Hochschule für Technik
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Life Cycle Analysis and Comparison of Different Construction Materials of Residential Buildings for Sustainable Construction Choice

Master Thesis

International Master of Science in Construction and Real Estate Management

Department 2

From

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Conceptual Formulation

Residential Buildings are the most common type of buildings, especially in the urban areas. In Pakistan, besides being the major reason behind land-use, residential buildings are also a big contributor to energy-use. However, the use of better and sustainable building materials in construction has been reported to lessen the amount of GHG emissions in the previous studies (Molin, Rohdin, &Moshfegh, 2011). Therefore, Life Cycle Analysis of residential buildings using various construction materials, designs, and processes, can help us evaluate the most suitable building material for lessening of GHG emissions from residential buildings.

This research project focuses identifying, comparing and analyzing the impact of different commonly used construction materials while constructing residential homes and buildings in Pakistan, and has been designed to recommend a suitable and sustainable residential building construction and material selection approach.

The basic questions that this research will answer are:

- How is LCA relevant in achieving sustainability and how can LCA be helpful for sustainable construction?
- Which of the stages of a building LCA consumes the most energy?
- Which construction material is suitable for designing a sustainable residential building?
- Does the region of a building, size of a building, and number of residents have an impact on the GHG emissions from a residential building?
- What are the main hurdles for a full use of LCA construction approach in Pakistan?
- What policies must be adopted to ensure green construction approach?

Supervisors for the thesis from Helsinki Metropolia Universitry of Applied Sciences and HTW Berlin University of Applied Sciences are Mr. Dieter Bunte and Mr. Eric Pollock.

Abstract

Approximately 30% of global energy consumption is attributed to the building sector. Out of these buildings and real estate, where residential buildings comprise of about 26% in the Europe and about 12% in Australia. Life Cycle Analysis (LCA) can be employed as an effective method for the assessment of overall greenhouse gas (GHG) emissions and the real energy consumption of residential buildings. This research project proposes the calculation of total embodied energy demands of buildings, in order to assess the life-cycle energy demands for the residential buildings for at least 50-75 years. By focusing on the LCA of residential buildings in Pakistan, this research prioritizes a building type that really has a huge impact on environment. This project aims to comprehensively and thoroughly calculate the embodied energy needs of two residential buildings in Pakistan using different construction materials like concrete, iron, wood etc., in order to find out the most sustainable building material. And by using the openLCA software, the environmental impact of the building materials and their production processes were assessed. In this way, the concept of 'green' building materials can be materialized efficiently. Moreover, we propose the use of different residential buildings made from a variety of construction materials as our case studies in order to develop a comprehensive LCA model for the residential buildings. Findings from the study shows that some of the most sustainable building materials are bricks, glass and tiles; while steel, concrete and cement cause the most damages to the environment and human health. This evaluation will assist in policy-making focused on lessening the total GHG emissions of residential buildings in the future and will also help the construction companies choose eco-friendly and green building material which is not harmful for the climate.

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List of Abbreviations

AIA : American Institute of Architects
AP : Acidification Potential
BOD : Biological Oxygen Demand
BSI : British Standards Institution
COD : Chemical Oxygen Demand
EIO-LCA: Economic Input-Output analysis based LCA
EP : Eutrophication Potential
FFC : Fossil Fuel Consumption
GHG : Greenhouse Gas
GWP : Global Warming Potential
HHRE : Human Health Respiratory Effect
HLCA : Hybrid Life Cycle Assessment
HSS : Hollow Structural Steel
HVAC : Heating, Ventilation and Air Conditioning
ISO : International Standards Organization
LCA : Life Cycle Analysis or Life Cycle Assessment
LCC : Life Cycle Cost
LCI : Life Cycle Inventory Analysis
LCIA : Life Cycle Impact Assessment
ODP : Ozone Depletion Potential
POCP : Photochemical Ozone Creation Potential
TRACI: Tool for the Reduction and Assessment of Chemical and other environmental Impacts
U.S. EPA: United States Environmental Protection Agency
UV : Ultra-violet
VOC : Volatile Organic Compounds
WRU : Weighted Resources Use

CHAPTER 1: INTRODUCTION

This chapter will give a starting point to this thesis on Life Cycle Analysis (LCA) of residential buildings. It will also introduce the discussion on sustainable construction choice on residential buildings. Furthermore, this chapter will highlight the research problem, objectives of the research and the questions of research that would be answered at the end of this thesis. Thereafter, the scope and assumptions made in this research will be mentioned and the chapter will close with the contributions that are expected to emanate from this research.

1.1 Background to the Research

Residential Buildings are the most common type of buildings, specially the urban areas (Adalberth, et al., 2001; Molin, et al., 2011). With the increase in population and the ever-expanding energy demands, there has been an immense increase in power generation through coal, oil, natural gas, hydropower, and nuclear energy (Stephan, 2013). However, these energy sources need to be improved in other to have a sustainable urban housing environment (Molin, et al., 2011). Therefore, LCA of residential buildings using various construction materials, designs, and processes, can help us evaluate the most suitable building material for lessening of GHG emissions from residential buildings (Matthias Buyle, 2012).

Several European States are already taking steps towards ensuring that their societies embrace sustainable construction practices through the implementation of the findings of their LCA studies on existing buildings (Oviir, 2016). The ultimate goal of these efforts is to be able to fashion out a construction system that will be sensitive to the total energy footprint of residential buildings while making recommendations on the most suitable construction materials to use on residential buildings. In this attempt, Asian nations must not be left behind.

To this end, the residential or housing sector of Pakistan will be studied to find out what building materials do the least harm to the environment and thereby encourage sustainability. It is expected that issues of pollution, greenhouse gases and global warming arising from construction and use of residential buildings in Pakistan will be brought to a minimum when the recommendations that will emanate from the findings of this study are implemented.

1.2 Research Rationale

Approximately 30% of global energy consumption is attributed to the building sector (Stephan, 2013). Out of these buildings and real estate, where residential buildings comprise of about 26% in the Europe and about 12% in Australia, LCA can be employed as an effective strategy for the analysis and assessment of overall GHG emissions and the real energy consumption of residential buildings (Lasvaux, et al., 2015).

This research project is embarked upon to calculate the overall environmental impacts that different materials of building have on the environment as well as calculate the' overall embodied energy, in order to assess the life-cycle environmental emissions and initial embodied energy demands for the residential buildings for at least 50-75 years. To do this, two (2) residential buildings in Pakistan will be studied and used for the analysis. Pakistan serves as a viable place for such studies as it is plagued with several environmental and energy issues such as heavy reliance on fossil fuels, air pollution, water pollution etc. arising, in part, from the harmful use of materials for building construction.

In the community of environmental research, the concept of Life-Cycle Assessment (LCA) has now been widely acknowledged as a most trusted base on which one can compare alternative building and production materials, components and element of structure, elements, services and even whole buildings (Ragheb, 2011). Hence this research is further justified in that the LCA notion will be adopted.

1.2.1 Research problem

Approximately 30% of global energy consumption is attributed to the building sector (Stephan, 2013). Out of these buildings and real estate, where residential buildings comprise of about 26% in the Europe and about 12% in Australia, LCA can be employed as an effective strategy for the analysis and assessment of overall GHG emissions and the real energy consumption of residential buildings (Lasvaux, et al., 2015).

This research project is embarked upon to calculate the overall environmental impacts of different materials of building have on the environment as well as calculate the embodied energy of material, in order to assess the life-cycle environmental emissions and initial embodied energy demands for the residential buildings for at least 50-75 years. To do this, two (2) residential buildings in Pakistan will be studied and used for the analysis. Pakistan serves as a viable place for such studies as it is plagued with several environmental and energy issues such as heavy reliance on fossil fuels, air pollution, water pollution etc. arising, in part, from the harmful use of materials for building construction.

1.2.2 Research Objectives

Based on the foregoing, the goal of study and this research project is to present an environmentally conscious residential house model and design. Greener buildings can be constructed through the devising of better construction plans, carefully using the construction material, reducing the construction waste, and application of effective environmental policies.

To achieve this aim, some objectives are identified including:

i. To study the relevance of LCA and sustainability for building sector.
ii. To determine the most suitable materials for the construction of sustainable residential buildings;
iii. To compute the embodied energy of the building materials used in the case study buildings;
iv. To determine some of the factors affecting the level of GHGs emission in residential buildings;
v. To adduce suggestions regarding decision-making on the design processes, materials, construction choice etc. based on LCA findings.

1.2.3 Research Questions

For the purpose of attaining of the set objectives of this thesis, it is pertinent to consider the following questions which would serve as the lead questions in this research. These questions are:

i. How is LCA relevant in achieving sustainability and how can LCA be helpful for sustainable construction?
ii. Which of the stages of a building LCA consumes the most energy?
iii. Which construction material is suitable for designing a sustainable residential building?
iv. Does the region of a building, size of a building, and number of residents have an impact on the GHG emissions from a residential building?
v. What are the main hurdles for a full use of LCA construction approach in Pakistan?
vi. What policies must be adopted to ensure green construction approach?

1.3 Delimitation

- This research is restricted to a study of residential buildings
- This research is also designed to focus on LCA of the case study buildings identified for this study in Pakistan.
- In addition, the construction materials to be studied include steel, wood, concrete, aluminum, glass and ceramic

1.4 Assumption

The guidelines already set out for Life Cycle Assessment (LCA) studies by the American Institute of Architects (AIA) are used as a standard for this research. Similarly, the method of application as used by earlier researchers within a ten-year period is taken to be useful guides for this study.

1.5 Expected Contribution to Knowledge

This research project will help in developing an affordable and sustainable building construction solution which will ensure less GHGs emissions by a standard residential home or building. Moreover, the prevalent problem of excessive fuel and energy consumption will be solved through the use of an LCA model for sustainable or greener buildings. This reduction in GHGs emissions from the buildings will indeed be of an immense importance for the country. The suggestion for a sustainable building material usage will be very essential for mitigating climate change globally. Overall, the issue of global warming is not only affecting us like changing the availability of water, but has also caused increased sedimentation in water reservoirs and the increased invasion of the deltaic region.

Therefore, this research project is aimed at lessening the GHGs emissions by residential buildings and a suitable suggestion for usage of a sustainable building material. This will be a way forward for the global climate change negotiations and securing economic growth for many countries around the world. This research will also help in countering the negative consequences of climate change and will increase the investment in low carbon technologies. Overall, this research study is meant to focus on the green growth for all the countries thriving to reduce their carbon footprint. By taking help from the estimated projected growth of GHG emissions of residential buildings of different sizes and comparing the effect of different construction materials, suitable policies can be designed and decisions can be made in order to reduce the GHG emissions by residential buildings.

1.6 Structure of thesis

Chapter One has been an introduction to the central ideas that this research seek to advance. It has provided the research problem, its objectives and research questions. It has also stated some assumptions that will be made in this study and equally highlighted the expected contribution to the already existing body of knowledge on the subject matter.

Chapter Two will provide a broad desk review of the relevant literature for LCA, sustainable construction, building materials and residential buildings.

Chapter Three describes the methodologies of the research being considered and adopted for the study and its relevance to the research problem is made apparent. The method will consist of using LCA software that accounts for the total embodied energy for raw material extraction, construction and manufacturing of a building. Moreover, the environmental impact of the construction materials are also considered alongside the discussion of the research questionnaires.

In Chapter Four, the results from the case studies will be presented and important findings will be highlighted. Also, answer to research question will be answered in chapter Four.

Chapter Five discusses how the research carried out fulfills the research objectives outlined for this thesis.

Chapter Six will give conclusions and discussion drawn from results. It will also present recommendation for LCA improvement in Pakistan

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

In Chapter Two, a concise and coordinated review of past works related to the focus of this thesis will be made. First, the concept of LCA will be discussed in which its historical development, tools, processes and application will be mentioned. Next, commonly used construction materials in the study location will be briefly discussed. Thereafter, residential buildings will be looked at and the lastly, the idea of sustainable construction will be distilled. At end, the earlier stated areas of focus of this thesis will be apparent as being a furtherance of the works of past researchers into the subject matter.

2.2. Life Cycle Analysis LCA

LCA is a method of determining the primary energy uses of building and its impact on the environment over their projected life spans. In the building industry LCA technique is used to evaluate environmental impact during the building's whole life time(Asif, et al., 2007).Since LCA can be repeated, defended and yields consistent results, it is considered the number one scientifically defensible tool for environmental assessment.

For a correct study to be made on the buildings, only those environmental impacts of the buildings' life cycle are analyzed, investigated, and measured, which can be quantified. Some of which are: global warming, ozone layer depletion, abiotic depletion, eutrophication, photochemical oxidation, acidification, among others.

For several years, LCA tools for the purpose for the environmental assessment have been used for industrial products of all kinds, but only recently did its applications to the construction industry appear. And this was at the beginning of the 21st century where LCA has been successfully applied to assess the environmental impact of buildings and building materials (Petroche, et al., 2015).As a matter of fact, every aspect of the life cycle of a building from selection of the building (product) design to picking up the building materials and the building construction processes needs to be focused upon. Furthermore, we cannot neglect the reuse or recycling strategies and end of life cycle stage where final disposal occurs. All these factors and aspects of life cycle require thorough studies of resource use and energy consumption in order to find out the accurate environmental impacts of the overall process.

2.2.1 Historical Development of Life Cycle Analysis

Originally LCA was introduced for industrial productions and processes (Petroche, et al., 2015).Ragheb(2011) states that LCA studies began in the 1970s. In the 1970s, LCA methodologies aimed at measuring the energy consumption of materials for industrial production including glass, plastic, steel, and aluminum were being developed in Europe (Ragheb, 2011)

However, general reflection of life cycle use to construction and infrastructure systems were presented in the early 1990s by Novick(Petroche, et al., 2015).The formalization of the LCA methodology began when the British Standards Institution (BSI) provided the first environmental management system in 1992, which provided a stencil for the development of the ISO 14000 series. Precisely, ISO 14040 series deals with Life Cycle Assessment which soon after became the gold standard and most reliable technique for performing environmental impact assessment for buildings (Petroche, et al., 2015). The framework of the LCA process is shown in figure 1 below.

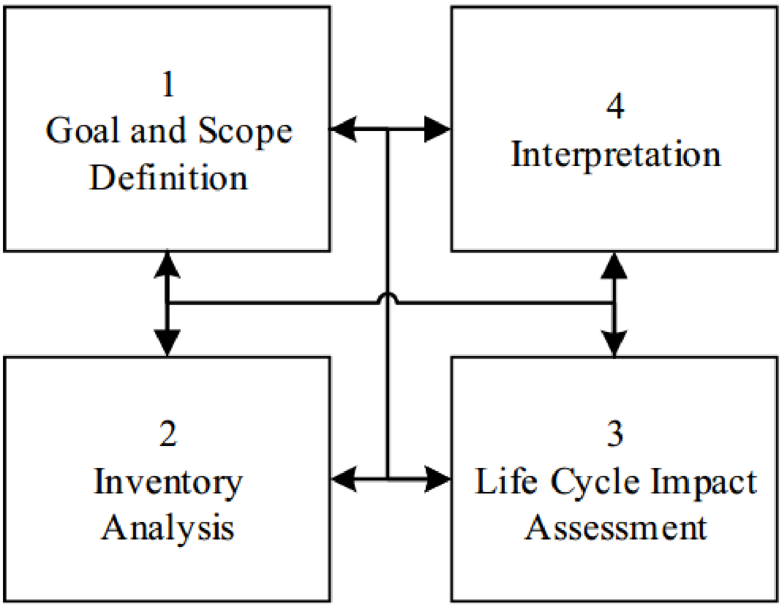


Figure 1: Framework of ISO 14040 for LCA

Source: Petroche, et al. (2015)

In infrastructure, LCA has been used by several practitioners to select suitable materials such as steel, reinforced concrete etc. for their products ranging from pipes and bridges to residential buildings and highways (Petroche, et al., 2015).

2.2.2 Life Cycle Stages of a Building

Stephan (2013) provided a simplified three (3) stages that can be identified as the make-up of the life cycle of buildings. These are: the construction phase, utilization phase, and demolition phase. Kumar, et al. (2015) identified that the methodology of LCA of buildings covers five (5) stages of a building's life. These different important stages of life cycle analysis include Product Phase as well as the Construction Phase and the Operational Phase. It also includes End-of-life Phase, and Beyond-Building-Life Phase for correct assessment of the impacts after the product's life has ended. This is corroborated by Asif, et al. (2007).

According to Petroche, et al.(2015), the stages of a building's life cycle are four (4) in number and they are:

- Pre-construction Stage,
- Building Construction Stage,
- Utilization Stage
- End-of-life Stage.

Pre-construction Stage basically deals with building materials production and it includes procedures of raw material mining and extraction of different materials which are to be used for building. It also includes the method of transportation to the site of refining, manufacturing process and revitalization of recycled material. *Building Construction Stage* of the life cycle has activities such as transportation of building materials from the site of manufacturing to the site, and then finally putting together the whole structure (building). Apart from that, an important stage is the *Use Stage* which deals with all the different processes and activities related to the utilization of the building. This means the activity of people living in it and the operating energy for different tasks. These may include *cooling*, use of AC, use of light bulbs, and cooking, etc. It accounts for 70% to 91% of the total life-cycle energy impact of the building (Petroche, et al., 2015). Oviir(2016) even opines that the Use Stage of the building makes up 62-98% of the total life-cycle energy of a building.

Lastly, the End-of-life Stage consists of the disintegrating of the structure, demolition of building, transportation to the landfill or the recycling of materials (Petroche, et al., 2015). It makes up less than about 0.2-5% of the total life-cycle energy of a building (Oviir, 2016).

Ragheb (2011) also identified five (5) stages in the life-cycle of a building. His nomenclature for the stages is: production of Building Materials, Transport of material, Building construction, Occupancy/Renovation, and finally Demolition.

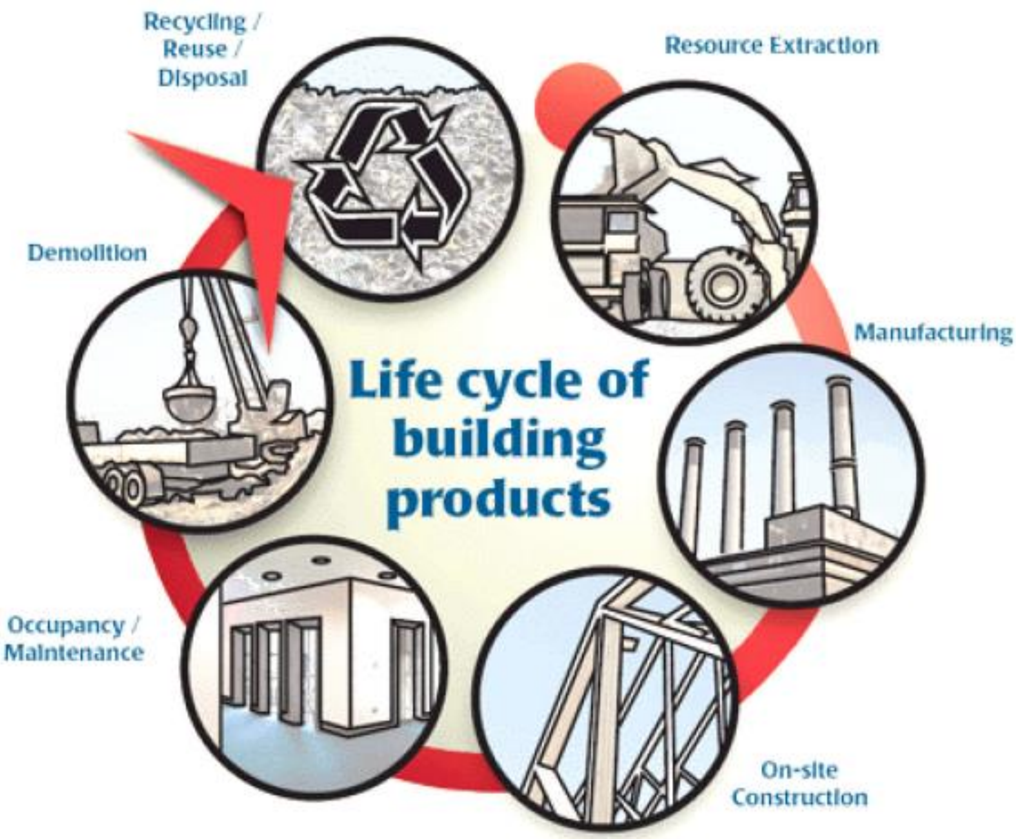


Figure 2: Life Cycle of a Building

Source: Ragheb (2011)

Thus, the five (5) stages are discussed below.

i. Resource Extraction Phase (or Product Phase)

For most building products, the first stage of their life cycle is the extraction of raw materials such as wood, ores, sand etc. These raw materials are the resources needed for the production of materials that will be actually used in the building project. At this phase, data on the energy used for the extraction of the raw resource, as well as the accompanying emissions from the process to land, air and water are collected per unit of resource in a process that is called life cycle inventory. Apart from the information gotten from the actual process of extraction – mining, quarrying, harvesting –, the data also includes the cost (in terms of energy consumption) of transporting the raw resource to the industry or plant where manufacturing begins.

Ragheb (2011) correctly stated that in assessing the environmental impact of resource extraction,oneof the more significant difficulties is that so many of the environmental effects that negatively affect people — such as the effects on biodiversity, quality of water and so other effects — are very location specific and not easily measured. As a result of that, these environmental effects are usually not considered when carrying out life-cycle inventory studies.

ii. Manufacturing Phase

In the life cycle of a building, manufacturing stage is the one that characteristically make up the biggest percentage of embodied energy and environmental emission. Whereas the extraction phase of resource ends with the transportation of raw materials to the industrial plant, the manufacturing phase begins at this point and finishes with the delivery of the products of building to the retailer or first consumer.

iii. On-Site Construction Phase

Picking up from where the Manufacturing Phase ended, On-site Construction stage begins with the delivery of the products of building to the construction location of building from the distribution centers. This stage also involves the putting together of single products, elements and sub-units that are needed in the construction and building of the entire building unit. The average or generic distance to construction building location is used in the LCA study process (Ragheb, 2011). This phase in the LCA of buildings is significant for energy use considerations and environmental impacts of emissions because it can lead accidental production of substantial quantities of waste and sometimes, pollutants. Added to transport energy of building products and other energy use there are other things such equipment transport, on site construction, temporary heating and ventilation are also considered.

Iii Operation/Maintenance Phase

Once construction is completed, the building enters into full operation. During the occupancy (operation) stage, due consideration must be given to functions like cooling, lighting, water use and heating. Floor, wall and ceiling finishes such as paints, wall paper, carpets etc. as well as other interior finishes should also be considered in this phase of the building life cycle. It must also not be lost in the scheme of things that in the process of making use of the building, the building may be modified or altered more than a few times over its life. These changes could result to alterations in the internal partitions of the building or even the introduction of an entirely new system in the building. Lastly, operation stage of the building life cycle also involves the maintenance activities that may be carried out on the building. These maintenance activities are to ensure that the building remains operational until the building is demolished.

iv. Demolition/Recycling/Disposal Phase

The final stage of a building life cycle is demolition phase. However, this does not mark the end of the individual components materials that make up the building as these components usually go into a recycling/disposal stage. However, with recycling and reuse, most of the environmental burdens resulting from processing the product back into its raw materials or components and then their transportation are, more appropriately, a change to the next stage of product (forming the closed-loop of recycling and supporting the concept of close economy). Thus, the concern for LCA will be mainly with environmental impacts of waste disposal either landfill or burning (Ragheb, 2011).

