studies were identified in Tables 1 and 2 that use plastics to manufacture plastic sand bricks. The average values were taken in experimental studies one and two. The values for compressive and water absorption tests were analysed. From the experimental studies conducted, it is noted that the plastic sand brick exceeds the control sample in respect of compressive strength. For example, in study 1, the ratio of 1:4, the compressive strength of 18.13 Mpa far exceeds the control sample (burnt clay brick) having 8.92 Mpa. In study 3, the ratio of 1:4, the compressive strength of 5.12 Mpa far exceeds the control sample (burnt clay brick) having 3.15 Mpa.

Table 1. Comparison of compressive strength (Mpa) of various experimental studies that manufactured plastic sand bricks.

Study	Plastic: Sand Ratio	1:2	1:3	1:4	1:5	1:6	Burnt Clay Brick (Control)	Fly Ash Brick (Control)	References
1		11.7	13.06	18.13	15.88	11.5	8.92	-	[139]
2		19.2	12.74	5.95	-	-	-	-	[59]
3		4.65	4.78	5.12	4.92	3.17	3.15	4.19	[142]
4		-	4.49	5	5.56	-	-	3.83	[141]

Table 2. Comparison of water absorption (%) of various experimental studies that manufactured plastic sand bricks.

Study	Plastic: Sand Ratio	1:2	1:3	1:4	1:5	1:6	Burnt Clay Brick (Control)	Fly Ash Brick (Control)	References
1		1.10	0.31	0.27	1.47	1.66	15.28	-	[139]
2		1.16	2.87	4.29	-	-	-	-	[59]
3		(1.10 * with no ratios reported)					9.086	8.012	[142]
4		-	0.935	0.727	1.033	-	-	6.97	[141]

Similarly, in study 3, the ratio of 1:4, the compressive strength of 5.12 Mpa far exceeds the control sample (fly ash brick) having 4.19 Mpa. In study 4, the ratio of 1:5, the compressive strength of 5.56 Mpa far exceeds the control sample (fly ash brick) having 3.83 Mpa.

From Table 2, all the tests revealed that the plastic sand brick resulted in a very low water absorption rate when compared to the control samples (burnt clay brick and fly ash brick). For example, in study 1, the ratio of 1:4, the water absorption rate of 0.27% is far lower than the control sample (burnt clay brick) having 15.28%. Similarly, in study 4, the ratio of 1:4, the water absorption test of 0.727% is far lower than the control sample (fly ash brick) having 6.97%. However, in experimental study 3 [142], with no ratios of plastic:sand being reported*, the water absorption results for the plastic sand brick, burnt brick and fly ash brick yielded 1.10%, 9.086% and 8.012%, respectively.

From the compressive and water absorption tests conducted, the results indicate there is promising evidence that recycled plastic could be potentially included in the manufacture of building products and its application for the construction industry. Several other studies show that using plastic waste in the manufacturing of building products helps reduce the problem of waste disposal [143–145]. Shah [146] also revealed that using plastic waste in its finest form to produce alternative building materials could contribute significantly to the construction industry. Ogundairo [147] stated that there was great scope for plastic waste to be used as alternative innovative material for the construction industry. It was also emphasised that the engineering properties of the products made from the plastic waste materials were improved. The inclusion of plastic waste in building products would result in materials having similar or exhibit increased properties compared to traditional building materials. Since plastics possess highly non-biodegradable properties, they are suitable for the inclusion of building products and for application in various engineering projects.

4.1. Types of Plastic Waste Used for the Manufacture of Plastic Sand Brick

According to [148,149], there are two classifications of plastics: thermoplastic and thermoset plastics. Thermoplastics can be broken down and remoulded upon heating; whereas, thermoset plastic is moulded once and cannot be remoulded when heated, which poses a challenge for recycling companies. Therefore, all types of plastics cannot be used for brick production, due to their differences in molecular structure. Thermoplastics

are recyclable and can be remoulded into other products, thus making it feasible for brick production. However, the potential of using certain types of plastic waste for brick manufacturing has already been investigated in several studies, as indicated in Table 3:

Table 3. Studies conducted on the potential use of plastic in brick manufacturing.

