LIFE-CYCLE ASSESSMENT OF COMPRESSED BRICKS USING CAMERON HIGHLANDS RESERVOIR SEDIMENT AS PRIMARY MATERIAL: RECIPE METHOD

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering

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September 2021

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **“LIFE-CYCLE ASSESSMENT OF COMPRESSED BRICKS USING CAMERON HIGHLANDS RESERVOIR SEDIMENT AS PRIMARY MATERIAL: RECIPE METHOD”** was prepared by **TAN JIA HUI** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Honours) Civil Engineering at Universiti Tunku Abdul Rahman.

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ABSTRACT

Disposal of dredged sediments has recently been linked to a multitude of environmental and health issues, rather than bringing any economic value to the country. Furthermore, the overexploitation of clay for brick production is destructive to the environment. Hence, it is essential to develop a decisive method to minimize the land and water pollution resulting from improper disposal as well as lessening the consumption of natural resources in the brick production. The key objective of this study is to identify environmental impacts of compressed bricks using Cameron Highlands reservoir sediment as primary material. OpenLCA software is used to evaluate the environmental impact of one kilogram of compressed sediment brick and compressed clay brick by using allocation of Ecoinvent. The life cycle assessment is conducted in a cradle-to-gate manner. The production process and brick mixtures are based on a recent study conducted in Malaysia. This study also presents the avoided process of recycled sediments in the life cycle assessment. Moreover, the ReCiPe Midpoint approach analyses the environmental impacts categories such as climate change, human toxicity and freshwater ecotoxicity, whereas the damage categories are quantified in terms of human health, ecosystem and resource availability by using ReCiPe Endpoint indicator. According to the results of the LCA, compressed sediment brick with a mix proportion of 70 % sediment silt, 20 % sediment sand and 10 % cement is favourable from an environmental perspective. In comparison to compressed clay brick, the compressed sediment brick offers promising options for the long-term because it contributes high environmental performance among all the impact and damage categories assessed in this study. A review of engineering properties and cost for various types of bricks are also involved in this study. Overall, the compressed sediment brick is a cost-effective solution because it has been proven to generate lesser environmental impact and cost without compromising engineering properties.

TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

Ag	silver
Al	aluminium
As	arsenic
B	boron
Ba	barium
Ca	calcium
Cd	cadmium
Cl_2	chlorine
CO	carbon monoxide
CO_2	carbon dioxide
CN	cyanide
Cr	chromium
Cr^{6+}	hexavalent chromium
Cu	copper
Hg	mercury
K	potassium
Mg	magnesium
Pb	lead
PM	particulate matter
Na	sodium
Ni	nickel
Se	selenium
Sn	tin
SO_2	sulphur dioxide
Zn	zinc
1,4-DCB	1,4-dichlorobenzene

AAC	Autoclaved Aerated Concrete
AIST	National Institute of Advanced Industrial Science and Technology
APOS	Allocation at the Point of Substitution

DALY	Disability Adjusted Life Years
DOE	Malaysian Department of Environment
EOFP	Photochemical Oxidant Formation Potential: Ecosystems
EPA	United States Environmental Protection Agency
EPDs	Environmental Product Declarations
FCBTK	Fixed Chimney Bull’s Trench Kiln
FEP	Freshwater Eutrophication Potential
FETP	Freshwater Ecotoxicity Potential
FFP	Fossil Fuel Potential
GHG	Greenhouse Gas
GVW	Gross Vehicle Weight
GWP	Global Warming Potential
HOFP	Photochemical Oxidant Formation Potential: Humans
HTPc	Human Toxicity Potential: Cancer
HTPnc	Human Toxicity Potential: Non-Cancer
IRP	Ionising Radiation Potential
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LOP	Agricultural Land Occupation Potential
METP	Marine Ecotoxicity Potential
NA	Not Applicable
NIST	National Institute of Standards and Technology
PMFP	Particulate Matter Formation Potential
ODP	Ozone Depletion Potential
RIVM	Dutch National Institute for Public Health and the Environment
RoW	Rest-of-World
SDGs	Sustainable Development Goals
SEC	Specific Energy Consumption
SOP	Surplus Ore Potential
TAP	Terrestrial Acidification Potential
TCLP	Toxicity Characteristic Leaching Procedure

TETP	Terrestrial Ecotoxicity Potential
TNB	Tenaga Nasional Berhad
UAB	Universitat Autònoma de Barcelona
US EPA	United States Environmental Protection Agency
VSBK	Vertical Shaft Brick Kiln Technology
WCP	Water Consumption Potential

CHAPTER 1

INTRODUCTION

1.1 General Introduction

The conventional brick has been widely adopted for general use in building since the early civilisations. The raw material for the conventional brick is clay. (Zhang, 2013). In addition, the clay brick is recognised as the first artificial building unit in the construction sector worldwide (Fernandes, 2019). Nowadays, the fast-growing construction sector leads to a high demand of conventional brick due to its cost-effectiveness. However, the embodied energy of conventional bricks is about 2.0 kWh. Regarding the constituents of pollutants, the conventional brick accounts for 0.41 kg of carbon dioxide emission per brick (Reddy and Jagadish, 2003).

The compressed sediment brick is introduced as an alternative to conventional brick. A study shows that the Cameron Highland reservoir sediment has been identified as a potential method to produce compressed bricks (Chua, et al., 2014). Based on the findings, it is discovered that a total of 421,765 $m^3/year$ sediment accumulated in the Ringlet reservoir, Cameron Highland (Razad, et al., 2019). As a result, the reservoir is unable to meet the expected service life as the large portion of accumulated sediments contributes to a progressive reduction in the water storage capacity. Therefore, it is suggested to use the dredged reservoir sediment as the primary raw material for compressed brick. Also, there will be no shortage of raw materials for the manufacture of compressed sediment bricks as there is a tremendous number of sediments trapped in the reservoir.

To improve the environmental performance of manufactured goods, it is compulsory to assess the entire life cycle of the product associated with the environmental impacts. Life Cycle Assessment (LCA) is one of the useful approaches for environmental management. The term life cycle assessment denotes the environmental effects corresponding to all the stages of a product’s life (Liu, et al., 2014). The main characteristics of applying LCA are intuitively evident as it can transfer a product’s life cycle into appropriate information and avoid the deteriorating environmental conditions (Marcelino-Sadaba, et al., 2017).

In this study, the life cycle assessment of compressed sediment bricks will be analysed using a cradle-to-gate method which is composed of raw material acquisition, material processing and factory gate of production. With the aid of LCA, the whole or partial environmental impact of compressed clay brick and compressed sediment brick are comparable. Hence, the industry is able to determine the most well-optimised solution based on the analysis of LCA results (Hossain, et al., 2016). For sustainable brick production, the authorities should establish strict regulatory standards for the brick industry in order to control and manipulate the quality of bricks. It is undeniable that the development of green buildings starts from sustainable construction materials.

1.2 Research Background

Brick plays a pivotal role in the building and construction sector. Studies have proven that the consumption rate of raw materials for construction industry is approximately 3000 $\mathrm{Mt/year}$ which is equivalent to 50 $\%$ by weight of the global raw material resource (Pacheco-Torgal and Jalali, 2012). The production of conventional bricks is estimated at 1500 billion units annually for construction purposes (Maithel, 2014). Thus, the proper selection of brick material is crucial for sustainable development in the brick industry.

The preliminary study offers insight into the environmental performance of fired clay bricks. Over decades, the practices that have been frequently adopted to manufacture bricks in the construction sector are the traditional method which is governed by polluting kilns that generate tremendous amounts of contaminants such as carbon monoxide (CO), carbon dioxide ($\mathrm{CO_2}$), chlorine ($\mathrm{Cl_2}$), sulphur dioxide ($\mathrm{SO_2}$) and particulate matter (PM) into the climate (Ukwatta, et al., 2018). Rajarathnam, et al. (2014) point out that the brick kilns are responsible for 3.9 million tonnes of CO emission, 127 million tonnes of $\mathrm{CO_2}$ emission and 0.94 million tonnes of PM emission. The fired clay brick contributes significant greenhouse gas (GHG) emission which directly causes acid rains, global warming and climate change (Shakir and Mohammed, 2013). Thus, the environmental issues evolved from the manufacturing process of brick have become the main focus due to the rise of environmental concern.

In recent years, several studies have discussed the topic regarding the adoption of Cameron Highland reservoir sediments to replace compressed clay bricks (Manap, et al., 2016; Chua, et al., 2014). This is due to the fact that the sediment trapped in the reservoir drastically reduces the life expectancy of the reservoir. For instance, the storage capacity of Jor reservoir, Cameron Highlands experienced a reduction of 53 % in 2018 in comparison to the original design capacity of 3.85 million m^3 (Jansen, 2019). Hence, dredging of the sediments is one of the sedimentation control alternatives to restore the original intended storage capacity of Cameron Highland reservoir (Luis, et al., 2013). However, the disposal of dredged sediment to landfill brings adverse effects to the environment. When the dredged sediments are deposited in the disposal site, the leaching of contaminants affects the surrounding aquatic life and agricultural activities. Thus, the studies have been carried out to exploit the reservoir sediment in construction materials.

The study on properties of Cameron Highland reservoir sediment has been performed to investigate the potential usage of compressed sediment brick (Ooi, et al., 2015). The sources of sediment used in this study are extracted from the Cameron Highlands reservoir. The properties of compressed sediment brick are tested based on the allocated mix proportions of sediment silt, sediment sand and cement. Based on the result obtained, the most desired mix proportion of reservoir sediment is constituted of 70 % sediment silt, 20 % sediment sand and 10 % cement. It contains a relatively low concentration of heavy metals that show the absence of arsenic, chromium and zinc in the Toxicity Characteristic Leaching Procedure (TCLP). Hence, it completely adheres to United States Environmental Protection Agency (US EPA) regulatory limits which indicates the unavailability of hazardous content in the sediments. Thus, the compressed sediment brick is safe to be applied to the construction materials.

LCA is a good practice to assess the sustainability of construction materials (Russell-Smith, et al., 2015; Buyle, et al., 2013). Numerous studies show that the LCA is rapidly adopted for selecting suitable products with the least environmental impact as it is applicable to compare the same product made of different raw materials (Cabeza, et al., 2014). In general, the core of sustainable development is to holistically evaluate and manage the environmental effects of construction materials throughout their whole life cycle. To achieve goals towards a zero-emission and green construction, the essential efforts need scaling up through the implementation of LCA for all construction's phases.

The LCA studies have been performed for Mexico to outline the environmental effects of fired clay brick as well as enhancing the traditional process (López-Aguilar, et al., 2019). In this study, the brick kilns are categorised into scenario I (traditional manufacturing process), scenario II (traditional manufacturing process with one hopper-blower) and scenario III (traditional manufacturing process with two hopper-blower). The study is conducted in a cradle-to-gate method. Besides, LCA software SimaPro 7.3, Ecoinvent v. 2.2 databases and ReCiPe Midpoint method are the main parameters to analyse the environmental impacts in this study. The ReCiPe Midpoint method will assign 18 impact categories indicators so that the catastrophic consequences of each brick kiln scenario can be identified clearly. The result shows that the traditional manufacturing process with two hopper-blower attributes to a huge reduction of over 50 % in the environmental impact as compared to the traditional brick manufacturing process. In comparison to the traditional brick manufacturing process, the traditional manufacturing process with one hopper-blower and two hopper-blower contribute to a major part of climate change category reduction which drop 74 % and 67 % respectively. This research emphasises the importance of upgrading environmental technology in brick treatment to reduce life cycle impacts.

The scientific study has been dealing with the implementation of LCA to evaluate the fired clay bricks containing Waelz slag in terms of environmental impact (Muñoz, et al., 2018). This study assesses the environmental effects of fired clay brick and Waelz slag brick using a cradle-to-grave method. The ReCiPe Midpoint and Endpoint method are selected as LCIA method for this study. The outcome of ReCiPe method shows that the fired clay brick is the main triggering factor to fossil depletion with the impact output of 78.2 kg oil eq./tonne of bricks as compared to Waelz slag bricks with an output of 69.2 kg oil eq./tonne of bricks. As a matter of fact, Waelz slag brick with sulphur and fluorine content has been used during the firing process that promotes the discharge of toxic and acidifying species. On the contrary, climate change records the highest impacts generated in the fired clay bricks which amounted to 238 kg of CO_2 eq./tonne of bricks as compared to Waelz slag bricks with 210 kg of CO_2 eq./tonne of bricks. Regarding the ecosystem category, the Waelz slag bricks perform better than fired clay bricks as single point indicator for Waelz slag bricks (4.63 pt.) is lower than the fired clay bricks (5.16 pt.). Therefore, the LCA is undeniably important in selecting the suitable product that can minimise the environmental impacts.

1.3 Problem Statement

The manufacturing process of fired clay brick is the main problem that poses hazards to the environment. Clay is employed as the primary raw material for traditional bricks. For the production of fired clay brick, the brick will be fired at a high temperature in a kiln. Therefore, it is likely to have a high energy consumption for brick production through the firing process and directly releases an abundant amount of greenhouse gases that do not meet the minimum environmental standards (Monteiro and Vieira, 2014). Nonetheless, the fired clay brick production is not an eco-friendly method as it requires high quantities of non-renewable primary resources such as clay (Cappuyns, et al., 2015). The study done by Chen, et al. (2011) shows that China advocates the alternative bricks to limit the use of clay brick as the clay resources will be depleted soon with the continuous supply of clay brick.

Disposal of dredged sediments also becomes a problematic issue. Despite the continuous availability of sediments, the disposal area is limited in order to conserve the environment (Luis, et al., 2012). For waste disposal, Malaysia has 230 landfill sites (Mohd Masirin, et al., 2008). According to Xu, et al. (2014), many countries restrict the ocean disposal and landfills disposal for dredged sediments as it may cause profound environmental impact. For instance, the landfill gas and leachates are attributed to the improper conventional disposal method. Therefore, the Malaysia government introduces a proper landfill site categories guideline as a local benchmark to monitor and control the environmental impacts of the disposal site (Ahmad, et al., 2015).

In addition, there are fewer researchers applying LCA tools in their investigation as there is a limitation of database and information for the construction materials such as compressed sediment brick (Bovea and Powell, 2016). As mentioned in GlobalABC Regional Roadmap for Buildings and Construction in Asia, the ambitious regulations on LCA must be strictly executed for all building and construction sectors in 2030 (United Nations Environment Programme, 2020). This is because the existing project seldom takes LCA into consideration during the construction phase.

To date, there are no reliable studies to signify and compare the life cycle impacts of compressed clay brick and compressed sediment brick. Some studies have adopted LCA on the comparison between fired clay brick and harbour dredged sediment brick. Therefore, the LCA method will be fully utilised to present the first reliable result for the ecological impact of compressed sediment bricks. The attempt of this study is to examine the compressed bricks made of Cameron Highland reservoir sediments and their corresponding effects on the environment.

1.4 Aim and Objectives

The principal purpose of this study is to determine the life cycle assessment of compressed brick using sediment extracted from the Cameron Highlands reservoir with the aim to meet the progress towards Sustainable Development Goals (SDGs). After assessing the problems mentioned earlier, there are several objectives have been proposed as follows:

(i) To identify the life cycle inventory of compressed clay brick and compressed sediment brick using Allocation at the Point of Substitution (APOS) model.
(ii) To apply the ReCiPe method that could analyse the effects of compressed sediment brick on the environment.
(iii) To compare the environmental impacts resulting from the compressed clay brick and compressed sediment brick in a cradle-to-gate manner.

1.5 Scope and Limitation of the Study

The scope of the study is to examine the environmental impacts of the compressed brick using deposited sediments in Cameron Highlands reservoir as the raw material. The life cycle assessment of compressed sediment brick can be implemented to evaluate the environmental consequences of a product throughout its entire life stage after identifying all the inputs and outputs to be assessed in the study.

Nonetheless, there are some limitations in the scope of study area in order to narrow the research to a more explicit and specific topic. For example, the principal analysis of raw material in this study is the sediment deposited in the Cameron Highlands reservoir. The mixture proportion of compressed clay brick and compressed sediment brick are retrieved from the research studies of Ean (2014). Thus, it will be applied for LCA in this study.

The cradle-to-gate method is the constraint in the system boundary of the LCA. The cradle-to-gate method is usually used to evaluate raw material extraction, material processing and factory gate of product. As this method only involves partial life cycle assessment, the transportation of product from factory to market, product usage and disposal phase will not be analysed in this study.

The central database used in this study is retrieved from the Ecoinvent although there are plenty of choices available to extract the data. The term Ecoinvent database is expressed as a Life Cycle Inventory (LCI) that is customarily used to gather all the relevant data and information of products. Moreover, the data can be obtained from the published report or academic publication if it is not accessible from Ecoinvent.

Apart from that, the ReCiPe method is selected as the life cycle impact assessment in this study. The ReCiPe is the system used to evaluate the life cycle impact assessment of compressed clay brick and compressed sediment brick. The ReCiPe Midpoint and Endpoint indicator will be applied in the study to identify the short-term and long-term environmental impacts.

1.6 Significance of Study

This study focuses on the life cycle assessment of compressed bricks using Cameron Highlands reservoir sediment as the primary material. As the construction sector is in a fast-evolving development, the demand for bricks is increasing ubiquitous. There is no doubt that rapid commercialism and urbanisation contribute to a potential risk to environmental quality. Therefore, it is necessary to employ other strategies to maintain the natural ecosystem whilst boosting human life quality.

Life cycle assessment is one of the most reliable methods to ascertain the environmental impacts of a product over its entire life cycle. With the aid of the LCA method, it is likely to provide a detailed and comprehensive explanation on the input and output of each brick's life stage. It enables the brick industry to compare the life cycle of compressed clay brick and compressed sediment brick in terms of environmental impacts. Therefore, the industry can promote sustainable bricks that cope with the vast amount of emissions. Additionally, the implementation of LCA as a building and construction guideline will significantly protect and enhance the environmental standard.

After applying LCA to a building project, the engineers can develop solutions to utilise the construction materials while considering the limitations imposed by environmental effects. Furthermore, the brick can be designed to be low-emitting construction material. This study stresses the importance of LCA application in the building and construction sector in order to minimise the emission of toxic and harmful substances. The construction material selections must harmonise with the environment.

1.7 Outline of the Report

In this study, there are a total of five chapters to elaborate the life cycle assessment of compressed bricks using Cameron Highlands reservoir sediment as primary material by adopting the ReCiPe method.

Chapter 1 in this study depicts introduction, research background, problem statements, objectives, scope of work, significance of study and outline of study. Thus, the reader has a better understanding of the topic that had been chosen to establish facts and new outcomes at the end of the study.

Chapter 2 mainly focuses on the literature review relevant to the compressed clay brick and compressed sediment brick in this study. This chapter will outline numerous comprehensive studies to overview impacts of brick production on the environment. It also highlights the advantages of using the LCA method in all life stages of a product. In the end, the significance of comprehending the application of the LCA method in assessing environmental effects is addressed.

The methodology of the study is discussed in Chapter 3 that covers a wide range of scopes, including the collection of brick characteristics, definition of system boundary, input of collected data, interpretation of life cycle assessment and so forth. Besides, it is required to establish the midpoint and endpoint indicators in the ReCiPe method in order to analyse the impacts of possible future scenarios.

In this study, Chapter 4 addresses all the results presented in the form of graphs, tables, and so forth; thus, a complete and clear discussion is made based on the results obtained. Furthermore, the most desired product with the minimal environmental impacts will be proposed after comparing the output of the products. It also highlights the engineering properties and cost as well.

Last but not least, Chapter 5 summarises all the outcomes of this study and the recommendations for further work. In future, the researchers can extend the analysis presented in this final year project to a broader scope.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter delivers a brief glimpse of compressed bricks using Cameron Highlands reservoir sediment and its corresponding environmental impacts. As brick production has increased substantially in recent years, the environmental impacts will be assessed based on phases from raw material acquisition until the factory gate of brick. It also discusses the application of life cycle assessment tool and database to generate a detailed assessment on the environmental effects of compressed sediment brick.

2.2 Clay Bricks

Brick is defined as one of the ancient man-made construction materials in the world. The researchers discovered the first hand-moulded and sun-dried clay bricks which are used to construct the Nile deposits in Egypt in the early 14 000 BC (Kadir, 2012). In South Asia, clay material has been mainly selected to manufacture bricks because it provides higher fire resistance and higher durability (Sutcu, et al., 2019). Besides, the clay brick is further distinguished into fired clay brick and unfired clay brick.

Several existing studies deal with the physical and chemical properties of fired clay bricks as well as the mineralogical composition. Gömze, et al. (2019) demonstrate that the fired clay brick has an advantage in producing high-quality ceramic roof tiles by adopting plastic forming technique. The result proves that the ceramic roof tiles possess good bending strength when large quantities of amorphous nanoparticles exist in the clay.

For sustainable brick development, unfired brick has been promoted to replace the fired clay brick. Oti and Kinuthia (2012) state that unfired clay brick is the most favourable building material as compared to fired clay brick. The main environmental issues relating to clay brick production are evaluated using the BREEAM environmental and sustainability scoring framework. As a result, the unfired clay brick outperforms the fired clay brick in terms of energy saving. Unfired clay brick is a more environmentally friendly alternative.

2.2.1 Methods of Producing Clay Bricks

The production of clay bricks was established in the early Mesopotamian, Egyptian, and Roman (Fernandes, et al., 2010). The firing method is the most commonly used brick making process in the global brick industry. The raw material for traditional production of bricks is clay. The production of fired clay bricks takes account of several steps as shown in Figure 2.1.