2.2.3 Approaches Used for LCA studies (Life cycle assessment standards)

The need for LCA of products has brought about the development of a number of LCA methodologies. These methodologies often yield different results and unfortunately, the results cannot be correlated (Petroche, et al., 2015)

There are two (2) LCA approaches to LCA that are conceptually different: One is process-based LCA which looks at the processes independently, and the other one is economic input-output analysis based LCA (EIO-LCA) (Ragheb, 2011). EIO-LCA is more detailed in that it uses a macro economic model that takes into account all the financial impacts of a product or a service during that period (Ragheb, 2011).

.At this juncture, it is also important to mention that LCA studies can take different forms. The major examples are:

- Building Systems LCA Studies
- LCA Studies in Detail
- compound Case Studies of LCA
- LCA Studies with Sensitivity Analysis(Ragheb, 2011)

2.2.4 Phases of LCA Study

In the late 1990s, the International Standards Organization (ISO) released a series of documents which were aimed at providing guidance to professionals on how LCA should be effectively carried out. The series presented the principle, skeleton standards for accomplishing LCA studies (Ragheb, 2011). These consist of four (4) steps of the LCA. These four steps of LCA are: goal and scope definition of LCA, The inventory analysis of LCA, the impact assessment of LCA; and interpretation the results of LCA, as well as the general introductory framework (ISO1997; ISO1998, 14041; ISO1998a 14042; ISO1998b 14043).The research has been carried out according to this four steps LCA process which is accepted word wide. The Figure 3below shows the progression of these steps with interpretation coming in at every point.

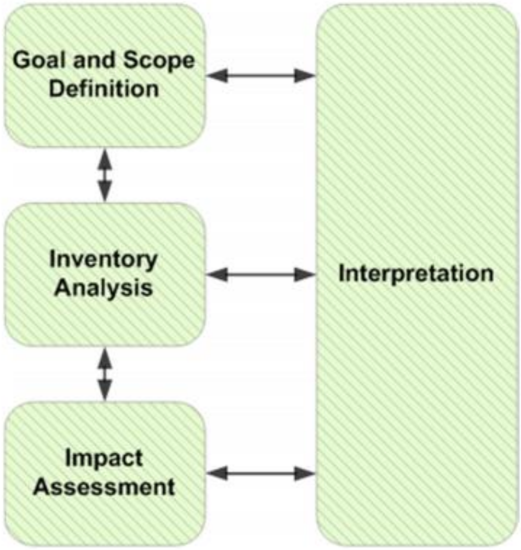


Figure 3: Life cycle analysis Phases as per ISO 14040

Source: Ali, et al., 2015

A brief look at each of these steps will now be taken.

i. Goal and Scope Definition

An LCA study begins with a definition of goal or target of study and the defining of the scope of the study. The goal of study consists and includes the main aim or rationale and purpose of performing the study as well the projected application of the outcomes and result and the intended audience. It is an explicit statement which lay down the perspective of study and enlighten how and to whom the study and its results are to be communicated. In the scope of an LCA the following items are considered and described as were equally mentioned byPetroche, et al.(2015):

- The functional unit.
- The boundaries of systems
- Type of impact assessment methodology and interpretation to be performed.
- Data requirements and quality.
- Assumptions and limitations.

The functional unit quantifies and measure the service delivered product system. It is usually defined based on the area taken during a lifespan of the product system. Petroche, et al.(2015) noted that there are different systems adopted to define functional unit. It can be “one square meter of usable floor area, over one year

(m^2/year)". All of these definitions of a functional unit enable comparison of two essential different systems to be made on a common platform. For example, the unit area (ft^2) can be defined as the functional unit for a paint system for a 10-year period. With this, it will be possible to compare the environmental impacts of any two different paint systems.

Essentially LCAs are conceded to assess current impact emission and predict the future impacts of the product. However, some of the limitations to time boundaries are as a result of the technologies involved, pollutants lifespan, etc.

ii. Life Cycle Inventory Analysis (LCI)

Life Cycle Inventory Analysis (LCI) follows the second Phase of LCA studies follow the goal and scope of LCA. LCI covers all the steps that cut across information gathering, recovery and management. LCI also takes into accounts the computations to measure the material and energy inputs and outputs of a building system (Ragheb, 2011). Pollutant and hazardous gas emissions are example of outputs as impact emission. LCI flows include energy and raw materials inputs. In the end, the results of an inventory is an LCI profile which presents statistics and data about all inputs and outputs in the shape of fundamental flow to and from the environment from all the unit processes.

Because the LCA process relies heavily on data, the collection of data must be done with utmost care notwithstanding the huge effort the process demands. To simplify the effort however, data could be obtained from other studies or databases and reused in the present study but caution must be taken to ensure that the data taken is truly representative.

Because the LCA process relies heavily on data, the collection of data must be done with utmost care notwithstanding the huge effort the process demands. To simplify the effort however, data could be obtained from other studies or databases and reused in the present study but caution must be taken to ensure that the data taken is truly representative.

iii. Life Cycle Impact Assessment (LCIA)

This is the third phase of LCA studies followed after LCI phase. The LCIA is the process of evaluating the computation of inventory process in the form of environmental impact assessment and its extent. It also provide information about the selection of categories of environmental impacts, which impact categories can be considered for impact emission and why (Ragheb, 2011).

It is important to know the Impact categories are chosen in line with the defined study objective according to the goal and scope of the LCA.

U.S EPA (2006), in its report, "*LCA- Principles and Practice*", highlighted ten (10)categories of environmental impact that are considered to be very significant and vital according to literature and from the point of view of environmental and political perspective. Table1 below shows the most commonly considered impact categories of which some are computed in this research.

Env'l Impact Category	**Scale**	**Relevant LCI Data (i.e., classification)**	**Common Characterization Factor**	**Description of Characterization Factor**
Global Warming	Global	Carbon Dioxide (CO_2) Nitrogen Dioxide (NO_2) Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH_3Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO_2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH_3Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SOx) Nitrogen Oxides (NOx) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH_4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents.
Eutrophication	Local	Phosphate (PO_4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO_2) Nitrates Ammonia (NH_4)	Eutrophication Potential	Converts LCI data to phosphate (PO_4) or to Nitrogen (N) ion equivalents.
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxident Creation Potential	Converts LCI data to ethane (C_2H_6) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC_{50}	Converts LC_{50} data to equivalents.
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC_{50}	Converts LC_{50} data to equivalents.
Human Health	Global Regional Local	Total releases to air, water, and soil.	LC_{50}	Converts LC_{50} data to equivalents.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Land Use	Global Regional Local	Quantity disposed of in a landfill	Solid Waste	Converts mass of solid waste into volume using an estimated density.

Table 1: Commonly Used Life Cycle Environmental Impact Categories

Source: U.S. EPA, 2006

iv. Interpretation of Results

This is the fourth and the last stage of LCA studies followed after LCIA. The main goal of this phase is to make interpretation of the LCIA and evaluate the findings. On the bases of evaluating the findings conclusion and recommendation are made. The findings are evaluated in line with the scope and goal definition of the set studies. The outcome of the LCI and LCIA are then put together and presented so as to give a comprehensive account of the study carried out.

The three (3) main elements which make up life cycle interpretation of an LCA or an LCI are:

1. Recognition of the important issues based on the outcomes of LCI and the LCIA phases of an LCA.
2. Assessment of results, which considers completeness, and consistency checks.
3. Based on evaluation making Conclusions and recommendations (Ragheb, 2011).

2.2.5 Operation Energy, Embodied Energy and Transport Energy

For any LCA study, energy models are used to determine the expected energy consumption of a building as it operates over a given time frame, which is typically one climatic year (Ragheb, 2011). The results gotten from the energy model when the building is put into use constitutes the operation energy of the building which will be used for LCA studies, mainly the operation phase. Operation energy is generally agreed by several researchers to account for a large percentage of the total energy footprint of any building in the LCA process (Oviir, 2016; Petroche, et al., 2015).

The second one is embodied energy. Embodied energy is characterize as the energy used to fabricate products, encompassing all related activities comprising of manufacturing, mining, transportation, and quarrying etc. Embodied energy consists of the energy needed for building materials production, construction and replacement (Stephan, 2013). The calculation of embodied energy requires two(2) components: the initial or first embodied energy and the recurring embodied energy component.

Having a clear understanding of embodied energy is useful in the drive to reduce operational energy in buildings (Ragheb, 2011).

Transport energy gives us the amount of energy for the transportation of required building crew(Stephan, 2013). This type of energy is often neglected in the study of energy use of buildings but is gradually becoming an important variable to be considered in researches such as this.

Operation energy is the type of building energy use which can be quantified and is quite easily measurable (Stephan, 2013). The last type of energy which is usually measured is embodied energy which makes up for energy use across the supply chains of building materials. (Stephan, 2013).

2.3 LCA of Construction Materials

From the earliest years of LCA as a reliable method for assessing the total energy footprint and the environmental impacts of buildings, several researchers have attempted to study how different building materials affect the energy requirements of buildings. Ragheb(2011) reported the studies of a number of authors who worked on this reearch area in the 1990s. Some of the building materials worked upon by the researchers include steel, wood, and concrete. Their findings suggest that total energy requirements of buiildings constructed with more wood, and with alternative structural assemblies is significantly less than buildings constructed with much concrte and steel (Ragheb, 2011).

The life cycle of any industrial material follows a cyclical loop that was first published by the Society of Environmental Toxicology and Chemistry in 1991 (Ragheb, 2011) is as follows:

a. Material Acquisition
b. Processing Manufacturing of materials
c. Distribution, Transportation of materials
d. Use, Reuse, Maintenance of material
e. Recycle of material
f. Waste Management of material

Some of the more common building materials used in Pakistan will be discussed briefly.

2.3.1 Wood

The wood which is suitable for building purposes is called timber. When lumber is sawn into various market forms like beams, battens and planks etc., it is called converted timber. Some of the more manufactured timber products used for building construction are laminated timber, plywood, batten board, particle board, and hardboard.

Before timber is used for any construction purpose, it is first seasoned to remove the moisture content in the wood. Seasoning also makes timber more stable when used for construction; it gives it immunity from rot and fungi attack, and also makes it easier to apply finishes such as painting.

2.3.2 Concrete

After laterite, concrete is the most universal material used all over the world for building construction. In Pakistan, about 15% of the population in cities lives in houses built of reinforced concrete (Badrashi, et al., 2010). Concrete is composed of cement, aggregates and water in predetermined proportions. Additional material called admixture may be added to influence the properties of concrete. Aggregates used for concrete-making are both coarse and fine and are measured separately according to the desired mix.

Concrete performs very well in compression and so can be used as plain concrete in places where great compressive strength is required. However, where tensile forces have to be resisted in the structure, reinforcement bars will be needed to cater for the tensile stresses in the system.

2.3.3 Glass

Glass is used in residential buildings mainly as flat glass. Glass has several desirable properties which make it to be used on buildings for diverse purposes such as aesthetics, insulation among others. Glass is could be transparent, translucent, opaque or colored in appearance. Glass is also extremely durable in normal conditions. Glass in buildings is required to resist loads including wind loads, impact by persons and animals and sometimes thermal and other stresses.

2.4 Residential Buildings

A residential building may be regarded as a combination of different construction materials, which is able to make space and room for living. It is used to provide housing or domestic services. Researches on LCA of Residential Buildings have been carried out in several countries of the world since the early 2000s.Petroche, et al.(2015) record that relevant cases revealed that there have been eight(8) studies from Europe, one (1) from Asia, two (2) from North America, and one (1) from Australia. Furthermore, the authors identified “Key study parameters” that are essential when carrying out any LCA studies on buildings. The parameters are:

- *Type of analysis*: which might be energy use comparisons, material comparative analysis, and overall analysis;
- *Functional unit*: which focuses on area occupied during a building lifespan;
- *System boundaries*: which could either be the construction phase or use phase of a building etc.;
- *Impact assessment methodology*: which varies widely based on its orientation;
- *Impact categories*:

2.4.1 Residential Buildings in Pakistan

Residential buildings in Pakistan are of different types. Some of them include the traditional detached houses, British 1-story bungalow houses and 2-story bungalow (Malik & Hassan, 2019). These houses are built to house the population of the country. In the more rural areas, detached houses built with mud bricks and other traditional building materials are most common.

However, in the recent decades, there has been an increase in the construction of reinforced-concrete buildings in Pakistan (Badrashi, et al., 2010). These building are usually erected on relatively flat terrains and have rectangular plans. The major cities of Pakistan like Karachi, Lahore and Islamabad have between 10% to 20% of their entire housing supply being reinforced-concrete structures which can typically house between 21 to 50 family units, depending on the number of floors in the buildings (Badrashi, et al., 2010). An increase in the number of reinforced concrete buildings in a city with high population poses significant threat to the environment over time.

Pakistan has a huge annual housing demand of 700,000 units in both rural and urban areas but only 250,000 units are provided annually (Hasan & Arif, 2018). This is mainly as a result of the high population in Pakistan who need decent housing. Of the figure stated above, 65% is for lower income groups, 25% for lower middle income groups, and 10% for higher and upper middle income groups (Hasan & Arif, 2018).

2.5 Sustainable Construction

The concept of sustainable construction is a philosophy that has ecological, economic and social dimensions. It is the idea of building in a responsible way such that respect is been accorded to both human needs and global ecosystems of the present.(Ragheb, 2011).

Right from the end of World War II when vast areas of the world (most especially in several parts of Europe) needed to be rebuilt, key stakeholders in the building and environmental fields have been concerned with the link between environmental well-being and economic development (Ragheb, 2011; Stephan, 2013). This concern is based on the idea that if people live and work in conducive environments devoid of pollution, they will be more productive and hence, there will be economic development.

At least, two (2) things need to be borne in mind to achieve sustainable construction. They are: the construction style and the construction materials. Building materials have a huge role to play in determining the sustainability of the buildings (Janjua, et al., 2018).

2.6 Chapter Summary

In this chapter, the main themes in this research have been explained. Several studies carried out on LCA have been brought to the fore, assessed and compared in order to come to a clear understanding of the issues on ground. The historical development of LCA has been covered as well as the steps involved in the entire process. Similarly, all the stages of a building's life cycle were also highlighted and explained to great detail to show how each stage is different from the other stages. Three (3) types of energy related to buildings – operation energy, embodied energy and transport energy – were also discussed and attempt was made to show how these specific energy types affect LCA results. Finally, sustainability in the construction sector was also considered. How all of this knowledge affects our work will be made clearer in the following chapters.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter deals with the methodology “Case Studies” and “Research Questionnaire” used for the research.

The goal of this thesis is to propose an environmentally conscious residential house model and design, in order to encourage sustainable development and construction. Relevance of case studies will be described in the following sections and a step-by-step procedure to conduct Life Cycle Assessment (LCA) on the case studies will be done. This will be followed by a statement on the reliability and validity of the method.

3.2 Research Design

Research design employs two approaches: case study approach that consists of two (2) cases and the use of questionnaires directed at LCA related respondents. The case study approach is an empirical analysis that examines a phenomenon in the context of its real life (Ragheb, 2011). The case studies chosen for the purpose of this study have been properly appraised to serve as tools for the realization of the set aim and objectives and enable the researcher to study their performance as a means of creating design solutions.

The case study method also needed the support of other sources to collect relevant data for this research. Some of those data included Building specification requirements, environmental reports, interviews and findings, energy data released etc. all of these information were needed to correctly assess the environmental impacts of the buildings. Furthermore, typical general buildings were been selected. This will help to applythe result of the study to other similar type of building in a generalized way. In this instance, simple residential buildings are studied.

Multiple case studies are preferred for this research because they provide an opportunity for comparisons to be made between the LCA performances of the case study buildings considered in this research. More so, for comparing different material of buildings, it is imperative that more than one case study should be considered.

After all, the results of comparative cases are often deemed more convincing than those of a single case (Ragheb, 2011).

3.3 Research Study Location: Pakistan

The research location chosen for this study is Pakistan. Two case study buildings from the cities of Karachi and Lahore were studied. Figure 4 below is a map of Pakistan.

Figure 4: Political Map of Pakistan showing Karachi and Lahore

Source: https://www.mapsofworld.com/pakistan/pakistan-political-map.html

Pakistan is located on the “Indian sub-continent” in South Asia. As per the 2017 census, the nation is having population of 207,774,520 people. Pakistan's climate varies widely, with significant variations among the high mountains and low plains.

The country has four seasons, although experiences of winter and summer could vary widely depending on the region one is.

Karachi is reputed to be the largest city in the nation and its having main road, industrial, commercial area, and manufacturing centers. Karachi is situated in the province of Sindh, and is the provincial capital. The city served as the first capital of an independent Pakistan from 1947 – 1959.Karachi stands first in terms of population in the country and it suffers serious challenges of housing. So with that is also the demand of housing in peak. With more population and more construction projects come more the threats of environmental damages. That is why one of the case studies is from Karachi. A residential housing complex in Karachi will be used as the first case study in this research.

Lahore is the capital of Punjab. Lahore is second largest city of Pakistan and holds great significance due to its rich cultural, political and architectural history (Malik & Hassan, 2019). Lahore hosts large number of beautiful and architecturally important buildings. Lahore has a variety of residential housing designs including traditional detached houses, British 1-story bungalow houses and 2-story bungalow houses among others (Malik & Hassan, 2019).Lahore also stands second on the pollution index after Delhi as per pollution index 2019.That is why sustainability is the main concern of the city. For which life cycle analysis can be one great tool that can help in achieving the goal. Therefore a detached wooden house in Lahore will be used as the second case study in this research.

Both Karachi and Lahore have been chosen as the cities from which to select the case studies because of their relative high population which makes building residential houses essential in these areas. Both cities are also the largest and second largest cities in Pakistan respectively. And with this, comes the challenge of ensuring that construction is sustainable to reduce the environmental impact that the construction activity would have had on the environment.

3.4 Research Instrument

To assess the environmental impact of the residential building, a lifecycle assessment framework is chosen as the primary research tool or instrument (ISO

14040, 1997).LCA can be expressed in a mathematical statement, thus in this study, LCA is described using a simple linear model. The functions in the equation are the results of observed, measured and downloaded data. LCA is a number of key studies rolled up into one. LCA pinpoints and computes energy and material use of a system.(Ragheb, 2011).

However, in spite of the robustness of this powerful research instrument used in this study, it still has some drawbacks. Ragheb(2011) noted that out of the four (4) steps that make up a complete LCA study, three (3) of them – namely scope definition, impact assessment, and interpretation – suffer from uncertainty and errors. Furthermore, several other limitations have been highlighted by ISO 14040 (ISO 1997) such as:

i. Inventory and impact measurement frameworks are restricted (e.g. linear ra ther than nonlinear);
ii. The quality of the analysis may be limited by the availability or usability of r elevant data.
iii. Sometimes the result cannot be adjusted to local conditions.

3.5 OpenLCA Life Cycle Program, Features and Limitations

OpenLCA is a Life Cycle Assessment (LCA) tool for building analysis developed by Green Delta, a company based in Germany. OpenLCA software can be downloaded from http://greendelta.com. For this study, OpenLCA version 1.9.0 was used. This program allows complete generic modeling of buildings and other products. Data used are established databases from different environmental bodies and they are usually industry averages adjusted to regional conditions. OpenLCA however has a collaboration server which helps to make data sharing easier.

OpenLCA Life Cycle System applies a collection of input takeoff construction algorithms to create a bill of geometry-based materials and building requirements. This products plan instead includes the openLCA Databases to create a building profile for the cradle-to-grave Life Cycle Inventory (LCI). The findings of the LCI assessment include the building's life cycle phases.

Since 2016, openLCA has added Life Cycle Cost (LCC) to their software package in which costs are modeled as properties and can be either positive or negative (Schmidt, 2018). OpenLCA uses “flows “to calculate LCC and LCA and, as have been pointed out earlier, it has a wide range of databases that can be used with the main software package such as databases from GaBi, Ecoinvent and US EPA databases among several others.

Interestingly Schmidt (2018) highlighted some of the strengths of openLCA to include the fact that:

(i) It contains local compensation mechanism to adjust value to local conditions.
(ii) Different currencies are included in the software
(iii) It includes uncertainty analysis
(iv) It contains a full set of all environmental impact categories.
(v) Results can be exported to Excel
(vi) Results can be adjusted to local situation and

3.5.1 LCA Collaboration Server

It is in the form of cloud that allows users operating from different computers to share and organize LCA data (e.g. flows, configurations, product processes or whole LCA models) making for unified, collaborative LCA modeling (GreenDelta, 2019).

3.5.2 Impact methods

There are several approaches of impact for the use in openLCA. These impact methods are the ones developed by American and European agencies, notably that of U.S.A the Environmental Protection Agency (U.S. EPA), and the Chemical and Other Environmental Impact Control and Assessment System (TRACI).

To create a complete profile of environmental impact, this study will includes the available impact assessment categories of TRACI available and is described in some detail later. Some of these areas for impact assessment include: use of primary energy (fossil fuel), weighted raw material usage, global warming potential, acidification potential, potential for eutrophication, photochemical smog potential, potential for human health respiratory consequences and potential for ozone depletion.

3.5.3 Data quality systems

OpenLCA has been supporting data quality systems for process data sets and exchanges (in process data sets) since version 1.6. Nexus ' ecoinvent and PSILCA databases already contain data quality systems and are used in openLCA to evaluate data quality in a product system calculation(GreenDelta, 2019).

3.5.4 LCA databases

By practice, each database can be imported directly into openLCA by EcoSpold or IL CD format (GreenDelta, 2019). Nonetheless, if research is to be performed on data from several sources, or on similar LCIA approaches, further work is needed to coordinate the different data sets better. The Nexus page (available at https://nexus.openlca.org/) can also be used to search for individual data sets and with different categories based on the requirement of analysis.

3.4.5 Limitations of OpenLCA

First, the calculations for the environmental impact of the buildings involve quite complex calculations that may go wrong if handled poorly. Secondly, the software requires regular updates to keep up with new data sets and changing environmental regulations which may affect the quality of the results of using the software. Thirdly, the software lacks sufficient amount of local data. Related to the third point is the fact that the person doing the calculations might have access to data in a format that is not compatible with the software and exporting and using that data within the software requires a lot of manual work. Actually, Schimdt (2018) identified some of the weaknesses of openLCA to include:

(i) Costs have to be entered manually
(ii) All inputs can be modified by the user which allows for a significant degree of subjectivity
(iii) LCC feature is new and more research into its reliability required
(iv) Lack of bulk edit function (such as changing the electricity mix for multiple processes in one step) (myEcoCost)
(v) Process data used

3.6 Modeling Steps

The process of creating the case study models involves some research about the component parts and systems of the buildings to be studied such as the type of building, the construction materials, HVAC systems etc. The primary data includes product specification, building component details, manufacturer, transportation details, and period of calculation, total quantities, operation energy and recycling criteria. These inputs generate results in terms of environmental impacts. Result can be checked system wise as well as a whole. A report can be generated from the result for each component and as a whole

The goal of this case study is to build a sensible model involving several different flows that allow an evaluation of the possibilities provided by the database and that is representative at the same time.

For the model, the new process available in openLCA 1.7.0 was used. A single process aggregated all the input flows for the model. In the next step, the amounts for each flow were set. Finally, the product system for process was created and a sensitivity analysis was made using the ReCiPe Midpoint (H) [v1.11, December 2014].

Lastly, the impact assessment of the residential building was determined based on the results generated on the openLCA software.

3.7 Research Procedure

The scope and procedure employed in this research follows that already discussed in this research regarding the phases of LCA so far. Under the first phase, Goal and Scope Definition, some of these procedures will be further broken down in the following sub-headings:

- The functional unit.
- The system boundaries.
- Data requirements and quality.

