ASSESSMENT OF CARBON FOOTPRINTS/EMISSIONS FOR SOLID WASTE ADDED CLAY BRICKS PRODUCTIONS

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Field of Study: Carbon Footprint and Circular Economy

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[ASSESSMENT OF CARBON FOOTPRINTS/EMISSIONS FOR SOLID WASTE ADDED CLAY BRICKS PRODUCTIONS]

ABSTRACT

Carbon footprint is an important component of ecological footprint because it quantifies the impact of specific products, activities, or industries in the form of carbon emissions. The higher the carbon footprint, the more greenhouse gases are emitted and contribute to climate change and global warming. The correlation between carbon footprint and waste recovery contributes towards combating environmental, social and economic issues through research and consistent applications. This comparative study was conducted based on three processes which are commercial, recovered clay bricks production and (S/S: stabilization and solidification) of SW204 sludge. The functional unit of 1kg is used throughout the study. The main aim of the study is to define the system boundary of the involved processes and access the carbon footprint. All the information used in this study for evaluation purpose is obtained from secondary data. The evaluation remarks that contributing factors to carbon dioxide emissions in the involved processes are electricity, water, fuel, raw material consumption, including solid waste and scheduled waste generation. The highest carbon footprint released is from process 3: (S/S) of SW204 sludge, which is 65 kg CO_2 where it is rooted in high raw material consumption, solid waste generation and electricity usage: 63 kg CO_2 ,1 kg CO_2 ,0.73 kg CO_2 (respective carbon emission). The disposal cost per kg of SW204 sludge is RM6.50, which is 70% higher than the other production costs discussed. Therefore, among several processes discussed, the best suggestion is the production of recovered clay bricks, which emit 21 kg CO_2 with a production cost of RM1.15 per kg. The findings generated from this study will show the outline of circular economy benefits and how cost effective it is in the clay brick industry as well as carbon footprint contribution.

Keywords: Carbon footprint, greenhouse gases emission, waste recovery, system boundaries, comparative study.

[PENILAIAN JEJAK/ PELEPASAN KARBON UNTUK PENGELUARAN BATU BATA TANAH LIAT YANG DITAMBAH SISA PEPEJAL]

ABSTRAK

Jejak karbon adalah komponen penting dari jejak ekologi kerana ia mengukur kesan produk, aktiviti, atau industri tertentu dalam bentuk pelepasan karbon. Semakin tinggi jejak karbon, semakin banyak gas rumah kaca dikeluarkan dan menyumbang kepada perubahan iklim and pemanasan global. Korelasi antara jejak karbon dan pemulihan sampah boleh memerangi masalah alam sekitar, sosial dan ekonomi melalui penyelidikan dan aplikasi secara konsisten. Kajian perbandingan ini dilakukan berdasarkan tiga proses iaitu pengeluaran batu bata tanah liat komersial, pengeluaran batu bata tanah liat yang dipulihkan dan (S/S: penstabilan dan pemejalan) enapcemar SW204. Unit berfungsi 1kg digunakan sepanjang kajian. Tujuan utama kajian adalah untuk menentukan sistem batasan bagi proses-proses yang terlibat dan mengakses jejak karbon. Semua maklumat yang digunakan dalam kajian ini untuk tujuan penilaian diperoleh dari data sekunder. Hasil penilaian menentukan bahawa faktor penyumbang bagi pelepasan karbon dioksida dalam proses-proses yang terlibat adalah penggunaan elektrik, air, bahan bakar, bahan mentah termasuk sisa pepejal dan sampah berjadual. Jejak karbon tertinggi yang dikeluarkan adalah dari proses 3: (S / S) enapcemar SW204 yang merupakan 65 kg CO2 di mana ia disebabkan oleh penggunaan bahan mentah yang tinggi, penjanaan sisa pepejal dan penggunaan elektrik: 63 kg CO2, 1 kg CO2, 0.73 kg CO2 (pelepasan karbon masing-masing). Kos pelupusan bagi 1kg enapcemar SW204 adalah RM6.50, yang mana kosnya 70% tinggi berbanding dengan kos pengeluaran lain yang dibincangkan. Oleh itu, diantara proses-proses yang dibincangkan, cadangan terbaik adalah pengeluaran batu bata tanah liat yang dipulihkan kerana ia mengeluarkan 21 kg CO2 dengan kos pengeluaran sebanyak RM1.15 bagi 1kg. Dapatan yang dihasilkan dari kajian ini akan menunjukkan gambaran mengenai faedah ekonomi pekeliling serta sejauh mana keberkesanan *kos* dalam industri batu bata tanah liat serta sumbangan terhadap jejak karbon.

Kata kunci: Jejak karbon, pelepasan gas rumah hijau, pemulihan sampah, batasan sistem, kajian perbandingan.

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Aeshwini Singarajan

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ASTM	:	American Society for Testing and Material
BTU/Btu	:	British thermal unit
CDC	:	Centers for Disease Control and Prevention
CF/CPF	:	Carbon Footprint
CFR	:	United States *Code of Federal Regulations*
CKD	:	Cement Kiln Dust
CO2	:	Carbon Dioxide
CO2e/CO2eq	:	Carbon Dioxide Equivalent
DOE	:	Department of Environment
DOSH	:	Department of Occupational, Safety and Health Malaysia
EPA	:	Environmental Protection Agency
EQA 1974	:	Environmental Quality Act 1974
GHG	:	Greenhouse Gases
ICEF	:	The Innovation for Cool Earth Forum
IPCC	:	The Intergovernmental Panel on Climate Change
KN	:	Kilonewtons
LCA	:	Life Cycle Assessment/Analysis
LCIA	:	Life Cycle Impact Assessment (LCIA)
LKD	:	Lime Kiln Dust
MPa	:	Megapascal Pressure Unit
OSHA	:	Occupational Safety and Health Administration
PEL	:	Permissible Exposure Limit
PSI	:	Pounds per square inch
RM	:	Ringgit Malaysia

ROI	:	Return on Investment
S/S	:	Stabilization and Solidification
SGD	:	Sustainability Goals
SW	:	Scheduled Waste
SW204	:	Scheduled Waste 204
TRACI	:	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
UNFCCC	:	United Nations Framework Convention on Climate Change
USEPA	:	United States Environmental Protection Agency
WHO	:	World Health Organization

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

1.1 Background of The Study

The Sustainable Development Goals (SDG), which were founded by The United Nations in 2015, has a collection of 17 interrelated goals that are designed with a mission statement that is "A blueprint to achieve a better and more sustainable future for all by 2030". The establishment of a generalised goal is for the purpose of moving towards combating urgent issues such as extreme poverty and hunger, economic growth, promoting gender equality and empowering women, ensuring environmental sustainability and developing a global partnership for development. The SDG goals such as decent work and economic growth (goal 8), responsible consumption and production (goal 12), climate action (goal 13) are linked to research study. The study based on carbon footprint and the possibility of promoting circular economy is directly related to SDG goals 8, 12, and 13.

The term "carbon footprint" is used worldwide to indicate the amount of carbon released by a specific activity, process, or particular organization. The approved definition given to carbon footprint by the World Health Organization (WHO) is that carbon footprint quantifies the impact of activities by measuring the amount of carbon dioxide being released through the burning of fossil fuels and conveying it as the weight of CO2 produced in tonnes. The Carbon Footprint (CF) is a tool used to calculate the amount of greenhouse gases emitted by a company or activity, including the life cycle of processes, products, and services, in order to determine the contribution to climate change (Fullana et al., 2008).The United Nations Framework Convention on Climate Change (UNFCC), which came into enforcement in 1994, stated that the greenhouse gases (GHG) protocol considers the counting of seven such as carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, sulphur hexafluoride, and nitrogen trifluoride.

The concept of carbon footprint assessment is related to the overall goal of the UNFCCC agreements, which is to stabilize greenhouse gas concentrations in the atmosphere through the prevention of anthropogenic interference with climate change; additionally, in a certain time frame, this action allows the ecosystem to adapt naturally and leads to sustainable development. The Paris Agreement, signed by 175 countries as part of the initiative, aims to limit global mean temperature rise to less than 2 degrees Celsius, and ideally less than 1.5 degrees Celsius (UNFCCC, 2015). According to the Intergovernmental Panel on Climate Change (IPCC), global annual Greenhouse Gas (GHG) emissions must be reduced by 42–57 % by 2050 (compared to 2010 levels) and by 73–107 % by 2100 (IPCC, 2015).

Carbon footprint has turned into a major part of environmental sustainability whereby calculation of carbon footprint is able to contribute towards controlling and stopping global warming. Subsequentially, carbon footprint is also related to the total amount of greenhouse gases (GHG) released directly and indirectly through various activities which involve anthropogenic routines. For example, from the perspective of production, the GHG total outcome results in a carbon footprint contributed by the usage of fossil fuel, natural gas, energy consumption, manufactured goods, materials, transportation, and waste disposal.

According to Susskind. L and et al (2020), Malaysia aspires towards commitment related to reducing the intensity of carbon emissions, particularly a 40% reduction (compared to 2005 levels) by 2020 and a 45% reduction (compared to 2005 levels) by 2030. The waste recovery concept is an opportunity for many stakeholders who are interested in converting waste into recovered valuable materials and even scheduled waste is possible to be recovered.

Collaboration with the fishing communities, for example, for marine plastic debris collection; on the other hand, those plastics waste are converted into fuel using the segregation and pyrolysis technique. Besides that, "plastic road" is another project supporting the circular economy by converting plastic waste, into asphalt mix, Suryandi, PT Chandra Asri Petrochemical Tbk-Indonesia based integrated petrochemical producer, (2019). Most importantly, in either commercial or recovered material production, the carbon footprint must be calculated to confirm the amount of pollution emitted into the environment. Besides that, the carbon footprint of disposal activities of certain waste should be verified as well, basically to give an overview of activity which contribute to a higher carbon footprint. In conclusion, data on inputs and outputs of each process needs to be identified, in order to ensure its relevancy and suitability in perspectives of carbon footprint as well as environmental friendliness.

"Conservationist Jane Goodall says climate change cannot be solved unless we tackle other problems like overconsumption" (CNA Insider, 2021).

1.2 Problem Statement

One of the current global issues related to the environment is the increasing in greenhouse gas emissions which has led to a tremendous hike in GHG concentration in the atmosphere. The excessive emission of GHG leads to global warming, climate change and other associated impacts. Therefore, many industries worldwide are currently taking action by reporting their carbon footprint. The implementation of measuring the carbon emitted from their products, processes and services. The still evolving and emerging carbon footprint calculation is a crucial tool of GHG management and the measurable methodologies are unique according to the scope of business and services life cycle assessments. As per the title, the study will be focusing on assessing the carbon footprint of commercial clay brick production and the solid waste being added value, then produced as recovered clay bricks and the solid waste being directly disposed of.

Considering clay bricks are an important element of the construction sector, if the waste recovery method is compatible and acceptable in terms of carbon footprint and economic feasibility, this initiative will lead to waste minimization and eventually zero waste is achievable. This study involves comparing and identifying among the production of commercial clay bricks, recovering solid waste added value from clay bricks and disposing of the solid waste in terms of the respective carbon footprint contributed.

It is expected that waste recovery options could contribute to better results in terms of carbon footprint rather than disposal activity of solid waste and producing commercial clay bricks. Finally, the three main processes will undergo a comparative study in terms of carbon footprint and economic feasibility.

1.3 Aim of the Study

The main aim of the study is to assess the carbon footprint of commercial and recovered clay brick production as well as solid waste disposal. The carbon footprint will be evaluated by evaluating the patterned-out system boundary of the involved processes. In addition to the carbon comparison analysis, options for economic feasibility, and emissions analysis will be analysed and included as well.

1.4 Objectives of the Study

The objectives of the research project are listed below:

I. To define the system boundaries of commercial and recovered clay bricks production as well as the disposal of solid waste.

II. To compare the carbon emissions of commercial and recovered clay bricks production with the disposal of solid waste.

III. To assess the potential economic feasibility of incorporating solid waste into clay bricks and other processes.

1.5 Research Questions

I. What is the system boundary used in defining the process of commercial and recovered clay brick production, the including disposal of solid waste?

II. Can the waste recovery process of recovered clay bricks contribute to better carbon footprint emissions compared to commercial clay brick production and solid waste disposal?

III. Which would be the better options from the perspectives of economic feasibility among commercial and recovered clay brick production as well as solid waste disposal?

1.6 Scope of The Study

The research study basically focuses on carbon footprint emissions from three main processes, which are commercial and recovered clay brick production, as well as solid waste disposal. For the carbon footprint, the scope, system boundary will be analysed together with the process flow as well as by evaluating the input and output data. There is a second part of the study for which the scope will be comparison done between commercial and recovered clay bricks production as well as solid waste being disposed in terms of carbon footprint calculation from each process. The aim of the comparison is to find out which process is the most environmentally friendly in terms of carbon footprint and has the least impact on the environment.

1.7 Significance of The Study

The significance of the study mainly focuses on the carbon footprint, which is an estimation of carbon emissions by anthropogenic-based activities that contribute to climate change and global warming. Besides that, climate change and global warming are causing problems such as imbalances in the carbon cycle, patterns of rainfall changes as well as alteration of the earth's energy balance. The high percentage of carbon footprints causes environmental impacts such as natural resource depletion. Therefore, initial control is crucial by implementing effective carbon management.

Implementation of carbon management is through better practises of energy and water consumption, assessing the inputs, outputs, and emissions from the processes as well as the supply chain. The specific significance is to publish work on the carbon footprint and waste recovery of solid waste being disposed of and converted into clay bricks and commercial clay bricks. Furthermore, the continuation is studying the life cycle assessment of commercial and recovered clay bricks, basically to find an environmentally friendly process.

1.8 Report Outline

This study is presented in six respective chapters as outlined below:

Chapter 1: Introduction

This chapter provides a general overview and lists of objectives of the study related to the carbon footprint of the involved processes. Besides that, information on the background and scope of the study, as well as the problem statement, are also included.

Chapter 2: Literature Review

This chapter includes various literature reviews that relate to the title selected as well as the waste recovery concept. Basically, the output of chapter two (2) comprises of reporting done by other researchers through their research and observation. All reports used for this study will be cited and references will be added to avoid committing plagiarism.

Chapter 3: Methodology

The research methodology chapter includes the method of study being done and the presentation of the procedure of data collection involved. The methodology flow chart will be included to outline the phases of this study. The data used for this study retrieve from secondary data sources as well as estimations according to a functional unit.

Chapter 4: Results and Discussions

This chapter involves a write up related to the result and detailed discussions of the study. This chapter is closely related to the quantifying and evaluation of carbon footprints involving three main processes. The consumption of important entities will be identified to foresee the total carbon footprint and economic valuation will be added as well.

Chapter 5: Conclusion and Recommendations and Suggestion

The conclusion includes a summary of the overall study and the final conclusion is drawn according to the results and discussions. In this chapter, some suggestions and recommendations are outlined for further studies. Further, studies can be conducted on the cleaner production and environmental impacts related to the suggested processes, and on the improvement as well as the reduction in consumption of recovered bricks produced to support the waste recovery concept.

**The citations, references, and appendices complete the research report.*

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter comprises a collection of numerous literature work review by other researchers based on the title selected. The primary focus will be on closing gaps between the selected processes, the linear and circular economies, and the carbon footprint. Furthermore, the definition of hazardous waste and its properties, research writing on waste recovery materials will be included as well. The environmental impacts such as global warming and climate change will be discussed as well, including the benefits of carbon footprinting.

The data from previously done research on waste recovery significantly from solid waste and other alternative options for converting waste to wealth will be extracted and added into the literature review. In conclusion, the literature review chapter consists of several overviews and significant findings about the current state of knowledge about the study, including suggestions for future studies or research.

2.2 Hazardous Waste in Malaysia

According to the USEPA under CFR, hazardous waste is defined as waste containing characteristics such as ignitability, corrosivity, toxicity, reactivity, infectious or pathogenic. The classification of hazardous waste is verified according to the content and physical characteristics of the waste generated. These types of waste undergo specific procedures including packaging, labelling, and disposal according to legal requirements. In Malaysia, there is a particular regulation for the handling of scheduled waste. The Environmental Quality Act 1974: Environmental Quality (Scheduled Wastes)

Regulations 2005 are under the enforcement of the Department of the Environment (DOE). Scheduled waste is categorised into five main groups:

Table 2.1: Code and Description of Scheduled Waste

1. SW1: Metal and metal-bearing wastes
2. SW2: Wastes containing principally inorganic constituents which may contain metals and organic materials
3. SW3: Wastes containing principally organic constituents which may contain metals and inorganic materials
4. SW4: Wastes which may contain either inorganic or organic constituents
5. SW5: Other wastes

(Source: DOE-Code of Scheduled Waste)

According to Aja.O.C et al (2016), the manufacturing sector was the first industry to be involved in toxic and hazardous waste generation in Malaysia. The booming of manufacturing between 1966 and 1988, is very much related to the noticeable hazardous waste issues in the 1970s and 1980s. Besides that, waste from industries such as household, agriculture/horticulture, medical, timber treatment, petrol storage, metal finishing, paint manufacturing, vehicle servicing, electricity distribution and dry-cleaning facilities is also classified as scheduled waste. "Scheduled wastes generated in 2019 was 4.0 million tonnes. The power plant, metal refinery, chemical industry and electrical & electronics contributed 57.1%, which is 2.3 million tonnes to the total scheduled wastes", Department of Statistics Malaysia (2020). According to the Environment Statistics 2020, published on scheduled waste and clinical waste generation: "The scheduled waste has increased by 8.3% annually for the period 2015 - 2019 and 4,013.2 tonnes were generated in 2019. Selangor recorded the highest scheduled waste of 1,019.9 thousand tonnes in 2019 with a contribution of 25.4%. Selangor also dominated the clinical wastes with 7.3 thousand tonnes as compared to other states".