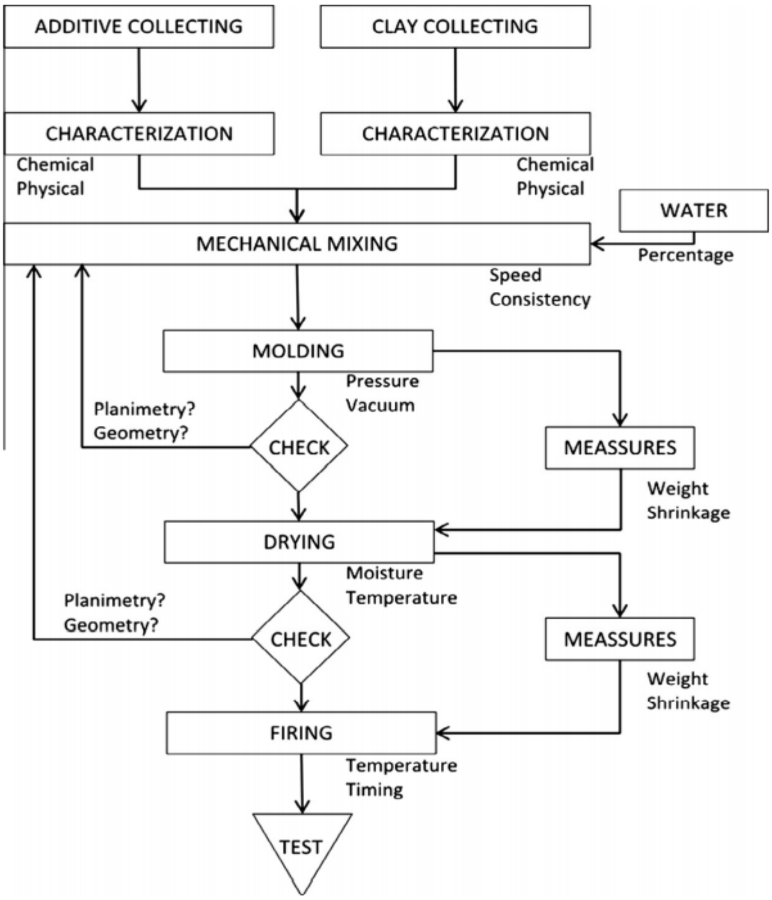


Figure 2.1: Brick Making Procedures (Muñoz, et al., 2014).

The first step of brick production is the excavation of raw material. After removing clay from soil particles, it will be sent to the kiln site to mix with water and other additives. The quality of clay will alter the physical and mechanical properties of the brick. Hence, the clay typically entails crushing and sieving before the clay moulding (Weyant, et al., 2016).

The traditional form of bricks is usually hand moulded and placed in an open area to make it sun-dried. In contrast, traditional hand moulding is getting replaced by mechanised moulding in this modern era. Undeniably, mechanised moulding improves the consistency and flexibility of bricks as well as combating the shortage of skilled workers in traditional brick production.

Drying is expressed as removing the additional water in the clay during the mechanical mixing stage. The clay must be kept in a dry condition after the brick has been moulded. It is exposed either in the open air-drying method or mechanical drying method. To avoid the swelling or bloating of the clay brick, the drying phase must be executed before the firing stage. This is due to high temperature of the firing process will trigger the expansion of entrapped water inside brick (Dalkılıç and Nabikoğlu, 2017).

Firing is the last phase of the conventional brick making process. The firing step is carried out with the aim to produce high strength clay bricks. The brick kiln firing normally requires high temperature ranging from 900 ℃ to 1000 ℃ (Yang, et al., 2014). Moreover, the quality of bricks is greatly influenced by the firing temperature and firing time. The firing temperature and time reveal several obvious consequences on the appearance of clay brick, including expansion, weight loss and an alteration in brick colours. Figure 2.2 indicates the most desired firing schedule to generate high quality of fired bricks.

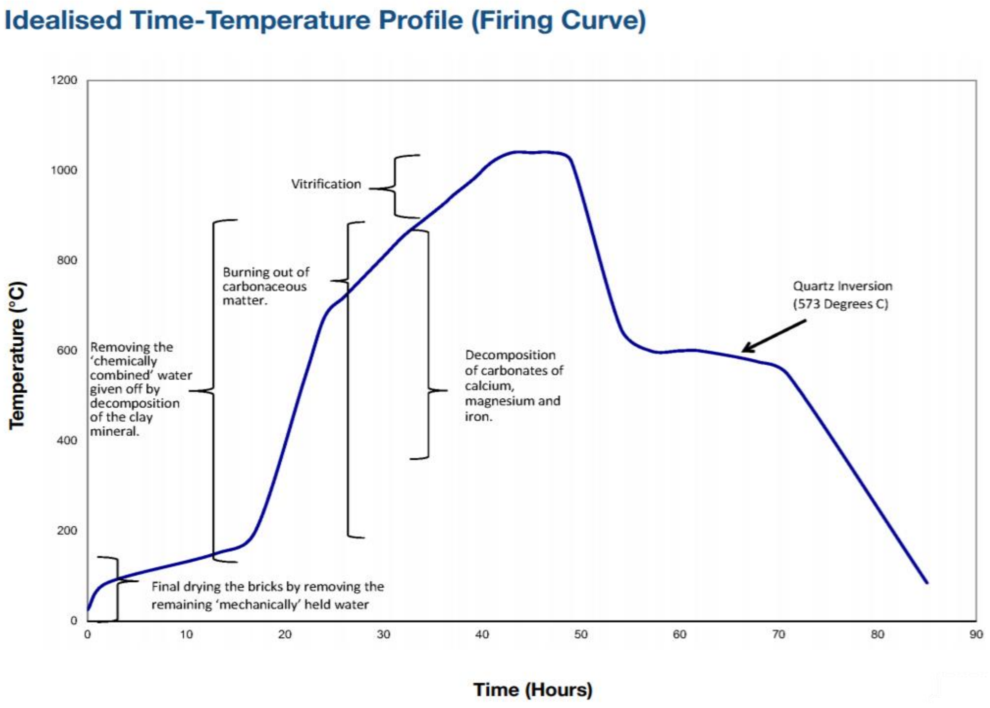


Figure 2.2: Schedule for Firing Temperature and Time (Brick Development Association, 2017).

In South and South-East Asia, various brick production technologies have been developed for brick kilns such as fixed chimney bull’s trench kiln (FCBTK), natural draught zigzag firing technology, high draught zigzag firing technology, vertical shaft brick kiln technology (VSBK), hoffman kiln technology, hybrid hoffman kiln technology, tunnel kiln technology and down draught kiln (Maithel, 2014). The selection of kiln technology by the brick manufacturer is focused primarily on the operational needs of brick. As the operation standard of each kiln technology is completely different, the energy consumption of the kiln technology is varying as well, and it leads to various emission factors.

The unfired clay brick is also known as compressed clay brick or green bricks. Unfired clay brick is usually formed by compaction. For the unfired clay brick, the manufacturing process is almost the same as fired clay brick except for the firing process. Instead of the firing method, the unfired clay bricks are left in the air to dry in a stable environment (Sutton, et al., 2011). Therefore, the total embodied energy of unfired clay brick is greatly reduced by the air-drying process.

2.2.2 Environmental Impact of Clay Bricks

Prior to the application of building materials, it is required to ascertain the environmental impact of clay bricks. The environmental assessment aids in generating low-emitting brick product throughout its life cycle.

The carbon emission is attributed to the entire life cycle of conventional brick from extraction of raw materials, production, distribution, construction to the end of useful life. Thus, the overall carbon footprint is conspicuously escalating as most of the building and construction sectors depend largely on the conventional method to produce bricks. Figure 2.3 depicts the amount of carbon emission for each stage of clay brick. It can be observed that 90 % of carbon emissions from the raw material and production phase. Furthermore, the bricks used for construction, distribution and disposal achieve the carbon emission rate of 5 %, 3 % and 2 % respectively. The brick will not emit any carbon dioxide into the environment when the brick is in use. Additionally, the reduction of carbon emission is indicated by the negative value. For instance, reuse and recycling of brick can save a total of 7 % of carbon emissions.

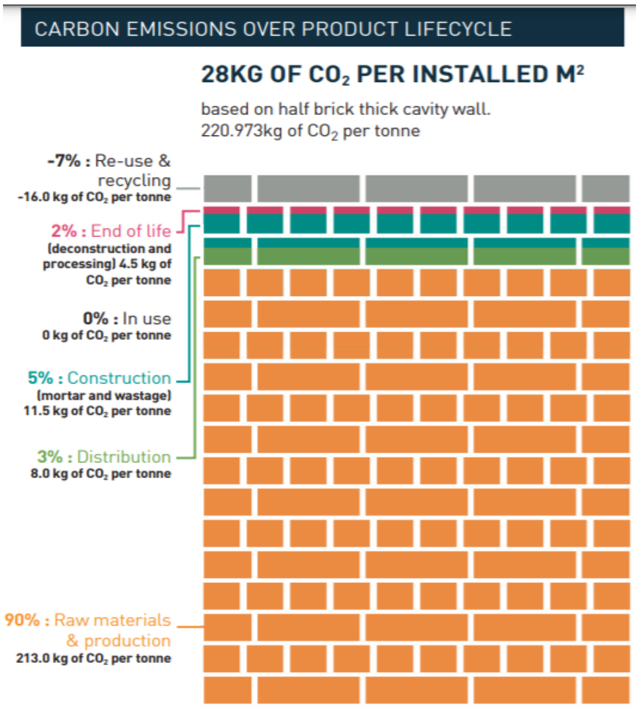


Figure 2.3: The Carbon Emissions of Clay Brick throughout its Lifecycle (Brick Development Association, 2020).

The clay brick leads to the reduction of clay soil if the clay soil is kept applied as the main raw material in the brick making process. Refer to the previous study, clay brick production shows a greater reliance on clay soil. Moreover, clay is known as a non-renewable material. It indicates that the clay source will eventually run out when the over-exploitation of clay resources occurs in the brick making process. As a result, China has forbidden the production and usage of clay bricks, and alternative methods are advocated to replace the clay bricks (Chen, et al., 2011).

Other than that, the fired clay bricks bring adverse effects to the environment. The fired clay brick consumes a substantial amount of energy as it requires a relatively high temperature to conduct the kiln firing stage (Ahmari and Zhang, 2012). The embodied energy is predicted about 2.0 kWh for each fired clay brick, and the production stage of fired clay bricks accounts for 0.41 kg of CO_2 into the environment (Hwang and Huynh, 2015). Therefore, the fired clay bricks produce significant amounts of carbon dioxide and greenhouse gases which are correlated to global warming and climate change.

Maheshwari and Jain (2017) study the carbon emissions of the fired clay brick manufacturing process in India. The primary intention of their study is to determine the overall environmental performance of fixed chimney bull's trench kilns during the firing process. The result presents that the contaminants originated from the combustion of fuels during the firing process in brick kilns. The fuels used in the brick kiln include coal, firewood, bagasse and rice husk. According to the investigations, the carbon emissions are found to be 1.614 $\mathrm{t\,CO_2/ton}$ of coal for the coal used in firing kilns. The total carbon emission from bagasse combustion is estimated around 709.9 g $\mathrm{CO_2}$/kg of bagasse. Thus, firewood is the major contributor to the emissions of greenhouse gases. The carbon emission for firewood biomass in the firing stage is 1.644 $\mathrm{t\,CO_2}$ of firewood. The carbon emission is approximately 880.48 g $\mathrm{CO_2}$/kg of rice husk which is derived from the rice husk during the firing process.

The brick kiln technologies pose a different level of adverse effects on the environment. Table 2.1 displays the environmental performance of kiln technologies during the firing stage. The environmental efficiency of brick kilns can be concluded based on the amount of harmful substances released from the kilns.

Table 2.1: Overview of Environmental Performance for Different Kiln Technologies (Maithel, 2014).

Parameters		**FCBTK**	**Natural Draught Zigzag**	**High Draught Zigzag**	**VSBK**	**Hoffman kiln**	**Hybrid Hoffman kiln**	**Tunnel**	**Down draft kiln**
Air Emission (g/kg fired brick)	CO_2	131	105	105	70.5	NA	100	166.3	282.4
	Black Carbon	0.13	0.01	0.02	0.001	NA	NA	0.00	0.29
	PM	1.18	0.22	0.24	0.15	NA	0.29	0.24	1.56
	CO	2.0	0.29	1.62	1.84	NA	NA	3.31	5.78
Fuel and Energy	SEC (MJ/kg fired brick)	1.30	1.06	1.03	0.8	1.36	1.20	1.4	2.97

Remarks:

1. SEC represents “Specific Energy Consumption” for fuel and energy.
2. NA denotes “Not Applicable” in determining the environmental performance for the specific kiln technology.

2.3 Sediment Bricks

Sediment brick is another alternative to be adopted in construction sites rather than clay brick. The researchers propose a new methodology of using reservoir sediment instead of clay in the brick production with the objective of transforming the world into completely "green" that will benefit future generations as well as our own. In this study, the primary raw material in the production of compressed bricks is extracted from Cameron Highlands reservoir sediment.

2.3.1 Reservoir Sedimentation

All reservoirs worldwide encounter a critical sedimentation issue as there is no flexible planning to facilitate the operation of reservoirs. The average sedimentation rates involving many regions in the world are tabulated in Table 2.2. The Middle East possesses the highest average sedimentation rate followed by Australia and Oceania, Africa and Asia (Batuca and Jordaan Jr, 2000). Besides, the hydropower dams require 80 % of water resources from the reservoir while another 70 % water resources will be served for other uses. For example, the Asia region will fully utilise 80 % of the reservoir's water storage for generating hydropower in 2100. However, the remaining 70 % of the storage capacity used for other purposes will eventually stop functioning in 2090.

Table 2.2: The Storage Capacity of Reservoir (Basson, 2009).

Continents	**Annual Sedimentation Rate**	**Hydropower Dams: 80%**	**Other Uses Dams: 70%**
Africa	0.85 %	2100	2090
Australia and Oceania	0.94 %	2070	2080
Asia	0.79 %	2035	2025
Central America	0.74 %	2060	2040
Europe	0.73 %	2080	2060
Middle East	1.02 %	2060	2030
North America	0.68 %	2060	2070
South America	0.75 %	2080	2060

The sediment deposition in the reservoir poses a serious issue as it directly affects the useful life of the reservoir. The study is done by Razad, et al. (2019) to calculate the sediment yield of Ringlet reservoir by adopting RUSLE-SDR. In 2016, the capacity of the Ringlet reservoir declined drastically with the storage volume decreasing from 6 700 000 m^3 to 3 264 644 m^3. The sediment yield in the reservoir is estimated at about 421 765 m^3/year, and indirectly led to the deduction of the existing reservoir's lifespan. Table 2.3 displays the overall operation of Ringlet reservoir, Cameron Highlands.

Table 2.3: Summary of Sediment Yield in Ringlet Reservoir (Razad, et al., 2019).

Description	**Ringlet Reservoir**
Catchment area (km^2)	183
Completion year	1963
Original storage volume (m^3)	6 700 000
Storage volume in 2016 (m^3)	3 264 644
Average rate of erosion (ton/ha/year)	90
Estimated sediment yield (m^3/year)	421 765

2.3.2 Study Area of Reservoirs

In this study, Cameron Highlands reservoir is selected as the research site. Cameron Highlands is part of Pahang state, Peninsular Malaysia. Cameron Highlands occupies about 71 218 hectare area (Gasim, et al., 2009). The latitude and longitude of Cameron Highlands range from 4°19'N to 4°37'N and 101°21'E to 101°31'E respectively. The altitude of Cameron Highlands lies at 1545 m as it is situated at high elevation. Bertam River, Telom River and Lemoi River are three leading rivers in Cameron Highlands that provide clean water resources for domestic and commercial purposes, such as recreation, navigation, agricultural, irrigation, and hydropower generations.

In early 1959, Tenaga Nasional Berhad (TNB) tried to establish the Cameron Highlands and Batang Hydroelectric Scheme (Luis, et al., 2012). As a result, the Cameron Highlands and Batang Padang Hydroelectric Scheme construction had been accomplished in 1964. The principal objective of Cameron Highlands-Batang Padang Hydroelectric Scheme is to generate and store the energy by involving three main reservoirs namely Ringlet, Jor and Mahang reservoirs. Under this scheme, the total hydropower generated from Jor, Woh and Odak power station is expected to achieve 262 MW hydropower. Figure 2.4 shows the area coverage of Cameron Highlands Batang Padang Hydroelectric Scheme.

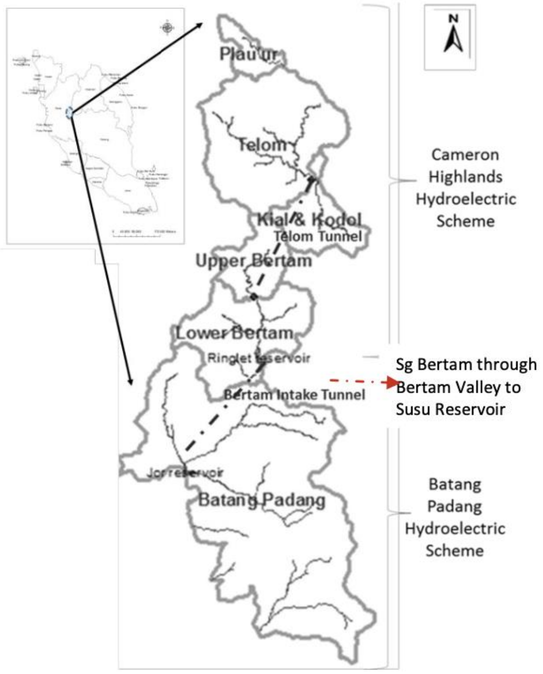


Figure 2.4: Cameron Highlands Batang Padang Hydroelectric Scheme (Razad, et al., 2018).

2.3.2.1 Ringlet Reservoir

In 1963, the Ringlet reservoir was built near the Sultan Abu Bakar dam (Jaafar, et al., 2010). The length of the Ringlet reservoir is designed approximately 3.2 km, whereas the width for the whole reservoir is 0.4 km (Tayebiyan, et al., 2016). It can store all the water discharged concurrently from Telom tunnel and the Bertam river. The maximum elevation level for the reservoir is 1070.7 m, while the reservoir area is 60 hectares (Luis, et al., 2013). The reservoir is expected to support 6.7 million m^3 of water storage. Based on research, the Ringlet reservoir provides 4.7 million m^3 of live storage, and another 1.6

million m^3 of inactive storage (Choy and Hamzah, 2001). Dead storage refers to a reservoir extending its period of operation around 80 years.

2.3.2.2 Jor Reservoir

Jor reservoir lies between Ringlet reservoir and Mahang reservoir. The estimated storage capacity of Jor reservoir is about 3.85 million m^3. For Jor reservoir, the capacity is filled with 2.1 million m^3 active storage while the residue stands for dead storage. The Jor reservoir is built with a 32 hectares reservoir area at the maximum supply level to safeguard the water storage is adequate for future use (Sidek, et al., 2011). Through Sultan Yussuf power station, Jor reservoir in Batang Padang district will receive the water resources from the reservoir at the upstream. After that, Jor reservoir will open the gate to discharge water into Woh power station.

2.3.2.3 Mahang Reservoir

Mahang reservoir is one of the crucial reservoirs that is engaged in the Cameron Highlands and Batang Padang Hydroelectric Scheme. Mahang reservoir is situated downstream of Jor reservoir. The operation of Mahang reservoir suits the design lifetime of the reservoir as the reservoir construction had been completed since 1963. The initial design capacity of Mahang reservoir is 0.4 million m^3 (Razad, et al., 2018). The main source of Mahang reservoir comes from the tailrace of Woh power station. Figure 2.5 shows a clear illustration of the discharge of water into Mahang reservoir.

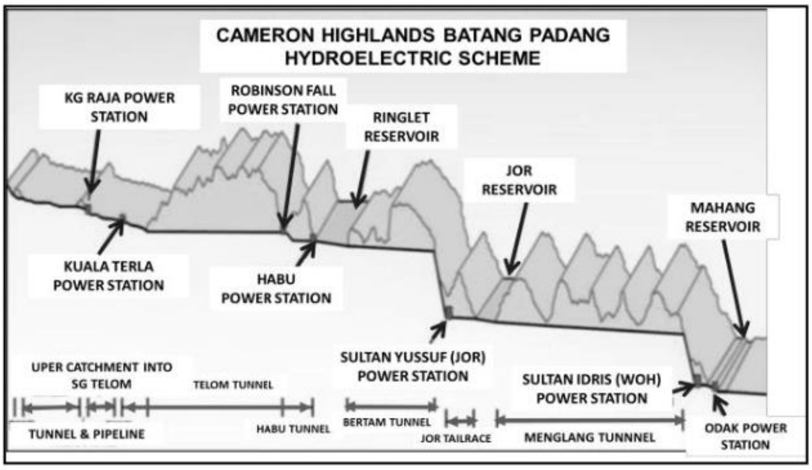


Figure 2.5: Reservoirs in Cameron Highlands (Razad, et al., 2018).

2.3.3 Sediment Characteristics

The sediment has been gathered from Sg. Habu and Sg. Jasik in order to investigate the properties of sediment trapped in Cameron Highlands reservoirs (Chua, et al., 2013). The identification of various sediment types in a particular area is specified based on particle size distribution by using the sediment classification scheme as shown in Table 2.4. The percentage of silt and sand in Sg. Jasik is 49.5 % and 35.4 % respectively, whereas the gravel fraction in Sg. Jasik is merely 4.4 %. Thus, the soil classification for Sg. Jasik is a well-graded clayey sandy silt. The sediment from Sg. Habu is distinguished as well-graded gravely sand due to the sand fraction in Sg. Habu has a relatively high percentage of particles (80.33 %) followed by gravel particles (19.67 %).

Table 2.4: Sediment Classification (Chua, et al., 2013).