3.7.1 Functional unit

The functional unit is the collection of different attribute that should be considered the same for analysis and comparing. One functional unit can be for this study as one family unit of the selected case study buildings family units. This practical structure has a living room, kitchen, service field, toilet, two bedrooms, garage and a broad yard, with an average total construction area of around 60m2. For ease of calculations and for better understanding of the study, the functional unit for this study is to be defined as a “square meter (m^2) of usable floor space”. As Ragheb (2011) pointed out, this functional unit is used extensively by researchers and will be convenient for comparisons and useful in drawing conclusions between the cases (Petroche, et al., 2015). On the other hand, the clause “usable floor area” is taken to mean the total floor areas of the buildings including staircases, pent floors etc. if any. In order to be able to reproduce the findings of the study, the conclusion of LCA settles on the impacts of environmental per m^2 of usable floor area of the case study buildings. This measuring of the result of the case studies on common unit will help other practitioners to compare the result of this study with similar work for other project.

3.7.2 System boundary

Simply put, the system boundaries state clearly what is to be added or disregarded in the LCA study. Specifically, it covers the entire energy and mass flows recorded in the building under study. As a result, transport energy and emissions from material are used. Conversely, some factors not directly related to building LCA will be ignored or disregarded. This is partly because of the difficulties associated with simulating these aspects of a building’s life cycle (Ragheb, 2011). Some of these factors to be excluded in the study include material production loads for household, bathroom and other place suppliers etc.(Ragheb, 2011).

3.7.3 Data Requirements and Quality

Relying on established processes and methods such as ISO 14040, the data from the study will be assessed both quantitatively and qualitatively. These methods are generally accepted as reliable means of testing and will add credence to the authenticity of the study. The sensitivity is a process where you change your inputs parameter for the design of a process to see the change on the results (Ragheb, 2011).

3.7.4 Life Cycle Inventory (LCI)

When mentioned above, LCI requires data collection on the topic and measurements, in order to measure the content and energy inputs and outputs of the case studies of the project. Primary data sources for the case studied building, i.e. materials and energy identification and quantification, are materials bills, material sheet specifications, floor plans offered by architects and made available online. Other necessary information about the two cases are accumulated through site visits and information provided by contractors. Using openLCA life-cycle software and calculation program the life cycle inventory process was completed. (Figure 5)

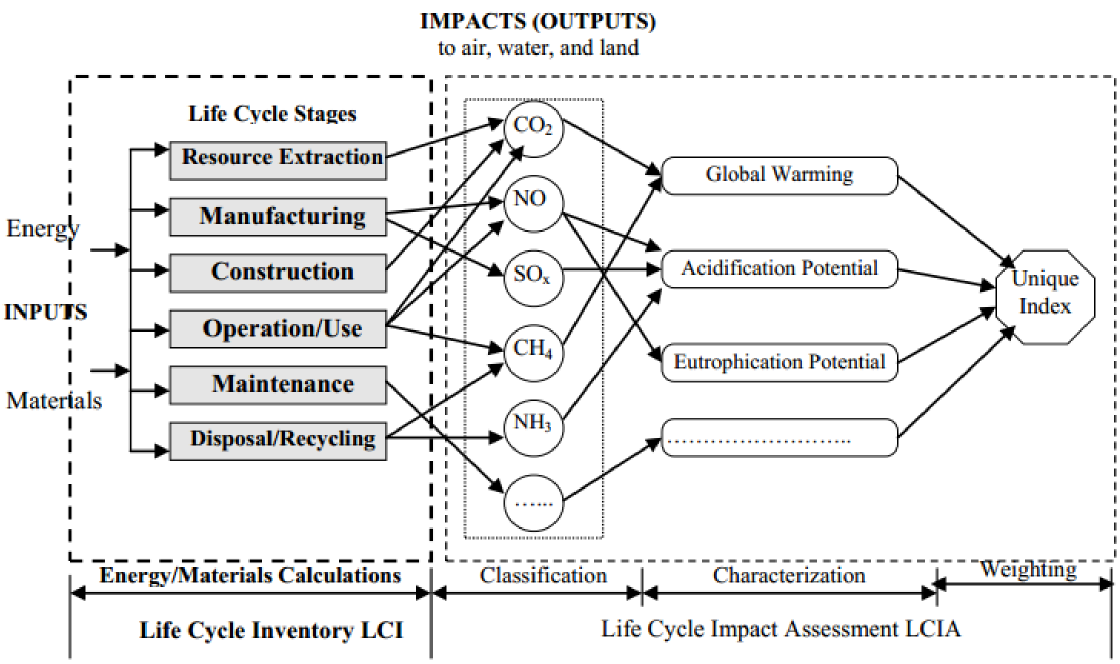


Figure 5: Model - Life Cycle Inventory LCI Stage

Source: Field Work

a. <u>Materials Extraction and Manufacturing</u>

This phase includes energy from the extraction of raw, refinement of raw materials into designed materials, and production. The embodied energy of the engineered materials is the addition of all energies used during extraction, refining, and production of material plus energy of transportation to refinery fro point of extraction.

b. Transportation

As could be seen earlier in this study, usually there are (3)transportation phases in a life cycle of building as main phases. The first one is from the site from which the raw resource is extracted down to manufacturing facility. The second transportation phase takes place when the manufactured material is moved from the factories to the building sites during renovation or construction. The third phase is concerned with the transportation of the material from the building site to the final disposal/recycling plant. However, most available data sets for materials already take the first phase of the transport energy into account. A cumulative distance of 160km is considered as a generic value.

c. Building Construction

The construction process is composed of all the products and resources used for on-site operations. Data available was based on resources used in the form of electricit, construction equipment and construction materials transport to the site (at a cumulati ve distance of 160 km).

d. Building Operation and Use

We evaluate the influence of step of service of buildings by examining their use of resources. Ground water heating / cooling and electricity use are generally considered for the building during the working process (Ragheb, 2011). For energy use purposes, case buildings are calculated and contrasted to the real value of being used for 60 years at 168 hr / week.

e. Maintenance

Usually, the maintenance phase is associated with building life consisting of material substitute, construction, and waste produced from discarded material during most of the building's 60-year life span. Because maintenance relies on many variables and its exact nature cannot be calculated for a long time based on unexpected events, for this research study assumption were produced that no material substitution, renovation or extension and other improvements during this 60-year building life span.

f. Demolition

There are many associated activities for demolition phase, i.e. demolition activities, transportation of these materials to disposal point and others to recycling. For this study, 75% of the total material was deemed to be landfill at a distance of 80 km and 25% was deemed to be recycled at a distance of 115 km. OpenLCA measurement software forecasts resources for destruction and transportation, respectively, depending on construction criteria and transportation lengths. (figure 6).

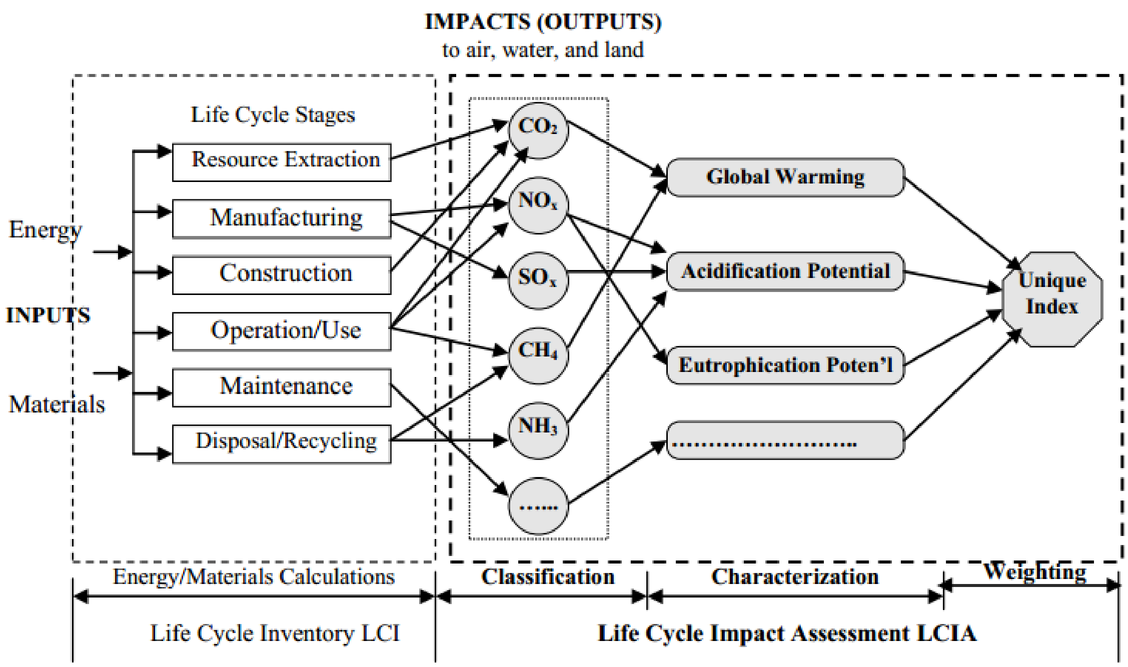


Figure 6: Life Cycle Impact Assessment LCAI Stage/ openLCA Model Used

Source: Own Fieldwork

3.7.5 Life Cycle Impact Assessment (LCIA)

Step of the LCIA assesses the importance of environmental impacts based on the results of the LCI. Figure 6 above shows the LCIA stage model used for this analysis. The research also measures the assemblies of building systems such as foundations, structural components etc. for the related environmental impact, so that these impacts can be measured and contrasted within each building system

For the intent of this research, and also taking into account the position of this analysis, the following effect categories are considered throughout building environmental profiling in the two (2) case study buildings: The rationale for choosing such environmental impact categories is that in literature selection of these categories is deemed quite significant (Schmidt, 2018)and also because from environmental and political point of view set by US EPA (2006).

Detail of each category of these environmental impacts considered for the evaluation of results is follows.

3.7.6 Environmental Impact Categories

a. Fossil Fuel Consumption (FFC)

Petroleum, coal and natural gas are all fossil fuels. FFC is usually expressed in mega-joule (MJ) as the primary energy intake or fuel depletion. It affects group tests for electricity for the transport and raw material production. Middle energy during the process of use (e.g. 1 kWh of electricity) and main energy that is FFC should not be confused or miscalculated (Ragheb, 2011).

b. Global Warming Potential (GWP)

GWP also known as the Greenhouse Effect or alternatively Carbon Footprint. This impact results in a mean rise in earth temperature due to oxidation of hydrocarbon-based fuels and other sources of energy resulting in higher greenhouse gas levels. Carbon dioxide CO2, CFCs and methane (CH_4) gases are typical examples. The possible long-term global effects are a major focus when studying the impact of GHGs. Therefore, as usual, a time frame of 60 years for assessment must also be specified. Carbon dioxide equivalents (kg CO_2-eq.) are used for the gases which are other than CO_2.

c. Acidification Potential (AP)

Acidification is generally the way a compound is made acidic. In other words, it is associated with processes that developed acidity in water, in air and in soil systems (hydrogen ion). When the acidity of the atmosphere is increased, acid rain is occurs when rain falls. Acid deposition also has damaging (corrosive) impacts on buildings, monuments, and historical artifacts.

d. Eutrophication Potential (EP)

EP is also termed as “Over-fertilization”. Thus “eutrophication” describes the process of adding nutrients to bodies of water either adding naturally or adding artificially. It also refers to the effects of the added nutrients. Phosphate and nitrates are produced in the water. The water becomes polluted. The water bodies utilize these nutrients in excessive amount and are died. Algae rise greatly when these nutrients are in the water and as with the time the algae in the water dies in the water and decompose there, high percentage of organic matter and the decomposing organisms present in the water deplete the existing water of its available oxygen.

e. Photochemical Ozone Creation Potential (POCP)

POCP, which is called as “Summer Smog”, is the phenomenon that produces ozone at the ground level. When nitrogen dioxide reacts with the VOX it produces POCP.VOC is volatile organic compounds, and when VOC in combination with NOx come in exposure to UV, certain reaction take place. The air emission under certain atmospheric condition are trapped in it which in the presence of sunlight It is converted in the form of photochemical smog This smog is very dangerous and can result in serious health and environmental issues.

f. Human Health (HH) Respiratory Effect

Different sizes of particulate matter (PM) PM10 and PM2 have significant impacts on public health. United States EPA (2002) (as cited by Ragheb (2011)) Due to its effect on the human health such as respiratory problems- such as asthma, bronchitis, and acute pulmonary disease, etc have been listed as the number one reason of health deterioration. Thus, although particulates are a significant environmental output of manufacturing of construction products, they still need to be traced and addressed. Measurement of this effect measure is the corresponding PM2.5 basis.

g. Ozone Depletion Potential (ODP)

ODP is the process of depletion of the upper layer of atmosphere. This is also called “Ozone Hole”, the process occur in the part of atmosphere called stratosphere. The UV rays of sun are been absorbed by ozone and a catalytic reaction occurs that degrade the ozone to oxygen. This degradation create hole in the ozone layers. (Ragheb, 2011). The absence of ozone layer or small concentration of ozone layer increases the harmful UV rays. These rays affect the human, plants and animal negatively. The ozone depletion potential is represented in the form of mass equivalence of Trichlorofluoromethane (CCl_3F = CFC-11.

3.7.7 Energy Sources

The emissions that occur from producing energy is important to understand to measure the impact on environment correctly. The source of energy or the energy supply system can change several times during the 60 years life span of the building, however we have assumed it here that the source of energy remain the same for this period of 60 years for the life cycle of the building and it is important to consider.

3.7.8 Water Pollution Emissions Categories

Contamination of water bodies such as rivers, lakes, oceans and groundwater is water pollution. This happens when pollutants are added to water bodies directly or indirectly without removing the toxic substances, and without proper treatment. Contamination of water is really a big concern for the modern world leading to death and diseases (Janjua, et al., 2018). Water contaminants can take many forms such as synthetic contaminants such as these compounds like insecticides, herbicides, hydrocarbons and many other chemical contaminate water; and inorganic contaminants that comes with the compounds like such: sulfur dioxide and acid rainfall, fertilizers etc. (.(Ragheb, 2011).

3.8 Research Questionnaires

Before I conclude this chapter, the research questionnaire used in this study will be briefly discussed. The research questionnaires are used as a second research tool to collect important information about life cycle assessment in Pakistan. The research questionnaires were developed and sent out via the internet as interactive Google forms to LCA related respondents in Pakistan. This was to ensure that informed responses obtained from the respondents, reflected the views of individuals that are actually exposed to LCA. The main goal of the questionnaire was to know about barriers to LCA implementation in Pakistan. The research questionnaire was sent to those respondents who have relevant experience to LCA and know about life cycle assessments and its goals.

3.8.1 Data Analysis

The questionnaire was distributed to about 100 relevant respondents related to LCA through different channels i.e. Social media, LinkedIn email etc. However, about sixty-six (66) questionnaires were useable as some others were not filled out properly. Content analyses were used to evaluate responses. Sixty-six (66) responses were valid and were utilized for evaluation of results. See Table 2 below

		N	%
Cases	Valid	66	100.0
	Missing	0	.0
	Total	66	100.0

Table 2: Case processing Summary SPSS

Source: Own Field work

However, for a questionnaire to be accepted as a correct tool for any analysis, it has to be both valid and reliable. The validity of a questionnaire checks whether the questionnaire actually measured what it is meant to measure and can be known in several ways such as ensuring that the scope of questions covered in the questionnaire exhausts the subject been studied. This is content validity. On the other hand, reliability of a questionnaire measures the consistency of the questionnaire and ensures that every time the research is carried out using that tool, the outcomes will be similar. The questionnaire was validated and dually check with the supervisor to see whether the questionnaire measure and served the required objective of research or not. Recommendations were made by the supervisor for the questionnaire and were included. For reliability, a reliability test was performed using the software SPSS which stands for statistical package for the social sciences. SPSS is primarily used by scientific and academic researchers. The reasons why SPSS was used are:

I. The results of SPSS are reliable

II. SPSS has a very easy to use interface. It is user friendly. It has point and click interface which allows you to assemble codes very quickly.

III. You can save these codes in the form of syntax file, you can share it and re adapt it.

Using the Cronbach Coefficient Alpha for reliability test for questionnaires of Barrier to implementation in Pakistan, the value of 0.730 was gotten which indicate that the data gotten from the use of the questionnaire is of an acceptable standard. See Table 3 below

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.730	.747	10

Table 3: Reliability Statistics of Questionnaire

Source: Own Field work

Structure-wise, the questionnaire was divided into three (3) main parts. In the first part, information about socio-demographics was collected. In the second part, LCA related information were collected and analyzed. In the third part, information about barriers to LCA implementation was collected. Both opened end and closed end questions were asked. For the barriers to LCA implementation, which was the main goal of this survey, respondent has to choice a barrier on a scale from 1 to 5.The questionnaire and the frequency of respondents are attached in the appendix.

Findings showed that there were twenty seven (27) female respondents and thirty nine (39) male respondents representing 41% and 59% respectively. This is shown in figure 7below.

Also, the age range of the respondents showed that most respondents (50%) were aged between 28-37 years, 36% of the respondents are aged between 18-27 years and 14% of the respondents are aged between 38-47 years. These are shown in figure 8 below.

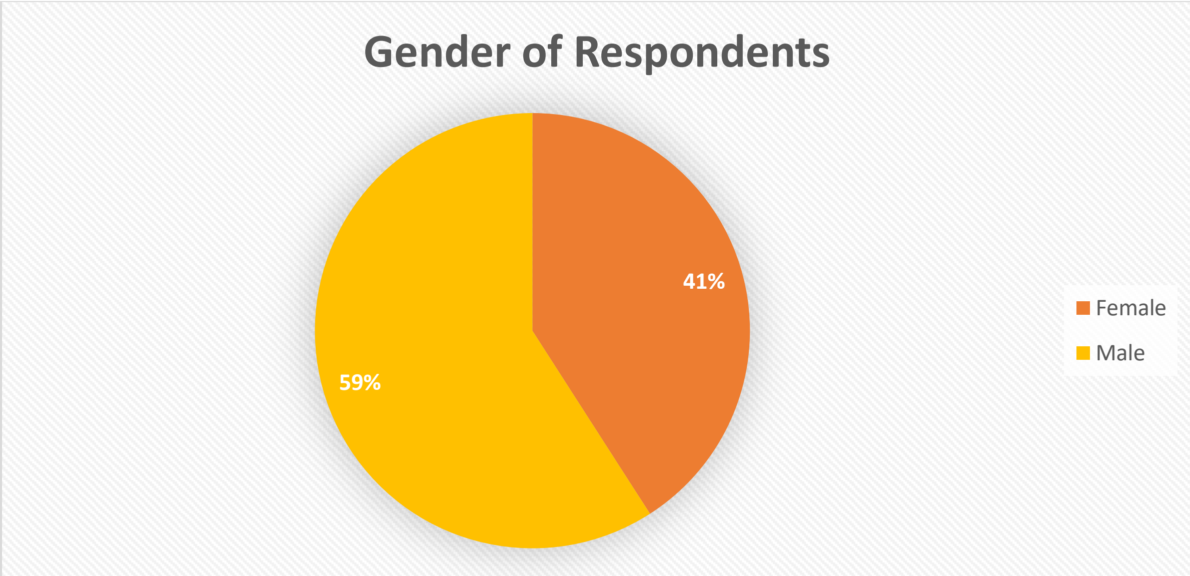


Figure 7: Gender distribution of Respondents

Source: Own Fieldwork

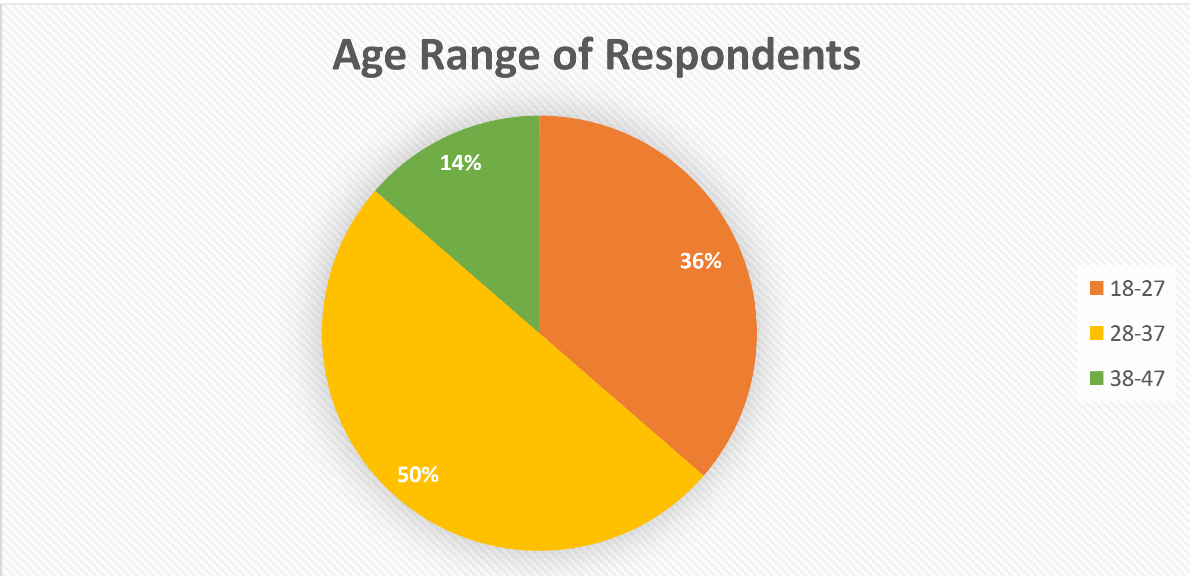


Figure 8: Age Range of Respondents

Source: Own Fieldwork

Going further, the location of operation of the respondents was found to be diverse, covering most major parts of Pakistan such as Karachi, Islamabad and Lahore. In Figure 9 below, we see that Lahore has the highest number of respondents, twenty two (22). There were seventeen (17) respondents from Karachi, Ten (10) from Islamabad, seven (7) from Peshawar and eight (8) from other cities as Multan,Gujrat, and Gwadar.

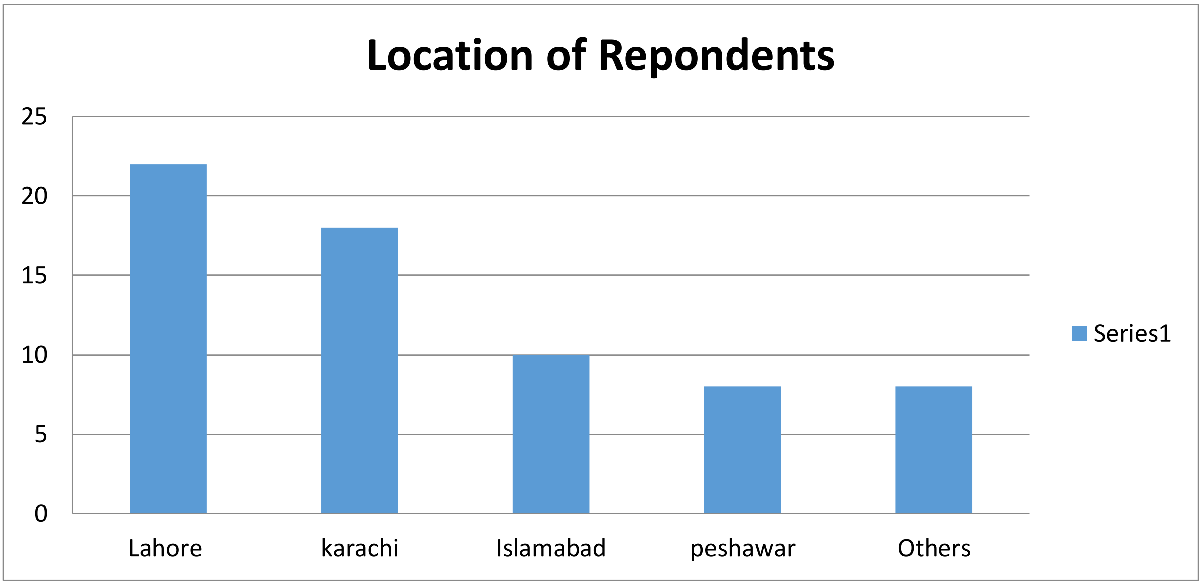


Figure 9: Location of Respondents

Source: Own Fieldwork

The respondents were also found to be serving in varying levels in their professional life. The majority of the respondents was formed by civil engineers (27 respondents), other including architects (14 respondents), LCA practitioners (5 respondents), environmental engineers (9 respondents), sustainability specialist (7 respondents), project manager (2 respondents) and others (2 respondents). Figure 10 below shows these details.