According to Jamin.N.C and Mahmood.N. Z (2015), the end-of-pipe strategies are Malaysia's current management system, which prioritises disposal above other management options, causing environmental concerns owing to increased demand for disposal land, leachate issues from illegal dump sites and greenhouse gas emissions.

The main concern should be the establishment of environmental awareness and basic infrastructures in order to deal with the large amounts of hazardous waste generated by numerous economic sectors. The increasing load of hazardous waste generated by various sectors in Malaysia needs an appropriate management system that directs towards more sustainable management approaches.

2.2.1 Treatment of Hazardous Solid Waste (Sludge): Stabilization and Solidification

According to Kualiti Alam of Cenviro, Stabilization and Solidification (S/S) treatment targets immobilise the toxic constituents of hazardous wastes in order to prevent contaminants leaching from the wastes once disposed of. The treatment usually entails mixing the waste with binders to minimise the volume of contaminant leachability through physical and chemical properties, then the waste would be more suitable for landfill. Stabilization is the process of altering the physical and chemical properties of a waste to lower its solubility or chemical reactivity. Solidification, on the other hand, attempts to turn waste into readily handled solids with a minimal level of hazard, Tajudin.S.A.A *et al* (2016).

The EPA describes stabilization and solidification as a process that is related to accomplishing one or more of the following criteria:

1. Improve the handling and physical characteristics of waste;
2. decrease/shrinking surface area of a waste mass through which transfer/contaminant leakage can occur; and
3. limit the solubility of hazardous constituents in waste (EPA, 1989) [Geoengineer.org, 2013].

S/S treatment involves utilization of mixing a binding reagent into the contaminated waste. Portland cement, cement kiln dust (CKD), lime, lime kiln dust (LKD), limestone, fly ash, slag, gypsum and phosphate mixtures, other proprietary reagents are among list of binder material commonly in usage. In addition, each hazardous waste needs to be studied on content due presents of numerous and variations of contaminants. Prior studying the waste, the mix design of binder will be selected according to suitability (Weitzman 1989).

Table 2.2: Selection on S/S methods depending on the type of waste

Type of S/S treatment method	Types of waste
Solidification with cement additive	Sludges, contaminated soil
Solidification process with lime additive	Some inorganic wastes, waste from desulphurization treatment of waste gases
Solidification with thermoplastic materials	Radioactive waste
Encapsulation	Sludges, liquids and specific materials
Vitrification	Radioactive waste, extremely hazardous waste

(Source: Vojka.G et al,2013)

The choice of appropriate binders and additives is perhaps the most challenging and complex task of S/S. Portland cement is among the binders that have the ability to both stabilize and solidify. Usually, stand-alone materials are utilised, and employing an additional material may improve their performance. To improve the stability of some metal pollutants, phosphate, a stabilising agent, can be combined with soil or sludge before mixing with a cementitious binder. There are advantages and limitations to S/S technology being implemented for treating and disposing of hazardous waste. The selected advantages and limitations of S/S are listed below, [Environment, Health, and Safety (EHS),2013].

These are the advantages of S/S treatment:

1. Most S/S methods are capable of treating complicated combinations of various wastes.
2. S/S can be used to remediate materials that have been polluted with organic compounds.
3. The majority of binding agents are affordable.
4. Both dry or wet waste conditions can be used, easing dewatering and waste management difficulties.
5. Most S/S techniques necessitate a low level of ability.
6. The technology can be used for both in-situ and ex-situ treatment.
7. Equipment is widely available and simple (construction equipment).

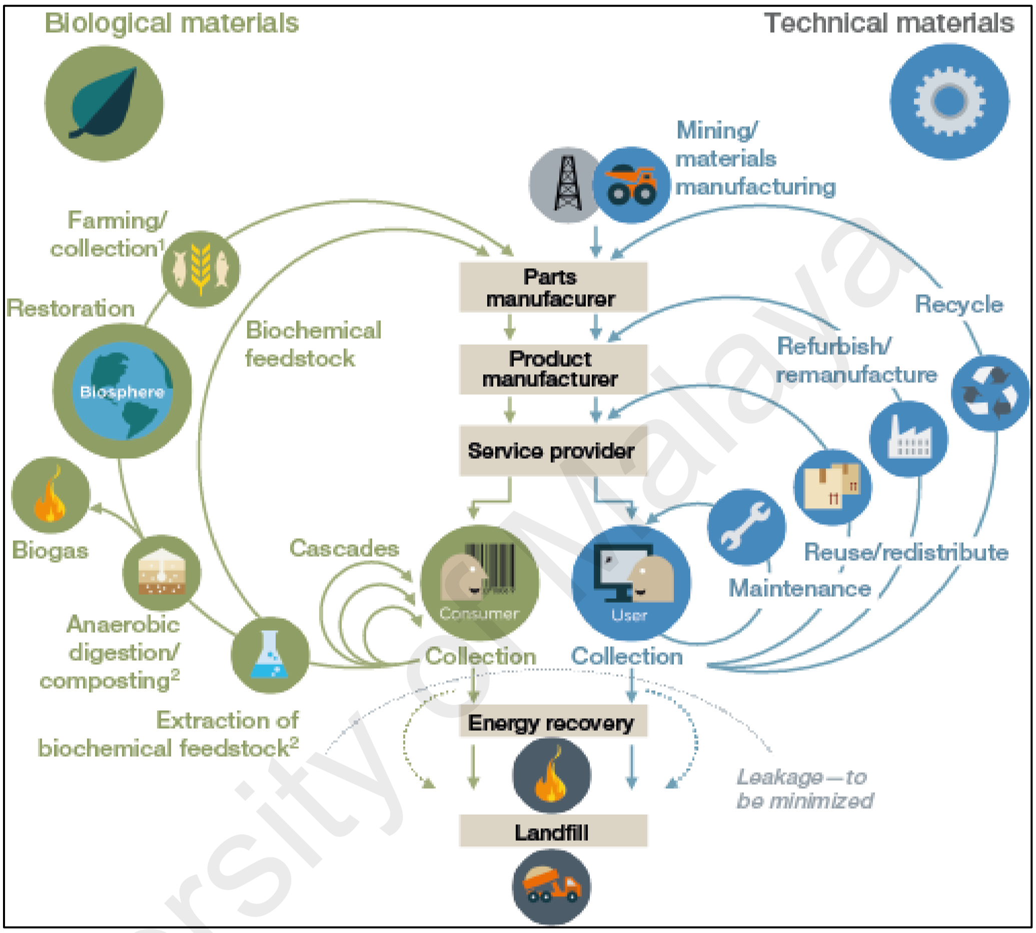
These are the limitations of S/S treatment:

1. Contaminants have not been eliminated or removed from the soil, or even decreased contaminant toxicity has not been achieved.
2. A significant increase in treated hazardous waste loads.
3. Volatile organic compounds and some particulates are possible to get released/escape during the treatment process.
4. It's challenging to get reagents deep into waste and mix them evenly.
5. The site of in situ S/S may not be redeveloped, and the S/S of vulnerable sites may obstruct future comprehensive restoration efforts.
6. The long-term efficiency of S/S treatment is undetermined.
7. It's possible that long-term monitoring will be required.
8. Debris or underground barriers must be removed before S/S treatment can start (preliminary work leads to more carbon emissions).
9. Changes in the physical environment such as groundwater flow and mounding may need to be evaluated.
10. For specific contaminants (e.g., some organic species, such as volatile organics or highly mobile species), S/S efficacy may necessitate additional testing and design procedures. Cementitious S/S methods are often ineffective in treating volatile organics or metals that do not create very insoluble hydroxides (e.g., chromium (VI)).

2.3 Linear and Circular Economy Approach

2.3.1 Definition of Circular Economy

The World Economic Forum (2021) has provided a detailed definition of circular economy: *"A circular economy is an industrial system that is restorative or regenerative by intention and design. It replaces the end-of-life concept with restoration, shifts towards* *the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse and return to the biosphere, and aims for the elimination of waste through the superior design of materials, products, systems, and business models."*

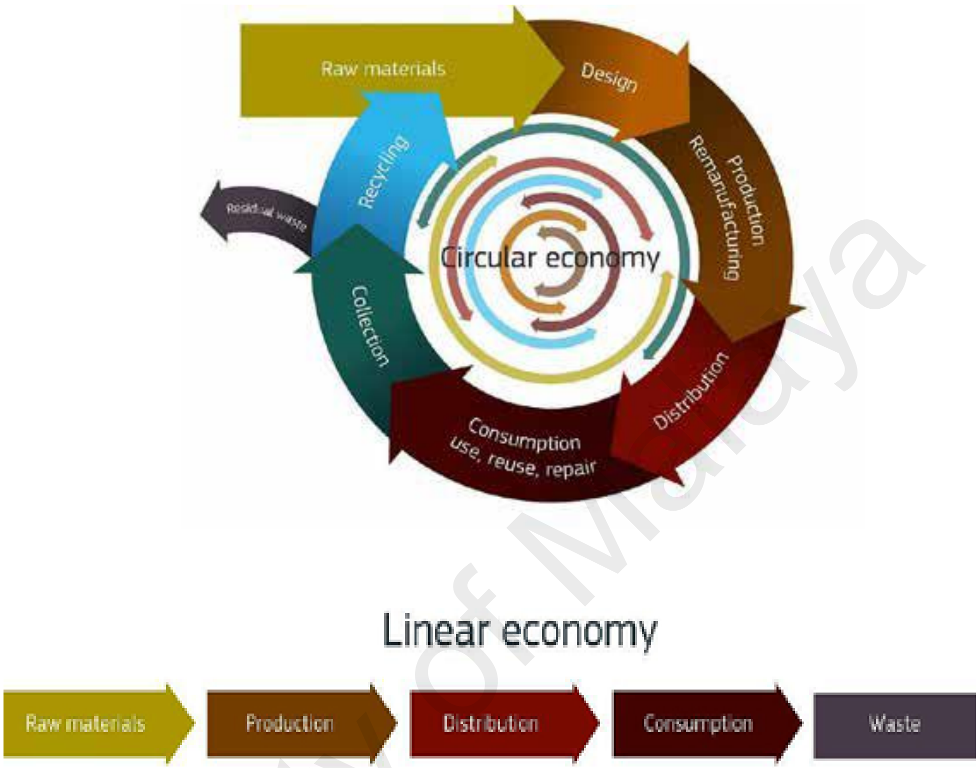


(Source: The World Economic Forum, 2021)

Figure 2.1: The circular economy—an industrial system that is restorative by design

2.3.2 Linear Economy Versus Circular Economy

The circular economy contrasts with the linear economy in several ways. The linear economy's fundamental principles, which rely on a wasteful take-make-dispose loop, are harmful to the environment, unable to provide necessary support to our planet's rising population and naturally lead to limited profitability. In the meantime, in the circular economy, resource cycles are replaced with appropriate recyclable materials to close the loops, (Sariatli.F,2017). The circular economy is compared to the linear economic model in which the life cycle ends with the disposal stage, whereas the circular economy approach leads towards closing all the available loops in the life cycle and continuous usage of resources.



(Source: Plastics and Circular Economy: Community Solution: Chen.S, Bruyne.C.D and Bollempalli.M, 2019)

Figure 2.2: Circular Economy Versus Linear Economy

2.3.3 The Transition of Circular Economy

The rate of awareness among various stakeholders, including people around the globe, has increased in terms of knowing the challenges contributed by the "take-make-dispose" approach towards the manufacturing sector and consumption. For example, in 2019, over 92 billion tonnes of resources were extracted and processed, which contributed to about half of global CO2 emissions.

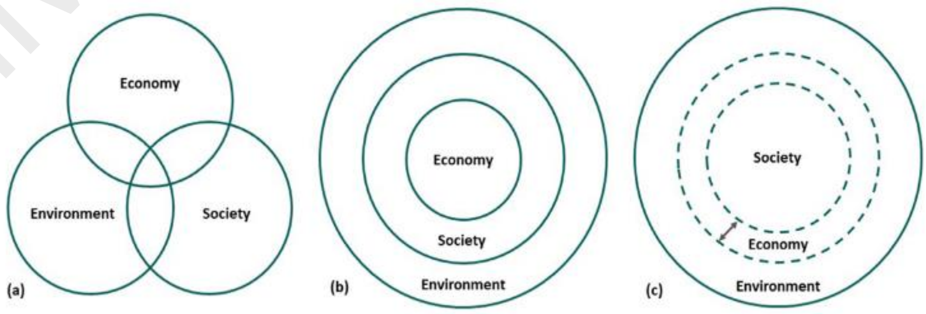
For example, waste generated which includes plastics, textiles, food and electronics, is having a negative effect on the environment and human health. The circular economy, which encourages waste reduction and the sustainable use of natural resources, provides the possibility of generating (estimated) up to $4.5 trillion in economic benefits by 2030. Furthermore, the circular economy is currently practiced by approximately 8.6% of the world's population, implying that achieving this transition will necessitate massive collaboration, action, and awareness, Gawel.A (2021).

2.3.4 Barriers of Implementation of Circular Economy

According to Bharadwaj.R (2018), there are barriers in promoting the circular economy concept.

I. Insufficient technological advancement
II. Evaluated through the lens of traditional return on investment (ROI)
III. Lack of rules and regulatory drivers
IV. Lack of circular economy value chains
V. Fixed corporation involved in controlling waste management.

2.3.5 The Framework of Sustainable Circular Economy



(Source: Chen.S, Bruyne.C.D and Bollempalli.M,2019)

Figure 2.3: Framework of Sustainable Circular Economy

According to Velenturl.A.P.M and Purnell.P (2021), a sustainable circular society is a community with a mentality towards continuing efforts to allow environmental quality and economic prosperity for present the and coming years.

The indicator A, which is social and individual well-being, creates conditions that promote equity in achieving a standard of living that at the very least meets human rights standards. Next, is indicator B, which would be environmental quality, whereby process of using all resources gained within planetary boundaries, enhancing natural capital within and across generations.

The indicator C is economic prosperity, which explains how to enable societal and individual well-being while also improving environmental quality. Collectively organising equal access to resources within and between generations is necessary.

2.3.6 Principles of Sustainable Circular Society

I. Beneficial reciprocal flows of resources between nature and society: Society is an open system embedded in the biophysical environment for their mutual sustainable co-existence. Reciprocal flows of materials both extract from and add value to natural capital, with rates of resource extraction and return to the environment lower than the regenerative and absorptive capacity of the earth.

II. Reduce and decouple resource usage: Reduce and decouple resource usage: By promoting resource sufficiency, efficiency, and dematerialization through governance that decouples progress from unsustainable material usage.

III. Design for circularity purpose: This principle concentrates on coming out with blueprint, creating options and bringing changes into industrial systems, supply chains, resources and products. The entire system is about interpretation of key solution to maximum yield and cover up all available loops in resource flows channel. Through this method the raw material acquiring and waste production with providing best outcome for community, as well leading routes towards reintegration of materials which cultivate continuous processes nurturing sustainable method, through innovation, and vanishing out unsustainable practices, through exnovation, to implement and maintain a sustainable circular community.

IV. Citizen participation in sustainable transitions: Enable community participation in social innovations driven by transformational resource usage by connecting basic level activities, ideas and opinions to local, national, and international policy emergence and decision-making through participatory platforms.

V. Circular business models to integrate multi-dimensional value: Expansion of innovative based business models and with reference boundary of frameworks to incorporate social and environmental costs of materials and products into their prices and recompense with circular practices rather than resource intensive practices to enable the optimisation of resource values.

VI. Transform consumption: Modification from producer-driven consumerism and toward configuration of systems that allow responsible, market-based resource use, as well as more collaboration, service and experience perspective consumption.

VII. Coordinated participatory and multi-level change: correlate the development, integration utilisation of circular economy action plan and actions across societal stakeholder including government, industry, civic sector, consumers and academic experts. From local to international scales, defining the key intervention points were commitment of resources such as business funding, policy change and expertise offer the most benefits for achievement of circular economy.

VIII. Mobilise diversity to develop a plurality of circular economy solutions: Encouraging the diversity of viewpoints and strategies for circular economy and a culture of information inter-sharing and learning process across society, to produce a worldwide information database based on local support, setting subordinate execution, to work in strength against unreliability that goes with progress measures with adequate back-up arrangements and to receive a precautionary approach for arrangements that may not be pretty much as feasible as imagined.

IX. Political economy for multi-dimensional prosperity: Instilling strong sustainability in political-economic systems, shifting from a focus on short-term economic progress [GDP] growth to long-term multi-dimensional prosperity in light of environmental, social, and economic challenges.