Soil Types	**Percentage of Particles (%)**	
	Sg. Jasik	**Sg. Habu**
Gravel	4.4	19.67
Sand	35.4	80.33
Silt	49.5	-
Clay	10.7	-

2.3.4 Sediment Transport

The sediment load denotes the entire volume of sediment particles being distributed by flowing through the reservoir. The sediments load to the reservoir can be transported in many forms such as bed load, suspended load and so forth. It mainly depends on the grain size of sediments and the surface area of drainage. For instance, the bed load is composed of coarse sediment (Annandale, et al., 2016). The bed load is transported closely with the river bed, whereas the suspended load shows an inverse sediment transport method to the suspended load. In addition, there are few types of suspended load in the transport processes, namely sand, clay and fine silt (Wohl and Cenderelli, 2000).

2.3.5 Factors that Contribute to Reservoir Sedimentation

The majority of the reservoir is subjected to sedimentation which endangers the sustainability operation of the reservoir. Hence, the authorities need to examine the origin of reservoir sedimentation before applying their professional and scientific knowledge to solve the existing reservoir threats. There are some triggering issues that cause the accumulation of sediments in the reservoir.

Watershed topography is one of the noteworthy factors that provoke reservoir sedimentation. The study shows that 18 226 hectares or 26 % of the region in Cameron Highlands is categorised as a steeper slope with a gradient of more than 25° (Razali, et al., 2018a). The slopes with a degree exceed 35° is merely occupying 3 % or 2039 hectares of lands in Cameron Highlands. The study also mentions that the areas with steep slopes greater than 25° are not suitable for construction as they possess a high probability of soil erosion (Razali, et al., 2018b). The transportation rate of soil particles will vary depending upon the amount of soil erosion. The soil erosion consequently induces a large amount of sediment into the reservoir.

Land use evolution in the watershed area may evoke the reservoir sedimentation issue. To attain the vision towards a prosperous country, the land clearing activities for agricultural, mining, roads, and residential development have been progressively conducted. As a matter of fact, sediments in reservoirs originate from soil erosion in respect to the swift conversion of land use to commercial and residential events. According to Muhammad, et al. (2015), it is discovered that 18.95 % of land transformation in 1997 to 2014. The extensive deforestation in Cameron Highlands will be further conducted using 3.66 % of land from 2014 to 2020. It is forecasted that a large scale of land will be used for mixed farming (12.24 %) followed by open land (5.47 %), new town (0.85 %) and open water (0.54 %). The extensive change in land use accelerates the process of sedimentation in the reservoir.

In summary, the sedimentation problems may seem complicated because the reservoir fails to meet the initial designed demand. Therefore, a great deal of sediment management must be employed to tackle the potential problems before the storage volume of the reservoir is totally lost to sedimentation.

2.3.6 Impacts of Reservoir Sedimentation

The original concept of reservoir design is introduced by the design engineer in order to modernize the engineering applications. However, the sediments deposited in the reservoir do not meet the desired outcome of the design intention. Thus, it is essential to moderate the impacts of sedimentation.

The severity of storage loss is the key deficiency of sedimentation (Chaudhry, 2012). The reliability of water supplies has rapidly decreased when the sediment concentration in the reservoir is steadily increasing. The depletion of reservoir storage indicates that the life of a reservoir will be shortened as well. Hence, it is unable to serve for irrigation and municipal water supply in the future.

The water supply from the reservoir is not suitable for water consumption. The reservoir filled with excessive sediments constitutes a health risk for human beings if the water quality is being badly degraded by the pollutants (Habibi, et al., 2019). It also requires a high water treatment cost to treat the contaminants. This regrettably exploits the deposition of sediments in the reservoir, resulting in a loss of water storage capacity and water supply.

The reservoir sedimentation contributes to the greatest impact on the operation performance of hydropower stations (Haun and Olsen, 2012). The hydropower station will be subjected to functional loss of energy generation due to frequent hydropower station closure. From the economic perspective, it is forecasted to cause a drop in the revenue for hydropower reservoirs. Human beings will face a shortage of resources as the hydropower station will no longer accommodate the energy supply.

The reservoir sedimentation has resulted in high exposure to flooding events, especially during the monsoon season (Luis, et al., 2014). The flood disaster will directly affect the safety of the human population and huge damages to property. Owing to the accumulation of sediments in reservoirs, the authorities need to spend high expenses of reservoir maintenance and service in order to excavate and dispose of millions of tons of sediments in the reservoir.

In short, the reservoir sedimentation brings a lot of negative impacts associated with the environment, economic and social activities. There is the necessity for the authorities to speed up the sustainable development, research, enactment and integration of sediment removal technologies.

2.3.7 Sediment Mitigation Methods

The sediment mitigation method is an adaptive strategy to extend the design lifetime of a reservoir. The sediment mitigation methods aid the authorities in strengthening their remedial approaches and undertaking advanced sediment removal techniques so that the deposited sediments in the reservoir can be periodically removed. Several attempts are being made by the authorities to recover the design life of a reservoir. According to Razad, et al. (2019), Tenaga Nasional Berhad (TNB) paid enormous expenses with a total amount of RM 180 million to remove the sediments trapped in the reservoir since 2001. As the quantities of sediments deposited in the reservoir were on the rise, an upturn in recurring expenses had reached to RM 40 million in 2014. The government aims to excavate a total of 750 000 m^3 sediments annually so that Ringlet Reservoir can restore its original intended storage capacity. Figure 2.6 shows the sediment removal approaches that had been used in the Ringlet reservoir, Cameron Highlands. There are a wide variety of sediment mitigation methods to be adopted in the reservoir. The authorities have to consider all the local criteria in the reservoir such as reservoir condition and sediment types in order to decide the best practical way that suits the current situation.

Figure 2.6: Sediment Mitigation Approaches in Ringlet Reservoir (Razad, et al., 2019).

2.3.7.1 Dredging

Dredging is the most frequently applied strategy to combat the sediment retained in the reservoir. The tools used for the dredging activities consist of backhoes, trucks, draglines, clamshell and so forth. With the aid of dredged equipment, it tends to alleviate the sediments deposition so that the storage capacity of the reservoir can be restored in a short period. In spite of this, the dredging method is limited to coarse sediment only; thereby, it is not applicable to excavate the fine sediments accumulated in the reservoir. After dredging the sediments trapped in the reservoir, it is transported to the landfill area for disposal. The cost for dredging and disposal of sediments is considerably expensive as compared to other methods (Kondolf, et al., 2014).

2.3.7.2 Flushing

Flushing is one of the remarkable techniques to manage and regulate the sediment retained in the reservoir. Flushing is the process of transporting the eroded and resuspended accumulated sediments through low-level gates under a critical flow velocity in the reservoir. During monsoon season, the low-level gates will be fully opened to remove the silt in the reservoir as there is a sharp rise in the water level. Flushing is perhaps the best method that can remove fine and coarse sediments at the same time. Nevertheless, the limitation of the flushing method is inefficient coarse sediment removal when discharge flow is extremely low during the non-flood season (Espa, et al., 2019).

2.3.7.3 Sediment Basin

Prior to the entry of water into the reservoir, sediment basin is offered to control the sediments in the catchment area. Typically, a sediment basin is constituted of dam, spillway and embankment to control the portion of sediment flowing into the reservoir. The sediment basin is divided into wet basin and dry basin. The types of sediment basin will be applied based on the reservoir criteria. The major functionality of sediment basin is to trap 70 % of coarse sediment with particle size exceed 0.04 mm (Department of Irrigation and Drainage Malaysia, 2010). The maintenance of the sediment basin should be implemented periodically to ensure the sediment basin works efficiently during its design life.

2.3.8 Manufacturing Process of Sediment Brick

The production of bricks will begin to operate by using the dredged reservoir sediment as the main source of raw materials. To minimise the carbon footprint, many studies have been proposed to convert the reservoir sediment today into brick resources. The firing and unfiring method are the most commonly adopted techniques to form sediment brick in the world.

The firing method is ideal to be applied in the production of sediment brick. A study performed by Slimanou, et al. (2020) has discovered that the sediment is extracted from the harbour to perform as the main resources in fired clay brick production. The brick samples with varying proportions of harbour dredged sediment are fired at temperatures ranging from 850 ℃ to 950 ℃. The findings reveal that the firing temperature and proportions of dredged sediment used in the building bricks are contributing parameters that determine the quality of the sediment bricks in terms of their physical and mechanical properties. Hence, harbour dredged sediment is appropriate to be used for the replacement of fired clay brick.

According to Xu, et al. (2014), the firing of brick can be used to generate highly insulating brick by adopting sediments from the urban river as primary raw material. The firing temperature is fixed at 1000 ℃, 1050 ℃ and 1100 ℃ for the mixture of urban river sediments and clay. The physical-mechanical properties of the fired sediment bricks like compressive strength will be examined according to the standards. After performing the brick test, it is discovered that the bricks with 50 % urban river sediments fired at 1050 ℃ display more desired attributes in contrast to other brick samples. In addition, the result reveals that the fired bricks containing urban river sediments are an appropriate alternative to the fired clay bricks.

On top of that, unfired brick is considered an environmentally friendly option for the sediment brick making process. Cheng, et al. (2014) suggests to create non-sintered cured brick by using hydropower plant reservoir sediment blended with cement and curing agent. The process of non-sintered cured brick is conducted under high pressure, and it requires 28 days to cure naturally. It is noticed that the non-sintered cured bricks have a relatively high density and low water absorption as compared to compressed clay bricks. Besides, the shrinkage exists on the brick and relies closely on the water absorption of the brick.

The sediment in unfired bricks is outlined in the study done by Wang, et al. (2017). The sediments studied are collected from the harbour and water channel. The collected sediments mix with binary cement which includes magnesium oxide cement and ordinary Portland cement. It is found that a sufficient amount of magnesium hydrates from binary cement aids in the metal sequestration. However, the compressive strength of sediment bricks is indeed very low due to the availability of magnesium oxide in binary cement. Consequently, the $\mathrm{CO_2}$ curing method is introduced to convert the soluble magnesium hydrate into balanced carbonates. The curing process with $\mathrm{CO_2}$ for the sediments take one day, and the air curing process will take seven days. This method demonstrates a significant reduction in porosity that supports the improvement of brick strength and carbon sequestration.

2.3.9 Physical Properties of Compressed Sediment Brick

It is important to consider the physical properties of compressed sediment brick in this investigation. Efflorescence and water absorption are associated with the physical properties of compressed sediment brick.

The occurrence of efflorescence has a significant impact on the quality and properties of compressed sediment brick (Nhabih, et al., 2020). On the seventh day of curing, an efflorescence test is performed on compressed sediment brick. The compressed sediment brick sample is partially immersed in water whilst another brick sample is not exposed to water. After that, both of the brick samples are compared in order to detect the presence of efflorescence on the compressed sediment brick. The result of the efflorescence test reports that no “white spot” growths on the exposed area of the compressed sediment brick (Ean, 2014). Therefore, it can be concluded that efflorescence does not exist on the compressed sediment brick.

The study has been conducted by Ean (2014) on the water absorption of compressed sediment brick. Water absorption is a significant factor that alters the strength of compressed sediment bricks. In general, water penetration of the bricks is increased as the porosity of the bricks increases. On the contrary, the compressive strength for a brick with high porosity is relatively low in comparison to a brick with low porosity. The compressed sediment brick that is composed of 10 % cement only displays 15.1 % water absorption. In fact, the presence of high cement content increases the water absorption of compressed sediment brick by wholly occupying the pores within the sediment particles. In addition, Lafhaj, et al. (2008) reveal that the water absorption of the compressed sediment bricks has a direct correlation to the amount of sediment content in the brick. Figure 2.7 shows that the water absorption increases when the sediment content in brick increases. However, the compressive strength of compressed sediment brick is low when there is high water absorption in the brick.

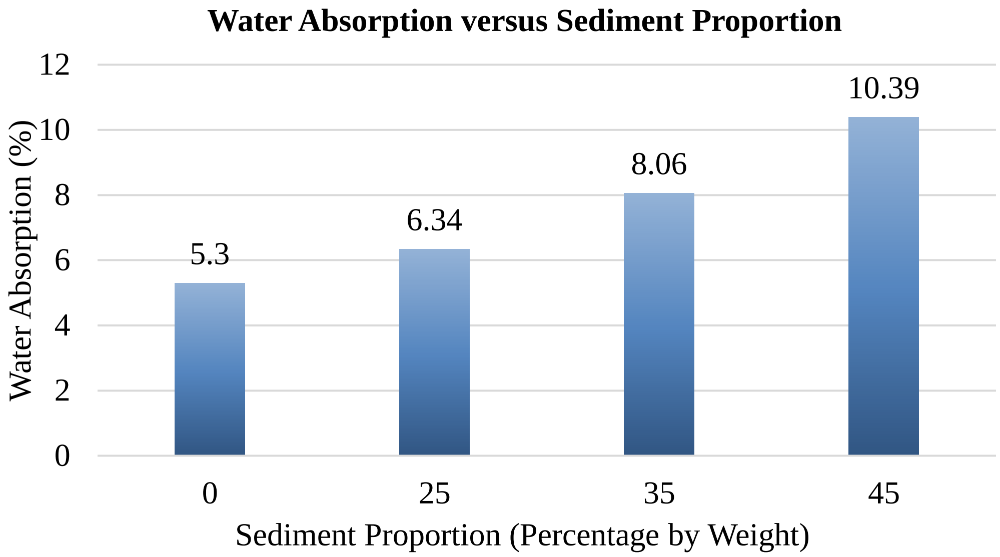


Figure 2.7: Water Absorption versus Sediment Proportion (Lafhaj, et al., 2008).

2.3.10 Mechanical Properties of Compressed Sediment Brick

The mechanical properties tests for the compressed sediment brick are tested to ensure that the compressed sediment brick adopted in this study meets the specifications. The compressive strength and heavy metal leachability fall under the categories of mechanical properties.

Compressive strength is expressed as an indicator to test the quality of bricks. Besides, compressive strength is typically utilized to determine the load-carrying capacity of brick. The compressive strength of compressed sediment brick on the 28th day is recorded as 6.3 MPa (Ean, 2014). On the other hand, the compressed clay brick corresponds to the highest compressive strength with

8.5 MPa as shown in Figure 2.8 due to its high plasticity. It indicates that the clay soil is good at bending without breaking or splitting. Nevertheless, the low compressive strength of compressed sediment brick is attributed to the low silica content in sediment silt compared to sediment sand. The increasing silica content in sediment sand produces greater bonding during the hydration process of cement corresponding to improve the compressive strength of sediment brick (Zhao, et al., 2012). The compressive strength of compressed sediment brick is acceptable as long as it meets the minimum requirement of ASTM and MS Standard which is greater than 4.1 MPa and 5.2 MPa respectively (Ali, 2005; Sajanthan, et al., 2019).

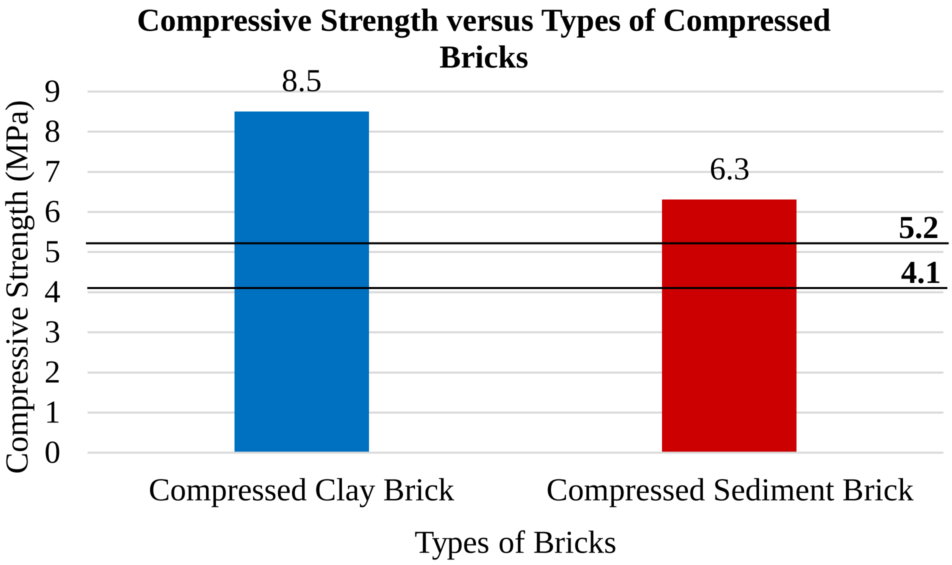


Figure 2.8: Compressive Strength versus Types of Compressed Bricks (Ean, 2014).

On top of that, the Toxicity Characteristic Leaching Procedure (TCLP) is performed on the compressed sediment brick in order to investigate the heavy metal leachability. The test is carried out in accordance with the SW 846 test methods outlined in the Malaysian Department of Environment (DOE) and United States Environmental Protection Agency (EPA) instructions for the implementation of unique management of schedule waste (EPA, 2020). Table 2.5 elucidates the TCLP result for the compressed sediment brick. The result reveals that the leachability of arsenic, boron, cadmium, chromium, lead, mercury, nickel, selenium, tin and zinc are absent in the brick sample. However, copper is leached from the compressed sediment brick with a relatively low concentration of 0.01 mg/L. It is even lower than the maximum allowable TCLP threshold of 100 mg/L. Hence, it proves that cement aids in the solidification process to capture heavy metals in the compressed sediment brick (Ma, et al., 2019). Apart from that, the highest leachability of chloride is detected in the sediment brick due to high consumption of water that consists of a large portion of chlorine in the phase of mixing and curing. Nonetheless, chloride is not categorized as a hazardous chemical substance in the criteria for the implementation of special management of schedule waste by the DOE and 40 CFR 261.24 by the EPA (EPA, 2001). Other than that, EPA does not provide any guidelines for the oil and grease, total organic carbon, and cyanide in solid waste.

Table 2.5: Leaching Test Results of Compressed Sediment Brick (Ean, 2014).

Heavy Metals	**Unit**	**Reference Range**	**Result**
Arsenic (As)	mg/L	Max 5	Not detected
Barium (Ba)	mg/L	Max 100	0.06
Boron (B)	mg/L	Max 400	Not detected
Cadmium (Cd)	mg/L	Max 1	Not detected
Chromium (Cr)	mg/L	Max 5	Not detected
Copper (Cu)	mg/L	Max 100	0.01
Lead (Pb)	mg/L	Max 5	Not detected
Mercury (Hg)	mg/L	Max 0.2	Not detected
Nickel (Ni)	mg/L	Max 100	Not detected
Selenium (Se)	mg/L	Max 1	Not detected
Silver (Ag)	mg/L	Max 5	0.02
Tin (Sn)	mg/L	Max 100	Not detected
Zinc (Zn)	mg/L	Max 100	Not detected
Chloride (Cl)	mg/L	Max 2	18.46
Oil and Grease	mg/L	-	0.20
Total Organic Carbon (on dry basis)	mg/L	-	4.65

2.3.11 Environmental Impact of Compressed Sediment Bricks

The environmental effect of compressed sediment bricks is seldom taken into account in recent research. To maintain a stable civilisation that occurs in sync with the environment, the effects of the compressed sediment brick must be considered and weighed comprehensively before the compressed sediment brick is applicable in the construction industry.

The main environmental concern of compressed sediment brick is the existence of heavy metals in sediments. The study of Khairiah, et al. (2006) highlights that the contaminated soil samples gathered from Cameron Highlands contain a high concentration of heavy metals such as iron, zinc, cadmium, manganese, copper and chromium. Additionally, the organic content of soil samples collected is significantly low due to the soil in Cameron Highlands used for long-term farming events. Therefore, the low organic content of the soil indicates that the leachability rate of heavy metals is extremely high which releases the contaminants to the surrounding environment.

According to Wan Abdullah, et al. (2001), the Ringlet river contains a high concentration of phosphate and nitrate that exceed the tolerable standards. The key factor that leads to the high phosphate and nitrate level is the excessive use of fertilizers for agricultural activities in Cameron Highlands. Since the soil of the Cameron Highlands contains a high proportion of heavy metals, there is a considerable amount of heavy metals in the reservoir sediments.

2.4 Life Cycle Assessment

Life cycle assessment is an approach to identify the environmental impacts corresponding to the lifetime of a product. LCA is the short form of “Life Cycle Assessment”. In 1960, life cycle assessment was founded by Harold Smith in the United States of America (Aziz, et al., 2020). In 1963, LCA attracted widespread global attention through the World Energy Conference as Harold Smith unveiled the estimation of the total energy required to create chemical products (Visser, 2017).

The key feature of this application is the quantitative analysis that allows the assessment of overall environmental impacts in line with the life cycle stages. Thus, it is typically used to prioritise improvements on the life cycle of a product that may reduce the total environmental contribution. Apart from that, LCA is responsible for comparing products in the same functional unit by classifying products with the least environmental burden.

The framework of LCA is made up of four stages, including goal and scope definition, inventory analysis, impact assessment and interpretation of results (Muralikrishna and Manickam, 2017). LCA involves an iterative process within the phases as the comprehensive product information and its credibility are frequently being examined to achieve the desired outcome. Figure 2.9 shows the framework for life cycle assessment.

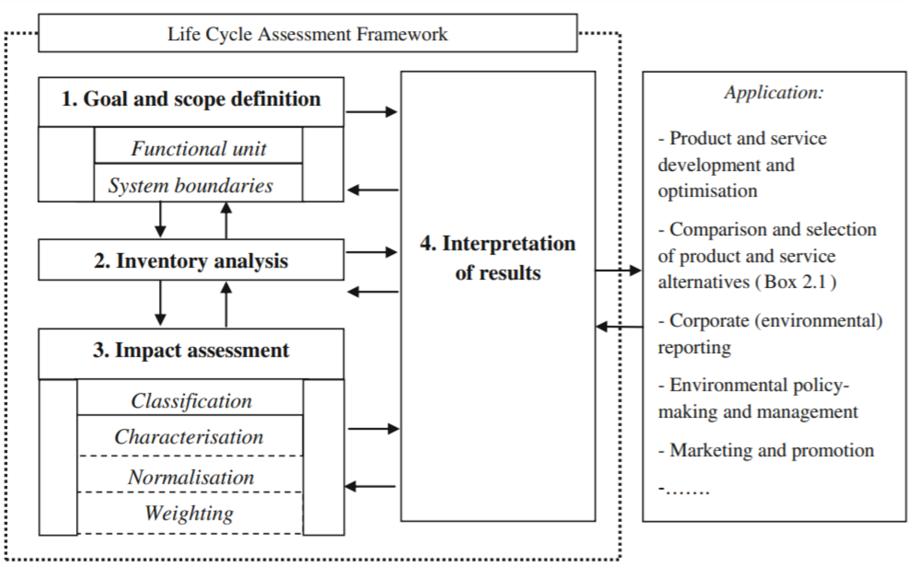


Figure 2.9: A Synopsis of the Important Phases and Applications of LCA (Filimonau, 2016).