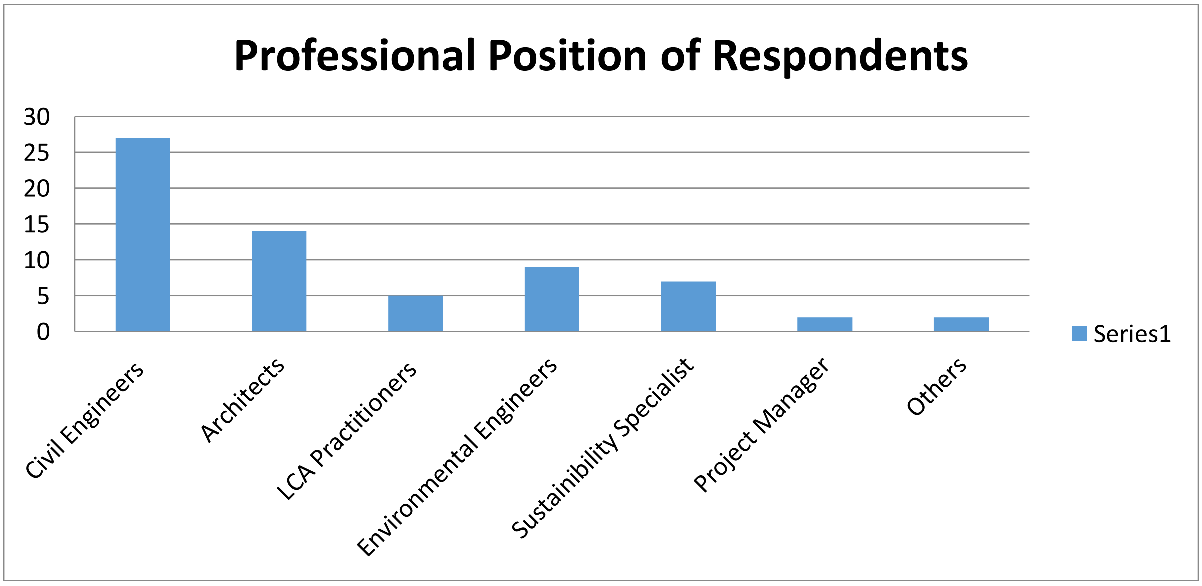


Figure 10: Professional Position of Respondents

Source: Own Fieldwork

In addition, the respondents were found to be making use of several LCA software. Gabi, OpenLCA and OneClickLCA had the most users with twenty (20) respondents in total making use of these softwares. Other respondents made use Traci, SimaPro and other type, however majority of the respondents thirty five (35) have not used any LCA software. See figure 11 for the breakdown.

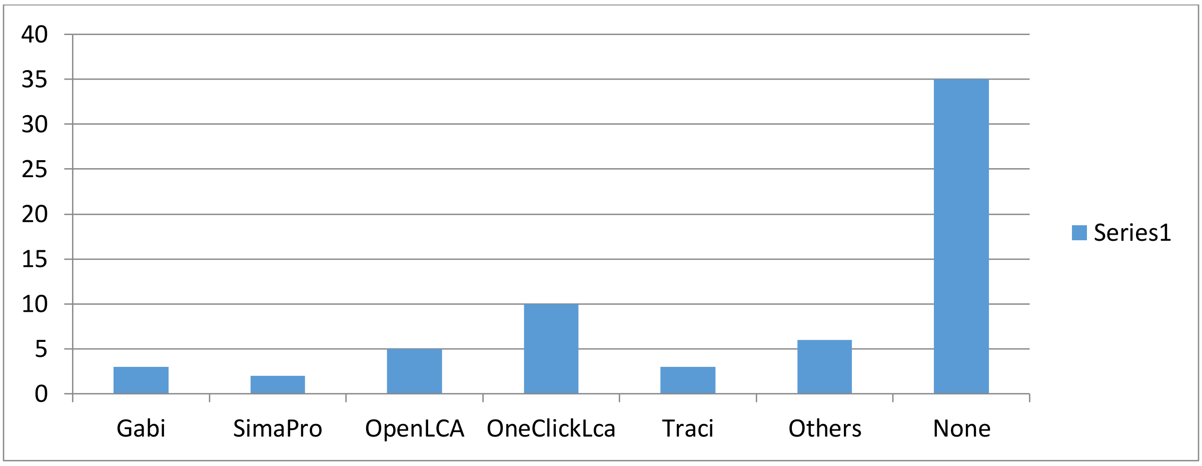


Figure 11: LCA Software's used by Respondents

Source: Own Fieldwork

Interestingly, a good number of projects have been executed by the firms our respondents are working with two (2) respondents stating that their firms have worked on about 100 LCA projects. Seventeen (17) respondents reported that their firms have carried out at least 10 LCA processes in Pakistan. Figure 12 below shows these data

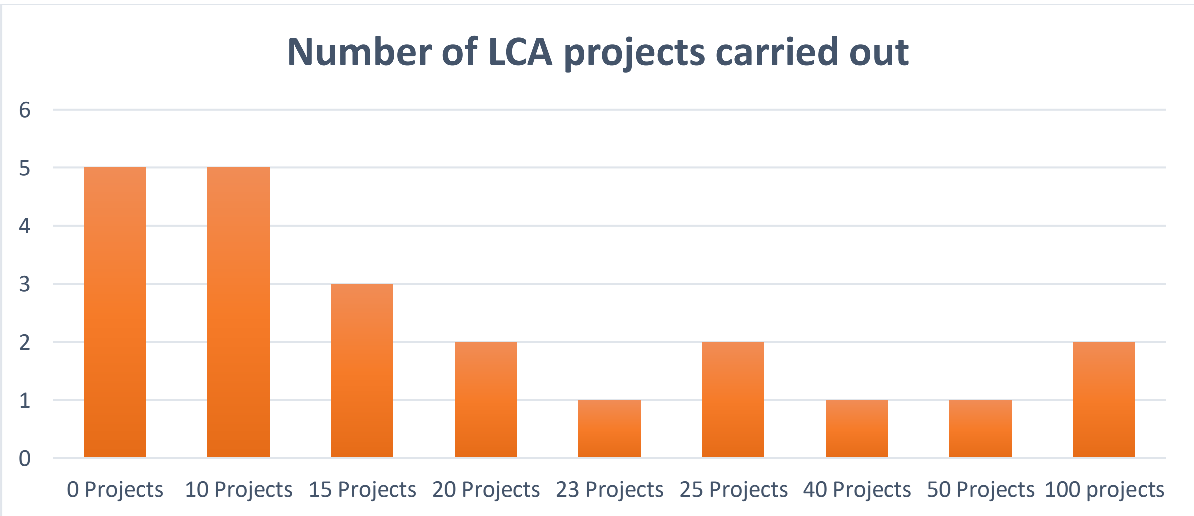


Figure 12: How many LCA projects has your firm performed LCA on?

Source: Own Fieldwork

However, while the number of projects on which LCA has been carried out is impressive, the respondents were further asked to state if they have personally or otherwise carried out LCA on buildings. I found out that there was an even split between those that have participated in LCA and those that have not done any LCA processes as 41% of the respondents each responded thus. Only 18% of the respondents have personally led an LCA study. See figure 13 below.

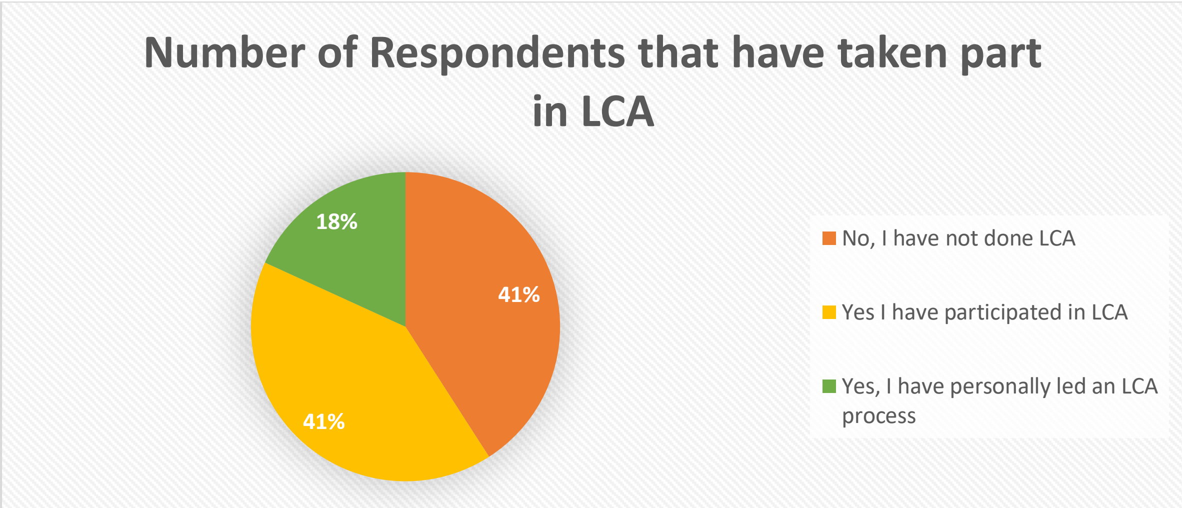


Figure 13: Number of respondents that have taken part in LCA

Source: Own Fieldwork

Other items on the questionnaire focused on the perception of LCA in Pakistan and how effective LCA approach has been for them in attaining sustainable construction. In addition, as a main goal of this questionnaire, the respondents were asked to identify possible hurdles to the widespread adoption of LCA in Pakistan and also to proffer plausible solutions to their challenges. About 10 questions were asked regarding the hurdles associated with the wide spread adaptation of LCA in Pakistan. The questionnaire survey is based on the Likert-scale from 1 to 5. Scale 1 represents “strongly disagree,” and scale 5 represents the “Strongly Agree.”

Response Scale	1	2	3	4	5
Factors/Variables	Strongly disagree	Disagree	Neutral/ Partially agree	Agree	Strongly agree

Table 4: Variables for questionnaires and their scale

Source: Own Fieldwork

3.8.2 Statistics

The descriptive statistics of the Questionnaire is follow.

	N	Minimum	Maximum	Mean	Std. Deviation
Is LCA completely strange for people in Pakistan?	66	1.00	5.00	3.6364	1.04714
Is absence of Skilled LCA Practitioners limiting LCA implementation in Pakistan?	66	1.00	5.00	3.7424	1.23177
Is lack of awareness regarding the benefits of LCA restricting LCA implementation in Pakistan?	66	1.00	5.00	4.5303	.78876
LCA software's affordability, Poor quality of Database and Inaccuracy of results adding barriers to LCA implementation in Pakistan?	66	1.00	5.00	3.4697	.89820
Is LCA considered a time consuming process that is why in Pakistan it is least considered?	66	1.00	4.00	3.3939	.69898
Is unwillingness of investors and stakeholders to pay for LCA is leading to LCA barriers in Pakistan?	66	1.00	5.00	4.2121	.83233
Are Engineers Architect and LCA experts not well paid for LCA calculations?	66	1.00	5.00	3.8333	.93781
Is there lack of regulations and Policies for enforcing sustainable development and sustainable environment in Pakistan?	66	1.00	5.00	4.0152	1.10234
Is LCA considered a complicated process in Pakistan?	66	1.00	5.00	3.5303	1.26758
Is there lack of inspiration and influence for those who have already performed LCA?	66	1.00	5.00	3.8788	.90324
Valid N (listwise)	66				

Table 5: Number of valid respondents, Mean, Standard deviation, minima and maxima of respondents to LCA barriers.

Source: Own Field Work

The table shows the mean and standard deviation of the responses. The value of the mean which is high or equal to the average mean of responses 3.84 is considered a significant barrier. Thus the data depict that all these given barriers are of significant value and importance.

The frequency distribution and percentage will be used to summaries the background information of respondents, while the Relative Importance Index (RII) will be used to the main responses (Sarhan et al., 2017). The RII is based on equation # 3, which is the sum of items scores for each identified barrier to lean construction divided by the highest weightage and the total number of respondents contributing to it. Therefore, RII represents the average of agreement among the respondents about barriers to LC in Pakistan (Sarhanetal.,2017).The five-point Likert-scale will be used, and the barriers which have RII value higher will be considered the most significant barrier, and also the RII value will also show which barriers are most common. RII is the sum of the score for each barrier to lean construction divided by the multiplication of the highest weightage and the total number of respondents (*AN*) weightage and the total number of respondents (*AN*)

$$RII = 5n5 + 4n4 + 3n3 + 2n2 + n1/AN * 100$$

Equation 1: Relative Importance Index (RII) equation

Where, n1= Total Number Of respondents who selected answer 1

n2= Total Number. Of respondents who selected answer 2

n3= Total Number. Of respondents who selected answered 3

n4= TotalNumber Of respondents who selected answer 4

n5= Total Number. Of respondents who selected answer 5

Where N = Total number of respondents of the questionnaire

A = the highest weightage, which is 5 in this case.

Data elicited from the research are presented using tables, charts and percentages. These are easy to understand. The other form of presentation used was flowing prose in which the findings are copiously discussed within the body of this work. The result of the findings of questionnaire about barriers to LCA implementation and other important information will be discussed in the coming chapters under the relevant topic.

3.9 Chapter Summary

In this chapter, we have taken care to outline the research methodology to be adopted in this study. The main tool for the LCA process was also identified to be openLCA developed by Green Delta. In the next chapter the findings of this study as carried out on the case study buildings will be presented.

CHAPTER FOUR: FINDINGS

4.1 Introduction

This chapter describes the results of analysis of life cycle assessment (LCA) carried out on two (2) case study residential developments. It will also provide reasonable answers to the research questions used for the purpose of research. Also, to apply the procedures of LCA on residential buildings so as to make comparisons on the performance of construction materials as regards sustainability. The result is presented in much shape and the findings are then interpreted. The result of analysis is represented in form of charts and description.

4.2 Case Study 1: Residential Housing Complex, Karachi, Pakistan

The first building that is considered for the case study is a standard contemporary low-energy building with reinforced concrete feature, constructed in the new residential area of the city Karachi, Pakistan. The building has 42 apartments and altogether occupies a gross floor area of 2,992m^2. Each flat of the building consist of abed rooms, a living room, a kitchen and a restroom. It is occupied by households with varying densities. The building has only seven storeys. The structural frame of the building is created by RCC structural steel (HSS) columns and supported with W section RCC beams. The Floors are 2"concrete topped metal decking. The exterior walls of the apartments are made of RCC backed by steel studs. The interior walls of the apartments made of galvanized stainless steel studs and concert.

As most of the electricity in Pakistan is from National grid, similarly for this building Electricity is also from National grid as the only source of operating energy that the building systems utilize. The building's bedroom is air conditioned with window air conditioning system. The set point for indoor temperature is around 25^{0}C. The energy of the life cycle of the building is assessed on the basis of a supposed service life of 60 years. The most important things that matters for this research is what material been used in the building and what is their quantities as these two parameter marks the main inputs to the inventory analysis. All the materials are manufactured in Pakistan. The key information about the types and quantities of materials as well as building components is derived from the design consultant's accurate estimates of the project, technical specifications as well as other relevant documents. These are shown in Table 6 below.(For comparable result same pattern of material was used as Emami 2019)

It was made sure that to have a comparable result to what have been done earlier regarding similar research, those methods which were used by earlier researchers within the last 10 tears and which were proven scientifically correct, were followed. Similar ideas of the work done in the past were taken into account and was used for this study in Pakistan, as the main idea remain the same but the location of research is changed.

S.NO	Systems of the Building	Material Description	Quantity of Material	Unit
1.00	**Foundation and external works**	Concrete	860.28	m^3
		Steel	15.89	ton
		Brick	4.07	ton
2.00	**Frame and roof Structure**	Concrete	3790.24	m^3
		Steel	27.24	ton
		Brick	5.98	ton
3.00	**Complementary works**	Aluminium	0.209	ton
		Glass	0.57	ton
		Brick	1.58	ton
4.00	**Finishes**	Ceramic tiles	11.184	ton
		Paint	1.525	ton
5.00	**Fitting Equipment**	Steel	1.07	ton
		Ceramic tiles	6	ton
		Aluminium	0.1	ton
6.00	**Mechanical Works**	Steel	1.2	ton
		Aluminum	0.08	ton
		Plastic	1.015	ton
		Copper	1.214	ton
		PVC	0.519	ton
7.00	**Construction Site**			

Table 6: The main building systems of Case Study 1 and the main materials in each system

Source: Own Fieldwork

4.3 Case Study 2: Detached Wooden House, Lahore, Pakistan

The detached wooden house considered for this study is in Lahore, Pakistan. The House has only 2 numbers of floors and having a gross floor area of 145 m^2 (each floor is 73 m^2).

The analysis of the study considers materials in particular those selected for the case study used in all parts of the wooden house. These include material used in substructure and super structure. Material used in the foundation, in the frame, in the roof, in the walls in the complementary works and in the finishing of the wooden building. In the evaluation, the exact material or substance could not always be found in the databases. In such a scenario, the material which matched the inventory data best was selected.

As mentioned earlier the most important things that matters for this research is what material been used in the building and what is their quantities as these two parameter marks the main inputs to the inventory analysis. All the materials are manufactured in Pakistan. The key information about the types and quantities of materials as well as building components is derived from the design consultant's accurate estimates of the project, technical specifications as well as other relevant documents. These are shown in Table 7 below.

S.NO	Systems of the Building	Material Description	Quantity of Material	Unit
1.00	**Foundation and external works**	Concrete	76.46	m^3
		Steel	0.503	ton
2.00	**Frame and roof Structure**	Concrete	25.14	m^3
		Steel	0.25	ton
		Wood	15.6	ton
3.00	**Complementary works**	Aluminum	0.0127	ton
		Wood Doors	6.44	ton
		Wood Windows	4.56	ton
4.00	**Finishes**	Glass	0.069	ton
5.00	**Fitting Equipment**	Steel	0.09	ton
6.00	**Mechanical Works**	Aluminum	0.0047	ton
		Copper	0.1027	ton
7.00	**Construction Site**			

Table 7: The main building systems of Case Study 2 and the main materials in each system.

Source: Own Fieldwork

4.4 Sensitivity Analysis or Validity

Analysis of sensitivity is a quantitative method for assessing the effect of data uncertainty in any LCA study (Ragheb, 2011). Sensitivity analysis ' main aim is to define and concentrate on the key data and the assumptions that have the greatest impact on an outcome. It can be used to facilitate the compilation and analysis of data without taken for granting the heftiness of an outcome or to classify crucial data.

Validity is a crucial element of this study and reference to similar studies by other researchers into the use of LCA which show outcomes parallel to those found here is necessary. As mention earlier It was made sure that to have a comparable result to what have been done earlier regarding similar research, those methods which were used by earlier researchers and which were proven scientifically correct, were followed. Similar ideas of the work done in the past was taken into account and was used for this study in Pakistan, as the main idea remain the same but the location of research is changed. Say for example takes the study byLasvaux, et al. (2015) in which they used LCA to assess the environmental impact of renovation woks on existing buildings in Switzerland. In this study, one of the main focuses was the embodied energy of the building and this was done in my research as well. Similarly, the effort by Emami, et al.(2019) in studying the contributions of construction materials to environmental degradation is in line with one of the targets of this study. Just as they found most construction materials to be harmful to the environment, so did my own field work reveal as we shall see later in this chapter.

4.5 Assessment

The selected building materials studied are: steel, wood, concrete, aluminum, glass, ceramic, and cement. These materials were assessed against the lifecycle assessment methodology context. Thus, consideration was given to all phases of an LCA methodology set out in accordance with regulatory framework. The results of the analysis made were presented using openLCA in the form of software-generated graphs (and presented in MS Excel), based on the inventory analysis of each material.

4.5.1 Assessment Scope

The research concentrated on the structure pillars. The subsystems and their related components are as follows:

i. Foundations of the Building: That consists of RCC, steel and cement.
ii. Super Structure of building: Consist of RCC wood, cement and steel.
iii. Masonry work of Building:Block of bricks covered with mortar.
iv. Wall cover of building: made of sprayed tiles, mortar; used materials: cement and ceramic.

v. Frames of the building: wooden windows and doors; materials used: wood, and steel.
vi. Roofing of the structure: Made of RCC, ceramic tile, two slopes roof and wooden structure.

4.6 Summary of Findings on Construction Materials

Having seen the construction materials used in the case study buildings, we will now proceed to see how these materials perform in terms of energy consumption and emissions based on the results of the LCA study. Here it is important to put this in mind for the clarity of understanding of the results that the results are represented in different form that support and answer the different objectives set for research and that helps the researchers and common man to take a wide range of take away from the research done. Keeping this in mind the findings are shown in the following manner.

I. In the form of embodied energy impact
II. Impacts by building systems
III. Impacts by materials (Total Quantity)
IV. Impacts by materials(Per Unit)

The following sections will explain these in detail.

4.7.1 Embodied Energy Impacts

The embodied energy associated with the building materials is obtained by adding up the product of quantity of materials used multiplied by their embodied energy coefficients (see Table 8).

In essence, the initial embodied energy is that energy which is used in the construction and contains energy (electricity) used for lighting, water lifting and diesel fuel used by on-site equipment for construction. These are then aggregated with energy consumption for the transport of building material to the building site. The materials identified for analysis are those used in the main building components, such as structural frames (beams and columns), slabs, floors, staircases, foundations, walls, windows, and finishes. Due to the difficulty associated with collecting of energy data of several materials such as fittings, sanitary fittings and appliances and related products are omitted from the analysis (Ramesh, et al., 2013).

Embodied energy coefficients of building materials are shown in Table 8 below.

Name of the material	Unit	Quantity (Case Study 1)	Quantity (Case Study 2)	Embodied energy per Unit (GJ)	Embodied energy of material (GJ) (Case Study 1)	Embodied energy of material (GJ) (Case Study 2)
Cement	ton	4.249	0.2	16.96	72.063	3.392
Steel	ton	45.4	0.753	85.46	3879.88	64.351
Bricks	ton	11.634	---------	2.235	26.002	---------
Gravel	ton	3.791	---------	0.538	2.03956	---------
Aluminum	ton	0.389	0.0174	236.8	92.1152	4.1203
Glass	ton	0.57	0.069	25.8	14.706	1.7802
Copper	ton	1.214	0.1027	110	133.54	11.297
Ceramic tiles	ton	17.184	---------	3.333	57.2743	---------
PVC	ton	0.519	---------	158	82.002	---------
Gravel	ton	3.791	---------	1.08	4.09428	---------
Paint	ton	1.525	---------	144	219.6	---------
Wood	ton	---------	26.6	21.3	----------	566.58
Concrete	m^3	4650.7	101.6	5.44	25299.8	552.704
Plastic	ton	1.015	--------	156.9	159.254	---------

Table 8: Quantity and embodied energy of materials used.