X. Whole system assessment: Considering the entire system strategy to understand problems and the capacity of proposed solutions in a precautionary manner and optimise material use within the structured framework for a sustainable circular economy through a method of continuous improvement guided by whole system assessments using holistic metrics before, during and after the application of circular economy approaches through a process of continuous improvement guided by whole system assessments using holistic indicators before, during and after the implementation of circular economy activities, (Velenturl.A.P.M and Purnell.P, 2021).

2.4 Case Studies of Waste Recovery Approach and Carbon Emission

2.4.1 Case Study 1: *The Use of Tannery Solid Waste in the Production of Building Bricks*

The waste utilised in this case study is tannery solid waste. Apart from the toxicity of the sludge, there are several environmental issues caused by large amounts of discarded debris. The research experiments were carried out to assess the possibilities of tannery solid waste obtained by drying the tannery sludge from The Rubiky leather city in Badr City (Egypt) in the preparation of clay bricks. The findings from the experiment show that the tannery powder from the drying process of sludge is used as an addictive clay material in the brick making process. The technical data of the brick is moulded using uniaxial pressure of 20KN force, with a 15% water addition. The firing process took place for 3 hours at 700°C, 750°, and 800°C, and for clay brick samples, the heating rate should be as similar to industrial conditions as possible. It is obvious from the study, that waste can be added up to 5% at a fire temperature as low as 700°C when the strength values are compared to the ASTM C62/2017 (8.7MPa) minimum permissible strength, resulting in a reduction in the weight of the manufactured bricks. The addition of waste sludge to clay brick has both economic and environmental benefits because it utilises polluting waste (S.A. Ghonaim et al., 2020).

2.4.2 Case Study 2: *Use of Sludge Waste as Ingredient in Making of Brick*

Waste can be defined as any unneeded material produced by industry, agriculture, or household activities after the manufacturing process. In the environment, waste produces numerous problems. The disposal of sludge from tannery effluent plants is a concerning issue due to the need to perform dewatered sludge prior to landfilling and limited land facilities. The amount of sludge produced in a tannery effluent plant is expected to increase year after year, posing a cost and time limitation in treating sludge. As a result, this research was conducted in order to use the sludge waste produced by the tannery effluent plant as a brick. The sludge brick combinations included a variety of sludge waste ratios. Fineness, specific gravity, water absorption, and compressive strength tests were all performed. The maximum value of compressive strength was obtained in the 20% of sludge replacement in bricks. Set 1 (60% quarry dust, 20% cement and 20% sludge) could be applicable for structural applications. As a result, brick with a

20% sludge waste utilisation rate is adequate for producing good quality brick. This research indicates that disposal of tannery suitable to be used to make bricks with a proportionate mix and design, (P.Amsayazhi and K.Saravana Raja.M, 2018).

2.4.3 Case Study 3: *Estimation of Carbon Dioxide Emission from Brick Kilns in Bangladesh*

Brick manufacturing firms are sprouting up all throughout Bangladesh on a daily basis. There are almost 6,000 brick kilns in operation over six divisions and divided into four groups based on structural design: BTK, FCK, Zigzag, and Hoffman. The other three types of kilns run on low grade coal and firewood, with the exception of the Hoffman kiln, which uses natural gas. In this study, CO2 emissions from brick kilns in Bangladesh, which contribute 60% to global warming, were projected for the years 2002 and 2007. It was reported that for the manufacture of 100,000 bricks, BTK emits 55.58 tonnes CO2, which is the highest among the four types of kilns, and Hoffman kilns emit 31.86 tonnes CO2 for the same production. The total amount of CO2 emitted in 2002 was 8.987 million tonnes. CO2 emissions increased by 7.37% each year in 2007 due to growing urbanisation, reaching 12.299 million tonnes (A. H. M. Saadat, et al., 2008).

2.4.4 Case Study 4: *Life Cycle Assessment of Traditional and Alternative Bricks: A Review*

According to Khondoker M H et al (2013), the study done was based on the discharge of arsenic–iron sludge and waste recovery. The arsenic–iron sludge was used to make bricks and the effects on the characteristics of the bricks were studied. The chemical composition of sludge from water treatment plants is quite similar to that of brick clay. As a result, sludge might be incorporated and produce a brick clay alternative. In this experiment, sludge was added in proportions of 3%, 6%, 9%, and 12% of the total weight of the sludge–clay mixture. The physical and chemical parameters of the formed bricks were then determined, analysed and compared to a normal clay brick. The quantity of sludge and the fire temperature were shown to be the two most important parameters in influencing the quality of bricks in various tests. The compressive strength of sludge-containing brick samples containing 3 %, 6 %, 9 %, and 12 % sludge was determined to be 14.1 MPa, 15.1 MPa, 9.4 MPa, and 7.1 MPa accordingly. The best amount of sludge to combine with clay for excellent bonding of clay–sludge bricks was discovered to be 6% (maximum) by weight. The study shows 6% of arsenic-iron based sludge is sufficient for recovered clay brick production.

2.4.5 Case Study 5: *Waste Recovery from Industrial Sludge*

In this study, the main concept involved is resource recovery from heavy metal-containing sludge released from a particular waste water treatment plant. Aluminum, calcium and ferum are the dominant elements, with traces of zinc, copper, nickel, magnesium and stanum. At first, metal traces were recovered using the electrodeposition technique and the residual components were utilized to create samples via the vitrification process after being mixed with clay. The samples are analysed for a variety of criteria in order to classify and evaluate their suitability as general building and engineering materials for a variety of applications. In this project, the sludge was dried and powdered before being mixed with clay in varied amounts. A manual press operating at 180 pressure (psi) was used to generate samples measuring 8"x31/2"x1/2". To optimise the vitrification process, the samples were dried in an oven at 105°C for 24 hours before firing in a kiln at a specified temperature of 1050°C. The good mechanical qualities and relatively quick strengthening of the samples suggest that waste water treatment sludge could be used to manufacture construction materials. It's cost-effective because the sludge is either free or can be obtained for a low price. Furthermore, as a result of the legislation, financial benefits can be expected as a result of the transformation of industrial hazardous waste into a value-added consumer product. Furthermore, when compared to the optimal temperature of 1180C, a lower firing temperature of 1050C resulted in lower energy consumption. Due to the general extensive use of industrial hazardous waste that would otherwise pollute or harm the environment, the large-scale application of vitrification technology is environmentally friendly. This would also minimise the amount of natural construction material extracted from open quarries.

This study is attempting to demonstrate that samples created by incorporating waste water treatment sludge into clay are not only suitable for use as building materials such as wall tiles, roof tiles, and facing bricks, but also for specialised technical applications. Basic physical studies on fired samples show that it can be used to construct long-lasting building materials. Investigations into how to make durable construction materials using more than 20% waste water treatment sludge should be done in order to achieve a more significant decrease in industrial hazardous waste in the future. The concept of sustainable development is possibly achievable with such efforts and studies.

2.4.6 Case Study 6: *Reducing Embodied Energy in Masonry Construction*

Fly ash unit masonry uses less energy to manufacture, emits less CO_2, and contains more recycled materials than traditional clay and concrete units. Raw material extraction, energy usage, and CO_2 emissions are all substantial environmental implications of clay masonry manufacture. The immediate implications of mining the raw material of clay and shale include the incidental removal of plants, grasses, flora and topsoil. When the land is not properly recovered, the state of the mined region might be harmful to the immediate and surrounding area. Next, depending on the brick and the effectiveness of the plant operations, an average of 6,000 BTUs of fossil fuel are burned during the manufacturing process of each brick. The main issue when it comes to CO_2

emissions is that the combustion of fossil fuels produces greenhouse gases that are emitted into the atmosphere. Recognised as a concern, the masonry sector is taking steps to reduce embodied energy and achieve the 2030 Challenge for Products' targets. The clay brick industry has developed or researched the following options in order to offset material use, reduce energy use, and minimise costs and CO_2 emissions.

I. Reduced material consumption: Currently, a clay brick is defined "solid" if the cored or void space accounts for no more than 25% of the volume. Some bricks feature voids of more than 25%, making the unit lighter and requiring less clay and fuel per brick. This could allow for more pieces to be shipped on a single vehicle, resulting in more efficient transportation.

II. Alternative materials consumption: To lessen the environmental impact of products, several producers use additional materials in addition to clay. Some companies, mix recycled glass, ceramics, and even treated sewage waste into clay mixture. However, the brick is still burnt in all of these scenarios, which indicates that while the clay material extraction is reduced, the energy and emission impacts are not always reduced because the burning stays the same. Concrete brick is a good example of a completely new material that may be used instead of clay. Concrete bricks have less embodied energy since they are not burned. As traditional clay brick manufacturing techniques are compared to fly ash brick manufacturing processes, 40% of the material is recycled, and 85% is saved.

Sun-dried bricks did not involve kiln burning in the early days, consuming zero fuel and emitting zero CO_2, while producing a brick durable enough to last till now. Furthermore, inefficient vertical brick kilns used a lot of fuel, roughly 30,000 BTUs per brick, and produced a lot of greenhouse gases in the process. It is possible that by using innovative fly ash brick making technologies, fuel consumption and greenhouse gas emissions could be decreased to levels similar to those seen in the early days of brick production. Brick masonry can generally be associated with this new thinking and fly ash-based technology, providing timeless character while also providing the sustainability attributes that the earth deserves, Peter J. Arsenault (2012), Continuing Education Center: Architecture and Construction).

2.4.7 Simplified Waste Recovery Studies

Table 2.3: Information on Simplified Waste Recovery Studies

Recovered Products	**Waste Recovery**
Production of Biodiesel	Production of biodiesel from sewage algae. (Shih-Hsin Ho et al.,2019).
Recovering Heat	Recovering heat from wastewater that enters waterways hot as result of industrial processes. (M. Arnell et al.,2017)
Extracting out nitrogen, phosphorus and potassium (fertilizing material)	Extracting fertilizing material from sewage. (M. Kamaruddin, et al.,2019).
Collecting metals and other valuable materials	Recovering precious metal and material from cell phones and electronics. (Chaudary.K and Vrat.P, 2020).
Separating water from wastewater	Pulling water from wastewater and placing back into system as clean, potable liquid. (Ezugbe.E.O and Rathilal.S, 2020).
Collecting waste item and refurbishing	“Waste items” and refurbishing them to work like new, such as electronics, appliances, kitchenware and instruments (Burton.L,2021).

2.5 Importance of Carbon Footprinting

The carbon footprint tool is used by many different media such as individuals, organizations, products, services to identify and measure carbon dioxide emissions occurring at each part of the process flow. There are numerous advantages to using carbon footprinting techniques. The greater the carbon footprint, the more harmful it is to the environment, the economy, and social and economic progress.

According to Syafudin.S and Zaman.B (2019), carbon emissions are main the contributor to climate change. Improvement made through the implementation of carbon footprint in the perspective of better action being taken towards climate change. An IPCC special report concluded that global warming of 1.5 degrees Celsius above pre-industrial levels, as well as related global greenhouse gas emission pathways, are contributing to a stronger global response to the threat of climate change, sustainable development, and poverty eradication efforts.

Carbon footprint approaches that promote the concept of lowering greenhouse gas emissions provide environmentally sound, efficient methods of operation. Furthermore, environmental impacts such as unpredictable weather changes, increasing temperatures, rising sea levels, and tremendous changes in rain fall patterns are caused by the impacts of drastic climate change. Therefore, application of carbon footprint will require effort in terms of changes in action taken against climate change and working towards a sound environment for humans to continue to live in a safer and healthier lifestyle.

Research and development grants are used to publish the carbon footprint as a catalyst for innovation by incorporating the carbon footprint into businesses, sustainably competent operations, and practices. An example of these remarkable concepts can be seen from the platform of The Innovation for Cool Earth Forum (ICEF), which has chosen the "Top 10 Innovations" in energy and climate change mitigation, featuring the most significant measures to reduce greenhouse gas emissions (GHG). Among the selected projects are " 31.17% solar sunroof triple-junction module efficiency is a solar project created by Sharp", "New world record for thin-film solar cells is a solar project produced by ZSW (Centre for Solar Energy and Hydrogen Research Baden-Württemberg)" and "Flight powered by biofuel made from residual wood is a biomass project created by Northwest Advanced Renewables Alliance, ICM, and GEVO". Application of carbon footprint has proven to be able to give out sustainable innovations that merit achievement in innovativeness, feasibility, and environmental friendliness.

Carbon footprinting approaches give an opportunity that is directly related to human health benefits. In recent days, the impact on human health has been caused by climate change and the rapid growth economy's development phases. The use of carbon footprint, which primarily aids in the reduction of emissions, can improve public health. According to the Centers for Disease Control and Prevention (CDC), human health is impacted by the interruption of physical, biological, and ecological systems. In addition, health impacts such as breathing related and cardiovascular disease, premature birth rate increase, water-borne and infectious diseases, and mental health disturbances are caused by climate change. The mitigation process through carbon footprint, including improvements and development into minimising emissions, environmental disruption, will point out initiatives towards better public health and an enhanced quality of human life.

2.6 Environmental Footprints

2.6.1 Ecological Footprint

According to Silalertruksa. T and Gheewala S.H (2019), the term "ecological footprint" is related to measuring the area of biologically productive land and water that is required for an individual or an activity to bring about the outcome from all the resources it consumes and to absorb the waste it generates, using current technology and resource management practices (Wackernagel and Rees, 1997). The carbon and ecological footprint are differentiated by their individual concepts. The ecological footprint focuses on correlating the total resources consumed by people with the area of land and water needed to replace those resources.

2.6.2 Water Footprint

According to the Water Footprint Network, the water footprint measures the total volume of water produced for each good and service. Water consumption can be calculated for single processes such as rice cultivation and jeans production, as well as entire levels of multinational industries. From different points of view, the water footprint is a multidimensional benchmarking system of volumetric water use and pollution, (Hogeboom R.J, 2020). Some of the terms used in water footprint reporting are gross, which means they measure the amount collected from water sources. The term net refers to water usage which is directly related to anthropogenic activities. Besides that, the term "consumption" is used in regards to the amount of water being used or lost from the system, which briefly explains that the water can no longer be used for other functions.

- **Green Water Footprint** indicates rainwater and soil moisture consumed by plants and crops in their cultivation.
- **Blue Water Footprint** indicates surface water and groundwater.
- **Grey Water Footprint** indicates that freshwater required to dilute pollution and recover the water resource to safe water quality standards, (Water Footprint Network).

2.6.3 Chemical Footprint

The definition of chemical footprint is a conceptual framework approach that connects life cycle assessment and planetary boundaries from the perspective of chemical pollution. The Chemical Footprint Project defines chemical footprint as the availability of baseline data to ensure the evaluation of performance and benchmarking system by converting from the use of harmful chemicals to better alternative options.

The concept functions in such a way that, at an initial stage, it identifies the account of chemical uses and emissions along the life cycle of a product, sector, or entire economy, to assess potential impacts on the environment, ecosystem chain, and human health. The next steps to be taken are to analyse the real emissions from chemical usage that deteriorate the ecosystem and the findings on its capability to recover. The last step might lead to a wide discussion on planetary boundaries for chemical pollution, whereby the thresholds that should not be exceeded to assure a sustainable use of chemicals from an environmental safety perspective (Sala.S, 2013).

2.6.4 Material Footprint

According to the United Nations Statistics Division, the term "material footprint" refers to the sum of raw resources or materials being extracted to meet the final consumption demands, which indicates the pressure on the environment to be capable of supporting economic development and fulfilling consumer needs. The material footprint is part of the SGD goal: responsible consumption and production. The material footprint is important in terms of growing natural resource security after recognising an increasing trend of dependent trading in acquiring resources such as biomass, fossil fuels, metal ores, and non-metal ores. Material footprint also contributes to the long-term viability of resource use and decision making (Wiedmann et al. 2013).