The life cycle of a product entails five stages from raw material acquisition, processing, manufacturing, distribution, use of the product to the end of life (Saaksvuori and Immonen, 2008). The first stage is to extract the raw materials. The raw material will be further undergone the processing of the raw material stage. After completing the manufacturing of product, it will be transported or distributed to the market across the globe. After that, consumers purchase products for personal consumption. The final disposal of a product implies that the product has reached the end of useful life. Figure 2.10 shows the life cycle stages of a product.

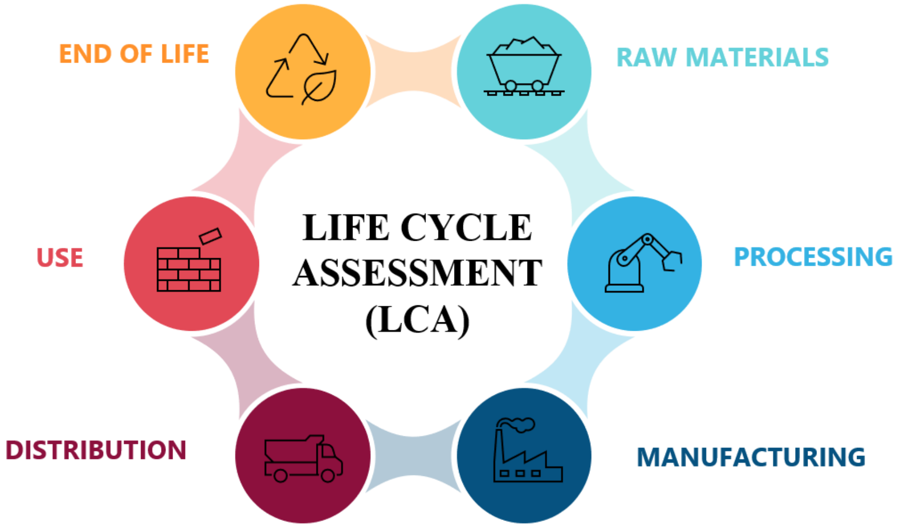


Figure 2.10: Life Cycle of a Product (Hauschild, et al., 2018).

The analysis technique of LCA can be classified into cradle-to-grave, cradle-to-gate and cradle-to-cradle. The cradle-to-grave concept is concerned with the entire life cycle assessment of a product from raw material acquisition through materials processing, manufacturing, distribution, product usage, and product disposal. On the other hand, the cradle-to-gate approach refers to an appraisal of a partial product life cycle from extraction of raw materials through materials processing to the factory gate of a product. The exceptional phase in the cradle-to-gate assessment includes transportation of the product, product use, and product disposal (Almeida, et al., 2010). Besides, the cradle-to-cradle definition is almost similar to the concept of the cradle-to-grave analysis method, excluding the disposal phase of a product. In cradle-to-cradle assessment, the recycling process is the end-of-life stage of the product. The products will be either recycled or reused to invent a new product, identical products or different products (Bakker, et al., 2010). The phases mentioned earlier of the life cycle will be selected based on the assessment scope.

2.4.1 Goal and Scope Definition

The first phase in LCA is to identify goal and scope. The goal of LCA aims to establish the intended application, main purpose of conducting LCA study, intended audience, expected products in which the assessment is to be achieved and projected outcome of LCA to be adopted in comparative assertions (Broun and Menzies, 2011).

Moreover, the scope of LCA is usually stated to identify the intended product system, functions of the product system, functional unit, system boundaries, allocation procedures, particular impact categories, data requirements, assumptions, limitations, preliminary data quality requirements, type of critical review and format of the report required based upon the goal and scope definition (Curran, 2017). In other words, the reliability of the study is contingent on the well-defined goal and scope in LCA.

2.4.2 Inventory Analysis

Life Cycle Inventory (LCI) is the second phase in LCA. In this step, the inventory analysis entails the data collection and compilation of all environmental inputs and outputs for a product over its whole life cycle as shown in Figure 2.11. The inputs of a product usually consist of energy requirements, raw materials and transportation methods. Subsequently, all the inputs will be transferred into the industrial system. Then, the product output and emissions to the environment will be assessed in relation to each stage of production (Menoufi, 2011).

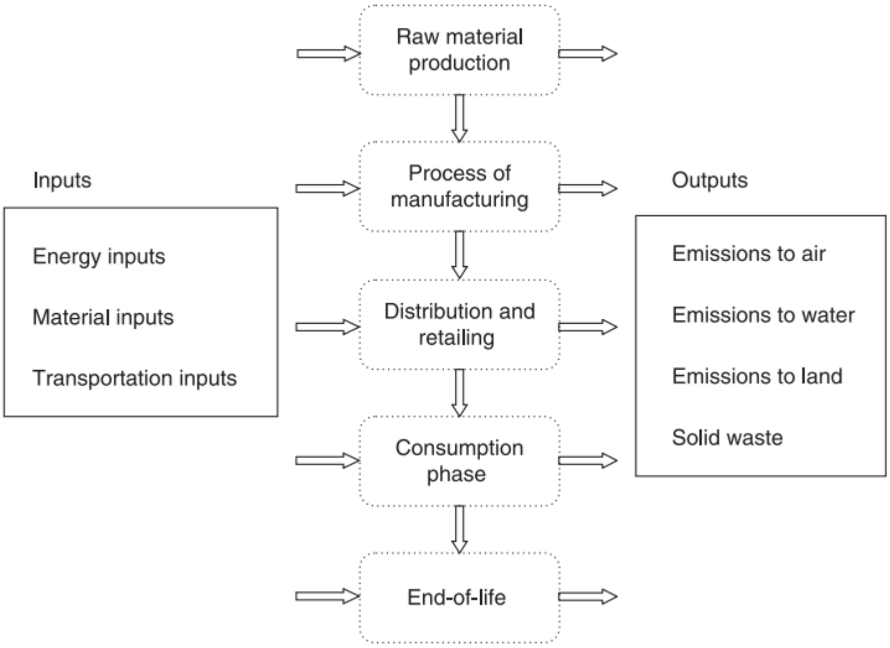


Figure 2.11: Process Flow of Inventory Analysis (Muthu, 2014).

There are four leading steps that are purposely designed for the life cycle inventory analysis. The first step is to create a flow diagram of the entire product procedures within the specified system boundaries. Next, the data collection methodology is essential to attain the goals of the LCA study. In the inventory analysis phase, the data collection must be correlated to the goal and scope specified for the study. Lastly, the results will be evaluated and presented to the stakeholders (Corporation and Curran, 2006).

2.4.3 Impact Assessment

The third stage of LCA procedure is Life Cycle Impact Assessment (LCIA). LCIA assists the interpretation of LCA by translating all the inputs from inventory analysis into a specific number of possible effect categories on the human health and environment for a commodity during its life cycle (Hauschild and Huijbregts, 2015). Additionally, LCIA plays a significant role for the potential remediation on the environmental effects in relation to the products inputs and outputs.

The structure of LCIA is composed of four main steps including classification, characterization, normalization and weighting. The first step is to classify the LCI outcomes to the appropriate environmental impact categories. The characterization step should be taken to model the environmental impacts coupled with the emissions of the product throughout its life cycle. After that, the normalization step in LCIA is used to estimate the characterized impact results to different product procedures allowing assessment of each emission (Lehtinen, et al., 2011). The last step for the impact assessment is weighting. It is applied to highlight the most significant possible environmental impacts in the midst of numerous impact groups results (Muthu, 2014).

The LCIA methodology can be classified into CML 2001, Eco-Indicator 99, IMPACT 2002+, ReCiPe method and so forth. The fundamental principle of LCIA methodology is to compute several life cycle impact indicators. The selection of the suitable LCIA methodology helps to meet the intended impact categories. In this study, the ReCiPe Midpoint and Endpoint indicator are chosen as the principal methodology to investigate the environmental impacts.

2.4.3.1 ReCiPe Method

The ReCiPe method is recognized as one of the impact assessment methods. Through collaboration between RIVM, Radboud University Nijmegen, Leiden University and PRé Sustainability, the ReCiPe method was first launched in 2008 (Huijbregts, et al., 2017b).

ReCiPe 2016 is an improved version of the ReCiPe 2008 impact assessment process. The establishment of ReCiPe 2016 relies closely on the cooperation between the Dutch National Institute for Public Health and the Environment (RIVM), Radboud University Nijmegen, Norwegian University of Science and Technology, and PRé Sustainability. The ReCiPe 2016 is an integrated system that links the midpoint approach of CML 2001 with the damage pathways of Eco-indicator 99 (Quirós, et al., 2015).

The core feature of ReCiPe 2016 is to adopt midpoint and endpoint indicators in transforming the LCI to a small range of life cycle impact assessment outcomes. It usually consists of eighteen midpoint categories and three endpoint categories. For instance, the eighteen midpoint categories are usually problem-oriented that are used to convey the global scale of characterisation factors. Meanwhile, the three endpoint categories refer to damage oriented which is classified into human health, ecosystems and resource availability respectively. Figure 2.12 displays the linkage between midpoint impact categories, damage pathway and endpoint area of protection that are enclosed in the ReCiPe 2016.

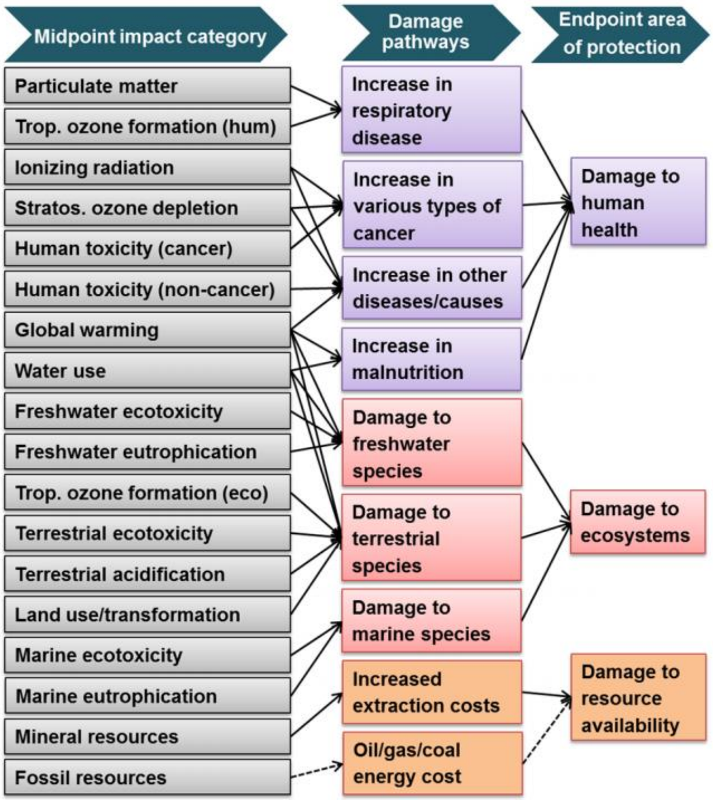


Figure 2.12: Summary of the Midpoint and Endpoint Indicators in the ReCiPe 2016 Methodology (Huijbregts, et al., 2017b).

In ReCiPe 2016, the cultural perspectives play a significant part in order to classify analogous types of assumptions and selections into midpoint and endpoint respectively. The perspectives stand for a set of choices on matters such as periods or opportunities that appropriate management or forthcoming technology advancement can prevent future damages. These perspectives comprise individualistic perspective, hierarchist perspective and egalitarian perspective. The individualistic perspective takes into account the shortest time frame. The characterization factors of individualistic perspective include certain acknowledged impact types and technological advance in relation to human adaptation. Comparatively, the hierarchist perspective is a scientific consensus model concerning the time frame and likelihood of impact systems. The egalitarian philosophy is the most cautious point of view as the impacts pathways are based on a relatively long period as compared to individualistic perspectives (PRé Sustainability, 2020). Table 2.6 shows the summary of the midpoint impact categories interrelated with its indicators, whereas Table 2.7 depicts the damage pathways in ReCiPe 2016.

Table 2.6: Overview of the Midpoint Impact Categories Associated with the Indicators (Huijbregts, et al., 2017b).

Midpoint Impact Category	**Indicator**	**CF_m**	**Unit**
Climate change	Infrared radiative forcing increases	Global warming potential (GWP)	$\mathrm{kg\ CO_2 - eq\ to\ air}$
Ozone depletion	Stratospheric ozone decreases	Ozone depletion potential (ODP)	$\mathrm{kg\ CFC - 11 - eq\ to\ air}$
Ionising radiation	Absorbed dose increases	Ionising radiation potential (IRP)	$\mathrm{kBq\ Co - 60 - eq\ to\ air}$
Fine particulate matter formation	PM2.5 population intake increases	Particulate matter formation potential (PMFP)	$\mathrm{kg\ PM2.5 - eq\ to\ air}$
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increases	Photochemical oxidant formation potential: ecosystems (EOFP)	$\mathrm{kg\ NOx - eq\ to\ air}$
Photochemical oxidant formation: human health	The intake of tropospheric ozone is increasing.	Photochemical oxidant formation potential: humans (HOFP)	$\mathrm{kg\ NOx - eq\ to\ air}$
Terrestrial acidification	Proton levels rise in natural soils	Terrestrial acidification potential (TAP)	$\mathrm{kg\ SO_2 - eq\ to\ air}$
Freshwater eutrophication	Phosphorus expansions in freshwater	Freshwater eutrophication potential (FEP)	$\mathrm{kg\ P - eq\ to\ freshwater}$
Human toxicity: cancer	Hazard increments of malignant growth illness	Human toxicity potential (HTPc)	$\mathrm{kg\ 1{,}4 - DCB - eq\ to\ urban\ air}$

Table 2.6 (Continued)

Human toxicity: non-cancer	Non-cancer disease incidence is on the rise	Human toxicity potential (HTPnc)	$\mathrm{kg\ 1{,}4-DCB-eq}$ to urban air
Terrestrial ecotoxicity	Hazard-weighted rise in natural soils	Terrestrial ecotoxicity potential (TETP)	$\mathrm{kg\ 1{,}4-DCB-eq}$ to industrial soil
Freshwater ecotoxicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	$\mathrm{kg\ 1{,}4-DCB-eq}$ to freshwater
Marine ecotoxicity	Hazard-weighted surge in marine water	Marine ecotoxicity potential (METP)	$\mathrm{kg\ 1{,}4-DCB-eq}$ to marine water
Land use	Occupation and time-integrated land transformation	Agricultural land occupation potential (LOP)	$\mathrm{m}^2 \times \mathrm{yr}$ annual cropland-eq
Water use	Water consumption increase	Water consumption potential (WCP)	$\mathrm{m}^3\ \mathrm{water-eq}$ consumed
Mineral resource scarcity	The extraction of ore upsurges	Surplus ore potential (SOP)	$\mathrm{kg\ Cu-eq}$
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	$\mathrm{kg\ oil-eq}$

Table 2.7: Damage Pathways in ReCiPe 2016 (Huijbregts, et al., 2017b).

Major Environmental Issue	**Buffer Zone**	**Damage Pathways**
Climate change	Human health	Years of life lost and injured as a result of increased malaria, diarrhoea, hunger, and natural disasters as the global mean temperature rises.
	Ecosystems (terrestrial)	Species extinction linked to shifting biome distributions as a result of the global temperatures.
	Ecosystems (freshwater)	The reduction in river flow has resulted in the extinction of fish species.
Stratospheric ozone depletion	Human health	Years of life have been sacrificed and disabled as a result of increased skin cancer and cataracts caused by UV exposure.
Ionising radiation	Human health	Many lives lost and disabled in the recent years due to a rise in cancer and genetic disorders as a consequence of radiation exposure.
Particulate matter formation	Human health	Years of life lost as a result of a rise in cardiopulmonary and lung cancer caused by exposure to primary and secondary aerosols.
Photochemical ozone formation	Human health	Years of life lost as a result of a rise in respiratory diseases brought about by ozone exposure.
	Ecosystems (terrestrial)	Plant biodiversity loss as a result of excessive ozone exposure.

Table 2.7 (Continued)

Terrestrial acidification	Ecosystems (terrestrial)	Plant species extinction due to a drop in soil pH.
Freshwater eutrophication	Ecosystems (aquatic)	The increasing of phosphorus concentrations causes the extinction of marine animals.
Toxicity	Human health	Years of life suffered and impaired due to cancer and non-cancer results from toxic substances intake and inhalation.
	Ecosystems (marine)	Species extinction in coastal waters due to chemical exposure.
	Ecosystems (terrestrial)	Chemical pollution in soils has resulted in the extinction of species.
	Ecosystems (freshwater)	Freshwater species extinction due to chemical exposure.
Water consumption	Human health	Water shortage leads to malnutrition.
Water consumption	Ecosystems (terrestrial)	The reduction in net primary productivity happens due to the water shortage as proxy for total species loss.
	Ecosystems (aquatic)	The reduction in river flow has resulted in the extinction of fish species.
Land use	Ecosystems (terrestrial)	Species loss due to various sorts of land use such as agriculture, forestry and built up. Species loss is attributed to the conversion of natural land to used land, including the duration to recover the land into natural land.

Table 2.7 (Continued)

Mineral resource scarcity	Resource scarcity	Costs rise as a result of mineral production.
Fossil resource scarcity	Resource scarcity	Budget increments because of fossil extraction increase.

The benefits of the ReCiPe framework that is worth of mentioning is the content of midpoint impact categories extend to a broad area. Also, it facilitates the impact assessment that involves a wide range of scope worldwide. In contrast to other methods such as Eco-Indicator 99, EPS Method, LIME, and Impact 2002+, the impact assessment of the ReCiPe method does not take possible impacts from future extractions into consideration. However, the assumption for impacts in the LCI has been performed in the ReCiPe method (Huijbregts, et al., 2017a).

2.4.4 Interpretation of Results

The last stage in LCA is life cycle interpretation. The interpretation of a life cycle involves a systematic method to conduct critical review, identification of information sensitivity, summary of assessment result and result presentation of the LCI and LCIA. Therefore, the recommendations for enhancing the environmental performance can effectively deal with the life cycle interpretation. The International Organization for Standardization (ISO) standards also recommend that comprehensive, sensitivity, and accuracy checks for documentation, limitations, and assumption of the assessment should be undertaken at this phase of LCA to guarantee the level of precision and comprehensiveness of the assessment (Corporation and Curran, 2006).

2.5 LCA Tools and Database

The simplified LCA tools are defined as decision-making methodologies for evaluating and comparing the environmental performance of products at various stages of their life cycle. On top of that, the LCA database is a valuable data source as it offers extensive global and regional datasets enabling users to accomplish an optimum result in their comparative studies. Therefore, the appropriate LCA tools and database support the life cycle assessment practitioners in collecting data coupled with the environmental impacts for the product life cycle. Table 2.8 reveals the details of various LCA tools. Table 2.9 outlines the existing LCA database with its specifications, whereas the commercial LCA database is presented in Table 2.10.

Table 2.8: List of LCA Tools (Lehtinen, et al., 2011).

Tool Name	Provider	LCI and/or LCIA*	Comprehensive LCA*	Language	Major Source of Data Collection	Exceptional Field if Available
AIST-LCA Ver.4	National Institute of Advanced Industrial Science and Technology (AIST)		Provided	Japanese	AIST-LCA database	
BEES 4.0	National Institute of Standards and Technology (NIST)		Provided	English	Bees database	construction industry
CCaLC Tool	The University of Manchester		Provided	English	CCaLC database including EcoInvent database	
Eco-Bat 2.1	Haute Ecole d'Ingénierie et de Gestion du Canton de Vaud	Provided		French, Italian, English	Eco-Bat database	construction industry
Ecoinvent waste disposal inventory tools v1.0	Doka Life Cycle Assessments (Doka Okobilanzen)	Provided		English	Ecoinvent database	waste management
EIME V3.0	CODDE		Provided	English	EIME database	electrical, mechanical and electronic products
Environmental Impact Estimator V3.0.2	Athena Sustainable Materials Institute		Provided	English	Personal database	construction industry
eVerdEE v.2.0	ENEA - Italian National Agency for New Technology, Energy and the Environment		Provided	Italian, English	ENEA database	

Table 2.8 (Continued)

GaBi 4	PE International GmbH University of Stuttgart, LBP-GaBi		Provided	English	Gabi database	
GEMIS version 4.4	Oeko-Institut (Institute for applied Ecology), Darmstadt Office	Provided		Spanish, Czech, German, English		energy, transport, recycling and waste treatment
KCL-ECO 4.1	VTT		Provided	English		
LEGEP 1.2	LEGEP Software GmbH		Provided	English, German	LEGEP database	construction industry
LTE OGIP; Version 5.0; Build-Number 2092; 2005/12/12	t.h.e. Software GmbH		Provided	German		construction industry
OpenLCA	GreenDeltaTC GmbH		Provided	English		
Qantis suite 2.0	Quantis		Provided	English	Qantis database	
REGIS 2.3	sinum AG		Provided	Japanese, Spanish, German, English	ecoinvent Data v1.3:	
SALCA-tools	Agroscope Reckenholz-Tänikon Research Station ART	Provided		German		agriculture
SankeyEditor 3.0	STENUM GmbH	Provided		English		

Table 2.8 (Continued)

SimaPro 7	PRé Consultants B.V.		Provided	Spanish, French, Italian, German, English	SimaPro database	
TEAM™ 4.5	Ecobilan-PricewaterhouseCoopers		Provided	English		
The Boustead Model 5.0.12	Boustead Consulting Limited		Provided	English	The Boustead Model database	
Umberto 5.5	ifu Hamburg GmbH		Provided	English	Umberto library	
USES-LCA	Radboud University Nijmegen	Provided		English		toxic impacts between substances
WRATE	UK Environment Agency		Provided	English		municipal waste management systems

Table 2.9: LCA Database (Lehtinen, et al., 2011).