Source: Own Tabulation

In Table 8 above, the sum total of the building materials used for the two case study buildings are shown. For each item, the embodied energy of the material is gotten by finding the product of the embodied energy coefficient of the material and the quantity of that material used throughout the project. Thus, considering Case Study One Residential Housing development, the construction materials with the highest total initial embodied energy are concrete at 25,299.8GJ and steel at 3,879.9GJ.Other construction materials in the project with significant amounts of initial embodied energy are paints (219.6GJ), plastics (159.25GJ), copper (133.54GJ), aluminum (92.12GJ), PVC (82GJ) and cement (72.06GJ).Ceramic tiles produced only 57.24GJ of calculated initial embodied energy. Figure 14below gives a graphical representation of the embodied energy contributions of the different materials used in the project.

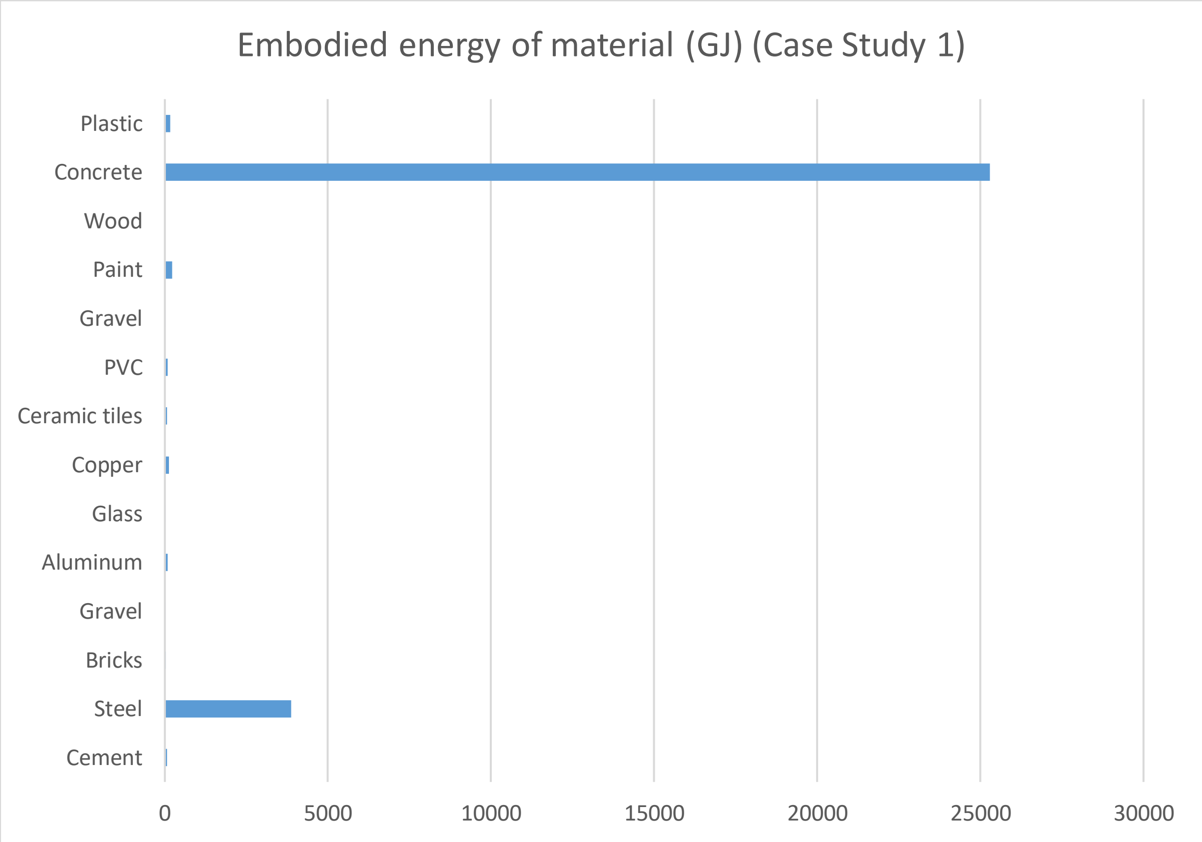


Figure 14: Initial embodied energy contributions of the construction materials used in Case Study 1

Source: Own Fieldwork

Similarly, in Case Study two detached wooden house, the construction materials with the highest total initial embodied energy are wood at 566.58GJ and concrete at 552.704GJ. Other significant contributors are steel (64.351GJ) and copper (11.297GJ). Figure 15 below gives a graphical representation of the embodied energy contributions of the different materials used in the project.

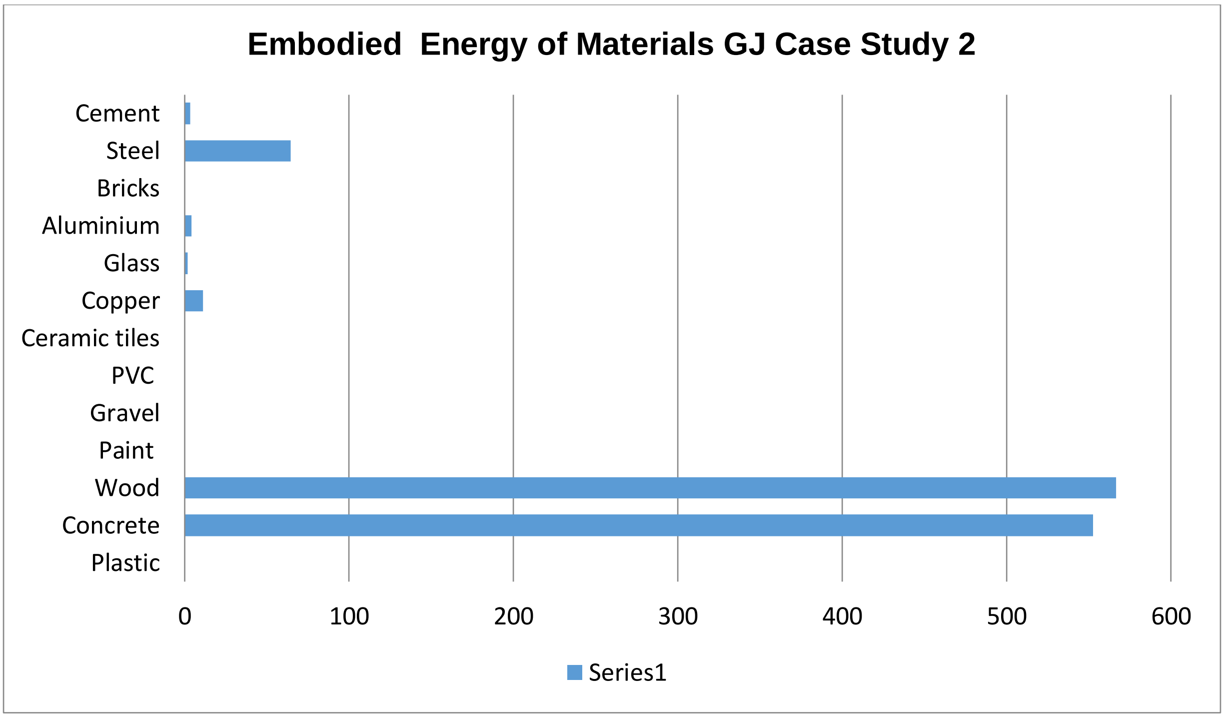


Figure 15: Initial embodied energy contributions of the construction materials used in Case Study 2

Source: Own Fieldwork

Then, based on the life span of the materials, recurring embodied energy can now be calculated by dong a simple multiplication exercise (Ramesh, et al., 2013). It should also be pointed out that the contribution of cement in concrete is taken into account in arriving at the embodied energy coefficient of concrete which was used in this study.

The embodied energy calculated and shown is not specifically meant for comparing of sustainability aspect here as the unit of measurement for all materials is not the same. However for material of similar unit, comparison can be made for embodied energy, as for example steel vs. brick, steel vs. aluminum and so on. On the other hand the quantities also remain different, for example materials like concrete has a very high embodied energy compared to the other material. But one logic behind this is the amount of materials used in the building which is obviously high compared to other materials used in the buildings. The more the material the higher the embodied energy and the high environmental impact and vice versa. But actually this represents the real case scenario when we construct a standard residential house. The actual quantity of material represents the real world scenario and is very important to consider as we build our residential buildings based on the real quantity therefore, for standard size of a building it is important to know the environmental impact of the actually used materials. And we should be aware what material takes more embodied energy and which one less. So as which material is more harmful and which is less considering the materials as whole.

The individual embodied energy per unit is given here.

Name of the material	Embodied energy per Unit (GJ/Unit)
Plastic	156.9
Steel	85.46
Cement	16.96
Wood	10.4
Concrete	5.44
Glass	3.66
Ceramic tiles	3.333
Bricks	2.235

Table 9: Embodied energy per unit of materials used.

Source: Schmidt, 2018

Now, it is also pertinent to highlight that the quantity of each material used affected the results above. Therefore, in Table 9 above, the embodied energy of the construction materials per unit used in both Case Study 1 and Case Study 2are shown in descending order. It is clearly seen that plastics and steel have the highest values for embodied energy at 156.9GJ and 85.46GJ respectively. And bricks and glass have the least embodied energy at 2.235GJ and 3.66GJ respectively.

4.7.2 Impacts by Building Systems

The second method of measuring the impact is, measuring the impact by building systems. This gives us the idea that which system of the building utilizes more energy and is more harmful and vice versa. In the following figures below, the environmental impacts of each of the building systems in the case studies are presented. These building systems are as presented in Tables 6 and 7. The effect categories evaluated in this report include: Fossil Fuel Consumption (FFC) (or primary energy consumption); Weighted Resources Usage (WRU); Global Warming

Potential (GWP) and others. However, for building system impact only that of GWP will be discussed here because it is specifically concerned with the emission of GHGs.

From the results of the calculated processes, it was found out that there was higher global warming potential results in both case studies for the building system of frame and roof structures where well over 600tons of CO_2-eq/m^{2}were emitted in Case Study 1 and over 70tons of CO_2-eq/m^2 were emitted in Case Study 2 building. Foundations, Complementary works and Construction Site building systems also accounted for significant amounts of contribution to global warming in the two case study buildings. (See Figure 16)

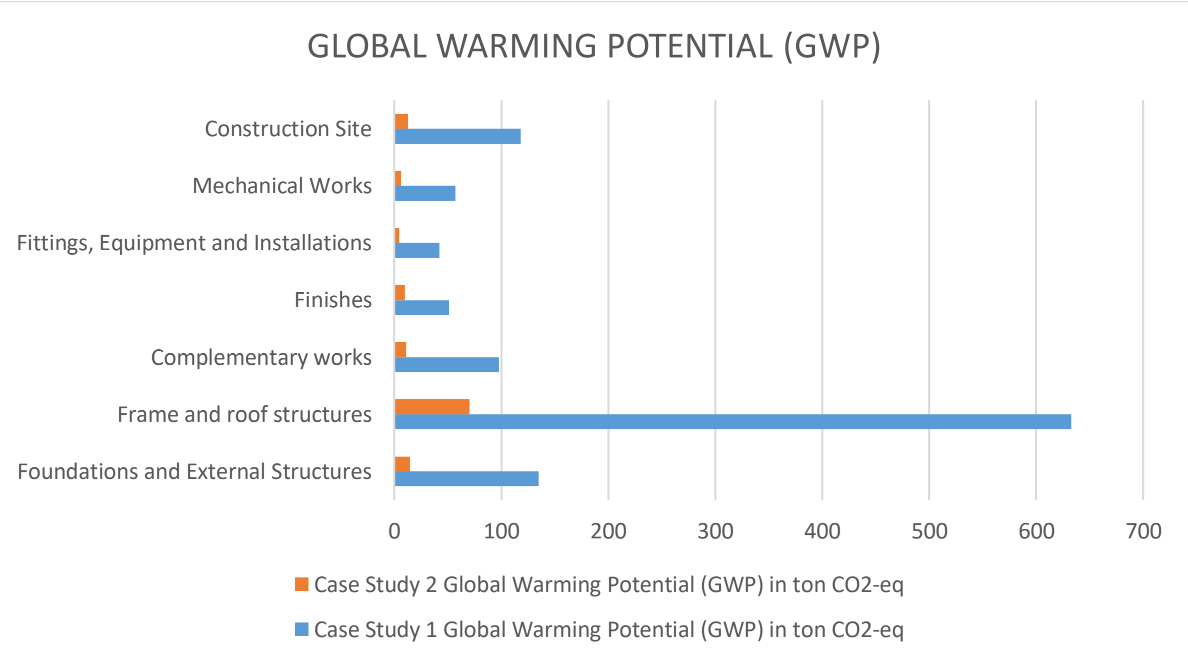


Figure 16: Global Warming Potential (GWP)

Source: Own Fieldwork

4.7.3 Impacts by Materials

The third way of presenting the findings is impacts by materials, which is the main goal and objective of the study. The impacts of materials here in this section are shown both for the quantity used in each case study and per unit of material in each case study. In order to assess the output of the construction materials in a holistic way, the material categories adopted by Emami et al. (2019) is herein used. These material type categories are: Concrete and Cement Products, Steel and Other

Metals, Wood, Plastic and Oil Products, Glass, Bricks and Tiles, and Fuels and On-Site Energy. This analysis holds several useful intents such as the fact that the findings here will actually help us to determine the overall environment impact of construction materials and this forms the core objective of this study. On another level, whatever the results will be in this analysis, it will help to determine whether or not it is actually the construction materials used that led to the impact results gotten when we analyzed the various building systems in the case study buildings. Again it is important to mention here that comparison of impacts is made both on the actual quantity of material and per unit .The actual quantity of material represents the real world scenario and is very important to consider as we build our residential buildings based on the real quantity and not per unit therefore, for standard size of a building it is important to know the environmental impact of the actually used materials.

Relying on the ecoinvent database to produce the results for the material impacts, the impacts of each material group on an LCA impact assessment category is presented as a percentage of 100 (which is taken as the total impact of construction materials used).These percentages are shown in a comprehensive table below wherein all the material contributions to the impact categories studied are presented. See Table 10 below.

Impact Category	Case Study Building (%)	Concrete and Cement Products (%)	Steel and Other Metals (%)	Wood (%)	Plastic and Oil Products (%)	Glass (%)	Bricks and Tiles (%)	Energy and On-site Fuels (%)
Fossil Fuel Consumption (FFC)	Case Study 1	24.1	22.9	9.6	24.1	3.6	2.4	13.3
	Case Study 2	8.3	8.1	16.7	11.9	1.6	0	33.4
Global Warming Potential (GWP)	Case Study 1	48.9	19.3	6.8	10.2	3.4	1.2	10.2
	Case Study 2	18.1	30.5	14.6	5.7	1.1	0	30
Acidification Potential (AP)	Case Study 1	25.5	20.2	8.5	9.6	6.4	17	12.8
	Case Study 2	7.4	20.6	23.3	4.2	1	0	43.5
Eutrophication Potential (EP)	Case Study 1	20.2	45.8	14.9	7.4	3.2	2.1	6.4
	Case Study 2	0	44.7	37.5	2	1	0	14.8
Photochemical Ozone Creation Potential (POCP)	Case Study 1	29.2	13.9	8.3	25	4.2	1.4	18
	Case Study 2	11.6	20.9	21.4	14.7	1	0	30.4
Human Health Respiratory Effect	Case Study 1	22.8	53.3	9.8	4.3	2.2	3.3	4.3
	Case Study 2	2.1	52.8	31.3	1.3	1.3	0	11.2
Ozone Depletion Potential (ODP)	Case Study 1	33.3	12.1	12.1	9.1	6.1	3.1	24.2
	Case Study 2	5.5	7.5	22.6	7.8	1.2	0	55.4

Table 10: Comparison of the contributions of the different materials to the selected Impact categories

Source: Own Tabulation

The table above shows how each of the material categories used in this study contributed to the different impact categories analyzed in this study. For ease of understanding and to further break things down, each impact category will be looked at one by one in order to help us appreciate the contributions of the construction materials to sustainable development.

a. Fossil Fuel Consumption (FFC)

The results from the two buildings we studied revealed that in Case Study building one, the building materials with the highest contribution to FFC are Concrete and Cement Products and Plastics and Oil Products with each contributing 24% to the consumption of fossil fuel. This is closely followed by Steel and Other Metals which takes up 23% of fossil fuel in the building. The materials with the least consumption of fossil fuel are Wood (10%), Glass (4%) and Bricks and Tiles (2%). Figure 17below gives the graphical performance of the building materials in this category.

On the other hand, Case Study building 2 had the least contributors to fossil fuel consumption as Concrete and Cement Products (8%) and Glass (2%). Steel and Other Metals (28%) and Wood (17%) turned out some of the highest FFC figures as can be seen in Figure 18 below.

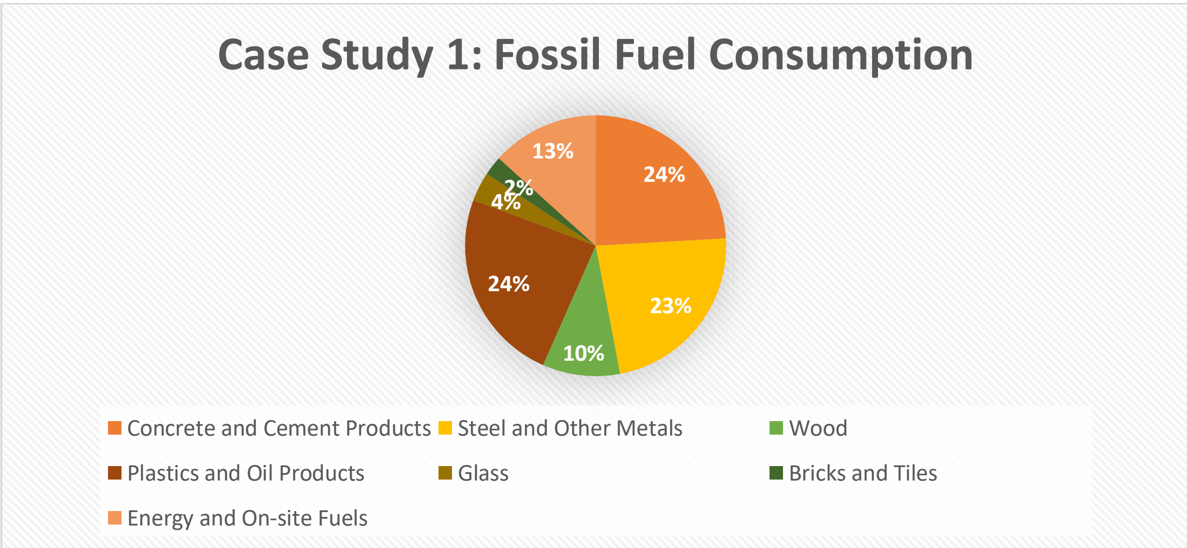


Figure 17: Case Study 1 Material Contribution to Fossil Fuel Consumption

Source: Own Fieldwork

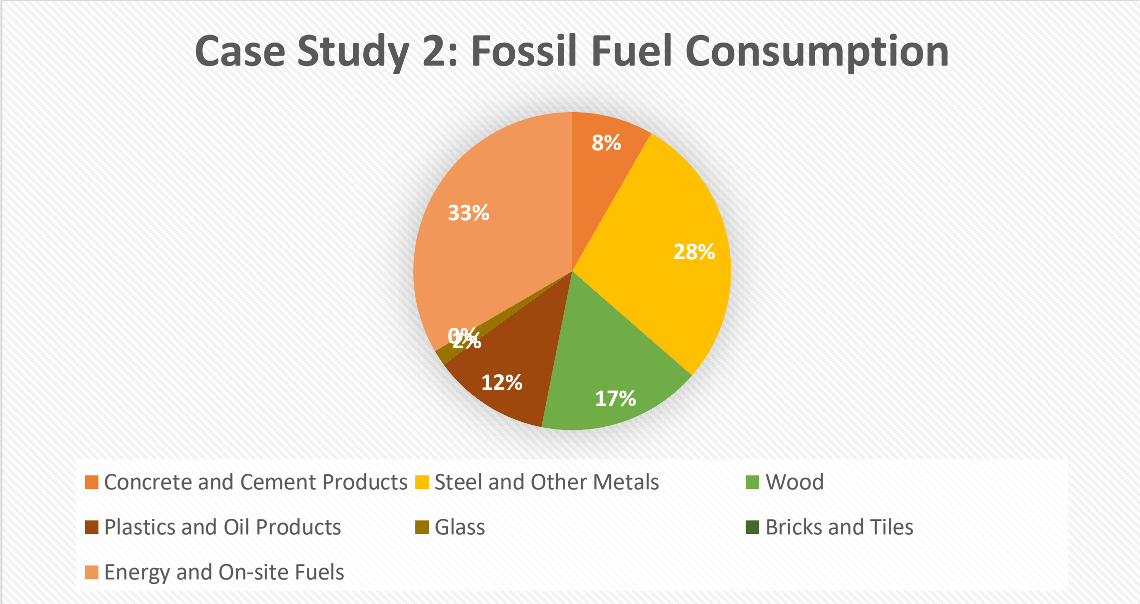


Figure 18: Case Study 2 Material Contribution to Fossil Fuel Consumption

Source: Own Fieldwork

However, when these materials are compared on a “per unit” level, it is found out that in both case study buildings, the highest contributors to FFC are Plastics and Oil products (55% in case study 1 and 56% in case study building 2) and Steel and other Metals (32% in case study 1 and 30% in case study 2). On the other hand, Bricks and Tiles, Glass and Wood made the least contribution to FFC per unit in both buildings. See Figures 19 and 20 below.