2.7 Environmental and Health Impacts

Table 2.4: Environmental and Health Impacts (Definition and Concept)

Environmental Impacts	Definition and Concept
High Water Consumption	According to the Water Footprint Network, high water consumption is calculated by water footprint. Water footprint is given a definition as the volume of water resources needed to produce goods and provide services. There are green, blue, and grey colour codes that indicate the differences.
Ecological Degradation	Environmental degradation is the disintegration of the environment through the depletion of resources such as air, water, and soil, the deterioration of ecosystems, and the extinction of wildlife. The definition defines any change or damage to the environment as being deleterious or undesirable. (D. M. Choudhary, G. Chauhan and Y. Kushwah, 2015).
Carcinogenic	According to the National Human Genome Research Institute, a carcinogen is a certain chemical or physical agent that may cause cancer in an individual when there is related exposure. Environmental impacts affect the human body through routes of entry which cover the skin part and the respiratory and alimentary systems, each with an array of organs and functions, and with an ultimate bearing on the structures and organs of the body. (T.T. Sreelekha et al., 2003).
Ocean Acidification	Ocean acidification occurs from anthropogenic activities which release carbon dioxide into the environment eventually cause atmospheric warming and climate change. Additional such releases also have direct chemical effects on seawater. The impacts are numerous and from various perspectives: I. Food supply is impacted, potentially affecting food security. II. Coastal protection: As a result of ocean acidification, marine ecosystems are under threat. For example, the reefs have

	functionally prevented loss of life, property damage, and erosion. III. The tourism industry is also impacted by ocean acidification, especially coral reef-based tourism. (National Climate Change Adaption Research Facility, 2017)
Smog Formation	The term smog was introduced in 1905 by Dr. Henry Antoine Des Voeux, who joined the words "smoke" and fog". The properties of ozone, which is highly reactive, have the ability to destroy lung tissue. The short-term exposures are related host of respiratory irritations, including coughing, wheezing, substernal soreness, pharyngitis, and dyspnea. For long term exposure, it potentially causes a risk of developing asthma.
Industrial Eutrophication	Eutrophication is caused by conditions where there are excessive nutrients, particularly Nitrogen (N) and Phosphorus (P) in freshwater and coastal areas. Industrial eutrophication is due to discharges from several sources, such as agriculture, aquaculture, septic tanks, urban wastewater, urban stormwater runoff, industry and fossil fuel combustion. Nutrients enter aquatic ecosystems via the air as well as surface water or groundwater (World Resource Institute). According to Chislock.F.M et al (2013), blooms of blue-green algae, polluted drinking water sources, decreased recreational activity prospects, and hypoxia are all documented outcomes of eutrophication.
Atmospheric Aerosol Loading	In the past 250 years, the global concentration has increased in double quantity due to anthropogenic activities which impact the precipitation patterns as well as the human respiratory system. Besides that, the agricultural industry was impacted, including forest cover and freshwater fish due to increasing atmospheric aerosol loading, (Velenturl.A.P.M and Purnell.P (2017).

Table 2.4: Environmental and Health Impacts (Definition and Concept)-Continued

2.8 Significance of Literature Review

The significance of the goal mainly focuses on the carbon footprint, which is an estimation of carbon emissions by anthropogenic-based activities. Industry waste that is classified under scheduled waste will undergo stabilization and solidification, eventually ending up at a landfill. The selected advantages and limitations of S/S technology have been stated, and it proves that hazardous waste disposal must be managed in different ways to reduce possible environmental impacts.

Besides that, an initiative for waste recovery has been identified so that hazardous waste can be recovered either by settling down for disposal or by being recovered entirely. When comparing closed loop options to liner economies, the circular economy provides more benefits in terms of economic, social, and environmental sustainability. The circular economy needs more exposure for implementation, and the concept of "waste to wealth" needs to reach more society members and be accepted. Calculating one's carbon footprint is critical because identified excessive carbon emissions cause climate change and global warming. The study will narrow down to defining the system boundary of involved processes as well as identifying the carbon footprint each process contributes based on selected components. Furthermore, elements such as economic feasibility, emission analysis will be studied as well. Various write-ups based on footprints and environmental impacts have been added for a better understanding of the study. The necessary literature has been added and published. The work will be on the carbon footprint of waste recovery of solid waste being disposed of and converted into clay bricks and commercial clay bricks compared to waste disposal.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The chapter of research methodology comprises the work flow of the selected processes. The main focus of the study is on the assessment of the carbon footprint for commercial and recovered clay brick production as well as solid waste disposal, including economic feasibility with selected components. The research methodology adapts both quantitative and qualitative approaches. The mixed mode approaches are planned to carry out the study. The data collection is based on life cycle assessment of each process, as well as analysing the input and output data. The life cycle assessment is done within the setup of the system boundary, which is a conceptual line that represents the system that will be assessed.

3.2 Calculation and Reporting of Carbon Footprint

According to Motzer. T (2020), the steps of successful carbon footprint been identified and the steps as per below:

1. Defining system boundaries, as well as developing greenhouse gases inventory.

The initial step will be to define system boundaries through mapping business and listing out the inventory involved. GHG emissions can vary depending on activities conducted in particular businesses and industry. As a result, the most related major contributor of carbon dioxide can be identified by listing the flow of activities. By analysing the scopes, the level of control and influence points to the maximum possible extent can be verified.

2. Determining the consumption values

Consumption data is equally important for the decisive calculation of carbon footprint. Based on activities or processes included inside and outside of the organization, the consumption of such as raw materials, energy, transportation, and waste handling are determined by the supply chain. Collection of data is important to maintain quality and reliability of data. Loops such as incomplete and missing data must be verified as well. The validity of the data is important as it can be used as related industries' standards and guidelines, which is very coinvent.

3. Calculating the carbon footprint

The calculation of carbon footprint is based on data availability and applies a standard-compliant emission factor which enables the calculation to be done. The crucial part here is GHG emissions per scope, source, operation, and by process (whichever applicable).

4. Developing a climate strategy, targeted reduction and performance indicator.

The initiative of sustainable and climate-change-related actions must be expressed in corporate strategies and factored into business competitiveness. It is important for business stakeholders to identify both the risks and opportunities available towards taking action on business in order to fight back against climate change. A GHG reduction target must be established in order to serve as a guide for tracking progress in lowering the carbon footprint. The business key performance indicators should be aligned with objectives related to finding gaps and implementing improvement areas related to the reduction of GHG emissions by analysis of the business processes and reviews of products and services.

5. Reporting carbon footprint.

In the final steps, the compilation of climate strategies, targets, risk analysis and GHG emissions, the data collections, figures and relevant background information need to be disclosed in the report.

3.3 Research Background

The study is related to identifying the carbon footprint value among the involved three processes, as per listed below.

- ➔ **Process 1: Commercial Clay Brick Productions**
- ➔ **Process 2: Recovered Clay Brick Productions Incorporating Sludge (SW204)**
- ➔ **Process 3: Stabilization and Solidification (S/S) of Sludge (SW204).**

3.4 Methodology Flowchart

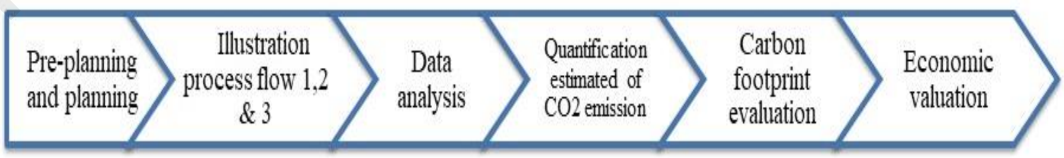


Figure 3.1: Overall Methodology of Research

3.5 Pre-Planning and Planning

The very first step involves pre-planning and is followed by planning. At this phase, it is important to plan the overall flow of the study towards achieving the research objectives. Therefore, the involved processes in this study are defined and continued with important data gathering as needed. There is other information planned to be added, such as goals and scope, functional unit, system boundaries, and inventories (input and output data). Furthermore, secondary data collection is planned with the assistance of an internet platform, reviewing through research papers, journals, and verified websites (governmental and non-governmental organisations). The essential elements extracted from input and output data based on the following reference and the five main components recommended for carbon quantification are:

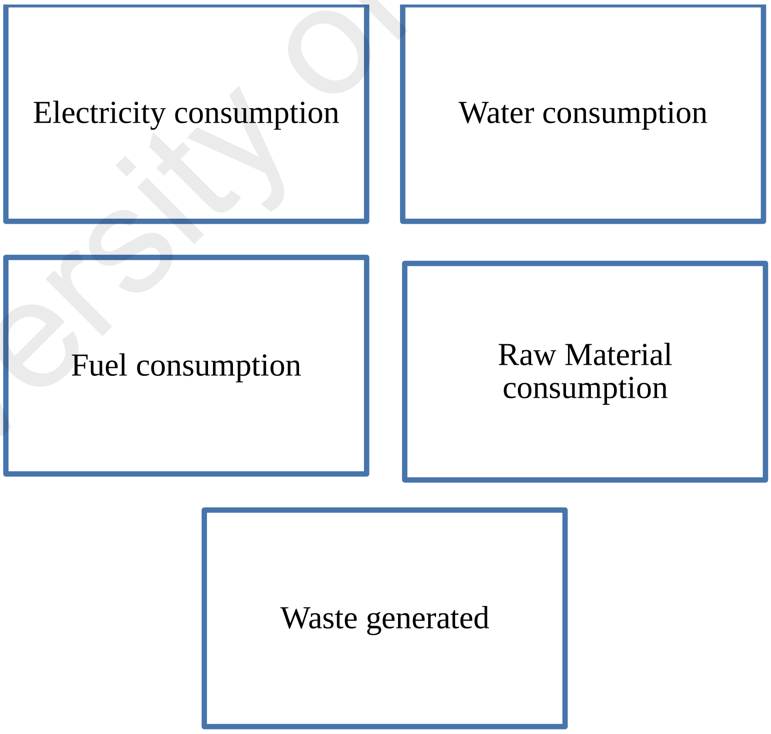


Figure 3.2: Components for Carbon Quantification

3.6 Detailed Flow Diagram of Involved Processes

3.6.1 Introduction

To conduct a comparative carbon footprint study, required secondary data is collected based on the process flow of each process. The understanding of the process flow of an individual process is necessary for further assessment. From the collection of data and analysis, the process flow diagrams were constructed and are presented in figures 3.3, 3.4 and 3.5. As per plan, the collection of data includes both qualitative and quantitative information. These data include raw material consumption, process flow of operations, CO2 and other emissions. Furthermore, additional information is collected, including the consumption of electricity, water, fuel, and waste generated. This data will be utilized to study the carbon footprint of the processes involved.

3.6.2 Goal and Scope

The main goal of this study is to analyze the carbon footprint of the three processes involved and to identify the process that contributes the highest carbon footprint to the environment. As part of the analysis, to access the carbon footprint released from the waste recovery process (process 2), to validate whether the SW204 sludge is better to undergo waste recovery or final disposal. Further study to foresee possible economic feasibility from the results presented.

3.6.3 Functional unit

Process 1: The functional unit is defined as 1 kg of clay bricks productions.

Process 2: The functional unit is defined as 1 kg of recovered clay bricks productions.

Process 3: The functional unit is defined as 1 kg of SW204 sludge that undergo S/S treatment.

3.6.4 Process 1: Commercial Clay Bricks Productions.

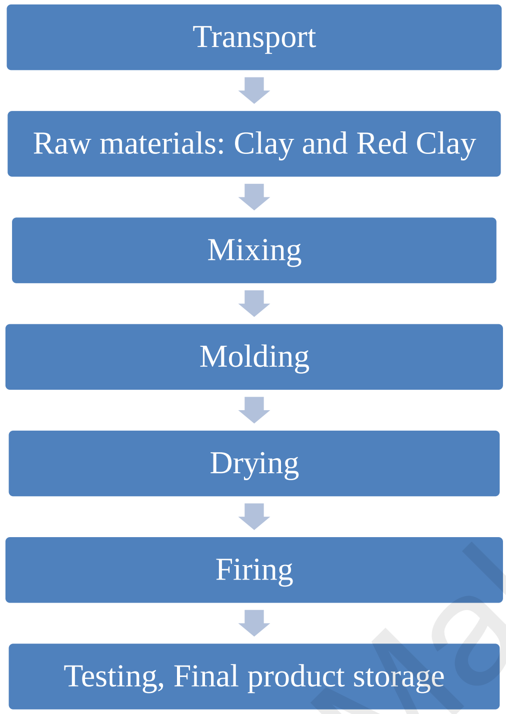


Figure 3.3: Commercial Clay Bricks Productions (Process Flow)

3.6.5 Process 2: Recovered Clay Bricks Productions

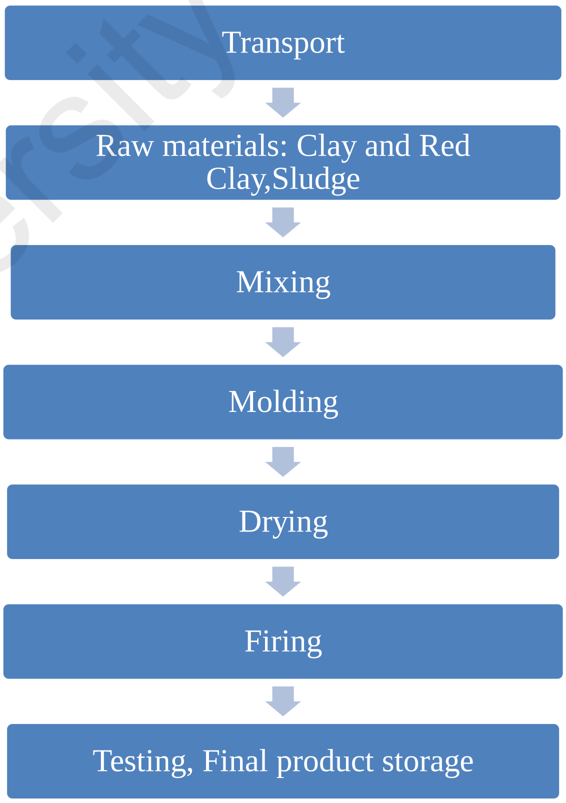


Figure 3.4: Recovered Clay Bricks Productions (Process Flow)

3.6.6 Process 3: Stabilization and Solidification (S/S) Treatment.

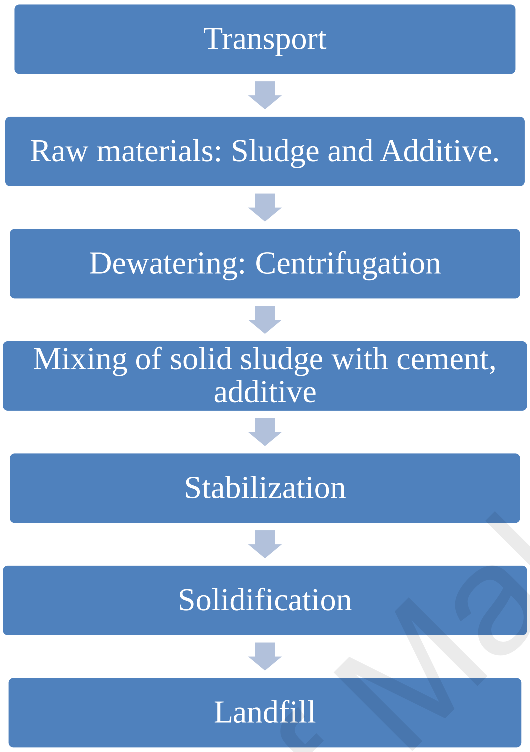


Figure 3.5: Treatment and Disposal of SW204: S/S (Process Flow)

3.7 Data Analysis

There are three sets of data obtained according to processes involved respectively. There are several crucial elements are taken into consideration. Those elements include consumption of raw materials, fuel, electricity, water, waste generated. This consumption is identified and adjusted based on fixed functional units, followed by data analysis to calculate the carbon footprint emission. Further analysis is carried out for the identification of possible options for potential economic feasibility with selected basic components. The other emissions such as CO, NOX, SO2, CH4 and other related emissions from the processes involved will be analysed as well.

3.8 Quantification of Estimated CO_2 Emission

According to Rahim and Raman (2016), "*CO2 emission of the studied plant was quantified by evaluating the inputs and outputs of five entities, which were water, electricity, fuels, and generation rate of wastewater and solid waste".* Therefore, by referring to (Rahim and Raman, 2015), the CO2 emissions for this study are quantified through three processes quantified by analytical reviewing the inputs and outputs of five entities as well, which are raw materials, electricity, fuel and water consumption and waste generated. Next, with reference to from IPCC's quantifying technique, an entity's CO2 emission are computed using a factor-based approach. The formulae start from multiplication of the component data (consumption or generation rate) with the components of Malaysian emission factors [formula provided and shown below], Rahim and Raman (2016) and Shaqina (2019).

An organization or research can benefit from analysing its carbon footprint by bringing in the latest innovations, implementing green-based initiatives, and identifying production chains with high carbon emissions, then taking action to modify them to reduce their carbon footprint. Evaluating carbon footprint is critical for identifying GHG emissions and is a critical component of almost all economic sectors on the path to a sustainable future. The preferred equation for calculating the total carbon footprint of the involved processes.

$$\textbf{\textit{Total CO2 emission (kg CO2)}} = \Sigma \textbf{\textit{ (Entity data} } \times \textbf{\textit{ Entity Emission Factor)}}$$

Table 3.1: Carbon Emission Factor

Resource and Waste	CEF Value	Unit
Light Fuel Oil	10.21	kg CO2/litre
Electricity	0.70	kg CO2/kWh
Water	0.32	kg CO2/m3
Raw Material	21	kg CO2e/ton
Solid Waste	3.7	kg CO2/kg
Waste Water	1	kg CO2/kg COD (removed)
Scheduled Waste	21	kg CO2e/ton

(Source: EPA,2016; IPCC,2006; Rahim and Raman,2015; Shaqina, 2019)

3.9 Carbon Dioxide Equivalent Evaluation

The standard unit referring to various greenhouse gases is carbon dioxide equivalent or simplified as "CO2e", "CO2eq" or "CO2equivalent". The CO2e value represents the total amount of carbon dioxide that contributes to an equivalent global warming impact, regardless of the quantity or type of greenhouse gas present. Therefore, with the available total of different emissions of carbon dioxide, methane, and nitrous oxide, a standard quantification can be done by multiplying the amount of the GHG by its Global Warming Potential-GWP (given in the table below). The benefit of utilising carbon dioxide equivalent is that it permits "bundles" of greenhouse gases to be stated as a single quantity, as well as comparisons between other bundles of GHGs in perspective of global warming impact.