Database Name	Provider	Languages	Exceptional Field if Available
CCaLC database	The University of Manchester	English	
CPM LCA Database	Centre for Environmental Assessment of Product and Material Systems - CPM	English	
Eurofer data sets	EUROFER	English	steel industry
GEMIS 4.4	Oeko-Institut (Institute for applied Ecology), Darmstadt Office	Spanish, Czech, German, English	energy, transport, recycling and waste treatment
Franklin Associates' Case examples	Franklin Associates	English	
ILCD	European Commission	English	
LC Data	Forschungszentrum Karlsruhe	German, English	energy, transport and end of life
LCA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)	Spanish, Catalan, English	biomass production, wood use and recycling, ecodesign, sustainable architecture, service systems and green chemistry
MFA_sostenipra_v.1.0	Universitat Autònoma de Barcelona (UAB)	Spanish, Catalan, English	

Table 2.9 (Continued)

PlasticsEurope Eco- profiles	PlasticsEurope	English	polymers (main) and their intermediates
ProBas	Umweltbundesamt	German	
US Life Cycle Inventory Database	Athena Sustainable Materials Institute	English	

Table 2.10: Commercial LCA Databases (Lehtinen, et al., 2011).

Database Name	**Provider**	**Languages**	**Exceptional Field if Available**
DEAM™	Ecobilan - PricewaterhouseCoopers	English	
EcoInvent Data v1.3	EcoInvent Centre	Japanese, English	
EIME V11.0	CODDE	Spanish, French, English	selection of products
esu-services database v1	ESU- services Ltd.	German, English	
GaBi databases 2006	PE International GmbH	Japanese, German, English	
Option data pack	National Institute of Advanced Industrial Science and Technology (AIST)	Japanese	chemical production, iron and steel, and waste management processes
Sabento library 1.1	ifu Hamburg GmbH	German, English	enzymatic processes and cell cultures
SALCA 071	Agroscope Reckenholz- Tänikon Research Station ART	German, English	agriculture
SimaPro database	PRé Consultants B.V.	English	
sirAdos 1.2.	LEGEP Software GmbH	German	construction
The Boustead Model 5.0.12	Boustead Consulting Limited	English	fuels, materials
Umberto library 5.5	ifu Hamburg GmbH	German, English	

2.5.1 Ecoinvent 3.5 Database

The Ecoinvent 3.5 database was issued on 23 August 2018 (The Ecoinvent Organisation, 2021). It covers a wide range of sectors including waste treatment, aquaculture and fish capture, aluminium supply and manufacture of containerboard with more than 2000 new and updated datasets. Furthermore, Ecoinvent is a database that can link to the LCIA approach, LCI datasets, and cumulative results to make the implementation of LCA easier. To ensure high accuracy and reliability of the database, the LCA experts normally will employ a peer review process to modify and review the data before it is accessible to the users through the Ecoinvent dataset.

The Ecoinvent database structure is divided into a number of individual sections. The first section comprises insufficient useful datasets, and it involves the EcoEditor to aid in the re-evaluation of datasets. The existing datasets under review are categorized as the second stage. The third part of the Ecoinvent database includes the production side of the database that has been approved by the database administrator. Therefore, it will be integrated and finalised into the database. The outcome of the temporary pre-release candidate will be calculated in the fourth section. Lastly, the end-users gain access to the present formal version through EcoQuery (Weidema, et al., 2013). Figure 2.13 shows the basic structure of the Ecoinvent database.

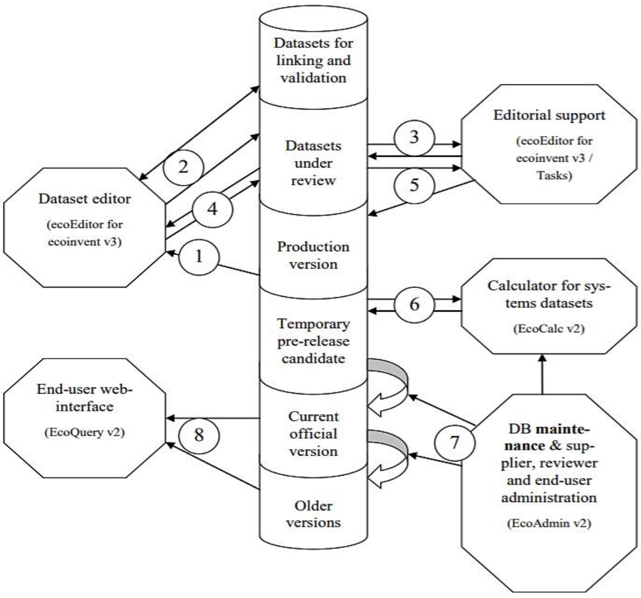


Figure 2.13: Procedure for Ecoinvent Database System (Weidema, et al., 2013).

There are three main system models in the Ecoinvent which consists of allocation cut-off by classification, allocation at the point of substitution and consequential data (Yang, et al., 2020). The cut-off system model is more focusing on the recycled materials. For instance, the primary waste producers are not entitled to any benefits or impacts for the provision of recyclable materials after disposing of their waste products. Apart from that, the APOS system model is defined as the model allocation at the substitution point (Hellweg and Zah, 2016). The APOS system model is used to enlarge the allocation system to comply with the additional treatment process for byproducts. The principle of the consequential system model is mostly dependent on the substitution-based method (Wernet, et al., 2016). Based on different fundamental assumptions, the consequential system model evaluates the effects of a shift in the current system.

2.6 Applications of LCA

Life cycle assessment is recognized as a valuable mechanism for various industries and policymakers to enhance the overall processes and services associated with the environmental burdens. The utilization of LCA plays an integral part in exploring the most efficient life cycles throughout the world. According to LCA Malaysia (2021), the application of LCA involves a broader field to serve for benchmarking and performance, environmental management strategy and marketing purposes.

The LCA is commonly applied in the benchmarking and performance of the entire product’s life cycle. Hence, the industry or public organizations can decide the priorities in the internal strategic planning, design product, and process adjustment based on the valuable decisions resulting from LCA. A recent study shows that the LCA is developed as an environmental benchmark for buildings (Frischknecht, et al., 2019). As a result, the reduction of carbon emission will take place if the benchmarks tighten up.

Another topic evolving from the LCA application is the environmental management strategy. The well-planned environmental management approach leads to a minimal negative environment impact at each phase of the product life cycle. A study is accomplished on the application of LCA as a component in environment management techniques. The previous research is mostly clustered on the environmental management strategy of Poland, Sweden and Germany (Lewandowska, et al., 2013). As a result, the increasing number of ISO 14001 certificates issued in Germany, Sweden, and Poland aids in the environmental improvement of products.

On the other hand, the LCA has become apparent as a criterion in the markets as well. The practicality of LCA aids in promoting green marketing by introducing environmental claims, environmental declaration and eco-labels. The eco-labels on the products must obtain an authorised licence in order to signify its good performance in the environmental concerns (Iraldo, et al., 2014). The environmental declaration provides a better illustration regarding the LCA results of a product to the public, especially wholesale dealers and environmentally conscious users. Likewise, the environmental claims are mainly applied to deliver the life cycle viewpoints for marketing environmentally products.

2.7 Limitations of LCA

Though the life cycle assessment is widely adopted in industry, some limitations still exist due to its complexity and highly data intensive. In that case, the shortcomings of existing LCA studies cannot assure the immediate need of the user and the pathway towards sustainable development. The limitations of LCA will be discussed as the following.

The LCA studies emphasise the environmental aspects of a product only while neglecting the economic or social facets of a product (Guinee, et al., 2011). Majorities of LCA models concentrate on environmental impacts associated with the industrial events, whilst no detailed LCA analysis had been done to reflect the market mechanisms or secondary influences on scientific development. Even though LCA is a steady-state methodology, the framework of LCA is prohibited in dealing with the localized impacts. The economic and social impacts should be clearly stated as part of the LCA studies to improve the whole life cycle of the product.

The application of LCA is confined to serve as a decision-making tool in waste management and policy formulation (Ekvall, et al., 2007). The LCA is merely applicable in discovering the potential impacts instead of the actual impacts throughout the life cycle of a product. Besides, the reliability of the LCA studies becomes a main concern due to different assumptions being exploited in the LCA. The quality of databases is also a problematic matter which may cause the wrong direction in combating the environmental impacts. In addition, the results obtained from a comprehensive LCA study cannot meet the specific user needs in other locations as the LCA model focuses principally on the particular area.

Nonetheless, data uncertainty is one of the constraints of LCA. The data uncertainty analysis is expressed as the techniques used for verifying the variability of the datasets and their effects on the final findings. It is generally applied to both the LCI and the LCIA in order to identify the unknown errors and typical variations in the data. There are insufficient research efforts for uncertainty analysis to manage the data and information. Thus, the LCA practitioners are unfamiliar with defining and interpreting the data uncertainty in both LCI and LCIA (Curran, 2012).

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter focuses on the methodology of the entire study by presenting and examining the life cycle assessment framework. The life cycle assessment framework is constituted of four main stages, including definition of the goal and scope, life cycle inventory, life cycle impact assessment and life cycle interpretation. As the limited information and data in the production process, few assumptions are made in this study.

3.2 Goal and Scope Definition

According to ISO 14040, the definition of goal and scope is typically used to determine the intention of LCA and the probable outcomes of the research (Curran, 2017). The main purpose of this life cycle assessment study is to determine the environmental impacts from the productions of compressed clay brick and compressed sediment brick. At the end of this study, the intended audience is able to achieve the desired results so that the brick with the least environmental impacts can be produced. In addition, the study will take into account the environmental impact of recycled materials. Besides, it is necessary to state the scope of this study evidently which includes functional unit, system boundary and transportation energy requirements.

3.2.1 Functional Unit

In the LCA studies, the functional unit plays a significant role in the product or process studied. The key purpose of establishing a functional unit is to ensure that the input and output of the product link to a particular function. Nevertheless, the functional unit should be selected wisely when it is performed to make a comparison between two or more products (Youssef, et al., 2019). For instance, the identical functional unit should be assigned to each product so that the user obtains an equivalent amount of product. Furthermore, the appropriate scale of the functional unit should be adopted in the study as it greatly influences the impact assessment. Most of the study adopt 1 kg of brick as a functional unit to evaluate the inputs and outputs in the system (Almeida, et al., 2010; Haddad, et al., 2013). For the purpose of the existing study, one kilogram of brick has been applied as a functional unit that serves as the base for environmental assessment of compressed clay brick and compressed sediment brick.

3.2.2 Transportation Distance

The study aims to find out the distance of transportation so that the result of this study is more reliable. Usually, the raw material is obtained from the market in close proximity to the production site so that it can reduce the transportation fee. Hence, it is supposed that the raw material acquisition for compressed brick production comes from Selvaraju Trading Sdn Bhd in Cameron Highland. The assumption on the transportation distance of raw materials to the brick production plant is almost 13.6 km. Furthermore, the assumption for the total distance of transporting dredged sediment silt and sand from Sultan Abu Bakar Dam to landfill are roughly 1.49 km and 2.34 km respectively.

Moreover, several locations have been chosen to collect the samples for this study. The sampling location includes Sg. Jasik dumping area and Sg. Habu. Table 3.1 shows the location to collect the raw material of dredged sediments.

Table 3.1: Location of Sediment Sampling Points.

Raw Material of Sediments	**Location of Sampling Points**
Sediment Silt	Sg. Jasik
Sediment Sand	Sg. Habu

Prior to the brick production plant, the dredged samples are removed from the sediment disposal regions that have been excavated, deposited and settled for a minimum period of three months. Table 3.2 shows the transportation distance from various disposal sites to the factory. The transportation distance of dredged sediments from the disposal site to the brick production plant is measured based on Google Earth. In this study, the brick factory is located 1 km away from Sg. Jasik dumping area. It is assumed that the transportation distance of dredged sediment silt from the disposal site to the brick production plant is approximately 1 km. The transportation distance of dredged sediment sand from Sg. Habu disposal site to Sg. Jasik dumping area is shown in Figure 3.1. Thus, the assumption for the total transportation distance of dredged sediment sand from the disposal site to the brick factory is 2.42 km.

Table 3.2: Transportation Distance from Disposal Site to Brick Factory.

Disposal Site to Brick Factory	**Transportation Distance (km)**
Sg. Jasik dumping area – Sg. Jasik factory	1.00
Sg. Habu – Sg. Jasik factory	2.42

Figure 3.1: Transportation Distance of Dredged Sediment Sand from Disposal Site to Brick Factory is Measured by Using Google Earth.

3.2.3 System Boundary

The system boundaries of the entire production procedures should be satisfactorily defined to make sure that the scope, extent and depth of the study are coherent and appropriate to undertake the specified goal. In this study, the system boundary is constrained to a cradle-to-gate assessment that only involves partial life cycle of a product from the extraction of raw material, transportation of raw materials to production plant until the manufacturing of products.

However, the product usage and disposal of the product are not included in this study.

Figure 3.2 signifies the expanded boundary and system boundary of the compressed clay brick and compressed sediment brick. The whole life cycle assessment of the compressed clay brick is indicated by using the blue rectangular box. In contrast, the red rectangular box represents all the stages of compressed sediment brick’s life. The black solid box refers to the whole system boundary of compressed clay brick and compressed sediment brick where processes from the extraction of raw materials until the manufacturing of brick products are taken into consideration. Furthermore, the black dotted line is used to highlight the expanded boundary.

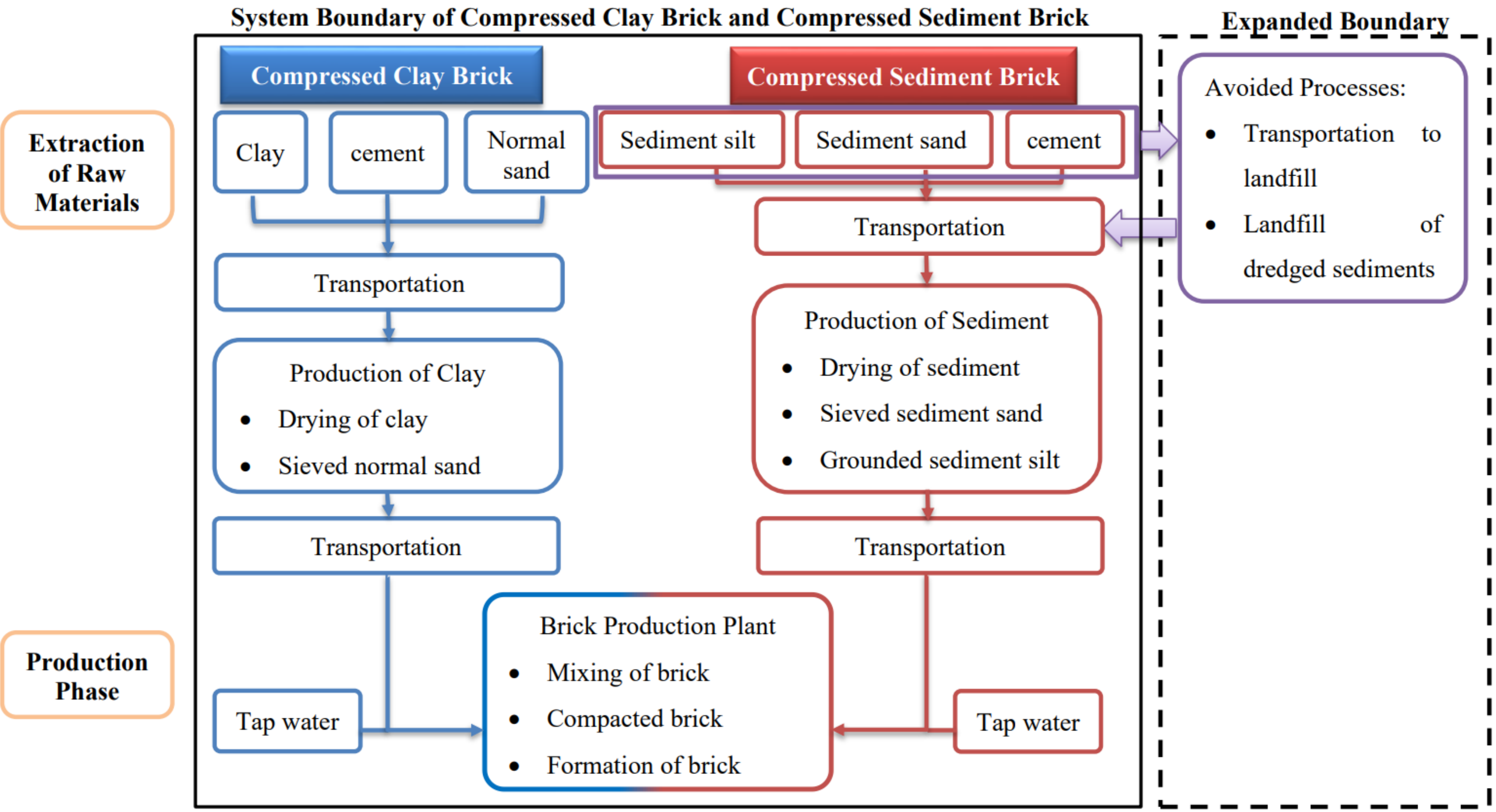


Figure 3.2: System Boundary of Brick Production.

3.3 Life Cycle Inventory

The second stage of the LCA is the life cycle inventory which is concerned with gathering the relevant information in order to accomplish the goals of the study. To achieve high reliability and accuracy data in the study, it is necessary to control the data quality when inventorying the input and output data for the brick production process. The input data primarily consists of the raw material acquisition, energy, water and transportation, whilst the output comprises the waste, emission to air, wastewater and soil contamination.

In this study, the data for the mix proportion of compressed clay brick and compressed sediment brick are retrieved from the study by Ean (2014). The mix proportion for the compressed clay brick and compressed sediment brick used in this study is shown in Table 3.3. The compressed sediment brick is labelled as S70. As a tremendous amount of sediment silt accumulated at the landfill, the content of compressed sediment brick is mainly constituted of a large portion of sediment silt compared to sediment sand. The sediment silt is the most extensive content in sediment brick with 70 % of total weight followed by sediment sand and cement which dominate 20 % and 10 % of total weight respectively. The main reason to remain sediment sand content at 20 % is to prevent the occurrence of potential problems related to raw materials. Other than that, the compressed clay bricks are designated as C70 and C90. For instance, the composition of C70 includes 70 % of clay, 20 % of normal sand and the equivalent amount of cement and water. Both of the compressed clay bricks are used to compare with the mix S70 so that the desired mix proportion of bricks can be chosen.

Table 3.3: Mixing Design Ratio (Data for the Functional Unit: 1kg of Brick).

Mix No.	Sediment Silt (kg)	Sediment Sand (kg)	Clay (kg)	Normal Sand (kg)	Cement (kg)	Total (kg)
S70	0.70	0.20	-	-	0.10	1.00
C70	-	-	0.70	0.20	0.10	1.00
C90	-	-	0.90	-	0.10	1.00

Apart from that, the compressive strength of mixing proportions of compressed clay brick is analysed in order to compare with the compressed sediment brick. Generally, the curing period of cement takes 28 days to complete the hydration process so that the bricks can achieve up to 100 % of compressive strength (Lin, et al., 2010). Figure 3.3 indicates that the compressive strength of S70 with 10 % cement content can withstand a maximum amount of 6.3 MPa loads, whereas the compressive strength of mix C90 is recorded as 6.9 MPa. Mix C70 shows the highest compressive strength among three bricks which is 8.5 MPa. Hence, the compressive strength of mix C70 and mix C90 is higher than the compressed sediment brick due to its low plasticity of sediment silt. It is discovered that an increment in the plasticity of natural clay can improve the compressive strength of compressed clay bricks (Ural, 2018). Nevertheless, the compressed sediment brick still can be adopted as it fulfils the lowest compressive strength required of 4.12 MPa in ASTM C129 (Sajanthan, et al., 2019). Moreover, the compressed sediment brick is acceptable as the compressive strength of S70 is 6.3 MPa which exceeds the minimum compressive strength of 5.2 MPa in MS 76 (Ali, 2005).

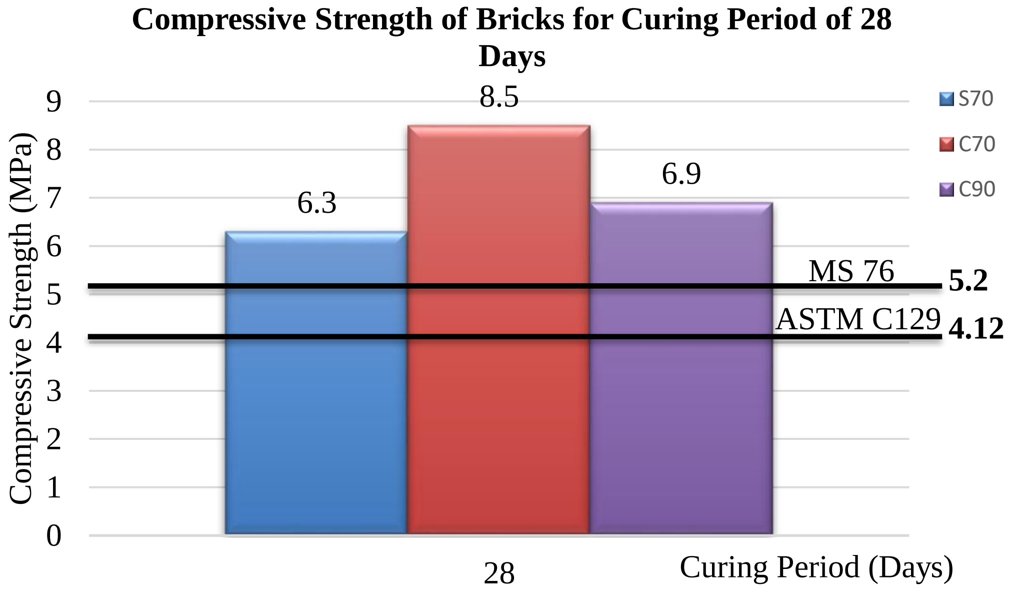


Figure 3.3: Comparison of Compressive Strength of S70, C70 and C90 bricks (Ean, 2014).