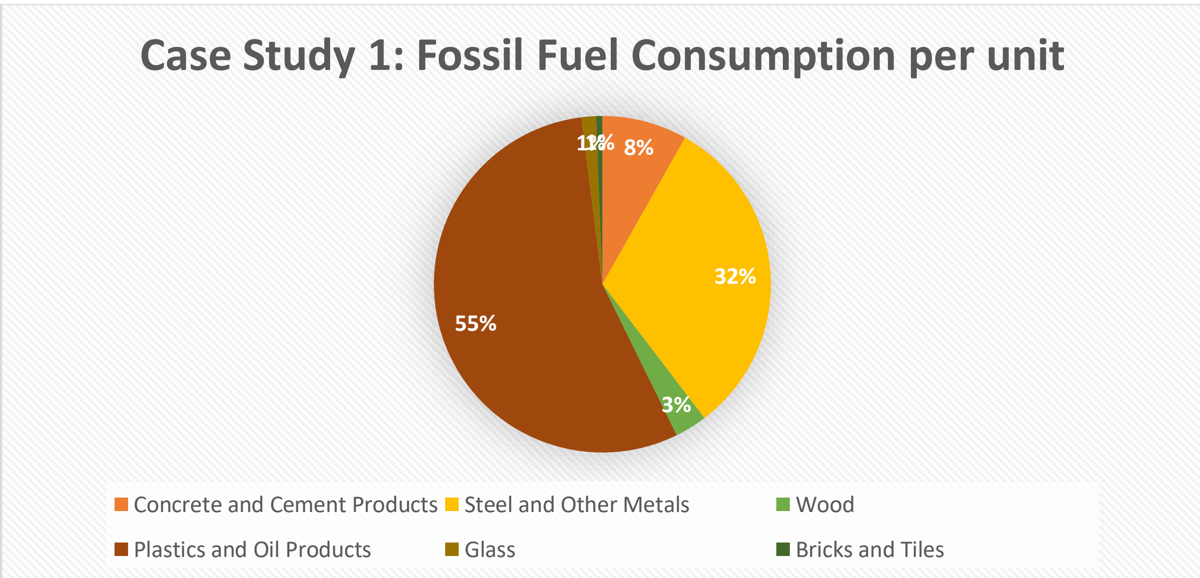


Figure 19: Case Study 1 Material Contribution to Fossil Fuel Consumption per unit

Source: Own Fieldwork

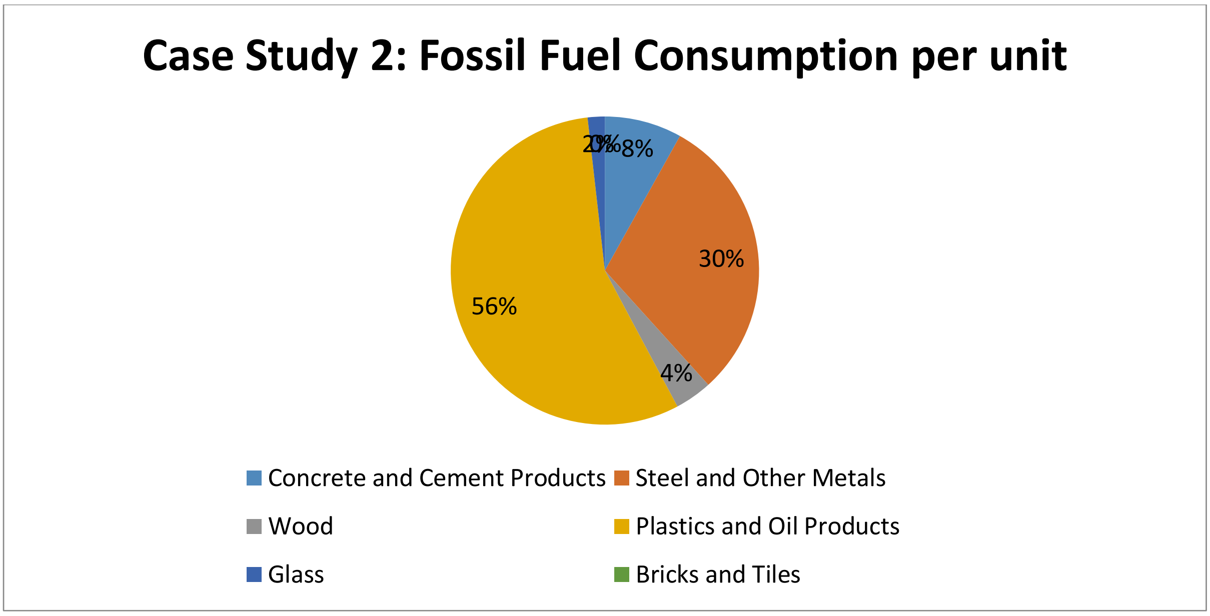


Figure 20: Case Study 2 Material Contribution to Fossil Fuel Consumption per unit

Source: Own Fieldwork

b. Global Warming Potential (GWP)

In Case Study Building One, it was found out that about half of the total emissions that can lead to global warming came from Concrete and Cement Products (49%). Steel and Other Metals (17%) as well as Plastics and Oil Products (10%) rank next as high contributors to global warming in the building. While Wood (7%), Glass (4%) and Bricks and Tiles (1%) had the least GWP figures. Figure 21shows these data.

On the other hand, Case Study Building 2 had Steel and Other Metals (30%) as one of construction materials with the highest GWP. Next we had Concrete and Cement Products (18%) and Wood (15%). Glass and Plastics and Oil products had the least GWP. Bricks and Tiles were however not used in the project. See Figure 22for the details.

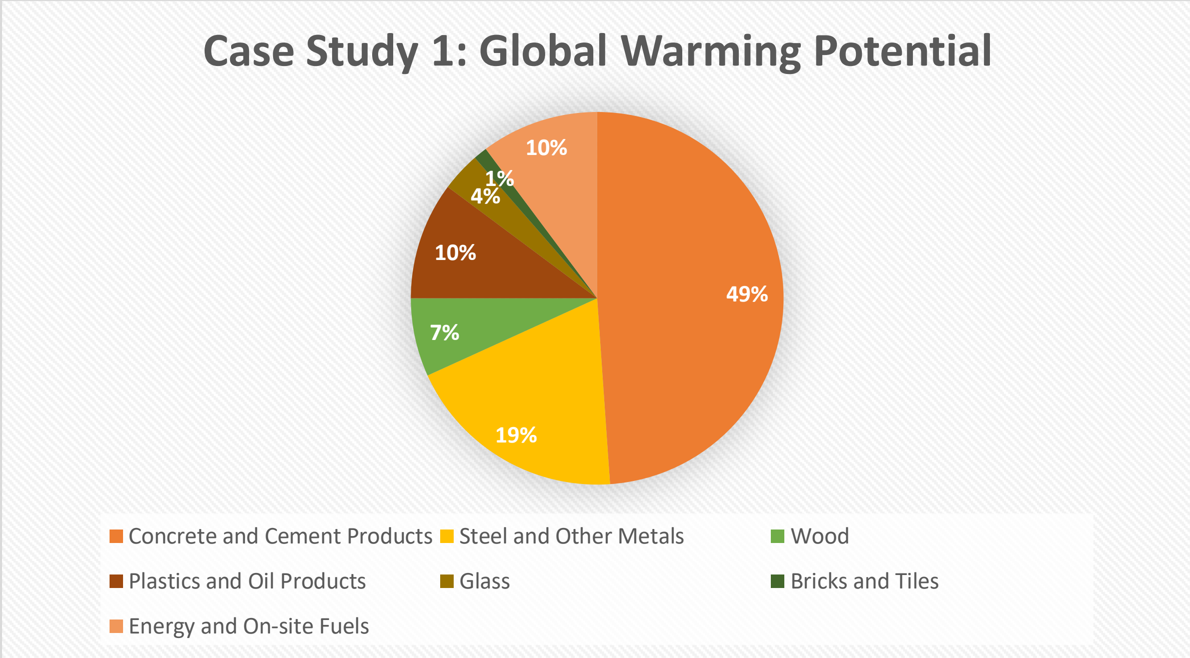


Figure 21: Case Study 1 Material Contribution to Global Warming Potential

Source: Own Fieldwork

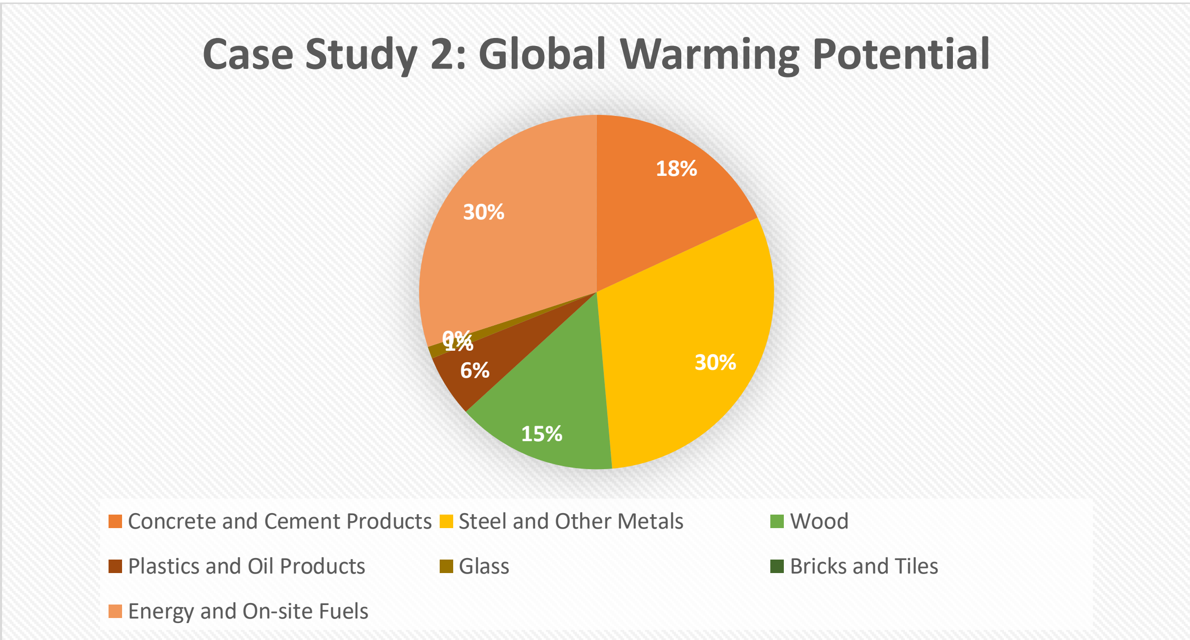


Figure 22: Case Study 2 Material Contribution to Global Warming Potential

Source: Own Fieldwork

Plastics and Oil products and Steel and Other Metals have the highest GWP on a per unit basis. In Case Study 1, the highest GWP per unit was produced by plastics and oil products making up 56% of the total GWP per unit, while glass had the least

GWP per unit at 1.7%. In Case Study 2, plastics also made up 55% of the total GWP per unit of materials used, while glass made up the least at 1.7%. See Figures 23 and 24.

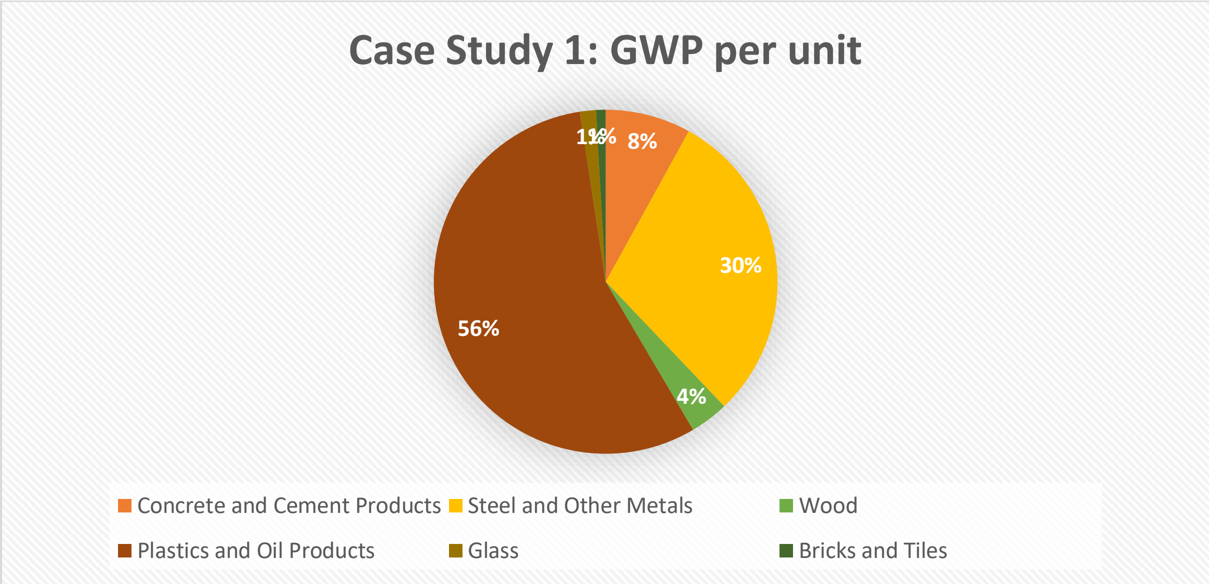


Figure 23: Case Study 1 Material Contribution to Global Warming Potential per unit

Source: Own Fieldwork

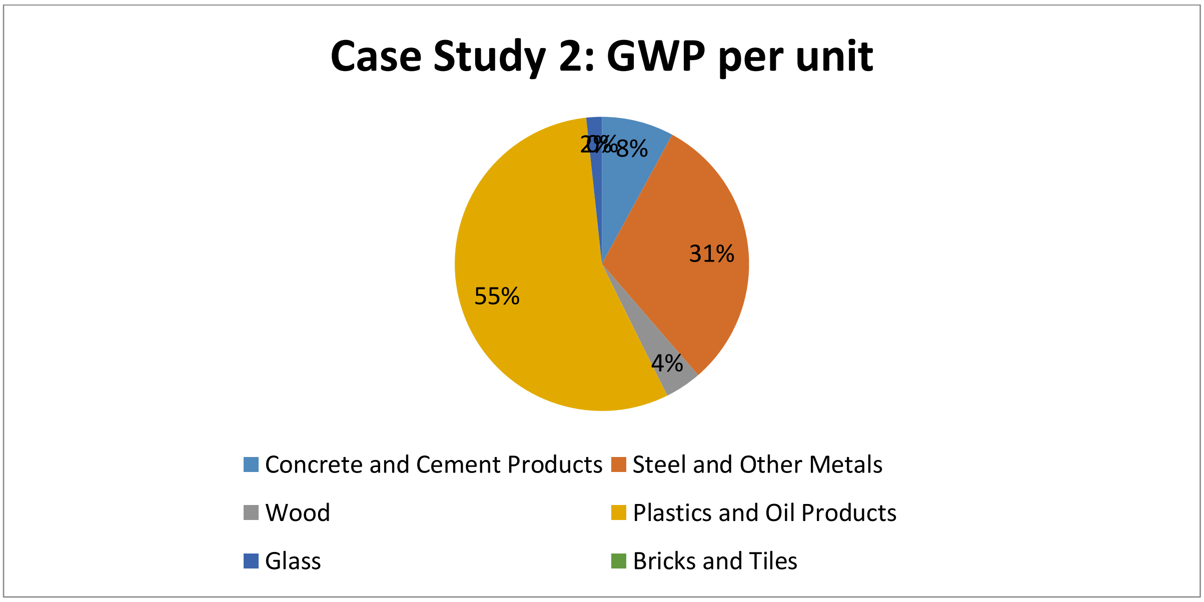


Figure 24: Case Study2 Material Contribution to Global Warming Potential per unit

Source: Own Fieldwork

c. Acidification Potential (AP)

AP is an indicator of the potential acidification of soils and water due to the release of gases such as nitrogen oxides and sulphur oxides.

In Case Study 1, all the construction materials made some significant contributions regarding acidification. However, Concrete and Cement Products had the highest AP. This is closely followed by Steel and Other Metals (20%) and Bricks and Tiles (17%). The materials with the least AP were found to be Plastics and Oil Products (10%), Wood (9%) and Glass (6%). See Figure 25below.

In Case Study 2, energy and fuels used on site had the highest AP at 44%. Coming to building materials, Wood and Steel and Other Metals had the highest AP at 23% and 21% respectively. Unlike in Case Study 1, Concrete and Cement products had a relatively lower AP at 7%. Plastics and Oil Products and Glass had the least AP at 4% and 1% respectively. See Figure 26 below.

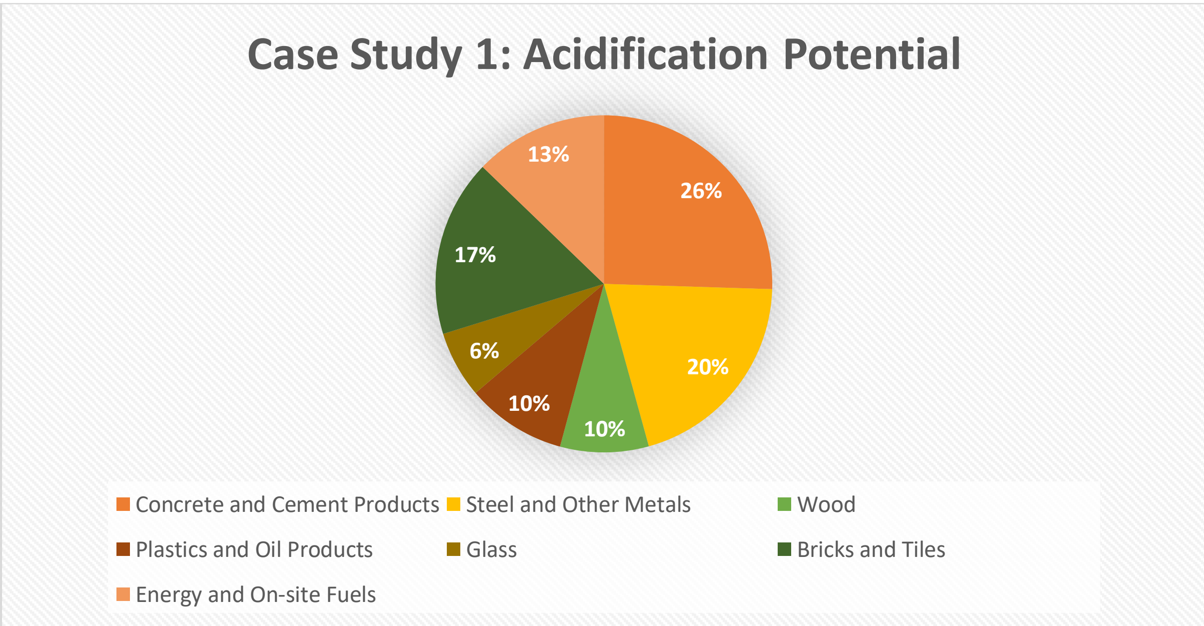


Figure 25: Case Study 1 Material Contribution to Acidification Potential

Source: Own Fieldwork

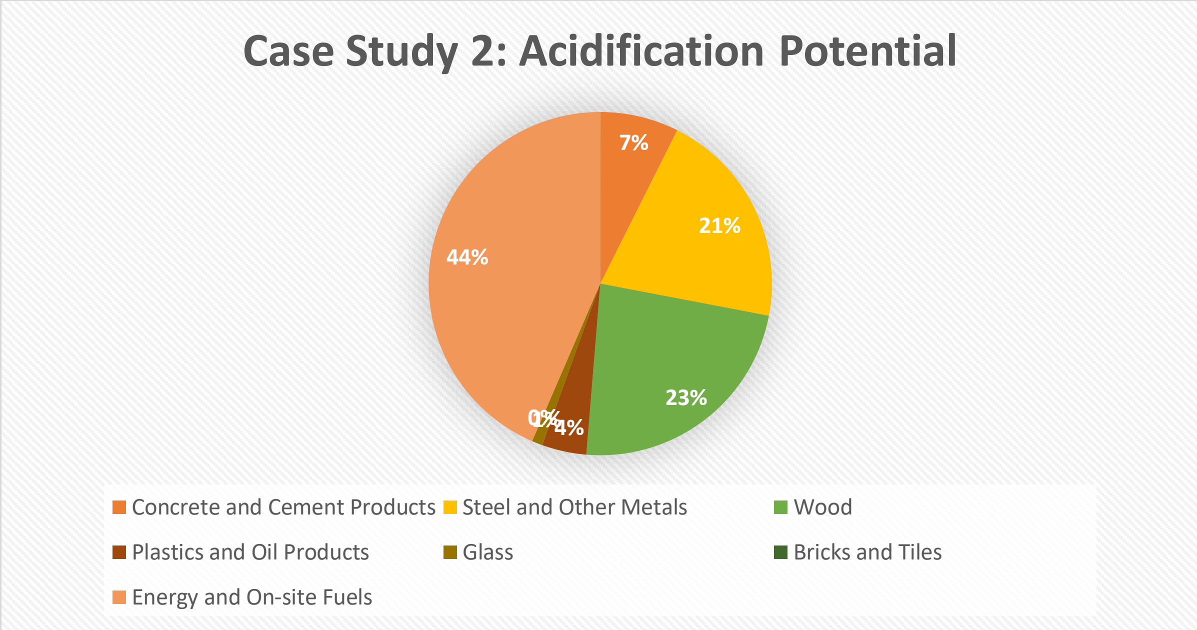


Figure 26: Case Study 2 Material Contribution to Acidification Potential

Source: Own Fieldwork

On a "per unit" level, wood, glass and bricks and tiles are the building materials with the least AP in both buildings; whereas, Plastics and concrete have very high AP per unit in the two case study buildings. See figures 27 and 28 below.

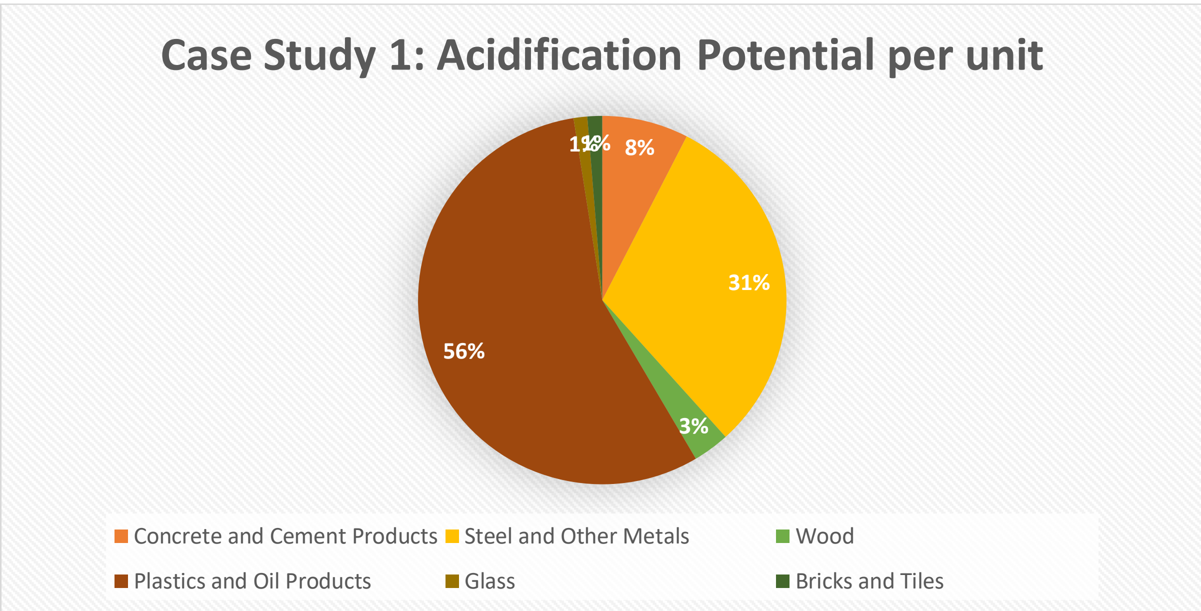


Figure 27: Case Study 1 Material Contribution to Acidification Potential per unit

Source: Own Fieldwork

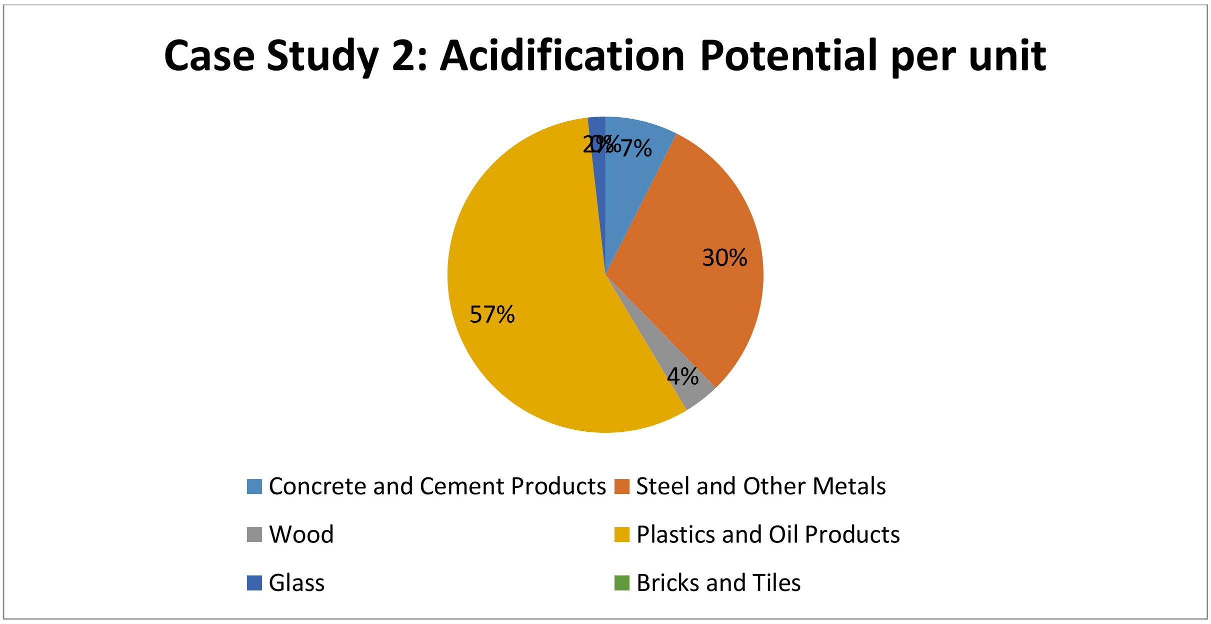


Figure 28: Case Study 2 Material Contribution to Acidification Potential per unit

Source: Own Fieldwork

d. <u>Eutrophication Potential (EP)</u>

EP is an indicator of the enrichment of the aquatic ecosystem with nutritional elements, due to the emission of nitrogen or phosphor containing compounds.