Table 3.2: Global Warming Potentials (IPCC Fourth Assessment Report) [UNFCCC, 2021]

Species (Chemical Formula)	Global Warming Potential (100 year time horizon)
Carbon dioxide (CO_2)	1
Methane (CH_4)	25
Nitrous oxide (NO_2)	298

(Source: IPCC Fourth Assessment Report)

3.10 Environmental Impact Assessment

For this study, SimaPro (Life Cycle Assessment software) was used to determine the environmental impact assessment of clay brick production with chemical usage and landfilling of hazardous waste with a functional unit of 1 kg. The data analysis is based on the environmental impact assessment tool "TRACI: The Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts". Life Cycle Impact Assessment (LCIA), industrial ecology, and sustainability indicators are all characterised by this tool. In common equivalence units, characterization factors estimate the possible consequences of inputs and emissions on certain impact categories. The list of impact categories includes (USEPA, 2020):

- ozone depletion,
- climate change,
- acidification,
- eutrophication,
- smog formation,
- human health impacts, and
- ecotoxicity

The write up on environmental impact assessment is based on assumptions due to utilising pre-existing data related to research study. The analysis presentation will be covered in the next chapter.

3.11 Economic Feasibility

The economic feasibility can be determined by performing a cost-benefit analysis, which takes into account raw material consumption, operational costs, and technology utilization. The cost benefit analysis enables evaluation of all the involved costs and benefits of the particular process or project. According to Boardman (1996), the paper defines cost benefit analysis of the project as including all potential negative impacts and positive impacts (Tangvitoontham.N and Chaiwat.P (2012). The final outcome of the analysis is considered during the decision-making period to confirm which process among the studied processes has economic benefit. Besides that, to consider a process economically feasible, the benefits should outweigh the costs within a defined period of time agreed upon by related stakeholders.

3.12 Safety and Health Aspects

Safety and health are critical components that require appropriate management based on the process or industry. There are several perspectives involved, such as the implementation of a safety culture, focusing on compliance, hazard identification, and risk control. According to the CSA Z1002 Standard, "Occupational health and safety involves hazard identification and elimination and risk assessment and control" uses the following terms, "harm" – physical injury or damage to health" and "hazard" – a potential source of harm to a worker". (Canadian Centre for Occupational Health & Safety, updated 2021). Based on the processes involved in this study, safety and health elements are essential to be added once addressed. It should be included in the safety and health policy of the respective workplace to maintain workers' health and safety and promotes a safer workspace.

3.13 Analysing and Reporting

All collected data were planned to analysed by utilising Microsoft Word version 2019. For data analysis and results presentation in the next chapter, various functions will be incorporated, such as diagrams, charts, and tabulations from the MS Word program. The SimaPro software will be used to retrieve and analyse several datasets related to the study (environmental impact) and use it for results and discussion.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

This study has been carried out to achieve the three main objectives as stated in part 1.4, and this study is based on secondary research or desk research. Series of results and discussion presentations to be done by evaluating three main processes (outlined in chapter 3), with detailed elaboration added throughout this chapter. Mainly, in this chapter, respective input and output values, analysis results, carbon footprint analysis evaluations, and recommendations will be included based on compiled data of the process being studied.

4.2 System Boundary and Process Analysis

4.2.1 Defining System Boundary

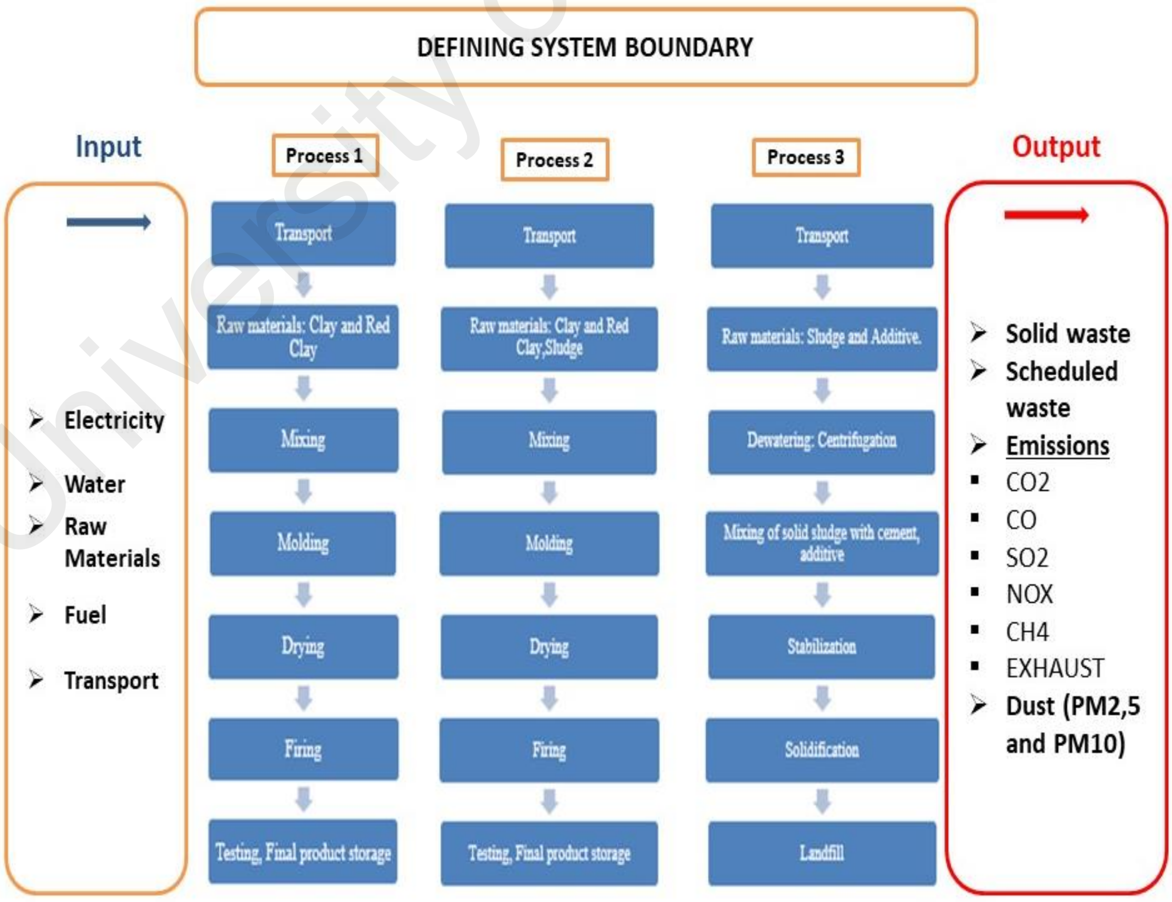


Figure 4.1: Defining System Boundary

4.2.2 Data Analysis

The presentation of the results is based on a functional unit of 1 kg. According to Consequential-LCA (2015), in comparative studies, the functional unit has to be set to the same quantification and standard units, mainly to ensure addressing of obligatory properties as well as the duration of the product's performance, impact assessment. Arzoumanidis.I et al (2019), "A function may be based on different features of the product under study, such as performance, aesthetics, technical quality, additional services, costs, etc."

The system boundary of Process 1, which is commercial clay brick production, is from raw material transportation to final product storage. Clay bricks are widely used in the construction industry and are usually in rectangle-shaped blocks. This process method is based on the consumption of raw materials such as clay, red clay, additives, and water. This process involves cradle to gate, evaluation of a partial of a product's life cycle, from extraction of resources (cradle) to gate (waiting for consumer consumption).

The process 2 involves the production of recovered clay bricks, as an initiative of waste recovery incorporation. The system boundary is the same as in commercial clay brick production. The changes occur at the initial stage. The raw material is added up with SW204 classified sludge to produce recovered clay bricks that have the same function as commercial clay bricks, which are used in building and construction. According to EQA 1974 (first schedule-regulation 2), sludge with a code of SW204 contains one or several metals, including chromium, copper, nickel, zinc, lead, cadmium, aluminium, tin, vanadium, and beryllium. The process includes turning sludge into recovered bricks and transforming them into valuable brick materials. The concept of waste recovery and circularity are implemented. This production is a closed-loop system (cradle to cradle), which is a better option for recycling rather than disposal.

Next, the stabilization and solidification treatment method is used to dispose of the SW204 sludge, and the treatment is performed at the disposal site (ex-situ treatment). The system's boundary extends between the transportation of sludge and additives towards landfilling at the end. The sludge is transported using a licensed vehicle specialist for scheduled waste, and steel drums are used to collect the sludge load.It is essential to carry out stabilization and solidification treatments on SW204 to avoid leaching of heavy metals into the soil and ground water supply. Therefore, consumption of Portland cement, additives into stabilization and solidification, is to limit the diffusion of heavy metal contaminated waste through leaching.

There is an involvement of various inputs at different ranges for selected three processes, and the output is listed accordingly. Further discussion involves input consumption rate, carbon footprint evaluation, economic feasibility, assumptions of environmental impacts according to pre-setting data, and safety aspects.

4.3 Analysis on Electricity Consumption

The electricity consumption is based on the production and waste treatment of 1 kg of material. The electricity tariff data is referred to on Tenaga Nasional Berhad (TNB)'s official website. The tariff is used for the calculation of electricity from the industrial base category. Therefore, 0.38 cents/kWh is charged for the first reading of 200kWh per month (1-200kWh), whereas 44.10 cents/kWh is charged for the following reading of 201kWh onwards.

The stabilization and solidification consume the highest amount of electricity, about 1.04 kWh which is 36%, whereas other processes intake the same amount of electricity, which is 0.908 kWh, 32% respectively. The electricity consumption of stabilisation and solidification is contributed by processes such as dewatering using centrifugation and mixing of solid sludge with cement and additives. For process 3, a total of RM0.40 is charged for electricity consumption to proceed with treatment and disposal of 1kg of SW204 sludge, whereas RM0.35 is the value to be paid for electricity usage for processes 1 and 2.

Table 4.1: Electricity Consumption

Process	Consumption of electricity per 1kg processing (kWh)	Percentage (%)	Valuation (RM)
Process 1: Commercial Clay Bricks Process	0.908	32	0.35
Process 2: Recovered Clay Bricks Process	0.908	32	0.35
Process 3: Stabilization and Solidification (S/S)	1.040	36	0.40

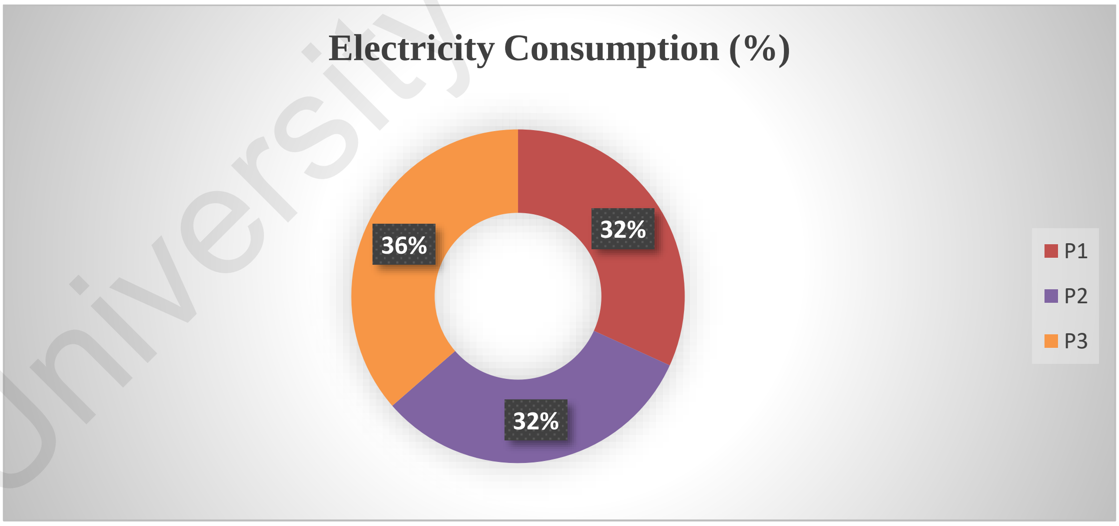


Figure 4.2: Distribution of Electricity Consumption

4.4 Analysis on Water Consumption

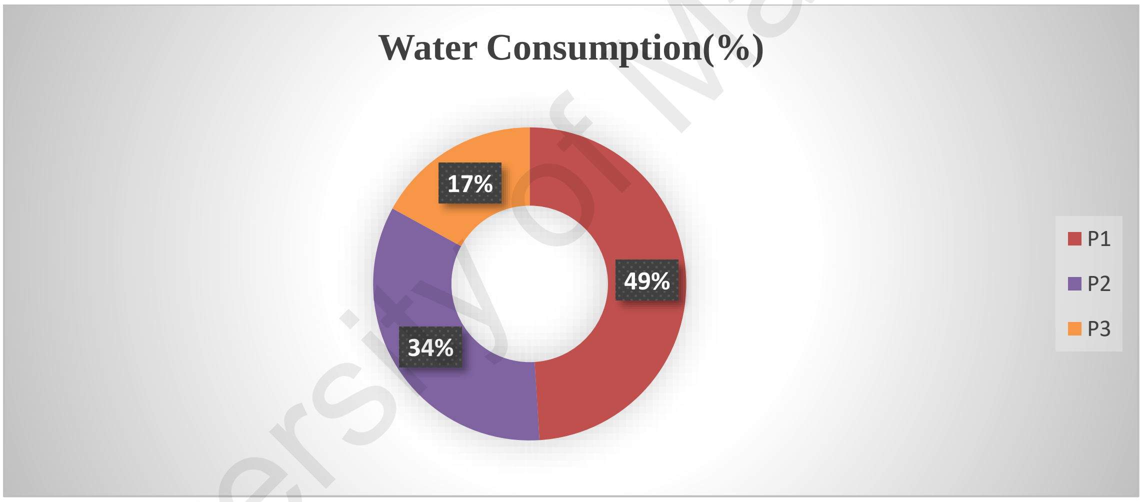
Water is essential for all industries to perform their routine production and activities involving the mixing of raw materials and cleaning of machines and tools. Water tariff information is referred to on the official website of Pengurusan Air Selangor Sdn.Bhd and the category selected is commercial. The rate given is based on the first 35 m^3 being charged at RM 2.07 and followed by exceedingly first 35 m^3 being calculated at RM 2.28.

The highest consumption of water with 49% is making commercial clay bricks with 0.130 m^3 and lowest about 17% of water consumption for stabilization and solidification which is 0.091 $m^{3.}$ For process 2, making of recovered clay bricks require 0.091 m^3 with 34%. Process 1 uptake water source for mixing of clay, red clay and mixture is added to mold for molding bricks shape as well as sufficient wet is essential maintain their shape after forming. For process 2, the making of recovered clay bricks requires 0.091 m^3 at 34%. Process 1: Uptake water source for mixing of clay, red clay, and mixture is added to the mould for moulding bricks into shape, as well as sufficient water and wetness are essential to maintain their shape after forming. Next process 2, involvement of sludge as part of raw material with sufficient water content for mixing clay, red clay and 0.091 m^3 water is consumed for other activities such as washing and cleaning. For process 3, which involved the lowest water consumption, which used to wash and cleaning only. To stabilize and solidify the partially aqueous sludge, the mixed cement and additives are added. For process 1, water supply is charged at RM0.27 with a consumption of 0.130 m^3 and the least charged at RM 0.09 is the price of 0.046 m3 for process 3.

Table 4.2: Water Consumption

Process	Consumption of water per 1kg processing (m^3)	Percentage (%)	Valuation (RM)
Process 1: Commercial Clay Bricks Process	0.130	49	0.27
Process 2: Recovered Clay Bricks Process	0.091	34	0.19
Process 3: Stabilization and Solidification (S/S)	0.046	17	0.09

Figure 4.3: Distribution of water Consumption



4.5 Analysis for Raw Material Consumption

Any industry must be able to determine and verify the raw materials required for smooth production, and raw material consumption in studies varies according to Process 1, Process 2, and Process 3. The process requires the highest load of raw material for stabilization and solidification, which is about 3kg with a cost of RM 6, charged for additives and cement to stabilize and solidify hazardous sludge. The important raw material in P3, which covers 67% of total consumption, is additives and cement, which have a crucial function in stabilizing and solidifying the metal contained in sludge. The S/S process is typically able stabilize to encapsulate these contaminants in a matrix and impede their mobility. S/S methods are generally the most effective for non-volatile heavy metals (EPA, 1993).

The second highest consumption of raw materials, of 0.97kg, is needed to produce 1 kg of recovered clay bricks. The cost is about RM 0.61 for raw materials such as clay, red clay, additives, and sludge (no charges). For this process, raw materials are reduced and incorporated with sludges, followed by making recovered clay bricks. The following is a total of 0.93 kg of raw material needed for the production of commercial clay bricks (per kg). The total of RM 1.05 is inclusive of raw materials such as clay, red clay, and additives.