The openLCA is nominated as the primary LCA software tool in this study. The application of openLCA is beneficial for Life Cycle Assessment (LCA) and Sustainability Assessment due to its open sources. In 2007, this software was originated by GreenDelta (Ciroth, et al., 2014). The open-source software is accessible to LCA practitioners without any license restrictions. The datasets are mandatory to perform this software which typically consists of ILCD, ecoSpold v1, v2, csv, Excel and JSON-LD. With the aid of openLCA software, the users are competent in modelling the process and diagrams for every component procedure. Another key feature of this software is to display LCA results by adopting a Sankey diagram and bar charts. In addition, the inventory analysis can be generated in a table form by utilizing openLCA software. The main advantages of this software are to import and export datasets as well as integrating with Environmental Product Declarations (EPDs) (Silva, et al., 2017).

In general, the openLCA software is used to model all inputs and outputs of the processes by strictly obeying the guidelines established in the ISO 14040 standards. The model system that has been selected in this study is the APOS model. Additionally, most of the data are obtained from the Ecoinvent version 3.5 database. Table 3.4 represents the inputs of raw material for the brick production process taken from the Ecoinvent version 3.5 database, whilst Table 3.5 shows the origin of the dataset. As the database for compressed sediment brick production is unavailable in Ecoinvent version 3.5, some of the inputs and outputs will be retrieved from the study on compressed sediment brick production completed by Ean (2014).

Table 3.4: Input for Raw Material Production.

Material	LCI Data Source	Data Quality Assessment
Cement, Portland	cement production, Portland | cement, Portland | APOS, U	• The dataset covers the representative production mix of CEM I 42.5 and CEM I 52.5 R as described in EN 197-1 and describes cement (CEM I) production in Switzerland. • The activity begins with the clinker in the cement silo and the additional cement materials at the cement plant's entrance. • The activity also involves the use of electricity for clinker grinding, griding aids, and heat for drying additions, and concludes with the cement formed in the cement mill. • The dataset excludes packaging and administration.
Clay	clay pit operation | clay | APOS, U	• This dataset reflects the output of one kilogram of clay in a mine, assuming a clay layer thickness of 30 meters in nature. • The transportation to the first grinding machine brings the dataset to a close. • The dataset provides information on the area's land use, transformation, and re-cultivation. • The additional clay treatments like water consumption are not included in the dataset.

Table 3.4 (Continued)

Energy Usage at Brick Production Plant	electricity, high voltage, production mix | electricity, high voltage | APOS, U	• In this sector, the shares of electricity technologies are relevant for the year 2014. • The transmission and distribution of electricity is carried out using standard technology. This includes both underground and above-ground lines.
Sand	gravel and sand quarry operation | sand | APOS, U	• This dataset reflects the production of 1 kg of sand (35 %) and gravel (65 %). The gravel round and sand dominate 85 % of the overall sectoral production volume of mined gravel round, crushed and sand. • The gravel and sand are dug, and the recultivation process is completed at the end of this operation. • The dataset contains the entire production process for digging gravel round and sand as well as internal procedures, equipment service infrastructure, and quarry land use. • The land-use of paved roads and houses, administration, dust pollution, and wastewater are not included in the dataset.

Table 3.4 (Continued)

Water	tap water production, conventional treatment | tap water | APOS, U	• This dataset is a child of the global dataset with edited output rate, operation ties, and river or lake water exchanges ratios that are important to this geography. • This dataset reflects the output of 1 kg of pressurised tap water at the facility gate, ready for network delivery. It portrays the standard process of a traditional treatment system for producing tap water. Coagulation and decantation, filtration, and disinfection are all common treatments. • This dataset concludes with the under-pressure processing of tap water at the facility entrance. It involves energy for intake pumping, treatment system, lighting and heating of the building as well as the energy of the pump pressurizing water to the beginning of the network. • Emissions to the atmosphere that occur during treatment and delivery were not considered because they are considered to be insignificant. • In wastewater treatment, the key contaminants in water that will be released into the atmosphere are assumed to be taken into account.

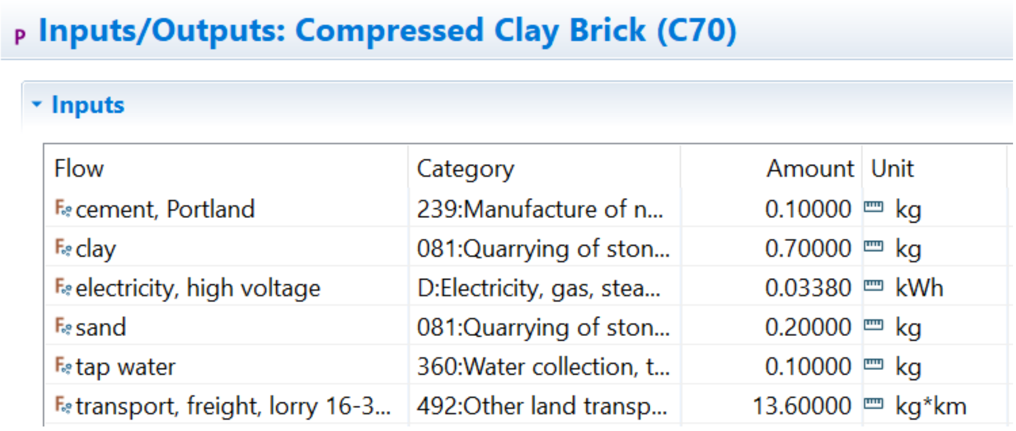
Table 3.4 (Continued)

Transportation	transport, freight, lorry 16-32 metric ton, EURO3 | transport, freight, lorry 16-32 metric ton, EURO3 | APOS, U	• This dataset describes a 1tkm freight transport service in a lorry with a gross vehicle weight (GVW) of 16-32 metric tonnes and a Euro III emissions class. • The transport datasets cover the entire transportation life cycle, including vehicle and road infrastructure construction, service, repair, and disposal.
Landfill of dredged sediment	treatment of inert waste, inert material landfill | inert waste, for final disposal | APOS, U	• Land restoration is carried out after terminating landfill events. • Half of the sites adopt a base seal and leachate assembly procedure.

Table 3.5: Origin of Dataset.

Dataset	Origin
Clay, cement, sand, tap water, energy used for brick production plant, landfill of dredged sediment	Switzerland
Transportation	RoW (Rest-of-World)

In the system boundary, it is found that the normal sand will be sieved first before proceeding to the production of compressed clay brick. The assumption for the total energy consumption of sieving normal sand and drying of clay is 0.03380 kWh (Almeida, et al., 2010). In addition, the input data for the whole manufacturing process flow of one kilogram of dredged sediment brick involves drying of sediment, sieving sediment sand, grounding sediment silt, mixing of sediment brick, compacting sediment brick and production of sediment bricks. Thus, the electricity consumption for the entire process is approximately 0.02086 kWh (Ean, 2014). All the input data for compressed clay brick (C70) will be inserted into openLCA software as shown in Figure 3.4. Figure 3.5 represents the input data for compressed clay brick (C90), whereby Figure 3.6 shows the input data for compressed sediment brick (S70).

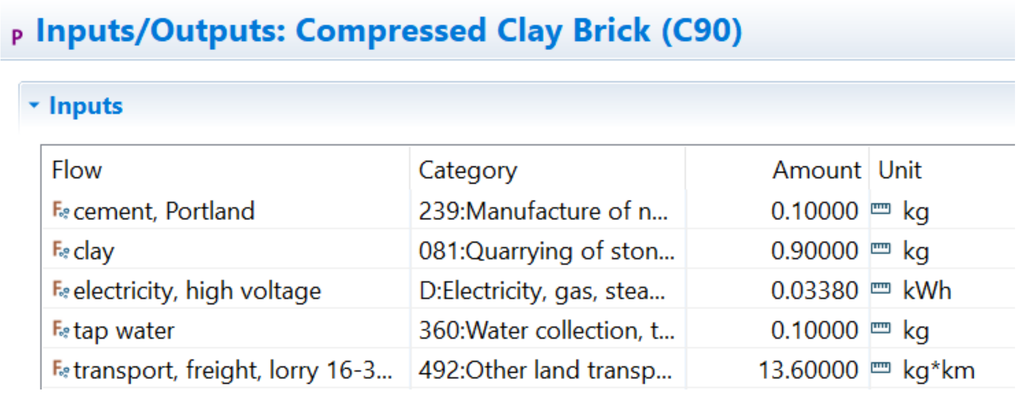


Inputs/Outputs: Compressed Clay Brick (C70)

Inputs

Flow	Category	Amount	Unit
cement, Portland	239:Manufacture of n...	0.10000	kg
clay	081:Quarrying of ston...	0.70000	kg
electricity, high voltage	D:Electricity, gas, stea...	0.03380	kWh
sand	081:Quarrying of ston...	0.20000	kg
tap water	360:Water collection, t...	0.10000	kg
transport, freight, lorry 16-3...	492:Other land transp...	13.60000	kg*km

Figure 3.4: Input Data for Compressed Clay Brick (C70).

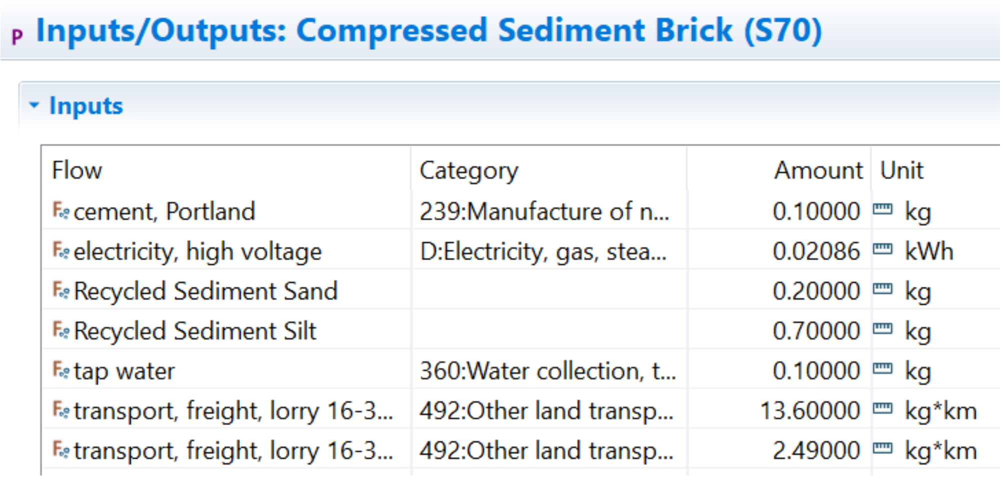


Inputs/Outputs: Compressed Clay Brick (C90)

Inputs

Flow	Category	Amount	Unit
cement, Portland	239:Manufacture of n...	0.10000	kg
clay	081:Quarrying of ston...	0.90000	kg
electricity, high voltage	D:Electricity, gas, stea...	0.03380	kWh
tap water	360:Water collection, t...	0.10000	kg
transport, freight, lorry 16-3...	492:Other land transp...	13.60000	kg*km

Figure 3.5: Input Data for Compressed Clay Brick (C90).



Inputs/Outputs: Compressed Sediment Brick (S70)

Inputs

Flow	Category	Amount	Unit
cement, Portland	239:Manufacture of n...	0.10000	kg
electricity, high voltage	D:Electricity, gas, stea...	0.02086	kWh
Recycled Sediment Sand		0.20000	kg
Recycled Sediment Silt		0.70000	kg
tap water	360:Water collection, t...	0.10000	kg
transport, freight, lorry 16-3...	492:Other land transp...	13.60000	kg*km
transport, freight, lorry 16-3...	492:Other land transp...	2.49000	kg*km

Figure 3.6: Input Data for Compressed Sediment Brick (S70).

3.3.1 System Expansion

System expansion serves as the avoided process method in the life cycle assessment. In other words, it acts as a replacement for allocation (Schrijvers, et al., 2020). The system boundary is defined in this study by taking into account allocation and system expansion. The processes with a negative sign are often applied to indicate that the environmental burdens resulting from the system expansion are avoided in the production process (Ekvall, 2019).

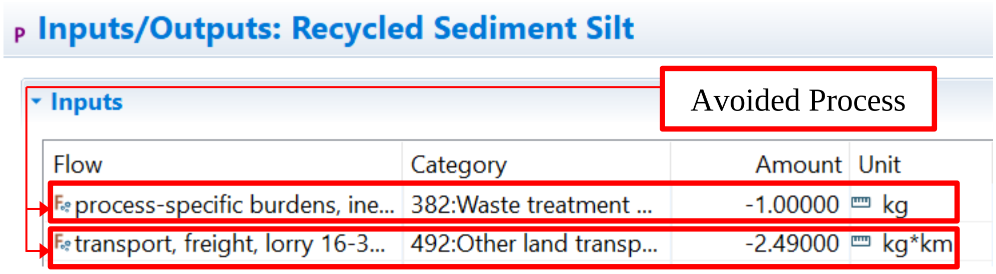
In this study, the transportation from the extraction point to landfill and the landfill of dredged sediment are all listed as an avoided process approach in the production of sediment brick. Therefore, there is a decrease in landfill waste as a result of avoiding the disposal of sediment in the landfill. Apart from that, the transportation distance of recycled sediment sand and sediment silt from the dam to landfill stated in respective Figure 3.7 and Figure 3.8 is recorded as a negative value. Thus, the cost savings of transportation are expressed by the negative value for transportation. This is due to the fact that the reduction in expenses of dumping sediment silt and sediment sand in landfill as they are no longer needed to be sent to landfill.

Inputs/Outputs: Recycled Sediment Sand

Inputs

Flow	Category	Amount	Unit
process-specific burdens, ine...	382:Waste treatment ...	-1.00000	kg
transport, freight, lorry 16-3...	492:Other land transp...	-4.76000	kg*km

Figure 3.7: Input Data for Recycled Sediment Sand.



Inputs/Outputs: Recycled Sediment Silt

Inputs

Flow	Category	Amount	Unit
process-specific burdens, ine...	382:Waste treatment ...	-1.00000	kg
transport, freight, lorry 16-3...	492:Other land transp...	-2.49000	kg*km

Figure 3.8: Input Data for Recycled Sediment Silt.

3.4 Life Cycle Impact Assessment

Life Cycle Impact Assessment (LCIA) is one of the stages in the life cycle assessment. The key goal of LCIA is to assess the possible impacts after converting the results of the LCI into a quantitative description of the environment. There are four main stages in LCIA, including selection and definition of impact categories, classification, characterization and normalization (Crawford, 2011).

ReCiPe method is designated as the impact assessment method to be adopted in the present study. To achieve the objectives of study, the selection of suitable methodology is equally important as each LCIA methodology comprises distinct impact categories (Lehtinen, et al., 2011). ReCiPe model is the most commonly used LCIA method as it is a holistic method to assess the environmental impacts based on both midpoint and endpoint levels (Bare and Gloria, 2006).

For the evaluation of environmental performance of different bricks production, the impact categories for midpoint and endpoint have been utilized as environmental indicators for this study. In this study, the impact categories for ReCiPe Midpoint indicators include climate change, human toxicity and freshwater ecotoxicity (Muñoz, et al., 2018; Huarachi, et al., 2020). Meanwhile, the damage to human health, ecosystems and resource availability are considered in the ReCiPe endpoint indicators.

Classification is expressed as the allocation of raw data from LCI to the respective impact categories that has been carefully chosen to be studied. Besides, characterization is typically used to compute the results of an impact indicator (Hauschild and Huijbregts, 2015). Normalization is the last step to be conducted in the LCIA method. It refers to the computation of the characterized impact indicator results that correspond to related information (Muthu, 2014).

3.5 Life Cycle Interpretation

The final step of the life cycle evaluation is life cycle interpretation, and it provides a starting point for judgement and suggestion (Laurent, et al., 2020). Typically, the outcomes of compressed clay brick and compressed sediment brick in relation to the environmental impact will be interpreted with the aim to improve the effectiveness of the brick industry in decision making. The characterization factors of brick usually will be taken into account for evaluating impact assessment results of the compressed clay brick and compressed sediment brick. Based on the result of impact categories, the brick industry always opts for the optimum brick product which means the brick product with the most negligible environmental impact throughout its entire life cycle.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter describes the outcomes of life cycle impact assessment of 1 kg of compressed clay brick and compressed sediment brick using ReCiPe Midpoint and Endpoint approaches. Under the APOS system model, the impact categories for the ReCiPe Midpoint method are considered in this research, namely climate change, human toxicity and freshwater ecotoxicity. Moreover, the damage categories for the ReCiPe Endpoint method include human health, ecosystems and resource availability.

The life cycle impact assessment method identifies the processes that have the highest direct contribution to the environment. After retrieving the analysis results from openLCA, the data will be converted to table and bar charts created by Microsoft Excel. Therefore, the optimum sustainable brick can be determined by comparing the environmental effect of compressed clay brick and compressed sediment brick.

4.2 LCIA under ReCiPe Midpoint Indicators

This research emphasizes on three ReCiPe Midpoint indicators which includes climate change, human toxicity and freshwater ecotoxicity. ReCiPe 2016 Midpoint (H) is selected as an impact assessment method in openLCA. For the ReCiPe method, the letter “H” stands for hierarchist which indicates that the hierarchist viewpoint mainly depends on scientific agreement with regard to the time frame of 100 years and credibility of impact systems.

4.2.1 Climate Change

For the impact category of climate change, it refers to a shift in global temperature induced by human activities that contributes to the emission of greenhouse gases. According to the scientific consensus, the high amount of greenhouse gas emissions causes a significant impact on the climate. Owing to the alarming rise of global temperature, it may bring adverse effects to the world, including climate change, desertification, global sea level rise and disease transmission. Therefore, the commonly used global warming potential (GWP) is assigned as the impact indicator for climate change. It is used to compute the integrated infrared radiative forcing due to the massive amount of greenhouse gas emissions (Stocker, et al., 2014). The global warming potential is typically measured in kg CO_2 equivalent.

Figure 4.1 depicts the impacts of global warming based on CO_2 equivalent from the production of various compressed clay bricks and compressed sediment brick. Moreover, the amount of global warming potential generated by the raw materials used for brick production is summarized in Table 4.1. C70 shows the highest environmental impact in comparison to C90 and S70. C70 is the major contributor to the global warming potential with the carbon footprint of 8.71E-02 kg CO_2 eq followed by C90 and S70 which record the total amount of carbon footprint with 8.62E-02 kg CO_2 eq and 7.59E-02 kg CO_2 eq respectively.

The ReCiPe Midpoint method points out the cement used in the brick production which contributes the most significant environmental impact with carbon emissions of 7.43E-02 kg CO_2 eq among three types of bricks. This is mainly due to the fact that a substantial amount of cement is being used in brick manufacturing which requires the cement to be heated to a relatively high temperature for the formation of clinker (Morsali, 2017). Hence, the massive amount of carbon dioxide is released through the calcination process of the cement production. Notably, the global climate change is uncommonly rapid increasing due to high concentration of CO_2 and greenhouse gases emitted from the brick industry.

In contrast, the tap water records the lowest environmental impact value of 2.17E-05 kg CO_2 eq in comparison to other inputs of the system. A low environmental impact denotes a low amount of carbon footprint released by the brick production. The result reveals that the impact of tap water is negligible to all the bricks in this study as they constitute the same amount of contribution to climate change. Despite the water required in brick production, it still remains as chemically inert. However, it will be evaporated in the form of water vapour to the atmosphere which may slightly increase the temperature. Therefore, some brick industries tend to reuse the recirculated water for brick production so that the amount of water usage in the brick manufacturing process can be decreased (Brick Industry Association, 2006).

Nonetheless, the recycled sediment silt and recycled sediment sand are the constituents of S70 which show a negative score of -2.09E-03 kg CO_2 eq and -6.70E-04 kg CO_2 eq respectively. Hence, it indicates that the environmental burdens have been avoided during the production of compressed sediment brick. These avoided impacts from the processes are sufficient to offset the impact caused by the cement used in brick production. Thus, it facilitates the production of a more sustainable brick which results in a low environmental impact.

Table 4.1: Summary of Global Warming Potential Impact for Production of 1 kg of Bricks.