In Case Study 1, Steel and Other Metals had the highest EP at 46%. This figure more than doubled the material in second place which is Concrete and Cement Products which contributed 20% to EP. Wood also contributed 15% to the overall EP of the building. On the flip side, Plastics and Oil Products (7%), Glass (3%) and Bricks and Tiles (2%) contributed the least to eutrophication. Figure 29below gives these findings.

Similarly in Case Study 2, Steel and Other Metals and Wood had high contributions to the EP of the building at 45% and 37% respectively. Glass and Plastics and Oil Products made the least contributions to the EP of the building at 1 (%) and 2 (%) respectively. See Figure 30 below.

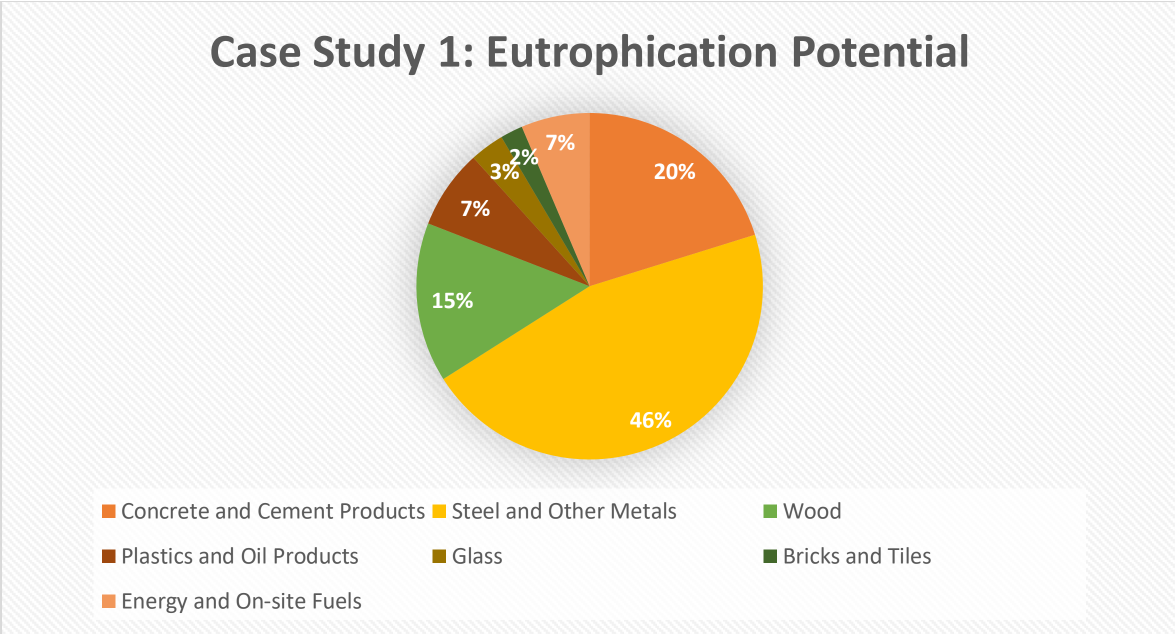


Figure 29: Case Study 1 Material Contribution to Eutrophication Potential

Source: Own Fieldwork

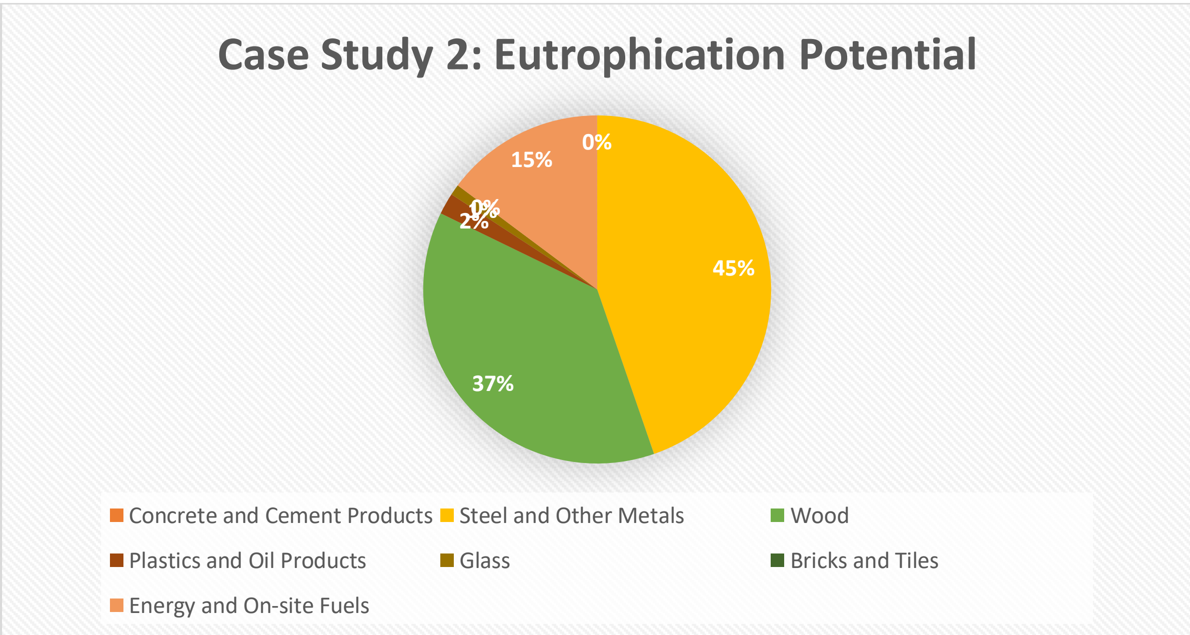


Figure 30: Case Study 2 Material Contribution to Eutrophication Potential

Source: Own Fieldwork

When we consider the percentage impact of the building materials on a “per unit” basis, it is found that in case study 1, plastics (55%) and steel (32%) were the major contributors to EP while glass (1.1%), bricks (0.9%) and wood (3.3%) were the least contributors to EP. Similarly, in Case study 2, plastics (58%) and steel (30%) were also the highest contributors to EP. See figures 31 and 32 below

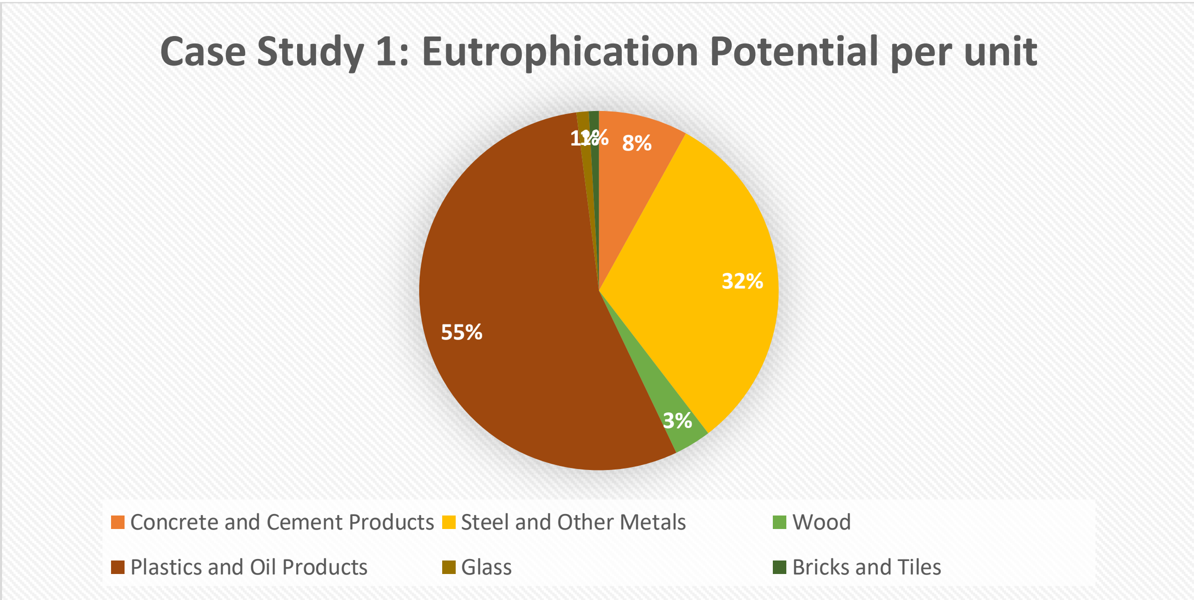


Figure 31: Case Study 1 Material Contribution to Eutrophication Potential per unit

Source: Own Fieldwork

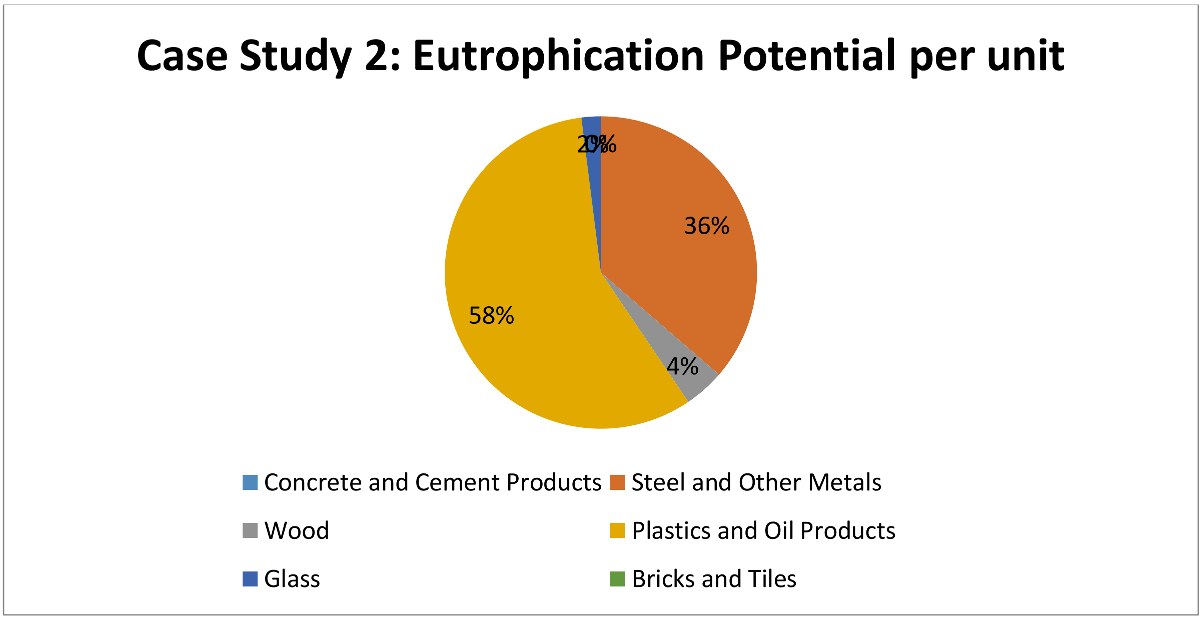


Figure 32: Case Study 2 Material Contribution to Eutrophication Potential per unit

Source: Own Fieldwork

e. <u>Photochemical Ozone Creation Potential (POCP) or Smog</u>

Smog or POCP is an indicator of emissions of gases that affect the creation of photochemical ozone in the lower atmosphere (smog) catalyzed by sunlight.

In Case Study 1 it was found out that the highest construction material contributors to smog are Concrete and Cement Products (29%) and Plastics and Oil Products (25%). Steel and Other Metals also accounted for 14% of the total smog emissions from the building. Building materials with the least contributions to smog are Wood (8%), Glass (4%) and Bricks and Tiles (2%). See Figure 33 below.

In Case Study 2, asides Energy and On-site Fuels contributions to smog emissions, Steel and Other Metals as well as Wood accounted for 21% each of the overall smog emissions from the building. Plastics and Oil Products and Concrete and Cement Products had 15% and 12% respectively. Glass gives the least smog emissions at 1%. See Figure 34below for the details.

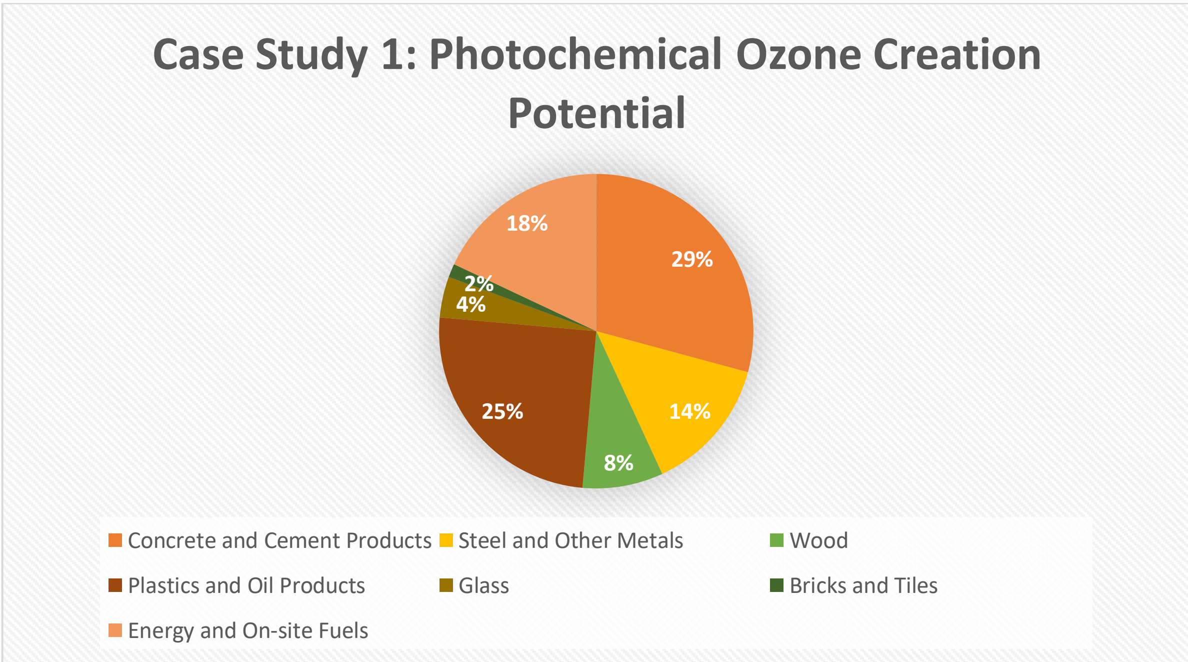


Figure 33: Case Study 1 Material Contribution to Photochemical Ozone Creation Potential

Source: Own Fieldwork

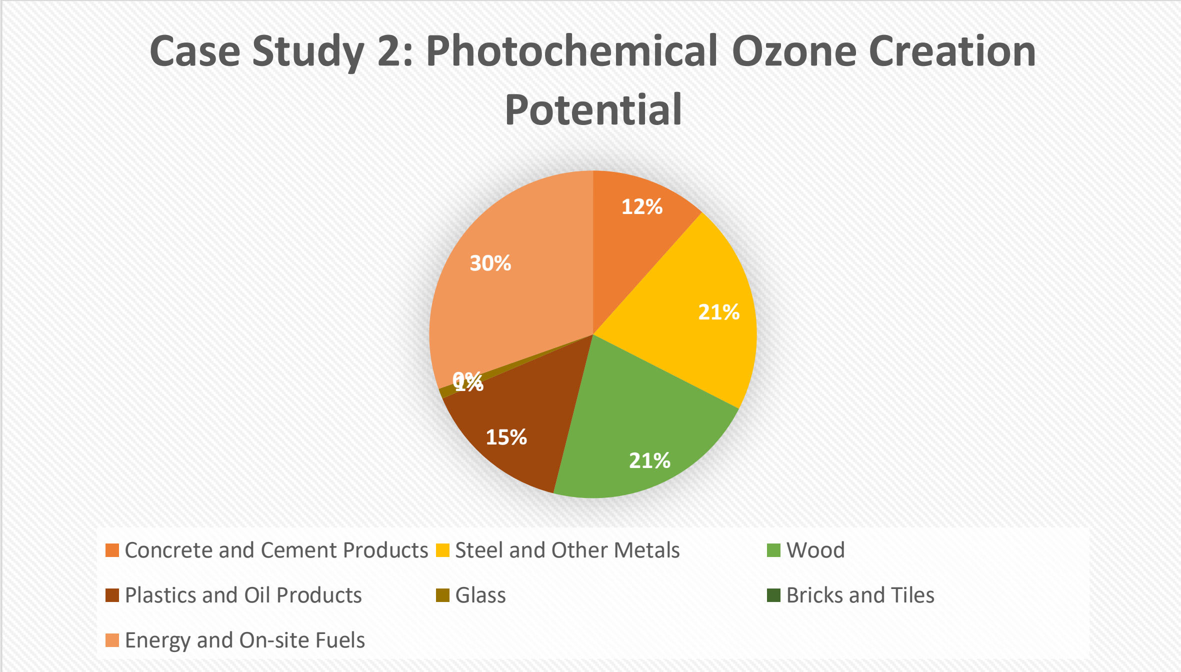


Figure 34: Case Study 2 Material Contribution to Photochemical Ozone Creation Potential

Source: Own Fieldwork

Plastics and Oil products and Steel and Other Metals have the highest POCP on a per unit basis. In Case Study 1, the highest POCP per unit was produced by plastics and oil products making up 56% of the total POCP per unit, while bricks and tiles had the least POCP per unit at 0.9%. In Case Study 2, plastics also made up 56% of the total POCP per unit of materials used, while glass made up the least at 2%. See figures 35 and 36.

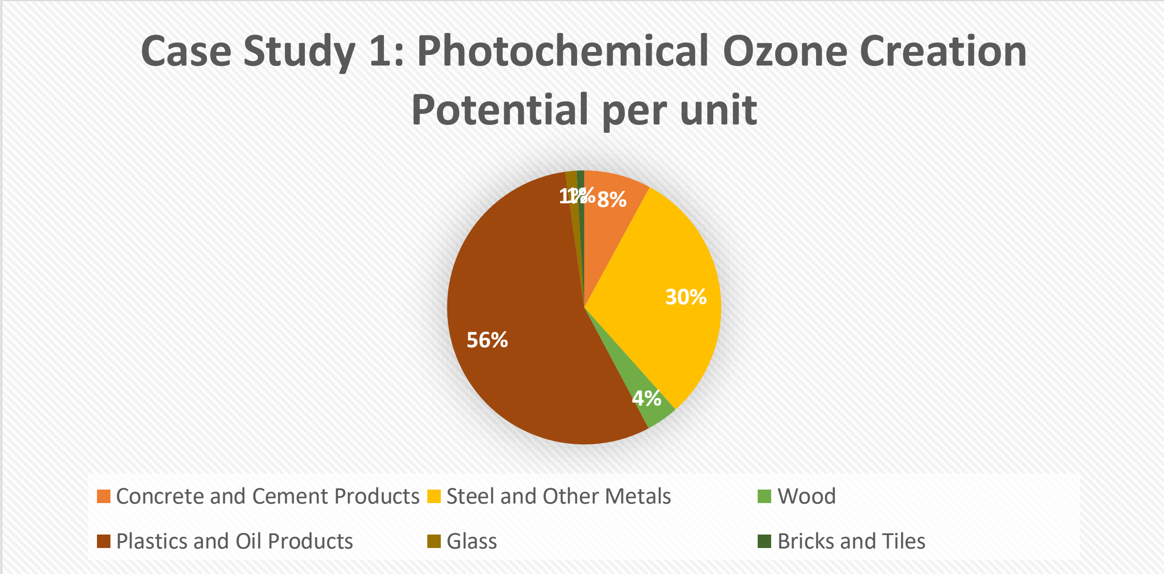


Figure 35: Case Study 1 Material Contribution to Photochemical Ozone Creation Potential per unit

Source: Own Fieldwork

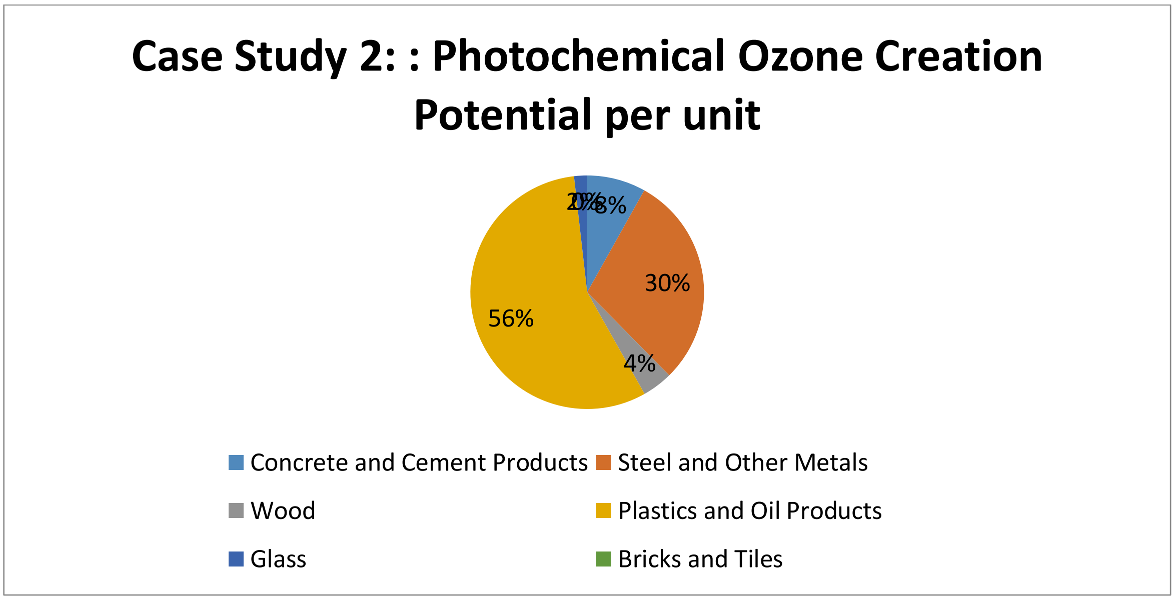


Figure 36: Case Study 2 Material Contribution to Photochemical Ozone Creation Potential per unit

Source: Own Fieldwork

f. Human Health Respiratory Effect

Human Health Respiratory Effect or simply Human toxicity is the impact that humans suffer as a result of the emission of toxic substances to the environment. This affects mainly the respiratory system.

In Case Study 1, Steel and Other Metals contributed the most to human toxicity at 54% while Concrete and Cement Products is the second highest contributor in this category with 23%. Wood accounts for 10% of human toxicity while Plastics and Oil Products (4%), Bricks and Tiles (3%) and Glass (2%) completed this category. See Figure 37below.

Similarly, Steel and Other Metals also contributed the most to human toxicity in case study building 2 with an amount corresponding to 53% of the total impact in this category. It was followed by Wood at 31%. Glass (1%), Concrete and Cement Products (2%) and Plastics and Oil Products (2%) were the least contributors in this impact category. See Figure 38 below.