Table 4.3: Raw Material Consumption

Process	Consumption of Raw materials per 1kg processing	Percentage (%)	Valuation (RM)
Process 1: Commercial Clay Bricks Process	Clay: 0.65 kg	74	0.65
	Red Clay: 0.26 kg	23	0.30
	Additive: 0.020 kg	3	0.01
	Total: 0.93 kg	**100**	**0.96**
Process 2: Recovered Clay Bricks Process	Clay: 0.50 kg	52	0.50
	Red Clay: 0.10 kg	10	0.10
	Sludge: 0.35 kg	36	-
	Additive: 0.020 kg	2	0.01
	Total: 0.97 kg	**100**	**0.61**
Process 3: Stabilization and Solidification (S/S)	Sludge: 1 kg	33	-
	Additive and Cement: 2 kg	67	6.00
	Total: 3 kg	**100**	**6**

4.6 Analysis for Fuel Consumption

The fuel consumption in this study refers to diesel utilisation by transport, mainly related to the transportation of raw materials used for processing (P1, P2, P3). The diesel is at a rate of RM 2.15 per liter as per the current fixed price. The highest fuel consumption is for process 2 (recovered clay brick production) with 51.3%, followed by 46.7% for P1 (commercial clay brick making), which is about 0.000704 kg and 0.00064kg. The price calculated for fuel consumption is RM 0.0015 and RM 0.0014 for P2 and P1 respectively, based on the fixed rate. The contributing factor of high fuel consumption is due to transportation of raw materials, which consist of clay, red clay, additives, and sludge added for process 2. Next, fuel consumed for process 3 is about 0.0000278kg, or about 2% of total consumption, with charges of RM 0.00006. The lowest fuel consumption is for sludge treatment and disposal is due to transportation of sludge and additives only involved. Diesel consumption has its own advantages and disadvantages, listed below:

Table 4.4: Advantages and Disadvantages of Diesel Consumption

Advantages	Disadvantages
Better Millage The greater fuel economy of diesel engines is a major selling factor. Due to the higher efficiency of diesel fuel and the direct fuel injection during the combustion process, diesels can get 25-30 percent better economy than gas engines.	**Difference in Fuel Cost** In Malaysia, the difference between diesel and petrol Ron 95 is about RM0.10, from fixed rate of RM 2.15 and RM2.10 respectively.
Lower Emissions Comparing to gas engines, modern diesel engines emit less Carbon dioxide and carbon monoxide.	**Pollution** Despite advancements, diesel fuel still emits dangerous pollutants such as nitrous oxide, carbon monoxide, Particulate matter and soot.

Less Maintenance Diesel engines may run for extended periods of time without needing maintenance because typically do not involve spark plugs and there are less stressed.	**Noisier** The fuel is injected into the already compressed air inside the cylinder in diesel engines. Because their mechanics function under higher pressure, these engines are substantially noisier than petrol engines.
Safer Diesel fuel is less volatile than gasoline, and the vapour is not as explosive. The risk of the fuel igniting and causing a vehicle fire is reduced as a result.	

Source: 2021 DRiV Incorporated

Table 4.4: Advantages and Disadvantages of Diesel Consumption-Continued

Table 4.5: Fuel Consumption

Process	Consumption of Fuel per 1kg processing	Percentage (%)	Valuation (RM)
Process 1: Commercial Clay Bricks Process	0.00064	47	0.0014
Process 2: Recovered Clay Bricks Process	0.000704	51	0.0015
Process 3: Stabilization and Solidification (S/S)	0.0000278	2	0.00006

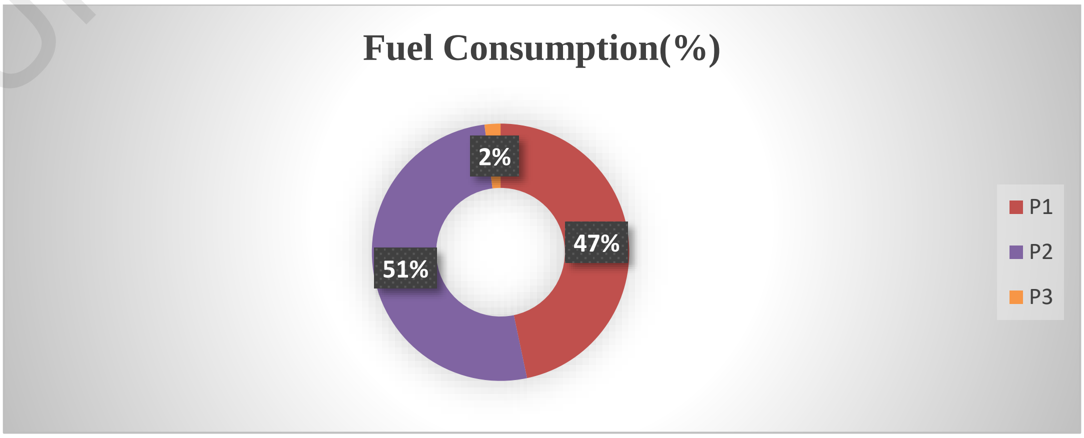


Figure 4.4: Distribution of Fuel Consumption

4.7 Analysis for Waste Generation

The generated waste from involved processes is classified into solid waste and scheduled waste. The quantification of waste produced from the processes involved (P1, P2 and P3) is presented below in table 4.6. The recyclable waste, such as paper and plastic packaging, is separated for the recycling process. The non-recyclables are sent to the appropriate disposal center, whereas scheduled waste categorised waste is collected and stored before being arranged for treatment and disposal by a licensed/authorized organization. The top load of waste generation is contributed by the stabilization and solidification process, with an amount of 2 kg per 1 kg of hazardous sludge, contributing a total of 94%, compared to the other two processes (P1, P2), which represent only 3% respectively. For P1 and P2, the estimated waste generated is 0.06kg, which is only 3% of each production, respectively. The end product from hazardous sludge treatment and disposal will end up on landfill which consuming more space on land.

Table 4.6: Waste Generation (solid waste and scheduled waste)

Process	Classification	Waste Generation per 1kg processing (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	Solid waste	0.06	
	Total	**0.06**	**3**
Process 2: Recovered Clay Bricks Process	Solid waste	0.019	
	Hazardous waste	0.041	
	Total	**0.06**	**3**
Process 3: Stabilization and Solidification (S/S)	Solid waste	0.30	
	Hazardous waste	1.75	
	Total	**2.05**	**94**

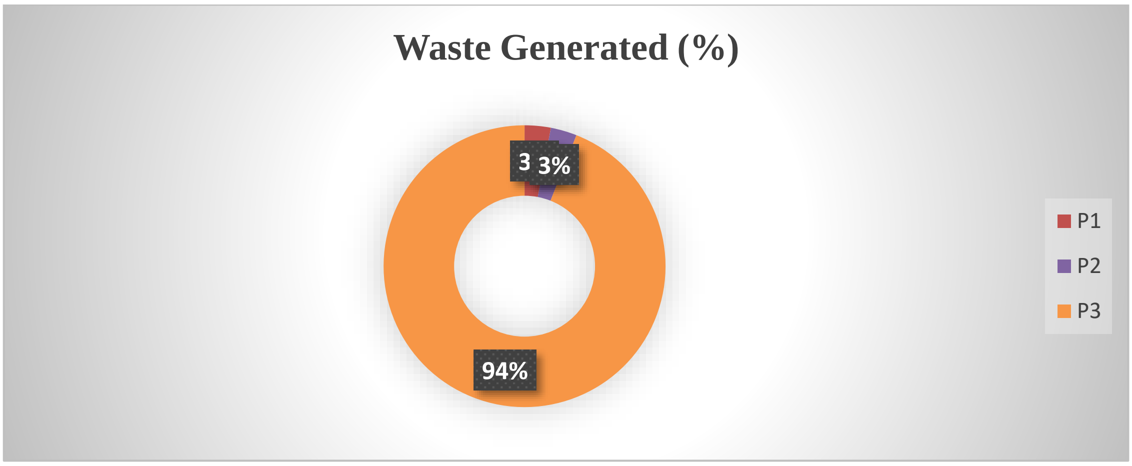


Figure 4.5: Distribution of Waste Generation

4.8 Carbon Footprint Analysis

By utilising available estimated data for three processes, the carbon footprint quantification is done. The main purpose of this calculation is to identify estimated carbon dioxide emissions from Processes 1, 2 and 3. The CFP calculation is done by taking into account several components, such as consumption of electricity, waste, raw materials, fuel, and waste generated (solid waste and scheduled waste). The results from the total analysis are presented below in table 4.7. The highest carbon footprint is contributed by Process 3: stabilization and solidification, with an emission of 65 kg of CO_2 per 1kg of sludge disposing which covers 61% compared to other processes. The second highest emission is from P2: the recovered clay brick process, which emits about 21 kg of CO_2 and the least amount of CO2 emitted is from P1, the commercial clay brick process, which also emits about 21 kg of CO_2. The P2 and P1 contributed about 20% and 19%, respectively. The differences between these two processes (P1 and P2) are not that significant.

The notable emission of P3 is 65 kg of CO2, the first reason for such high emission from electricity consumption. The electricity on-site is utilized mainly for dewatering of sludge, operational of mixers for the mixing sludge with additive, cement concoction. The carbon emission of 0.73kg CO2 is from electricity consumption only. Secondly, the consumption of a high load of raw material for stabilizing and solidification makes the highest internal carbon footprint contributor. The 3kg of raw material usage leads to carbon emission of 63 kg CO2 with contributing rate of 97% compared to other consumption and waste generation. Next, generated solid waste contributes carbon footprint of 1.11 kg CO2 with 1.7% which end up as waste compilation at the landfill.

For processes 2 and 1, internal consumption of electricity and raw materials were large contributors of CO_2 emissions. The emission from electricity is 0.64kg CO_2 for both processes, whereas for raw material consumption, P2 is about 20.4 kg CO_2 and P1 is about 19.53kg CO_2. The complete analysis is presented below the tabulation and labelling.

Table 4.7: Carbon Footprint Analysis of Commercial Clay Brick Productions

Process 1: Commercial Clay Bricks Productions		Calculation
Electricity	Average Electricity Consumption Estimated CFP	0.908kwh per 1kg production 0.908×0.70kg CO_2/kwh = 0.64kg CO_2 per 1 kg production
Water	Average Water Consumption Estimated CFP	0.13m^3 per 1kg production 0.13×0.32kg CO_2/m^3 = 0.04kg CO_2 per 1 kg production
Raw material	Average Raw Material Consumption Estimated CFP	0.93 kg per 1kg production 0.93×21kg CO_2 /kg = 19.53kg CO_2 per 1 kg production
Fuel	Average Fuel Consumption Estimated CFP	1.69×10^{-4} gal per 1kg production 0.000169×10.21 kg CO_2 / gal = 1.73×10^{-3} kg CO_2 per 1 kg production

Solid waste	Average Solid Waste Generated Estimated CFP	0.06 kg per 1kg production 0.06×3.7 kg CO_2 /kg = 0.02 kg CO_2 per 1 kg production

Table 4.8: Carbon Footprint Analysis of Recovered Clay Brick Productions

Process 2: Recovered Clay Bricks Process		Calculation
Electricity	Average Electricity Consumption Estimated CFP	0.908kwh per 1kg production 0.908×0.70kg CO_2/kwh = 0.64kg CO_2 per 1 kg production
Water	Average Water Consumption Estimated CFP	0.091m^3 per 1kg production 0.091×0.32 kg CO_2/m^3 = 0.03 kg CO_2 per 1 kg production
Raw material	Average Raw Material Consumption Estimated CFP	0.97kg per 1kg production 0.97×21kg CO_2 /kg = 20.4 kg CO_2 per 1 kg production
Fuel	Average Fuel Consumption Estimated CFP	1.86×10^{-4} gal per 1kg production 0.000186×10.21 kg CO_2 / gal = 1.9×10^{-3} kg CO_2 per 1 kg production
Solid waste	Average Waste Generated Estimated CFP	0.019 kg per 1kg production 0.019×3.7 kg CO_2 /kg = 0.07 kg CO_2 per 1 kg production
Scheduled waste	Average Scheduled Waste Generated Estimated CFP	4.52×10^{-5} ton per 1kg production 0.0000452×21kg CO_2 e /ton = 9.49×10^{-4} kg CO_2 per 1 kg production

Table 4.9: Carbon Footprint Analysis of Stabilization and Solidification (S/S)

Process 3: Stabilization and Solidification (S/S)		Calculation
Electricity	Average Electricity Consumption Estimated CFP	1.04kwh per 1kg production 1.04×0.70kg CO_2/kwh = 0.73kg CO_2 per 1 kg production
Water	Average Water Consumption Estimated CFP	0.046m^3 per 1kg production 0.046×0.32 kg CO_2/m^3 = 0.01 kg CO_2 per 1 kg production
Raw material	Average Raw Material Consumption Estimated CFP	3kg per 1kg production 3×21kg CO_2 /kg = 63 kg CO_2 per 1 kg production
Fuel	Average Fuel Consumption Estimated CFP	7.34×10^{-6} gal per 1kg production 0.00000734×10.21 kg CO_2 / gal = 7.49×10^{-5} kg CO_2 per 1 kg production
Solid waste	Average Waste Generated Estimated CFP	0.300 kg per 1kg production 0.300×3.7 kg CO_2 /kg = 1.11 kg CO_2 per 1 kg production
Scheduled waste	Average Scheduled Waste Generated Estimated CFP	1.93×10^{-3} ton per 1kg production 0.0019×21kg CO_2 e /ton = 0.04 kg CO2 per 1 kg production

Table 4.10: Carbon Footprint Analysis of Overall (P1, P2 and P3)

Components	Process 1	Process 2	Process 3
Unit	kg CO2	kg CO2	kg CO2
Electricity	0.64	0.64	0.73
Water	0.04	0.03	0.01
Raw material	19.53	20.4	63
Fuel	0.00173	0.0019	0.0000749
Solid waste	0.02	0.07	1.11
Scheduled waste	-	0.000949	0.04
Total kg CO2	**20**	**21**	**65**

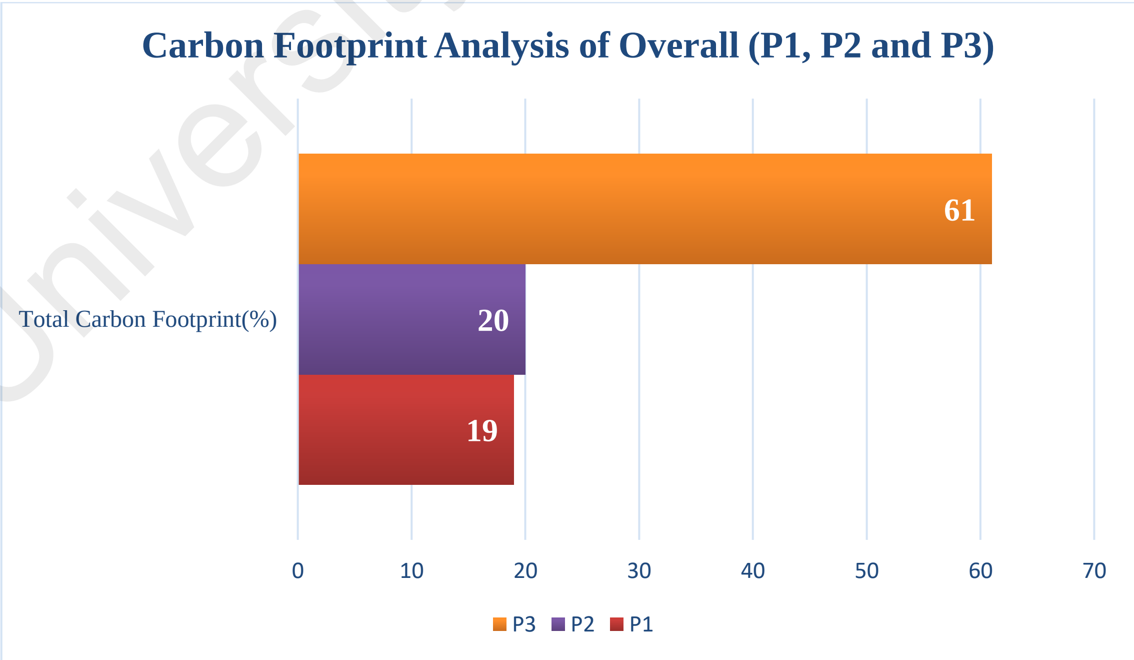


Figure 4.6: Carbon Footprint Analysis of P1, P2 and P3 (%)

4.9 Emission Inventory

4.9.1 Carbon Monoxide (CO)

Table 4.11: Emission of Carbon Monoxide

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	1.2×10-4	37
Process 2: Recovered Clay Bricks Process	1.5×10-4	47
Process 3: Stabilization and Solidification (S/S)	5.2×10-5	16