Inputs of the System	**Impact Categories for Global Warming Potential (kg CO_2 eq)**		
	C70	**C90**	**S70**
Cement	7.43E-02	7.43E-02	7.43E-02
Clay	5.36E-03	6.90E-03	0.00E+00
Sand	2.38E-03	0.00E+00	0.00E+00
Tap water	2.17E-05	2.17E-05	2.17E-05
Transport	2.26E-03	2.26E-03	2.68E-03
Recycled sediment silt	0.00E+00	0.00E+00	-2.09E-03
Recycled sediment sand	0.00E+00	0.00E+00	-6.70E-04
Electricity	2.74E-03	2.74E-03	1.69E-03
Total	**8.71E-02**	**8.62E-02**	**7.59E-02**

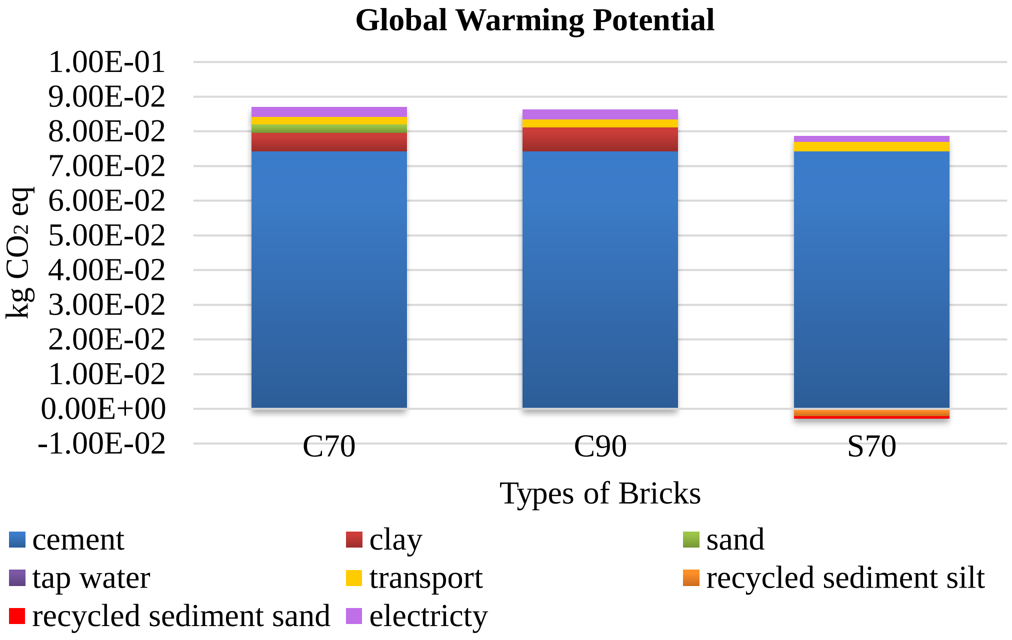


Figure 4.1: The Impact Category on Global Warming Potential for Production of 1 kg of Bricks Using ReCiPe Midpoint Method.

4.2.2 Human Toxicity

The human toxicity potential is an indicator that signifies the possible damage of a unit of chemical that is being discharged to the humans. It originates mainly from the intrinsic toxicity of a chemical and its potential exposures. The human toxicity potential is dominated by arsenic, sodium dichromate and hydrogen fluoride which are mostly formed by the generation of power from fossil fuels. These substances can be detrimental to humans if they are inhaled, ingested or come into contact with them (Acero, et al., 2015). Human toxicity is measured in the reference unit, 1,4-dichlorobenzene (Huijbregts, et al., 2005). The human toxicity potential impact including carcinogenic and non-carcinogenic risks are analysed in this study.

Figure 4.2 provides some insight into human toxicity potential whilst Table 4.2 exemplifies the impact value of human toxicity potential generated by the raw materials required for 1 kg of brick production. The result demonstrates that the score of C90 is higher than C70. C90 indicates an impact about 3.73E-02 kg 1,4-DCB higher than C70 with an impact value of 3.41E-02 kg 1,4-DCB. Thus, C90 results in a large number of carcinogens and non-carcinogens which has severe impacts on human health. Nonetheless, S70 presents the lowest impact with a value of 1.33E-02 kg 1,4-DCB.

In the case of compressed clay bricks, clay is the biggest contributor of human toxicity potential which increases the environmental burden up to 2.36E-02 kg 1,4-DCB. This is because a high portion of clay is used in the production of 1 kg of compressed clay brick. As the usage of clay increases, the human toxicity increases as well. This is due to the presence of heavy metals such as Hg, As, Pb and Cd in the clay which might cause serious health consequences to the human. It is important to notice that As and Cd have high possibility to provoke non-carcinogenic and carcinogenic risk, whereas Pb merely induces the growth of non-carcinogenic hazard to humans (Nkansah, et al., 2016). When the individual is exposed to clay for an extended period of time, it might lead to significant health problems such as kidney dysfunction, chronic liver failure and congestive heart failure. Hence, the replacement of clay by sediments is a sustainable alternative as it shows positive effects on human toxicity potential.

For the brick production, the cement use presents the second highest number of human toxicities which is 1.21E-02 kg 1,4-DCB. This is linked to the fact that the cement used as the main raw material in brick production has a significant impact on human health toxicity. The cement consists of hexavalent chromium (Cr^{6+}) which serves as a causative factor of human carcinogenic risk (Koh, et al., 2011). Consequently, hexavalent chromium is the main leading cause of skin lesions and results in dermatitis when the human is greatly exposed with cement containing Cr^{6+}. In addition, the cement dust can lead to chronic obstructive pulmonary disease prevalence as well as adversely affecting the lung function (Mwaiselage, et al., 2005). Therefore, it is considered as harmful raw material which might stimulate the cancer risk.

In the category of the human toxicity potential, the profile of sediment contributions seems to be insignificant, and the cancer risk can be neglected. Thus, the impact of recycled sediments resulting in negative value represents the environmental burden that has been avoided. The environmental performance of human toxicity for S70 is improved owing to impact savings attained from avoiding the landfilling of the sediments.

Table 4.2: Summary of Human Toxicity Potential Impact for Production of 1 kg of Bricks.

Inputs of the System	**Impact Categories for Human Toxicity Potential (kg 1,4-DCB)**		
	C70	**C90**	**S70**
Cement	1.21E-02	1.21E-02	1.21E-02
Clay	1.83E-02	2.36E-02	0.00E+00
Sand	2.04E-03	0.00E+00	0.00E+00
Tap water	2.97E-05	2.97E-05	2.97E-05
Transport	1.44E-03	1.44E-03	1.70E-03
Recycled sediment silt	0.00E+00	0.00E+00	-4.21E-04
Recycled sediment sand	0.00E+00	0.00E+00	-1.71E-04
Electricity	1.96E-04	1.96E-04	1.26E-04
Total	**3.41E-02**	**3.73E-02**	**1.33E-02**

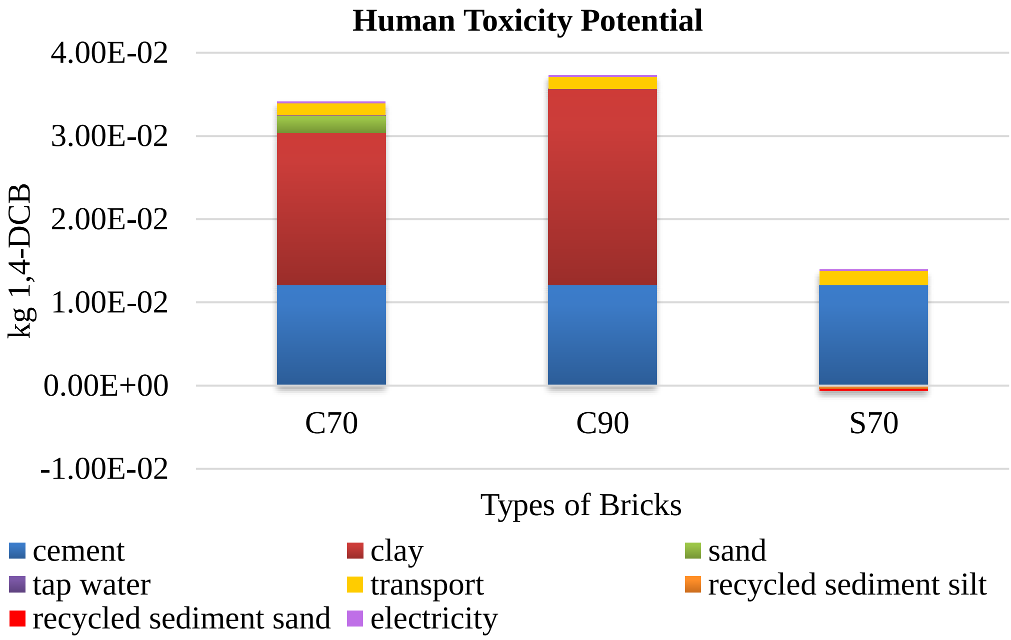


Figure 4.2: The Impact Category on Human Toxicity Potential for Production of 1 kg of Bricks Using ReCiPe Midpoint Method.

4.2.3 Freshwater Ecotoxicity

Freshwater ecotoxicity refers to the effects of harmful substances resulting from unforeseen by-products on freshwater aquatic ecosystems. Freshwater ecotoxicity is predominantly influenced by the emissions to water and air of toxins that negatively affect the freshwater ecosystems such as aquatic animals and plants. It is usually expressed in kg 1,4-dichlorobenzene (1,4-DCB).

Figure 4.3 elucidates the LCIA result of freshwater ecotoxicity of C70, C90 and S70 under APOS method. Concerning the production of 1 kg brick, C90 achieves the highest impact for freshwater ecotoxicity with an amount of 1.11E-03 kg 1,4-DCB as indicated in Table 4.3. In addition, C70 is the subsequent greatest contributor, with respect to freshwater ecotoxicity, based on the ReCiPe Midpoint results. For example, C70 exhibits 1.02E-03 kg 1,4-DCB which represents about 40 % of the total environmental impact of the brick production among three considered alternatives. Besides, S70 is the most sustainable brick as compared to other types of bricks because it contributes the least environmental impact value of 4.48E-04 kg 1,4-DCB.

For the compressed clay bricks, clay is the critical input that induces the environmental impact in the production of brick, and the proportions are 5.00E-04 kg 1,4-DCB and 6.50E-04 kg 1,4-DCB for C70 and C90 respectively. This is because a high concentration of heavy metal exists in the clay, thereby resulting in severe implications to the aquatic organisms (Nkansah, et al., 2016). The high level of heavy metals can lead to acute oxidative stress in aquatic animals and plants. In addition, the heavy metals are not easily degraded by microorganisms, and consequently survive in the marine environment continuously. The heavy metals also raise the pH of water and deplete oxygen in the water, leading to devastating impacts on the natural balance of the aquatic ecosystem (Jiwan and S., 2011)

For compressed sediment brick, cement is regarded as the greatest contributor to the freshwater ecotoxicity impact which accounts for 4.20E-04 kg 1,4-DCB. The cement will release toxic by-products such as gaseous waste and effluent into open water bodies. Hence, it is considered as a prominent ecological factor deteriorating the water quality of water bodies. The contamination of water generated by cement has a deleterious effect on the variety of aquatic organisms as well as adversely changing the plant defense systems (Erdal and Demirtas, 2010).

Table 4.3: Summary of Freshwater Ecotoxicity Impact for Production of 1 kg of Bricks.

Inputs of the System	**Impact Categories for Freshwater Ecotoxicity (kg 1,4-DCB)**		
	C70	**C90**	**S70**
Cement	4.20E-04	4.20E-04	4.20E-04
Clay	5.00E-04	6.50E-04	0.00E+00
Sand	5.78E-05	0.00E+00	0.00E+00
Tap water	8.62E-07	8.62E-07	8.62E-07
Transport	3.28E-05	3.28E-05	3.88E-05
Recycled sediment silt	0.00E+00	0.00E+00	-1.11E-05
Recycled sediment sand	0.00E+00	0.00E+00	-4.26E-06
Electricity	6.38E-06	6.38E-06	3.94E-06
Total	**1.02E-03**	**1.11E-03**	**4.48E-04**

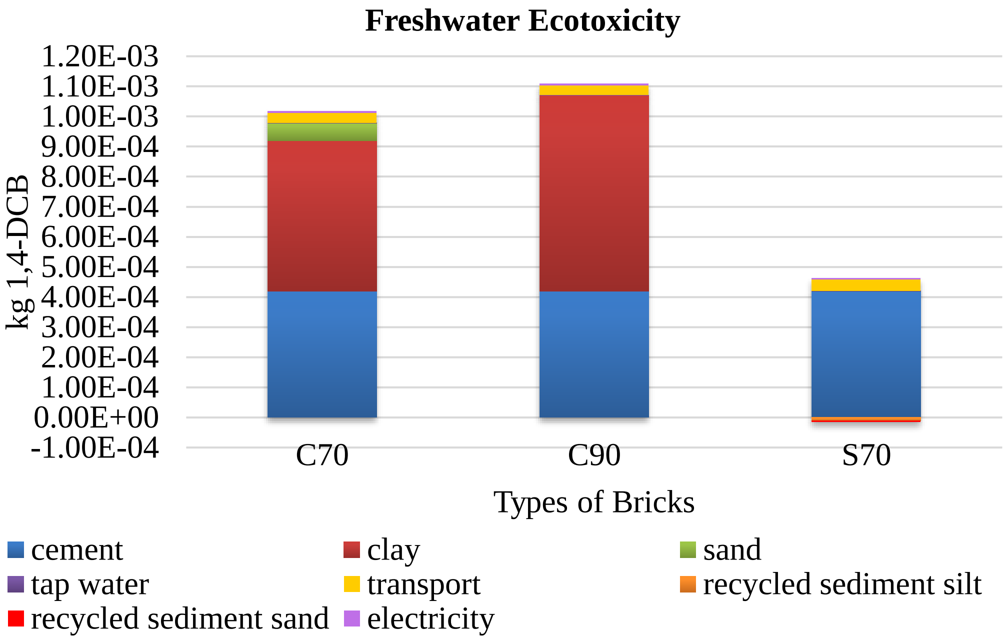


Figure 4.3: The Impact Category on Freshwater Ecotoxicity for Production of 1 kg of Bricks Using ReCiPe Midpoint Method.

4.3 LCIA under ReCiPe Endpoint Indicators

For this research, ReCiPe 2016 Endpoint (H) is carefully selected as an impact assessment method in openLCA to make sure that the application of midpoint and endpoint methods is consistent throughout the entire study. The following damage indicators for the ReCiPe Endpoint method can be discovered in this research, namely human health, ecosystems and resource availability. Thus, these indicators are examined and studied for the production of 1 kg brick.

4.3.1 Human Health

The damage to human health is defined as the probable effect of environmental degradation on human health. Therefore, it is mainly used to evaluate the incidence rates and number of years of life lost as a result of fatalities. There are several factors that come up with significant impacts on human health, namely fine particulate matter formation, global warming, stratospheric ozone layer, human carcinogenic toxicity, human non-carcinogenic toxicity, ozone formation, water consumption and ionizing radiation. The reference unit for human health damage implies the disability adjusted life years (DALY) lost in the human species (Dincer and Bicer, 2018).

Table 4.4 summarizes the damage values corresponding to three types of bricks utilized for the life cycle assessment in this study. These results are closely related to 1 kg of brick production. Figure 4.4 graphically represents the environmental impact for various types of brick production with ReCiPe Endpoint method. In the case of damage to human health, both C70 and C90 contribute the same amount of environmental burden of 1.17E-06 DALY. Conversely, S70 has the lowest damage value of 9.48E-07 DALY in terms of human health. In terms of the weighting of human health subcategories, the water consumption for compressed clay brick and compressed sediment brick has the highest damage value of 1.04E-06 DALY and 8.54E-07 DALY respectively.

Cement used in brick production has the biggest impact on human health. In this study, the damage value of cement used for manufacturing various types of bricks is 5.68E-07 DALY. The substantial impacts on human health are owing to the high concentrations of greenhouse gases and carbon dioxide discharged by the cement incorporated in the brick production. Moreover, the toxic elements leaching from the cement may trigger detrimental effects on the water quality (Młyńska, et al., 2019). Thus, it may pose severe human health problems when they consume disinfectant-free water. Other than that, there is a significant drop in the water alkalinity due to the formation of hydroxide during the chemical reaction between cement dust and water. The hardness of water is altered by the presence of salts of calcium (Ca), sodium (Na), potassium (K), magnesium (Mg) and aluminium (Al) as hydroxides, sulphates and silicates (Mishra, 1991). As a result, the human will be suffered from respiratory and gastrointestinal disorders when they intake the contaminated water (Muhammad, et al., 2021).

In comparison to other two types of bricks, S70 has a slightly high damage result in terms of transport to human health. For the transport, the damage value of S70 is approximately 1.01E-08 DALY. Meanwhile, both C70 and C90 have the same amount of damage value of 8.52E-09 DALY in terms of transport. Hence, the environmental burden of S70 is much higher than both C70 and C90. In fact, the potential environmental burden will be increased dramatically when the transportation distance of raw materials to the factory increases. In this study, the total transportation distance of S70 to the brick industry is 16.09 km, whereas C70 and C90 are transported to the brick factory with a distance of 13.6 km respectively. In comparison to S70, C70 and C90 require a short distance transport which induce less harmful human health effects such as lung cancer and other respiratory disease. Therefore, it is advocated to reduce the transportation distance of S70 so that the human will be less likely to be exposed to the noise pollution as well as air pollution caused by high traffic flow (Schalkwyk and Mindell, 2018).

Apart from that, it is noticeable that S70 reflects positive impacts in the damage to human health. This is because the recycled sediment sand and recycled sediment silt are adopted to replace clay used in the brick production. The sediments present a negative damage value which indicate the avoided landfill of sediment. Therefore, human health will not be affected as it is unlikely to pollute the water by the leaching of inorganic species from the landfill. Undoubtedly, the recycled sediment silt and recycled sediment sand are excellent in reducing the environmental burden created by the brick industry.

Table 4.4: Summary of Damage to Human Health for Production of 1 kg of Bricks.

Process	**Damage Categories for Human Health (DALY)**		
	C70	**C90**	**S70**
Cement	5.68E-07	5.68E-07	5.68E-07
Clay	6.20E-08	7.98E-08	0.00E+00
Sand	2.00E-08	0.00E+00	0.00E+00
Tap water	1.35E-09	1.35E-09	1.35E-09
Transport	8.52E-09	8.52E-09	1.01E-08
Recycled sediment silt	0.00E+00	0.00E+00	-7.46E-09
Recycled sediment sand	0.00E+00	0.00E+00	-2.42E-09
Electricity	5.13E-07	5.13E-07	3.78E-07
Total	**1.17E-06**	**1.17E-06**	**9.48E-07**

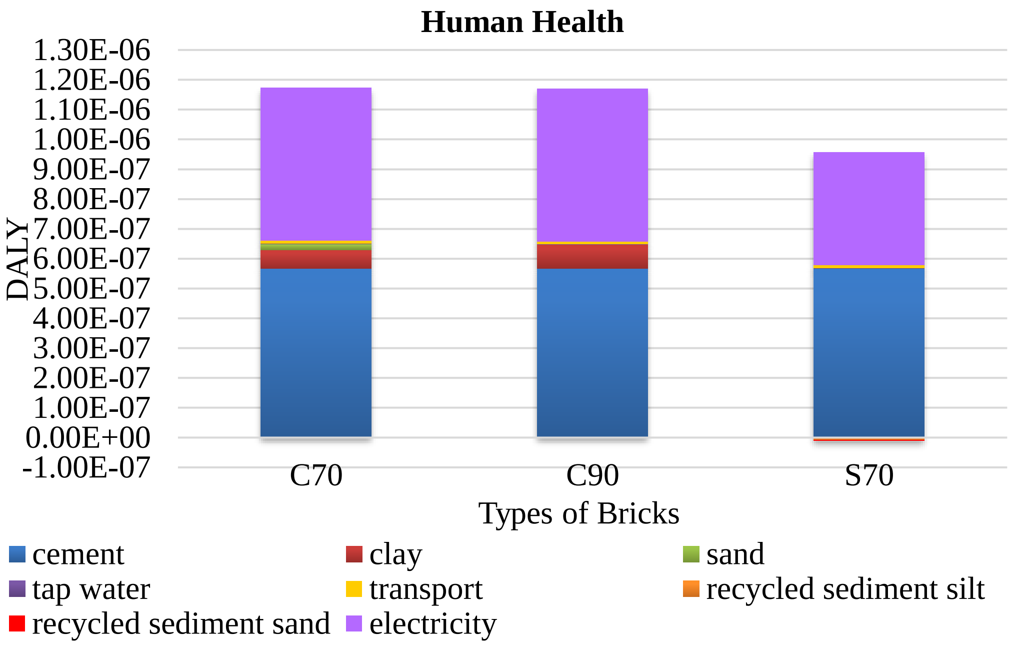


Figure 4.4: The Endpoint Damage on Human Health for 1 kg of Bricks Using ReCiPe Endpoint Method.

4.3.2 Ecosystems

The damage to ecosystems represents the effects of air emissions, water emissions and emissions to land on the environment and biodiversity over a particular region annually. The ecosystems are normally assessed by the subsequent categories, including freshwater ecotoxicity, freshwater eutrophication, global warming for freshwater, global warming for terrestrial, land use, marine ecotoxicity, marine eutrophication, ozone formation for terrestrial, terrestrial acidification, terrestrial ecotoxicity, water consumption for aquatic and water consumption for terrestrial. Moreover, ecosystems are measured in terms of the quantity of species that have been reduced or diminished over the years (Singh, et al., 2018).

C70 has a noteworthy contribution to the ecosystems damage as illustrated in Figure 4.5. According to Table 4.5, C70 constitutes 6.55E-09 species.yr or approximately 35.3 % of the total damage among three types of bricks. Besides, the damage of 1 kg of S70 is 5.44E-09 species.yr which is lower than the C90 with a damage value of 6.54E-09 species.yr. Furthermore, water consumption for terrestrial has the highest damage value of 6.93E-09 species.yr for C90 in terms of the weighting of ecosystems subcategories.

For all three types of bricks, the main damage to ecosystems is attributable to the cement. Based on the LCIA result, the cement used as inputs for life cycle assessment of brick production contributes 3.14E-09 species.yr of the total damage to ecosystems. Cement, which is used to make bricks, is a main source of CO_2 in the environment. Pertaining to the enormous growth in cement consumption, the anthropogenic emission of exhaust gas and dust have been increasing (Valderrama, et al., 2012). Moreover, the emission of fluorine, barite and barium from the cement have a large effect on marine ecotoxicity. Hence, the high cement usage may result in environmental degradation.