Types of Plastic Used	Studies Conducted on Plastic Sand Brick Manufacturing
HDPE	[135,150–152]
LDPE	[75]
PET	[59,134,139,143,153–155]
PET & LDPE	[3]
PET & PP	[74,145]
PE	[141]
PE & PET	[29]
PE & HDPE	[142,156]
PE & PP	[157]

4.2. Preliminary Study: Conversion of Plastic Waste into Plastic Sand Bricks at Durban University of Technology in South Africa

Figure 8 explains the plastic sand brick manufacturing processes and preliminary results. (a) Purchased recycled HDPE plastic pellets. (b) Purchased river sand. (c) Sand was sieved. The required amount of sand and plastic was measured. (d) Moulds were oiled and kept in readiness [59,142,151,157]. (e) Sand and plastic pellets were mixed, according to specified ratios. (f) The plastic sand mixture was fed into an extrusion machine. (g) The plastic sand mortar was filled into the oiled moulds. (h) Plastic sand sample bricks were allowed to cool, set and solidify. (i) Samples were carefully demoulded. (j) Samples were cut to a specific size and were tested with the following preliminary results: the average of the five samples was calculated in each of the six different mixed ratios where the inclusion of plastic ranged from 15% to 40%. The highest average compressive strength was 25.24 Mpa in mix 6, and the lowest was 19.58 Mpa in mix 5. The water absorption test showed excellent performance of the plastic sand brick. The average values ranged from 0.1347% to 0.3411% in the first 24 h, the lowest being in mix 2. After seven days, the values ranged from 0.4021% to 0.7928%, with the lowest being in mix 2. After 21 days, the values ranged from 0.6390% to 1.5895%, with the lowest being in mix 1.

4.3. Sustainable Development Goals

This paper takes cognisance of the UN SDGs that were developed in 2015, which are to be attained by 2030 [158]. Seventeen global goals were developed that are interlinked and served as a guideline to achieve a sustainable future for advancing society. The researcher proposed that the manufacturing of the plastic sand bricks and alternative building products would provide eco-friendly options for the construction industry. It would clean up the environment by removing plastic waste and converting it in a value adding process. This would then employ waste pickers and machine operators. The building products will contribute to eco-friendly and more affordable housing projects. Lastly, the plastic sand brick industry would reduce the rate of climate change, which is currently affecting all areas of society. This paper seeks to address the SDGs, particularly Goal 12, which refers to responsible consumption and production, Goal 13, which refers to climate change, Goal 14, which refers to life under water and Goal 15, which refers to life on land.