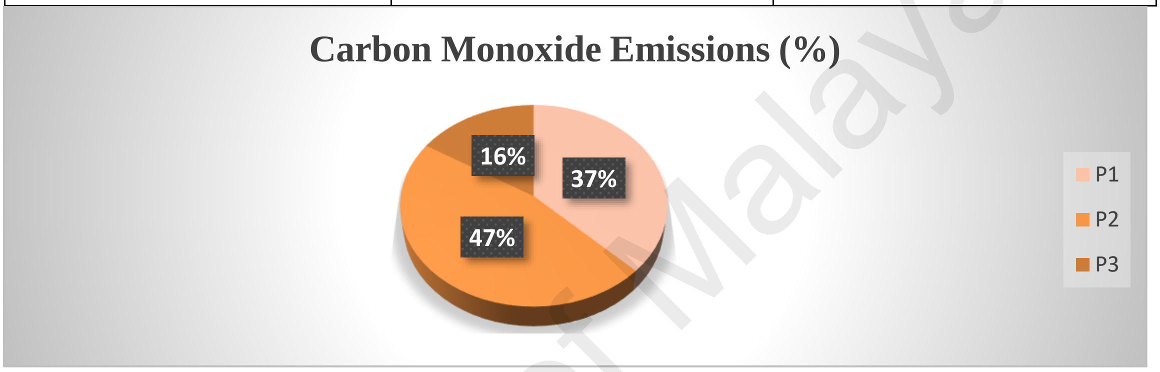


Figure 4.7: Distributions of Carbon Monoxide Emissions

4.9.2 Nitrogen Oxides (NOX)

Table 4.12: Emission of Nitrogen Oxides

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	7.21×10-4	41
Process 2: Recovered Clay Bricks Process	7.57×10-4	43
Process 3: Stabilization and Solidification (S/S)	2.93×10-4	16

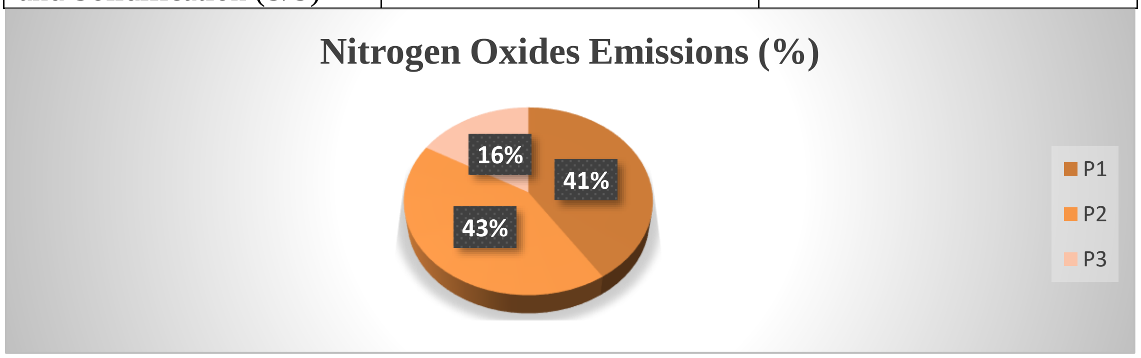


Figure 4.8: Distributions of Nitrogen Oxides Emissions

4.9.3 Sulphur dioxide (SO_2)

Table 4.13: Emission of Sulphur Dioxide

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	0.00206	33
Process 2: Recovered Clay Bricks Process	0.002163	34
Process 3: Stabilization and Solidification (S/S)	0.00210	33

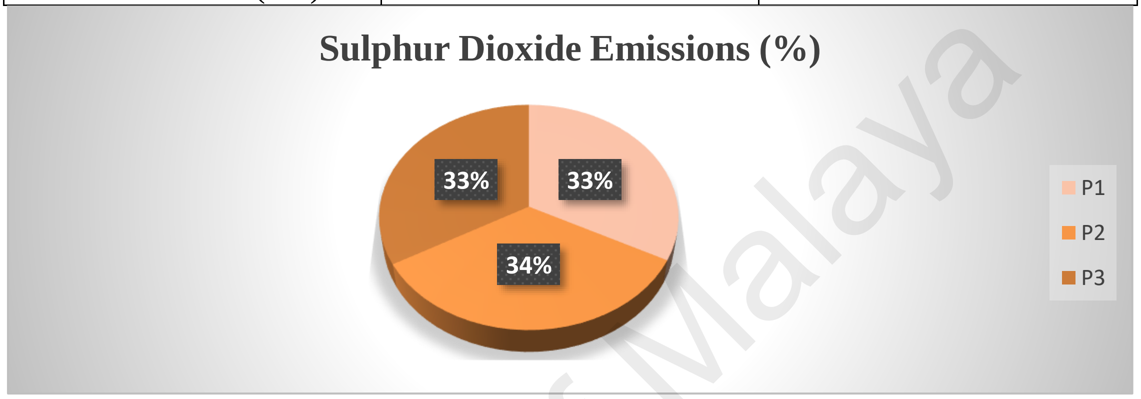


Figure 4.9: Distributions of Sulphur Dioxide Emissions

4.9.4 Methane (CH_4)

Table 4.14: Emission of Methane

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	3.61×10-4	41
Process 2: Recovered Clay Bricks Process	3.80×10-4	44
Process 3: Stabilization and Solidification (S/S)	1.32×10-4	15

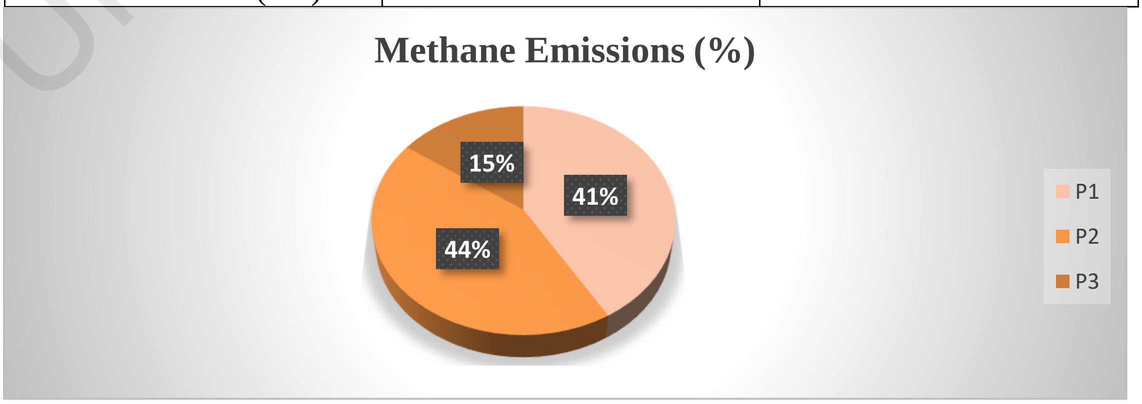


Figure 4.10: Distributions of Methane Emissions

4.9.5 Exhaust

Table 4.15: Emission of Exhaust

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	1.47	39
Process 2: Recovered Clay Bricks Process	1.54	40
Process 3: Stabilization and Solidification (S/S)	0.8	21

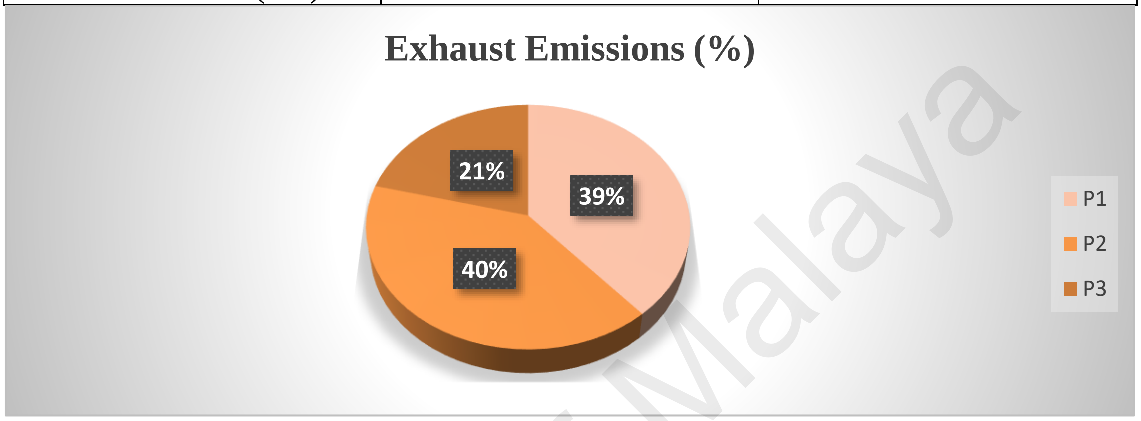


Figure 4.11: Distributions of Exhaust Emissions

4.9.6 Dust (PM2.5-PM10)

Table 4.16: Emission of Dust (PM2.5-PM10)

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	3.95×10-5	24
Process 2: Recovered Clay Bricks Process	3.95×10-5	25
Process 3: Stabilization and Solidification (S/S)	7.9×10-5	51

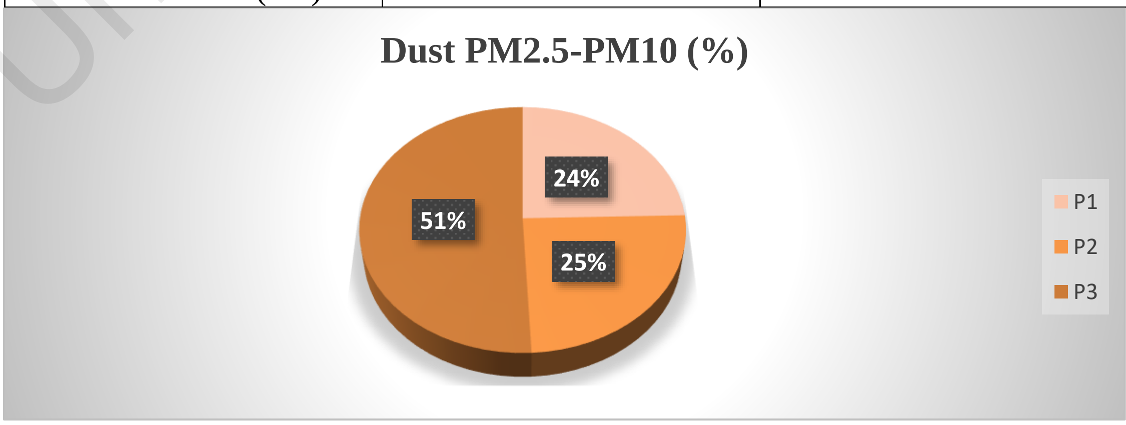


Figure 4.12: Distributions of Dust (PM2.5-PM10) Emission

4.9.7 Dust (PM2.5)

Table 4.17: Emission of Dust (PM2.5)

Process	Emissions (kg)	Percentage (%)
Process 1: Commercial Clay Bricks Process	2.2×10-5	25
Process 2: Recovered Clay Bricks Process	2.2×10-5	25
Process 3: Stabilization and Solidification (S/S)	4.5×10-5	50

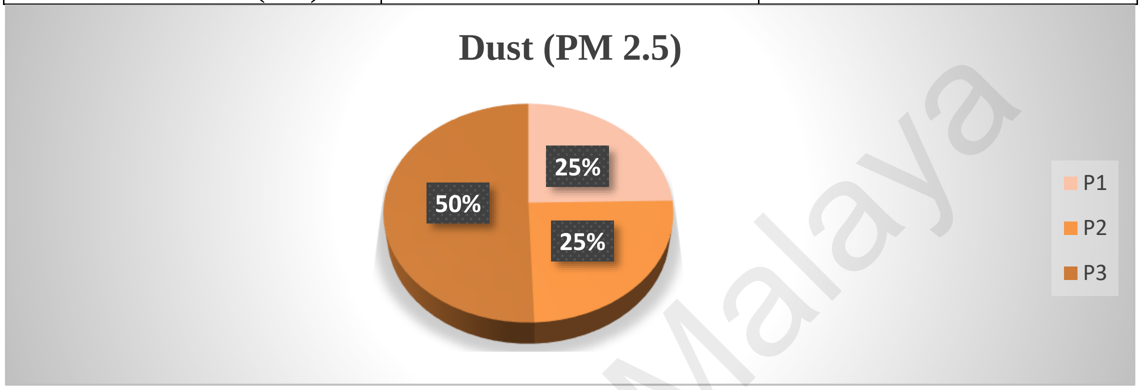


Figure 4.13: Distributions of Dust (PM2.5) Emissions

4.10 Analysis of Emissions Inventory

Table 4.18: Overall Emission Tabulation

Components	Emissions (kg)	Processes
Carbon Monoxide (CO)	1.5×10-4	Process 2
Nitrogen Oxides (NOX)	7.57×10-4	Process 2
Sulphur dioxide (SO2)	0.002163	Process 2
Methane (CH4)	3.80×10-4	Process 2
Exhaust	1.54	Process 2
Dust (PM2.5-PM10)	7.9×10-5	Process 3
Dust (PM2.5)	4.5×10-5	Process 3

The presented data tabulation is based on emissions released from processes (P1, P2 and P3) involved. Those emissions are carbon monoxide, nitrogen oxides, sulphur dioxide, methane, exhaust and dust in the range of PM2.5 to PM10. The highest carbon monoxide emitter is process 2 which is about 1.5×10-4kg and it is 46.6% compared to other processes. Process 2 emitted NOX and sulphur dioxide at about 7.57×10-4kg and 0.002163kg respectively, which is the highest emission as well. About 44%, 40% of methane and exhaust are emitted in process 2, equivalent to 3.80×10-4kg and 1.54kg. The pattern of emissions is highly emitted from process 2 due to the transportation of various raw materials needed for the production of recovered clay bricks, including sludge. Due to the involvement of a limited number of raw material transportations, processes 2 and 3 emit relatively low emissions. The nitrogen oxide emissions related to transportation facilities carrying the required raw materials for production compared to process 3 (transporting sludge and cement, additives) emitted only 2.93×10-4kg which contributes to 16.6%. Commercial clay brick production emissions were recorded at 7.21×10-4 which is 41%. Findings clearly show the process involves more transport services and emits more NOX.

Significant releases of dust from both categories (PM2.5-PM10, PM2.5) are identified in P3 with 51% and 50% comparisons done between P1, P2 and P3. The reason for such significant releases of particulate matter is the consumption of cement in large quantities for stabilization and solidification of SW204. The emission is about 7.9×10-5kg and 4.5×10-5 kg been identified.

4.11 Carbon Dioxide Equivalent Evaluation

Table 4.19: Overall Carbon Dioxide Equivalent Evaluation

Process 1: Commercial Clay Bricks Process				
Species (Chemical Formula)	Global Warming Potential (100 year time horizon)	Emission (kg)	Carbon Dioxide Equivalent (CO2eq)	Percentage (%)
Carbon dioxide (CO_2)	1	20	20	99
Methane (CH_4)	25	3.61×10-4	9.025×10-3	-

Nitrous oxide (NO_2)	298	7.21×10-4	0.215	1
			Total: 20.2	100

Process 2: Recovered Clay Bricks Process				
Species (Chemical Formula)	Global Warming Potential (100 year time horizon)	Emission (kg)	Carbon Dioxide Equivalent (CO2eq)	Percentage (%)
Carbon dioxide (CO_2)	1	21	21	99
Methane (CH_4)	25	3.80×10-4	9.5×10-3	-
Nitrous oxide (NO_2)	298	7.57×10-4	0.226	1
			Total: 21.2	100

Process 3: Stabilization and Solidification (S/S)				
Species (Chemical Formula)	Global Warming Potential (100 year time horizon)	Emission (kg)	Carbon Dioxide Equivalent (CO2eq)	Percentage (%)
Carbon dioxide (CO_2)	1	65	65	100
Methane (CH_4)	25	1.32×10-4	3.3×10-3	-
Nitrous oxide (NO_2)	298	2.93×10-4	0.087	-
			Total: 65.1	100

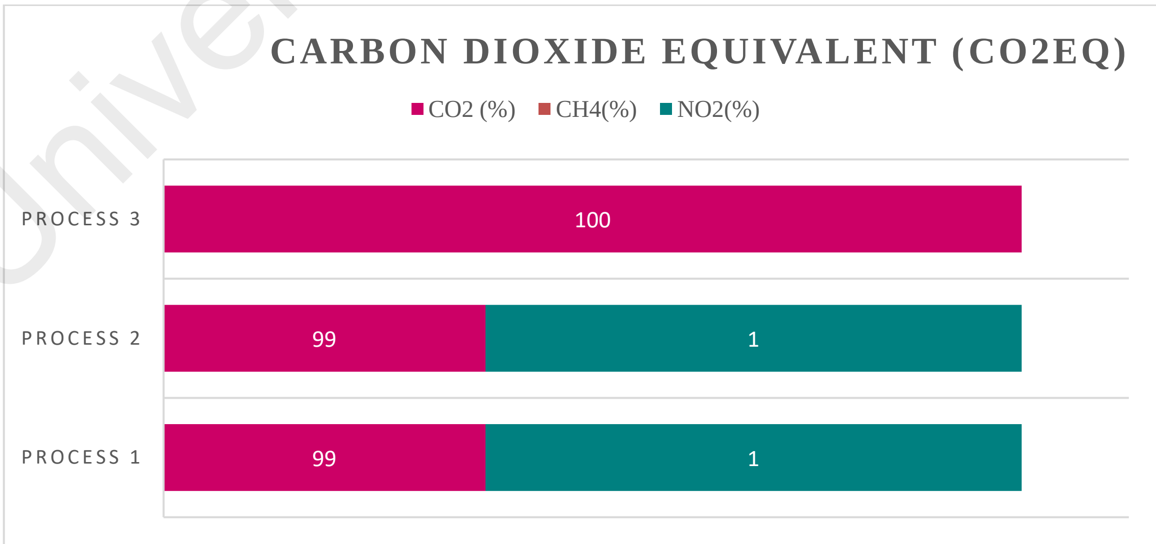


Figure 4.14: Carbon Dioxide Equivalent Evaluations

The carbon dioxide equivalent evaluations are performed for all processes involved in the study. The greenhouse gases involved in quantification are carbon dioxide (CO2), methane (CH4) and Nitrous Oxide (NO2). For commercial clay bricks production, carbon dioxide equivalent calculation base on emission rate is 20 CO2eq, 9.025×10-3 CO2eq, 0.215 CO2eq for respective CO2, CH4 and NO2. For recovered clay brick production, the total carbon dioxide equivalent is 21.2 CO2eq. Process 3 contributes 65.1 CO2eq, whereby the breakdown is 65 CO2eq, 3.3×10-3 CO2eq, and 0.087 CO2eq. The S/S (process 3) contributes the biggest value of carbon dioxide equivalent, which is 65.1 CO2eq, compared to commercial clay brick production, which contributes 20.2 CO2eq in terms of emissions of CO2, CH4 and NO2. The carbon dioxide equivalent form process 3 is a contributing factor to global warming, which is interrelated to climate change. The Global Warming Potential (GWP,100) has the potential to estimate the different gases in the same unit over a 100-year period, as well as the impact on the carbon cycle (United States Environmental Protection Agency).