Apart from that, the electricity used in brick production is the second highest damage value to ecosystems. C70 and C90 contribute the same amount of electricity with a damage value of 3.00E-09 species.yr. S70 alone contributes to about 2.29E-09 species.yr of damage coming from electricity. This is most likely triggered by the most energy-intensive cement during the brick production process (Shirkhani, et al., 2018). The exceptionally high energy consumption is required for the heating process of cement, thereby significantly increasing the amount of greenhouse gases in the atmosphere. Undoubtedly, this damage leads to an unnaturally high level of global warming which is tremendously hazardous to ecosystems. The energy-efficient practice should be adopted to create positive environmental impacts correlated with generating electricity. In comparison to other types of bricks, S70 is much less energy intensive which can ameliorate the efficiency of brick production.

Referring to the result, it also points out that the tap water has the minimal damage to the ecosystems which accounts on average for 7.75E-12 species.yr for each brick. This is because the water quality must meet the required standards prior to the brick production process. As a matter of fact, the solidification of cement is impaired by water containing heavy metals or other organic acids. Thus, any hazardous chemicals in water are strictly prohibited since they may interfere with the cement hydration process as well as the strength performance of brick (Venkatesan, et al., 2019). Besides, tap water is the one with the lowest damage value to the environment due to the low water consumption during the brick production. Therefore, it is reflected to have no significant damage on the ecosystems.

Table 4.5: Summary of Damage to Ecosystems for Production of 1 kg of Bricks.

Process	**Damage Categories for Ecosystems (species.yr)**		
	C70	**C90**	**S70**
Cement	3.14E-09	3.14E-09	3.14E-09
Clay	2.75E-10	3.54E-10	0.00E+00
Sand	9.68E-11	0.00E+00	0.00E+00
Tap water	7.75E-12	7.75E-12	7.75E-12
Transport	3.35E-11	3.35E-11	3.97E-11
Recycled sediment silt	0.00E+00	0.00E+00	-2.57E-11
Recycled sediment sand	0.00E+00	0.00E+00	-8.46E-12
Electricity	3.00E-09	3.00E-09	2.29E-09
Total	**6.55E-09**	**6.54E-09**	**5.44E-09**

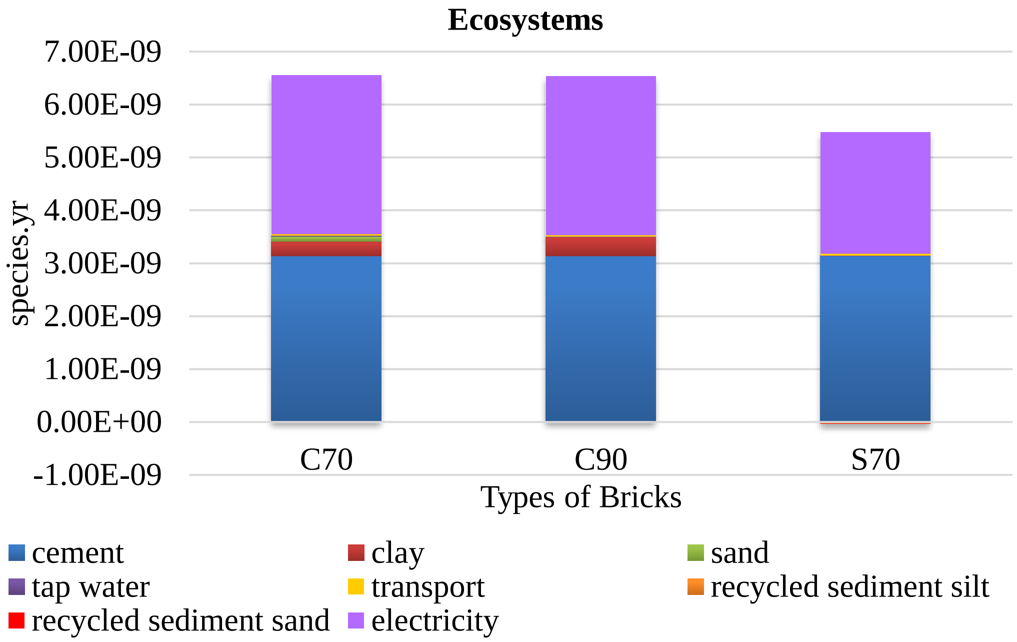


Figure 4.5: The Endpoint Damage on Ecosystems for 1 kg of Bricks Using ReCiPe Endpoint Method.

4.3.3 Resource Availability

Resource availability is one of the ReCiPe Endpoint methods that primarily depicts the exhaustion of the natural resources such as raw materials and energy supplies which poses a serious toll on the wellbeing of the population. In this study, the resource availability is derived from the fossil resource scarcity and mineral resource scarcity. It is quantified in terms of the excess energy which is mostly applied for exploiting the lower-quality energy and minerals in the coming years (Muthu, 2020).

In terms of resource availability, the LCIA results of various types of brick production are compared in Figure 4.6 while Table 4.6 tabulates all the damage value of inputs for 1 kg of brick production. C90 has the highest damage value corresponding to about 3.80E-03 USD 2013. When summing up the scores, the environmental impacts from the S70 are lower than C70 and C90 resulting from ReCiPe Endpoint methods. C70 reveals almost double impact in comparison to S70. Furthermore, fossil resource scarcity has the highest damage value of 1.70E-03 USD 2013 in terms of the weighting of ecosystems subcategories.

In the category of resource availability, the main contribution comes from clay. The result shows that the clay has the maximum damage value of resource availability of 2.19E-03 USD 2013 and 2.82E-03 USD 2013 for C70 and C90 respectively. This may be attributed to the overwhelming demands of brick which require a large proportion of clay to produce conventional brick. To satisfy the demand-supply gap, the over-exploitation of clay causes damage to land resources (Liu, et al., 2019). Besides, the source of clay will be exhausted soon due to the use of topsoil (Singh and Singh, 2020). In short, S70 is a sustainable brick as sediments act as the clay replacement in the brick production which reduces the scarcity of raw materials.

In comparison to clay, the cement is less relevant to damage to resource availability. The cement requires fossil fuel for the clinker manufacturing process, thereby resulting in high environmental burden. This is because fossil fuel is a limited commodity that cannot be replenished naturally. It is inferred that the fossil fuels will be depleted in one day if the cement demand is rising at an unprecedented rate. As a result, it might cause the environmental degradation associated with the shortage of raw materials (Bribián, et al., 2011). It is encouraged to use eco-efficient clinker production.

Table 4.6: Summary of Damage to Resource Availability for Production of 1 kg of Bricks.

Process	**Damage Categories for Resource Availability (USD 2013)**		
	C70	**C90**	**S70**
Cement	6.22E-04	6.22E-04	6.22E-04
Clay	2.19E-03	2.82E-03	0.00E+00
Sand	2.82E-04	0.00E+00	0.00E+00
Tap water	1.34E-06	1.34E-06	1.34E-06
Transport	3.41E-04	3.41E-04	4.01E-04
Recycled sediment silt	0.00E+00	0.00E+00	-3.11E-04
Recycled sediment sand	0.00E+00	0.00E+00	-9.97E-05
Electricity	1.21E-05	1.21E-05	7.47E-06
Total	**3.45E-03**	**3.80E-03**	**6.21E-04**

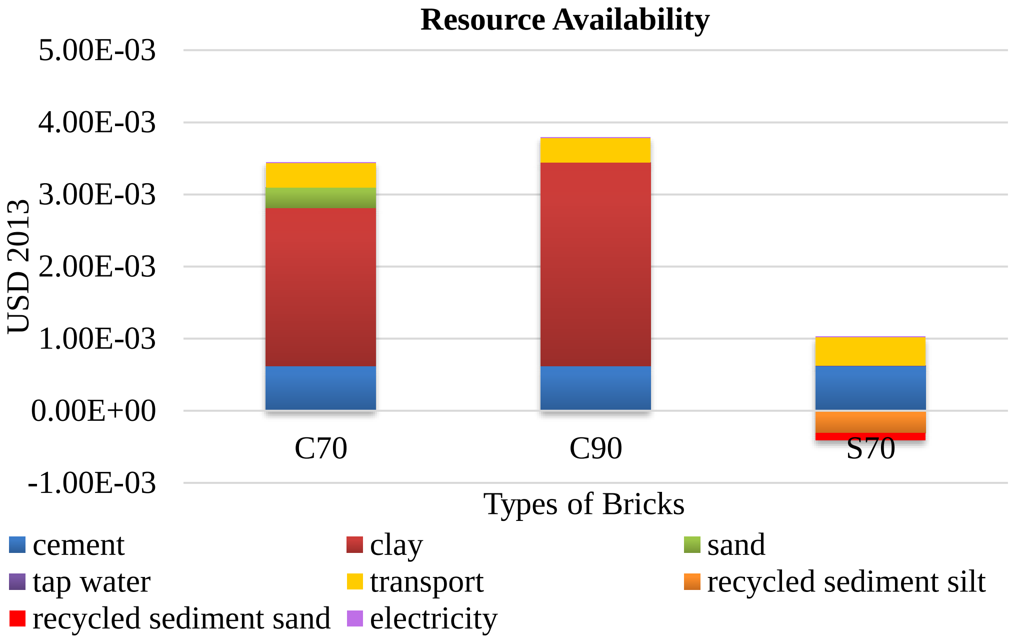


Figure 4.6: The Endpoint Damage on Resource Availability for 1 kg of Bricks Using ReCiPe Endpoint Method.

4.4 Comparison on Environmental Impacts, Engineering Properties and Cost

This study examines the environmental impacts of C70, C90 and S70 with the aim of rendering a greater potential for the green construction purpose. On top of that, it is required to determine the engineering properties and the cost linked to the brick production in order to offer the most sustainable brick. The comparison of environmental impacts, engineering properties and cost for various types of bricks will be outlined in the following parts.

4.4.1 Environmental Impacts

In this study, the relative indicator results are utilized as a means to select the optimum brick with the least environmental burden. The upper limit score for each indicator is fixed to 100 %, and the outcomes of other alternatives are presented with regards to this score.

Figure 4.7 indicates the relative indicator results of the respective LCIA categories using ReCiPe Midpoint method. C90 poses significant effects on the categories of human toxicity and freshwater ecotoxicity whilst C70 has a larger impact on climate change. With the lowest environmental burden, S70 can enhance the environmental profile of brick production in mentioned impact categories.

Figure 4.8 displays the relative indicator results of the respective LCIA categories using ReCiPe Endpoint method. S70 shows the lowest environmental impact in all 3 endpoint categories as compared to C70 and C90. S70 is perhaps the best brick in terms of sustainability.

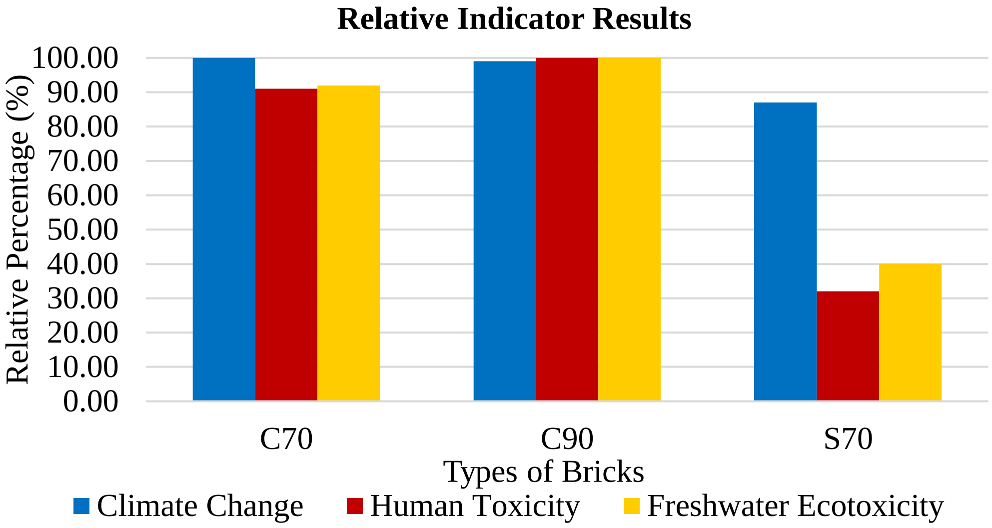


Figure 4.7: Relative Indicator Results for the Selected LCIA Categories by ReCiPe Midpoint Method.

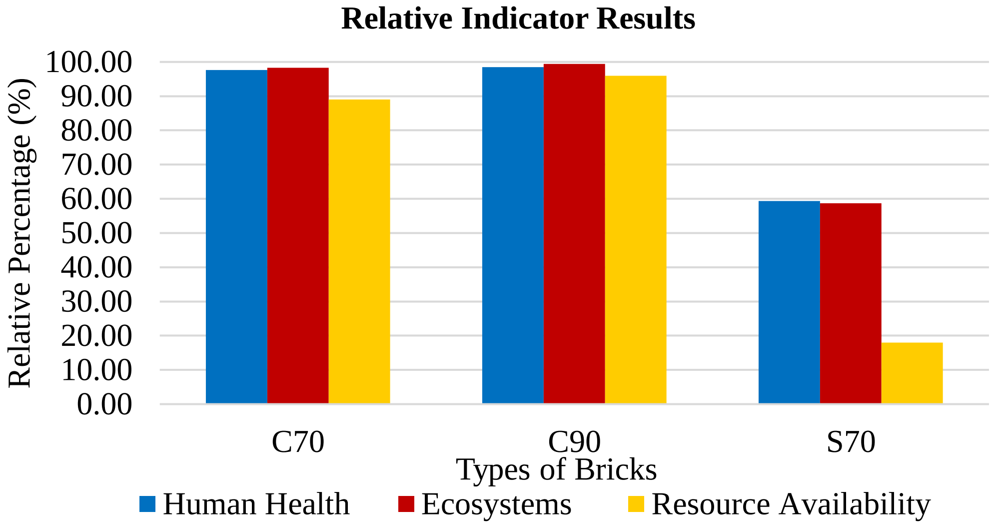


Figure 4.8: Relative Indicator Results for the Selected LCIA Categories by ReCiPe Endpoint Method.

4.4.2 Engineering Properties

Prior to the broad application of brick, the engineering properties of brick must be tested to ensure that the brick is designed based on the standard specifications. In this study, it is required to evaluate the compressive strength of various types of brick in accordance with ASTM C129 and MS Standard 76. In addition, this study considers the effects of clay replacement by sediments on the compressed brick, namely water absorption and TCLP leachate.

Compressive strength is defined as the ability of brick to endure loads imposed on it without deflection or cracking. Referring to the result of Ean (2014), the compressive strength of C70 and C90 is 8.5 MPa and 6.9 MPa respectively. In contrast, S70 gains the lowest compressive strength of 6.3 MPa for a curing duration of 28 days but still passes the minimum requirement of 4.12 MPa and 5.2 MPa in ASTM C129 and MS 76. Thus, it will not affect the overall performance of brick in terms of compressive strength.

The water absorption of S70 will be tested in order to measure the amount of water that infiltrates into the brick when it is submerged in water. The water absorption of S70 is 15.1 % which complies to ASTM requirements. When the amount of sediment increases, the water absorption increases. As a result, the compressive strength of sediment brick will be reduced. However, S70 is still able to reach the minimum ASTM requirements.

Apart from that, it is found that the presence of heavy metal in the sediments is relatively low in concentration. The heavy metal leachability of sediment brick is tested by TCLP in accordance with SW 846. Nonetheless, the result reveals that the concentration of As, Cr, Cu and Zn are within US EPA regulatory limits (Ooi, et al., 2015). Therefore, it is proven as the use of reservoir sediments is the most suitable clay replacement in brick production.

4.4.3 Cost

According to Ean (2014), the selling price for compressed clay brick and compressed sediment brick is depicted in Table 4.7. The production cost of compressed sediment brick is relatively low due to minimal dredging cost of sediment. Additionally, it aids in transporting the deposited sediments from the nearest landfill to the brick factory. However, there is an annual increment of sales price by two cents from the selling price of RM 0.17 per sediment brick in 2015. For the compressed clay brick, it shows a higher cost in comparison to compressed sediment brick. This comparatively high cost means that the raw materials produced far away from the brick factory where it is used. Therefore, it acquires high transportation cost. In summary, the brick factory always opts for minimising the need for costly investment in brick production, thereby rendering a cost-effective brick to the client.

Table 4.7: Selling Price for Various Types of Bricks.

Types of Brick	**Cost (RM)/Piece**
Compressed Clay Brick	0.40
Compressed Sediment Brick	0.29

4.4.4 Summary on Comparison

Based on the comparison, it can be concluded that S70 is the most desired brick to be used in the building and construction sector. S70 is a more environmentally friendly brick due to low adverse impacts on the environment. Despite the fact that the use of recycled sediments reduces the brick performance marginally, the compressive strength of S70 still complies with the minimum standard requirements. With regard to the selling price of bricks, S70 can save the construction cost up to 37.9 % as compared to C70 and C90. As a result, the brick industry is strongly urged to employ reservoir sediments as the clay replacement in compressed brick in order to promote higher rating construction material as well as achieving the cost optimization.

In contrast, C70 and C90 will induce an undesirable disturbance to the environment. Both C70 and C90 account for a tremendous amount of greenhouse gases and carbon footprint which subsequently turn out to be the main triggering factor of environmental risk. Nevertheless, C70 and C90 show a significant high performance in terms of engineering properties. C70 and C90 also present a considerable amount of increase in the cost of compressed brick. Therefore, C70 and C90 are unlikely to appeal to the brick industry as they not merely increase environmental impact but come with a higher cost.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study stresses on the life cycle assessment of compressed bricks using Cameron Highlands reservoir sediment as primary material. Moreover, this study infers that the results and discussion satisfy the aims and objectives which are identifying the life cycle inventory of compressed clay brick and compressed sediment brick using Allocation at the Point of Substitution (APOS) model, applying ReCiPe method that could analyse the effects of compressed sediment brick on the environment and comparing the environmental impacts resulting from the compressed clay brick and compressed sediment brick in a cradle-to-gate manner.

Furthermore, the results computed via ReCiPe Midpoint and Endpoint method includes climate change, human toxicity, freshwater ecotoxicity, damage to human health, damage to ecosystems and damage to resource availability. For the primary input in brick production, cement is the most significant contributor to climate change while clay shows the greatest impact on human toxicity and freshwater ecotoxicity. For damage categories, cement is the main contributor to human health and ecosystems whilst clay has the greatest damage value to resource availability. Subsequently, the results of one kilogram of S70 are compared with one kilogram of C70 and C90 in terms of the local economic, engineering properties and environmental aspects.

The result reveals that S70 delivers the desired results in terms of environmental impacts, engineering properties and cost. S70 has the lowest environmental burden as compared to C70 and C90 in all ReCiPe Midpoint and Endpoint categories. Furthermore, S70 is best suited for a wide range of applications due to its excellent engineering properties. As opposed to C70 and C90, S70 offers a reasonable and affordable price due to the low cost of recycled sediments. To arouse sustainable construction, S70 is definitely a viable alternative relative to compressed clay brick.

According to the findings of this study, recycled sediments probably are the privileged substitute for clay replacement in the production of compressed bricks. The negative value of recycled sediments denotes avoided impacts which corresponds to the credit given to the environment. The recycled sediments offer cost-effective measures to reduce carbon emission, transportation cost of dredged sediment and landfill of dredged sediment. There is no doubt that the utilization of dredged sediment is beneficial to the environment as it can greatly reduce and govern the detrimental impacts. Therefore, this recycled practice is a massive leap toward achieving the full potential use of the deposited sediment in the reservoir.

To conclude this study, life cycle assessment is an effective technique for evaluating the environmental impacts of construction materials. It also serves as a roadmap for the production of more eco-friendly construction materials and long-term development. Hence, the availability and accessibility of environmental information should be enhanced in order to drive markets towards green brick. To accomplish the green building concept, the construction materials also play a vital role in the delivery of net-zero carbon. S70 is highly recommended to be utilized in the construction sector as it is a low-carbon emission and nature-based brick.

5.2 Limitations of Study

The life cycle assessment in this study is constrained to the cradle-to-gate analysis method. It implies that the life cycle assessment deals only with the partial life cycle of compressed brick from raw material acquisition to the factory gate of bricks. Thus, the life cycle assessment of compressed brick is conducted without including distribution, use and disposal of bricks. Furthermore, the assumption for transportation distance for cement, sand and clay from the nearby hardware shop is 13.6 km while the recycled sediment sand and silt is transported over a 2.49 km distance. It may account for different distance travelled, resulting in variable emissions and fuel consumption. Additionally, there is insufficient local inputs and information on the environmental impact of construction materials required to undertake thorough life cycle assessment. As a matter of fact, the majority of the impact analysis relies on the sources from Switzerland and the rest of the world (ROW). In addition, the ReCiPe method is the only impact assessment method employed in this study, and it may eventually lead to less precise and reliable results.

5.3 Recommendations for Future Research

There are several recommendations that can be adopted with reference to the limitation of study in order to improve the reliability of the results:

(i) The cradle-to-grave approach, which includes the extraction of raw materials until disposal of brick, can be used to further evaluate this study.

(ii) The existing data source for the brick industry in Malaysia is limited, hence further data collection in local compressed brick production is necessary.

(iii) Transportation is of paramount importance in this study as it poses an incredible impact on the environment. Therefore, this study should focus mainly on a specific road and location.

(iv) There is no input data regarding the recycled sediment silt and sand in the openLCA software. Thus, more studies should be conducted to enhance the reliability and accuracy of the findings.

(v) Other life cycle impact assessment approaches, such as CML 2001, Eco-Indicator 99, and Impact 2002+, can be utilized to generate more extensive comparisons and improve the accuracy of the results.

(vi) To provide more comprehensive study, Exergetic Life Cycle Assessment (ELCA) is one of the refined analysis incorporated with LCA that deals with natural resource accounting.

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