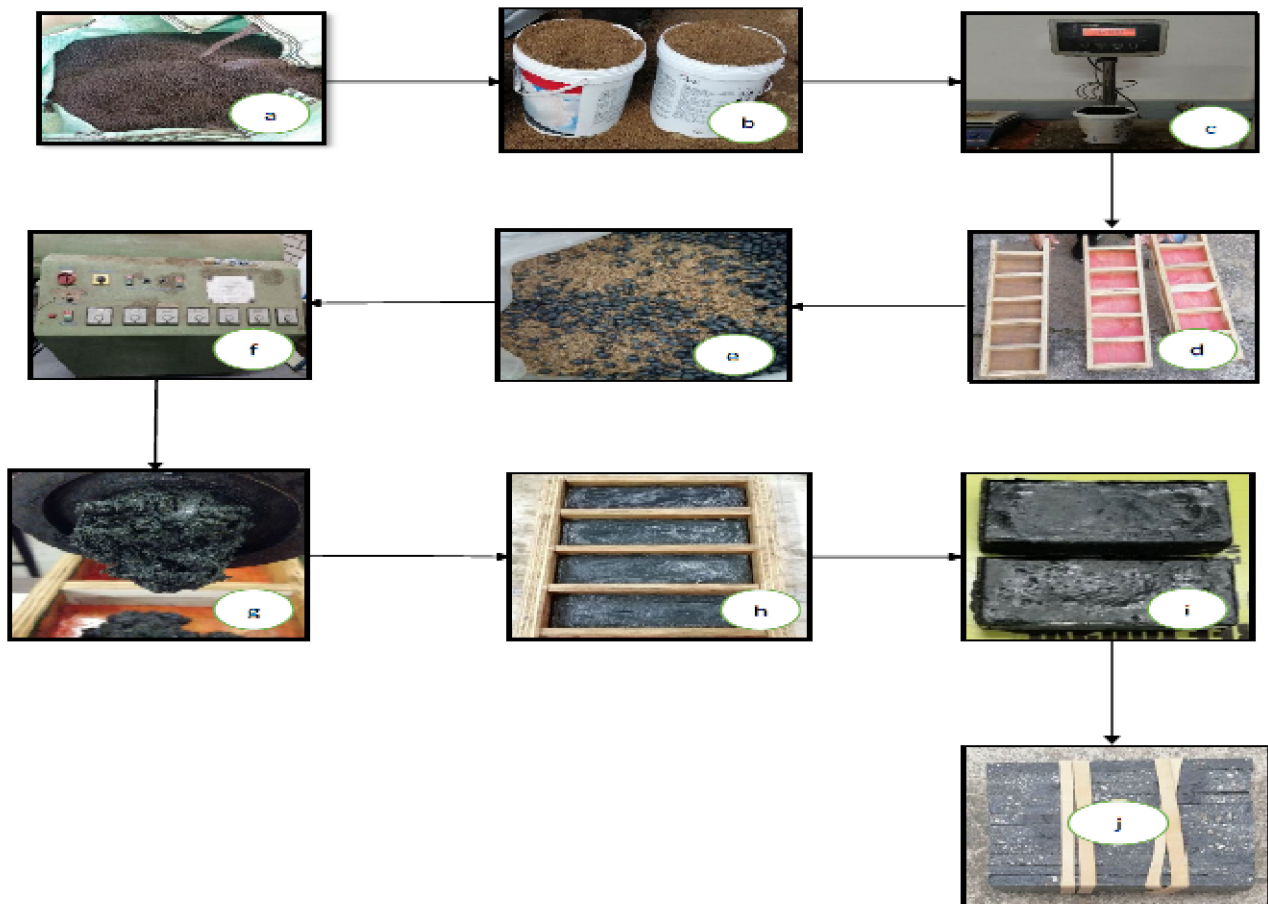


Figure 8. Manufacturing of plastic sand brick samples.

5. Conclusions

From the above discussion, plastic has multiple uses in everyday life; however, sadly, it also carries with it a host of negative impacts on the environment, society and on the economic sector. The concept of recycling will play a positive role towards sustainability and for addressing the four global crises; namely, plastic pollution, unemployment, shortage of affordable housing and climate change. Therefore, the manufacturing of plastic sand bricks as one of many solutions needs to be implemented as an immediate action, to safeguard our current and future generation in fundamental ways.

6. Gaps in the Literature

- There is currently inadequate literature on plastic sand bricks and its further application in the industry.
- Most of the literature reviewed on plastic sand bricks and other products lacked proper temperature control mechanisms and merely conducted their experiments over an open flame [59,134,139,141,142].
- Manual mixing methods employed in the manufacture of the plastic sand bricks could lead to inconsistent mixing of the mortar [59,134,141,142].
- Most of the experimental papers which were reviewed were conducted on a small scale. Currently, there are no studies to assess the viability of commercialising plastic sand brick manufacturing [59,134,135,137,141,142].
- There are insufficient regulations for recycling plastic waste and converting it into plastic sand bricks and for devising appropriate standards that need to be adhered to. This leads to incorrect testing methods and discrepancies in the results [149].
- There is limited research regarding practical matters such as fire resistance, thermal conductivity and production around plastic sand bricks [149].

7. Limitations

Several reports have highlighted the severity and magnitude of many national and global crises. However, the reports often overlap and intersect on topics such as violence, gender-based violence, education, food and nutrition, health, the environment, security, child labour, human trafficking and much more. It is difficult to unpack all these crises. However, this study focuses on four emerging crises, namely, plastic pollution, unemployment, shortage of affordable housing and climate change, that is escalating at an alarming rate in South Africa.

Solutions have been proposed to deal with all these threats. However, this review presents one of many solutions for utilising recycled plastic waste to manufacture plastic sand bricks, which serves as a platform for economic boost in South Africa.

8. Future Research

The number of opportunities for recycling plastic waste as part of the manufacturing of several other products in untapped areas is rapidly increasing. Hence, further research into the possibility of creating eco-friendly plastic sand tracks for athletes, runners and joggers; as compared to concrete and cement tracks in stadiums is encouraged. Future research could focus on scaffolding boards made from plastic waste, which has great potential in the construction industry since plastic waste is lightweight, durable and strong. Scaffolding boards with unique interlocking features and benefits would produce many advantages, compared to the traditional timber and steel alternatives currently being used, which are extremely heavy, difficult to assemble and costly to clean.

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