4.12 Economic Feasibility

The cost estimation analysis is done within limited boundary and data collection, utilizing the information on consumption of electricity, water, raw material and fuel. The process with the highest expenses is stabilization and solidification treatment, which cost about RM6.50 approximately per 1 kg sludge treatment and disposal. The process of commercial clay bricks requires approximate estimation of RM1.60 for producing 1 kg of clay bricks. The least expenses of RM1.15 is needed to produce 1 kg of recovered clay bricks. The waste recovery options of incorporating sludge into clay bricks making is the best cost saving process among all processes discussed within consumption boundary.

Table 4.20: Economic Feasibility

Estimated Expenses of Commercial Clay Bricks Process Per kg	
Components	**Pricing (RM)**
Electricity	0.35
Water	0.27
Raw material	0.96
Fuel	0.00
TOTAL	1.60

Estimated Expenses of Recovered Clay Bricks Process Per kg	
Components	**Pricing (RM)**
Electricity	0.35
Water	0.19
Raw material	0.61
Fuel	0.00
TOTAL	1.15

Estimated Expenses of Stabilization and Solidification Per kg	
Components	**Pricing(RM)**
Electricity	0.40
Water	0.09
Raw material	6.00
Fuel	0.00
TOTAL	6.50

4.13 Impact Assessment

The data presented below were obtained from SimaPro Software in order to perform an impact assessment. The analysis method of Traci is used to assess the impact of clay brick production on chemical consumption and the landfill of hazardous waste.

4.13.1 Clay Brick Production

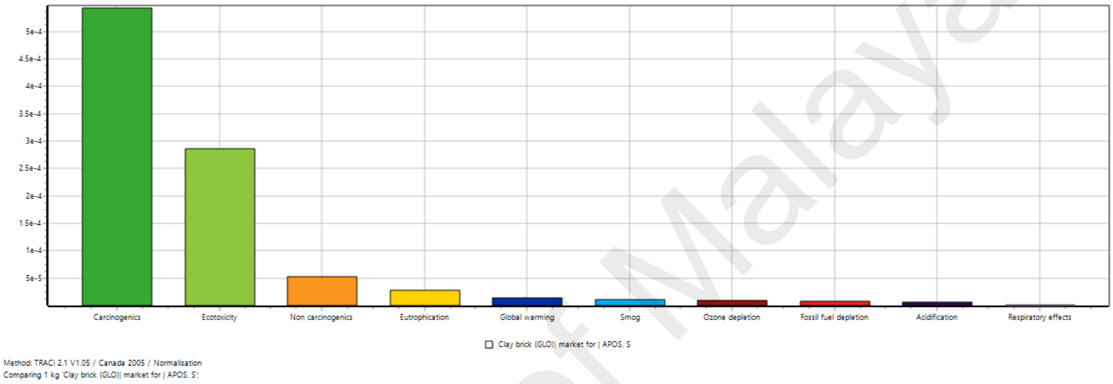


Figure 4.15: Impact Assessment of Clay Brick Production

Table 4.21: Impact Category and Impact Value of Clay Brick Production

Impact Category	**Impact Value**	**Percentage (%)**
Carcinogenics	0.000543	57
Ecotoxicity	0.000286	30
Non-Carcinogenics	5.27E-5	5
Eutrophication	2.85E-5	3
Global Warming	1.34E-5	1.4
Smog	1.02E-5	1.2
Ozone Depletion	8.67E-6	[redacted]
Fossil Fuel Depletion	8.03E-6	[redacted]
Acidification	6.8E-6	[redacted]
Respiratory effects	2.07E-6	[redacted]
Total	**0.00095**	[redacted]

The production of clay bricks discussed is involve in chemical consumption during the manufacturing process. The biggest impact contributed by this process is carcinogenic, which is 57%, followed by ecotoxicity with 30%. Therefore, the process studied in research does not use any significant amounts of chemicals. Therefore, it does not pose any threat to environmental, economic, or social factors. The other traces of negative impacts found in clay brick (with chemical consumption) are non-carcinogenic, eutrophication, global warming, and smog. Furthermore, even smaller traces of ozone depletion, fossil fuel depletion, acidification and respiratory effects.

4.13.2 Landfill of Hazardous Waste

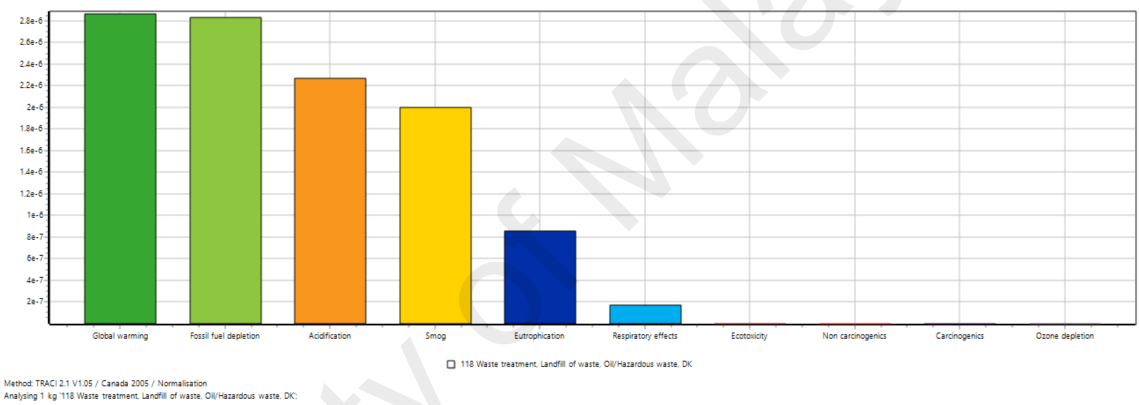


Figure 4.16: Impact Assessment of Landfill of Hazardous Waste

Table 4.22: Impact Category and Impact Value Landfill of Hazardous Waste

Impact Category	**Impact Value**
Global Warming	2.86E-6
Fossil Fuel Depletion	2.83E-6
Acidification	2.27E-6
Smog	2E-6
Eutrophication	8.6E-7
Respiratory effects	1.7E-7
Total	1.10E-05

The data shown above is the impact of landfilling hazardous waste. The impacts are global warming, fossil fuel depletion, and acidification. Other traces are, smog, eutrophication, and respiratory effects. The causes of such impacts are due to high raw materials (impact from mining and production) and electricity consumption (impacts of burning of fossil fuel). The waste must not end up in a landfill but can be utilised into more valuable material. Landfilling should be only considered for selected waste which is unable to be recovered at all.

4.14 General Safety and Health Aspects Based on Processes Involved in Study

4.14.1 Introduction

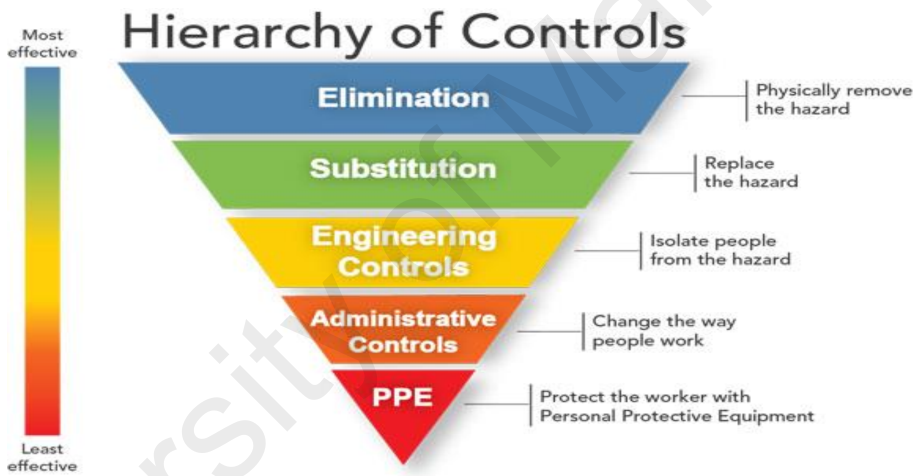
The Occupational Safety and Health Act of 1994, often known as Act 514, establishes the legal basis for all Malaysian workers' safety, health, and welfare. The principle is to prevent and protect workers from dangers and risks associated with their work activities. It mandates that all businesses establish and comply to documentation the following requirements:

1. safety and health policy,
2. the employer's, employees', and safety and health officers' responsibilities,
3. the company's safety and health committee, and
4. occupational safety and health inspections and officers.

Firstly, the implementation of safety and health in respective workplaces benefits both employers and employees. Secondly, workplace injuries and illnesses become preventable. Furthermore, by preventing workplace injuries and illnesses, the compensation cost is avoidable. Next, when workplaces commit to practising safety and health, the optimum productivity is achieved by reducing absenteeism and reducing down-time. Besides the long-term benefits, the practices of safety and health also create a positive image of a higher commitment level among customers and stakeholders. The following are among the measures to ensure the implementation of safety and health in any working facility.

4.14.2 Hierarchy of Controls

Limiting employee exposure to occupational hazards is the most basic approach to employee protection in any work condition and workplace. The processes involved in study also require aspects of safety and health for safe working condition. The hierarchy of controls helps in determining how to implement effective control solutions according to each condition at each worksite.



(Source: NIOSH)

Figure 4.17: Hierarchy of Controls

Effective controls assist organisations in providing employees with safe and healthy working conditions by protecting them from workplace hazards, preventing injuries, illnesses, incidents, and minimizing or eliminating minimising health risks. Implementation of the hierarchy of control assists organisations in building a safe operating system for their respective work spaces. The hierarchy of control must be carried out as per planned frequency to achieve maximum effectiveness in practicing safety and health aspects in any workplace or industry.

4.14.3 Good Practice of Housekeeping

Housekeeping can contribute towards controlling or eliminating workplace hazards. Incidents are frequently caused by poor housekeeping practices. Examples of typical components such as packaging, debris, clutter, and spills are considered serious threats and may be overlooked. It includes keeping work places clean and orderly, isolation of waste items and other fire dangers from work locations and keeping halls and floors free of slip and trip hazards. It also necessitates paying close attention to crucial elements such as the overall structure of the workplace, aisle marking, storage capacity, and upkeep. In addition to incident and fire prevention, good cleaning is essential. Housekeeping is effective if it is done on a regular basis (CCOHS, updated 2021).

4.14.4 Wearing Safety Gears

Safety gear is essential for certain jobs, as this equipment can safeguard workers from health and safety hazards while on the job and decrease employees' exposure to danger. Performing HIRARC or job safety analysis according to involved processes can identify the need for safety gear consumption. HIRARC related forms, table of risk severity is provided at Appendix section. The utilisation of safety gear provides protection to various body parts and functions. Example, respirators with appropriate filters, face shields and safety shoes suitable with work condition

Figure 4.18: Respirators on workers

According to emission results, the dust emissions in process 3 are relatively high, limiting the respirable crystalline silica (dust) permissible exposure limit (PEL) to 50 micrograms per cubic metre of air throughout an 8-hour shift. Silicosis is a chronic respiratory illness caused by inhaling large volumes of crystalline silica dust over a lengthy period of time. Silica is a mineral that can be found in a variety of stone, rock, sand, and clay. When working with these materials, a thin dust is produced that is easily breathed, National Health Service, (2021). Employers must apply engineering controls to reduce worker exposure, supply respirators if engineering controls are ineffective, limit worker access to high-exposure areas, and give medical evaluations to highly exposed workers, Industrial Safety and Hygiene News, (2017). Therefore, the employees need to be provided with suitable respirators to avoid silicosis disease. Silicosis is an interstitial lung disease caused by inhaling microscopic particles of silica, a common mineral. According to the American Lung Association (2020), exposure to silica particles causes pulmonary fibrosis, which is a persistent scarring of the lungs. The essential section before using safety gear is the understanding of the types of safety gear which are appropriate to the work industry and its nature.

A hazard assessment can be conducted at the workplace to identify suitable safety gear for consumption. Besides that, there should be awareness of the limitations and proper maintenance of safety gear. Training should be provided to expose the correct application and maintenance. By utilising safety gear in the correct way, the minimization of exposure to hazards that might cause significant numbers of workplace injuries and diseases.

4.14.5 Consistent and Adequate Training Opportunities

Providing safety training is a vital aspect as it benefits the overall workplace and its occupants as well, in terms of ensuring a safe and healthy work environment. The organization, by arranging safety training, helps employees identify safety hazards and take corrective actions. It permits employees to gain exposure to the most effective safety procedures and requirements. Furthermore, with consistent and adequate training, employees will have the ability to do their duties safely and without posing a risk to themselves or others. It is important to measure the efficiency of provided safety and health training to recognise if the frequency of training needs to be increased, followed by hands-on based training and implementation of continuous improvements.

CHAPTER 5: CONCLUSION AND RECOMMENDATIOS FOR FUTURE WORK

5.1 Conclusion

This study is primarily concerned with calculating carbon footprints, incorporating several processes such linear and circular economies, and treating waste with disposal methods. The first part of the study is done by defining the system boundaries of commercial and recovered clay bricks, as well as stabilization and solidification of sludge SW204. The system boundary of processes is identified and presented in flow chart form, which is complete with input, output, and emissions. After the defining phase, the inventory data and emission data of each process are collected by utilizing estimations based on secondary data available.

Next, the carbon footprint is calculated based on the consumption of electricity, water, fuel, raw materials, and waste generated. The calculation is based on the following equation: *Total CO2 emission (kg CO2) = Σ (Entity data × Entity Emission Factor).* The significant findings of the study are that the highest carbon footprint is released by P3: stabilization and solidification of sludge coded SW204, with an emission rate of 65 kg CO2 per 1kg sludge processing which is 61% comparative to other processes (P1 and P2). Using emission inventories, nine entities such as carbon monoxide, sulphur dioxide, and others, including exhaust, dust (PM2.5-PM10), and findings were varied according to the involved process. The following evaluation is done based on the economic feasibility of all the involved processes, selected components taken into consideration.

Based on several evaluations done, it can be concluded that process 2: recovered clay production is the best option in terms of carbon footprint reading and effective production cost. The total emissions emitted from recovered clay bricks per kg is 21 kg

CO_2 and the production cost is RM1.15. Besides the hazardous sludge being optimally utilised into building materials, cost savings is because disposal costs are avoided.

Developing recovery resource options from waste materials can curb issues such as illegal dumping into rivers, open fields, which at the end of the day will impact on water supply, ecotoxicity, river and marine life impacted, human health impact as well. The commercial clay bricks emitted 20 kg of CO_2 with a production cost of RM1.60. The emission is almost the same as P2 and the cost is higher by about RM0.50 (production cost). As mentioned above, P3: S/S treatment not only has the highest carbon footprint contributor but also the highest disposal cost, which is per kg of SW204 sludge requires RM6.50. With such expenditure, the waste load will end up in landfill without any beneficial value or profits. By reusing and recycling strategies (circular economy), it is possible to recover the economy. Sustainable waste management and lowering the carbon footprint are achievable.

5.2 Recommendations for Future Work

For future studies, there are several suggestions to be given. Firstly, carbon footprint analysis can be done on various waste recovery products or productions compare to commercial production, basically to suggest which process/activity is the better in terms of carbon footprint. Next, cleaner production assessment can be done for waste, emission and energy consumption reduction. A study on recovered clay brick production exemplifies the effectiveness of the circular economy.

Availability of data on appropriate compositions and leaching properties, will make recovered clay brick production more established. Following that, studies can be done on environmental impacts based on raw material consumption in P1, P2 and P3. The studies on efficiency of recovered material-based products compared commercially produced products. More research on the circular economy is needed to bring these concepts, which are economically beneficial and waste generation efficiently manageable, to fruition.

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