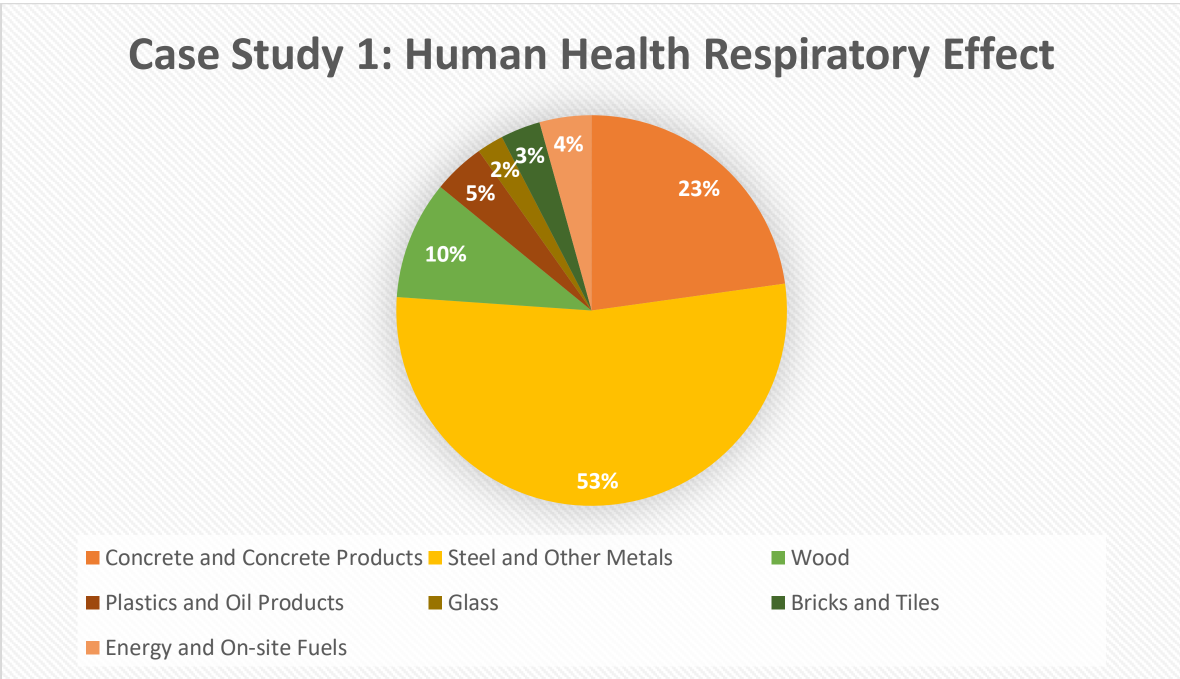


Figure 37: Case Study 1 Material Contribution to Human Health Respiratory Effect

Source: Own Fieldwork

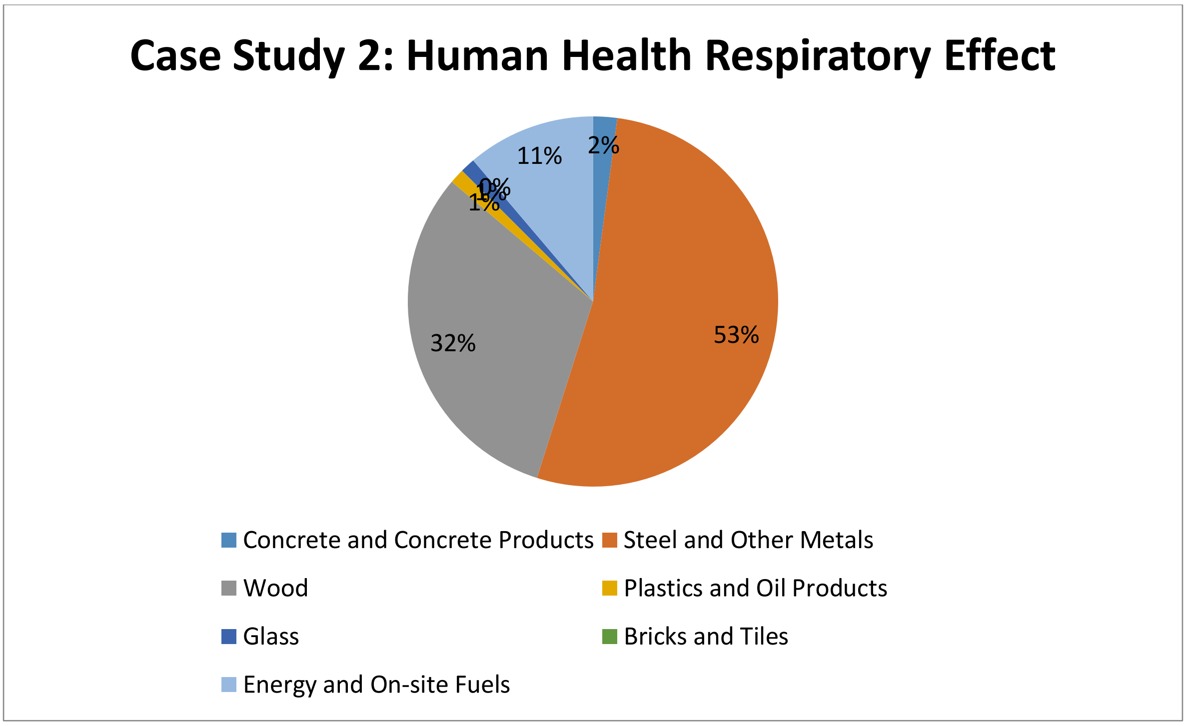


Figure 38: Case Study 2 Material Contribution to Human Health Respiratory Effect

Source: Own Fieldwork

On a "per unit" level, wood, glass and bricks and tiles are the building materials with the least HHRE in both buildings; whereas, Plastics and concrete have very high HHRE per unit in the two case study buildings. See figures 39 and 40 below.

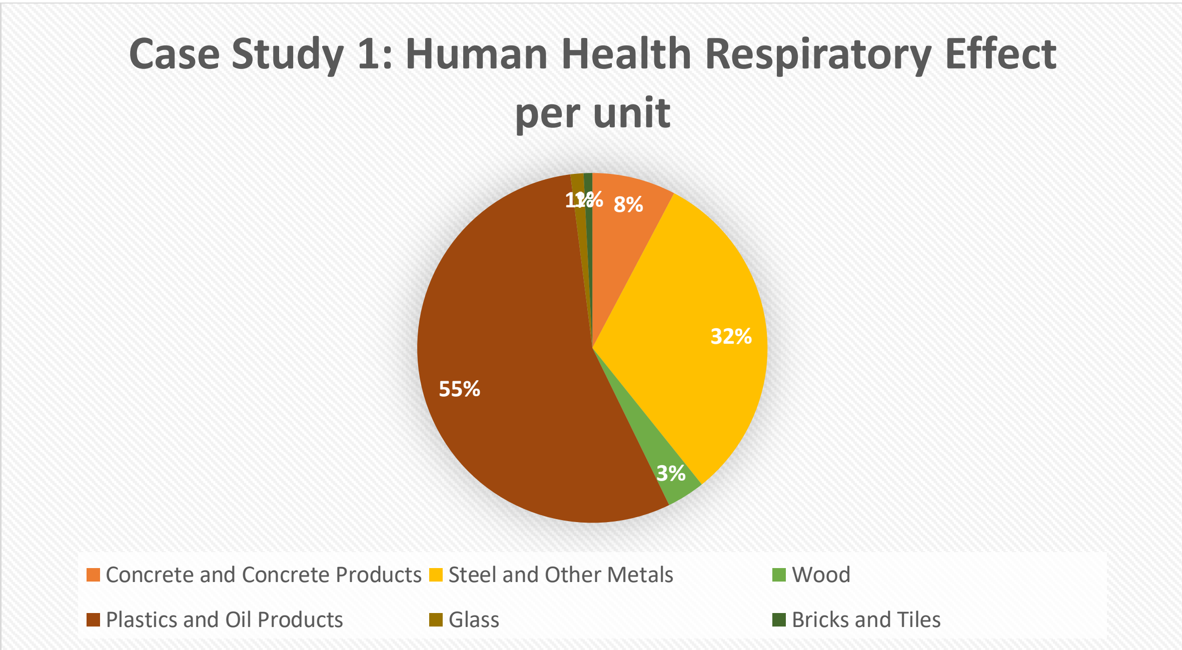


Figure 39: Case Study 1 Material Contribution to Human Health Respiratory Effect per unit

Source: Own Fieldwork

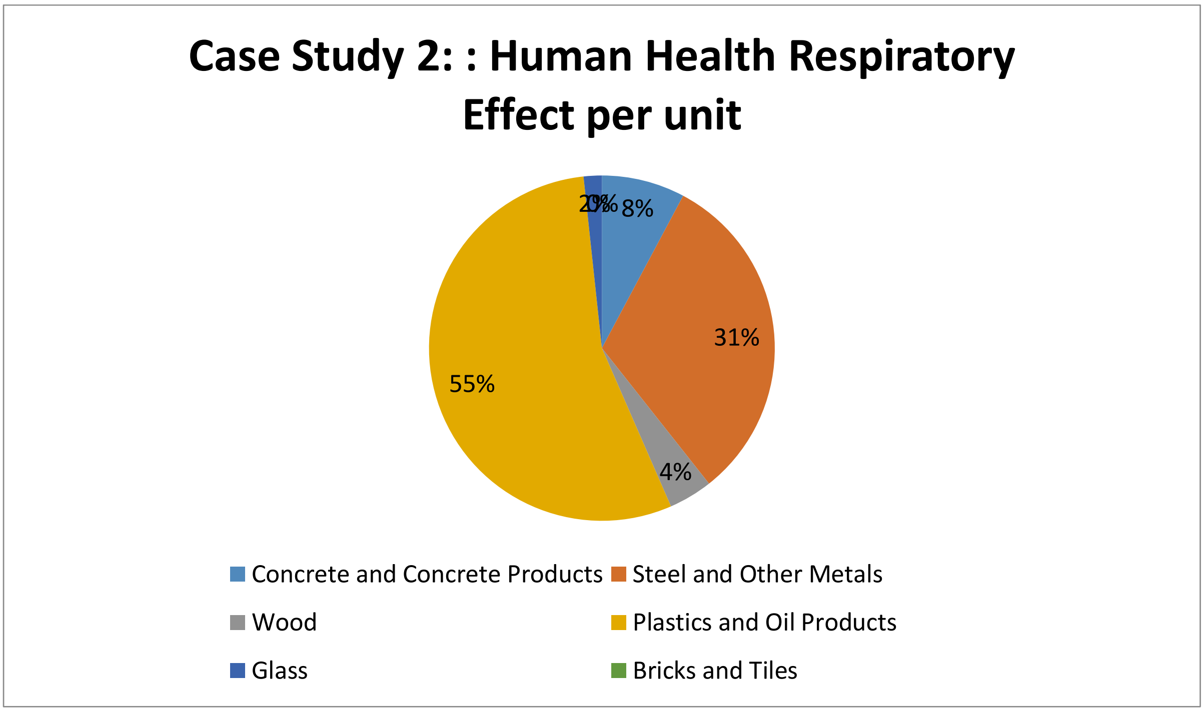


Figure 40: Case Study 2 Material Contribution to Human Health Respiratory Effect per unit

Source: Own Fieldwork

g. Ozone Depletion Potential (ODP)

ODP is an indicator of emissions to air that cause the destruction of the stratospheric ozone layer.

In Case Study 1, Concrete and Cement Products had the most contribution to ozone depletion at 34%. Energy and on site fuels also contributed 24% to the overall ODP of the building. Steel and Other Metals and Wood each contributed 12% while the least contributors were Glass (6%) and Brick and Tiles (3%). In Figure 41 below, these stats are shown.

While in Case Study 2, energy and on site fuels were the highest contributors to ODP (55%). This was followed by wood at 23% and the materials with the least ODP were Plastic and Oil Products (8%), Steel and Other Metals (8%), Concrete and Cement Products (8%) and Glass (2%). See Figure 42below.

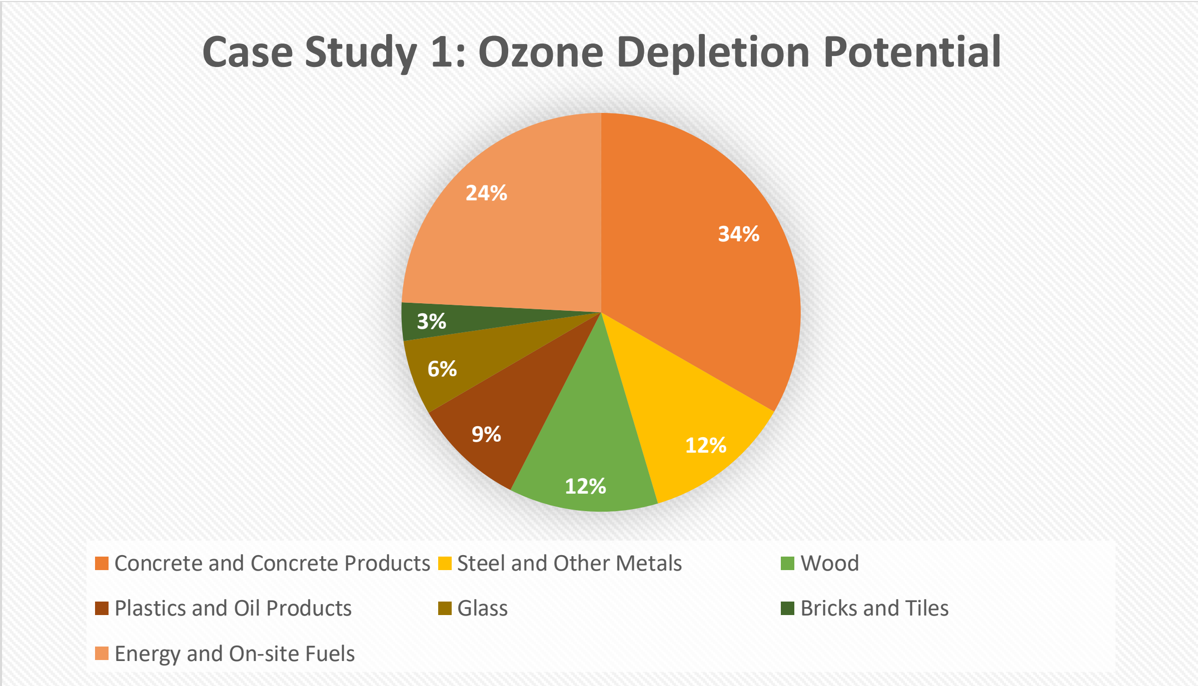


Figure 41: Case Study 1 Material Contribution to Ozone Depletion Potential

Source: Own Fieldwork

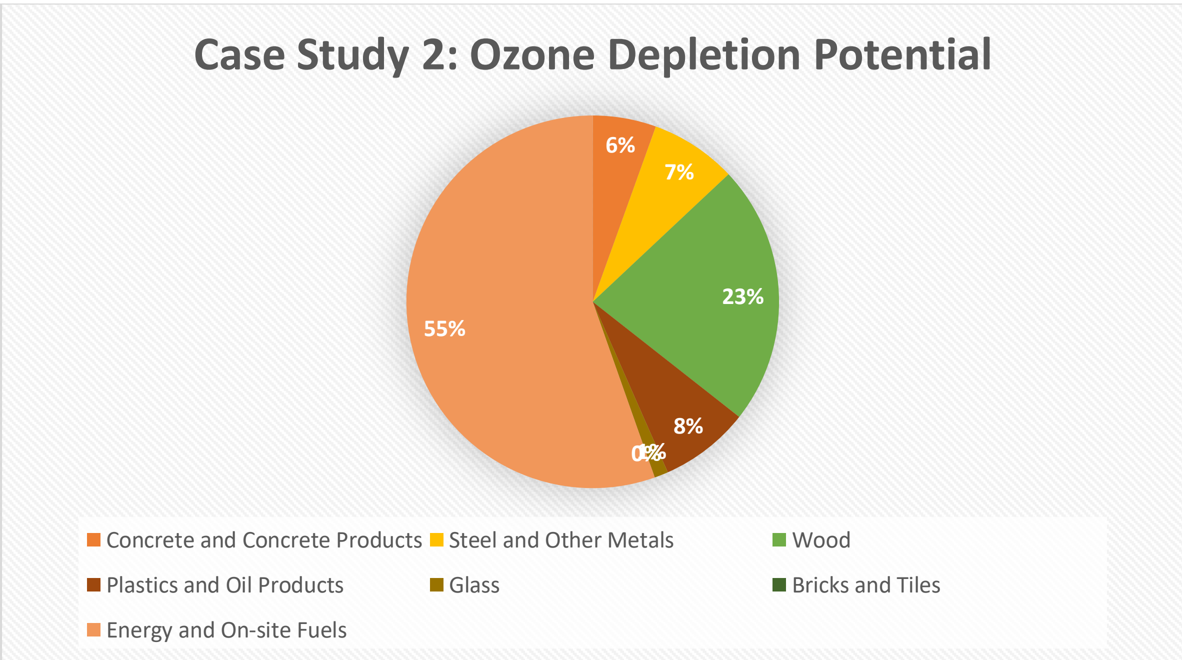


Figure 42: Case Study 2 Material Contribution to Ozone Depletion Potential

Source: Own Fieldwork

When we consider the percentage impact of the building materials on a “per unit” basis, it is found that in case study 1, plastics (56%) and steel (30%) were the major contributors to ODP while glass (1.5%), bricks (1%) and wood (3.6%) were the least contributors to ODP. Similarly, in Case study 2, plastics (58%) and steel (28%) were also the highest contributors to ODP per unit of material. See figures 43 and 44 below.

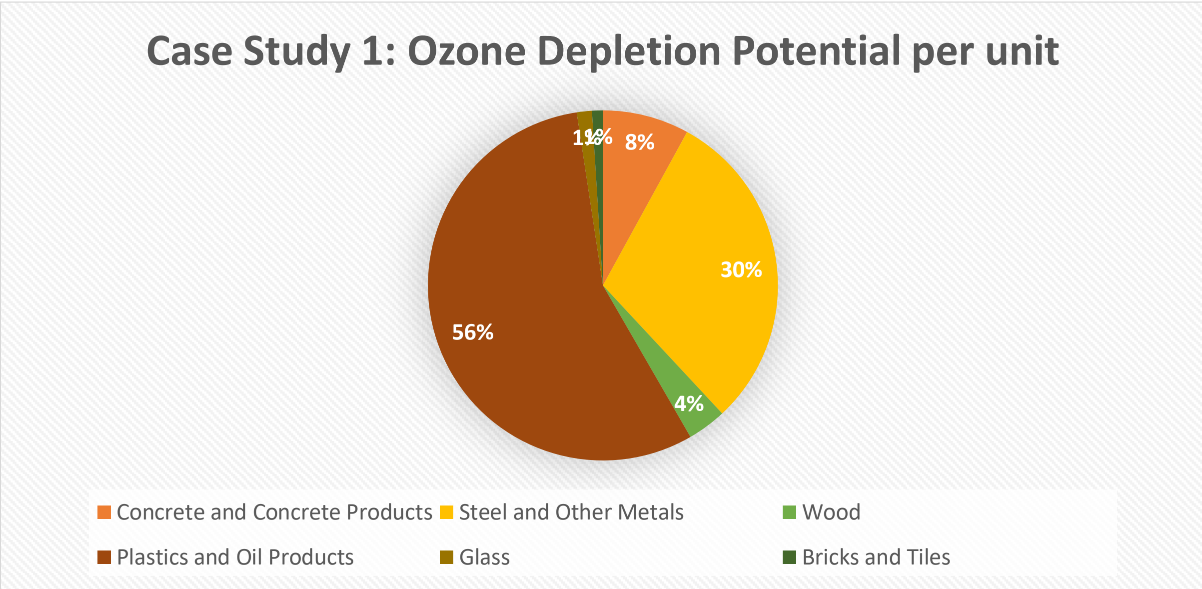


Figure 43: Case Study 1 Material Contribution to Ozone Depletion Potential per unit

Source: Own Fieldwork

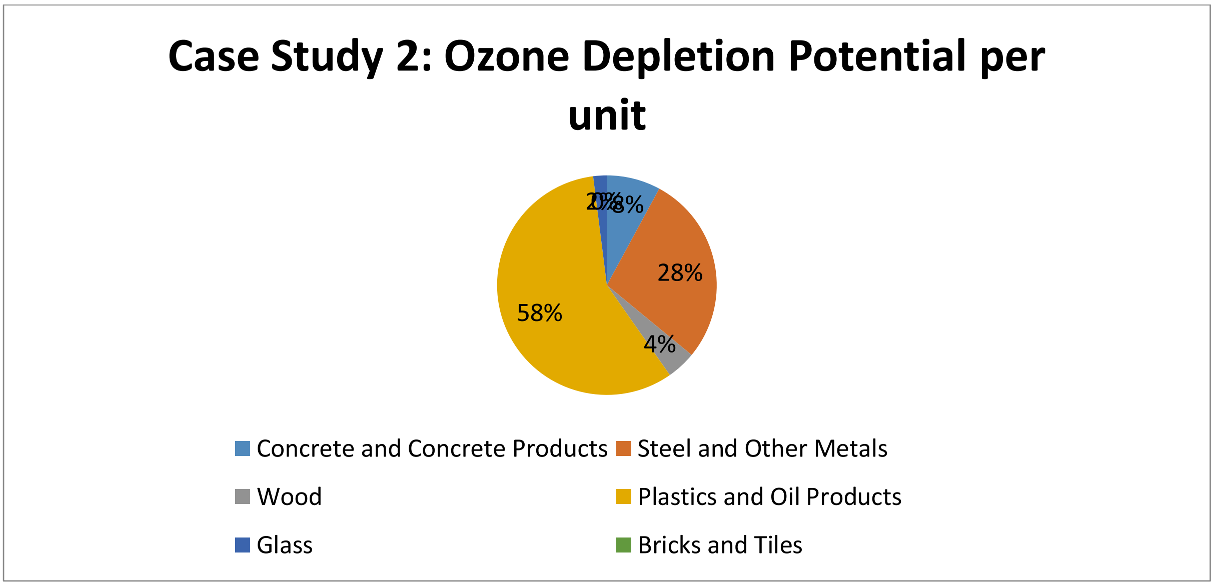


Figure 44: Case Study 2 Material Contribution to Ozone Depletion Potential per unit

Source: Own Fieldwork

4.8 Research question Answers

The answers to the research questions earlier listed will be provided from a combination of all the efforts put into this study. That is, answers will be drawn from the fieldwork carried out as well as desk review of relevant materials.

4.8.1 How is LCA relevant in achieving sustainability and how can LCA be helpful for sustainable construction?

The relevance of LCA in achieving sustainability is high. From the literature review carried out and from the fieldwork performed, it was found out that the most comprehensive method of assessing the overall life cycle of products, including buildings, is the Life Cycle Assessment (LCA) methods (). LCA takes into account every single process in the production of a product from "cradle to grave" and therefore provides a holistic view of the product while also assessing whether or not that product is a result of sustainable practices. In this, the huge relevance of LCA can be clearly seen in that the fact that LCA allows us to monitor and assess every production process makes LCA a most preferred tool for achieving sustainability.

Taking the case study buildings for example, I found LCA extremely effective in assessing the environmental impact of the construction materials used in the two buildings in a manner that showed just which of the materials turn out the least emissions to the environment. Needless to say, the building materials with the least emission per impact category are the most sustainable building materials. Furthermore, I selected five areas of sustainability in which LCA could play a role in order to answer this research question better. These areas are: reducing overall environmental impacts; choosing between alternative building designs; choosing between alternative choices of construction; reducing energy consumption in residential buildings; and encouraging environment friendly lifestyle of residents. The respondents were to choose between "very helpful", "helpful", "not helpful" and "don't know" to each of those parameters. The findings are presented below in simple charts.

Take Figure 45 for example, all the respondents considered LCA to be, at least, helpful in reducing the overall environmental impacts of buildings.

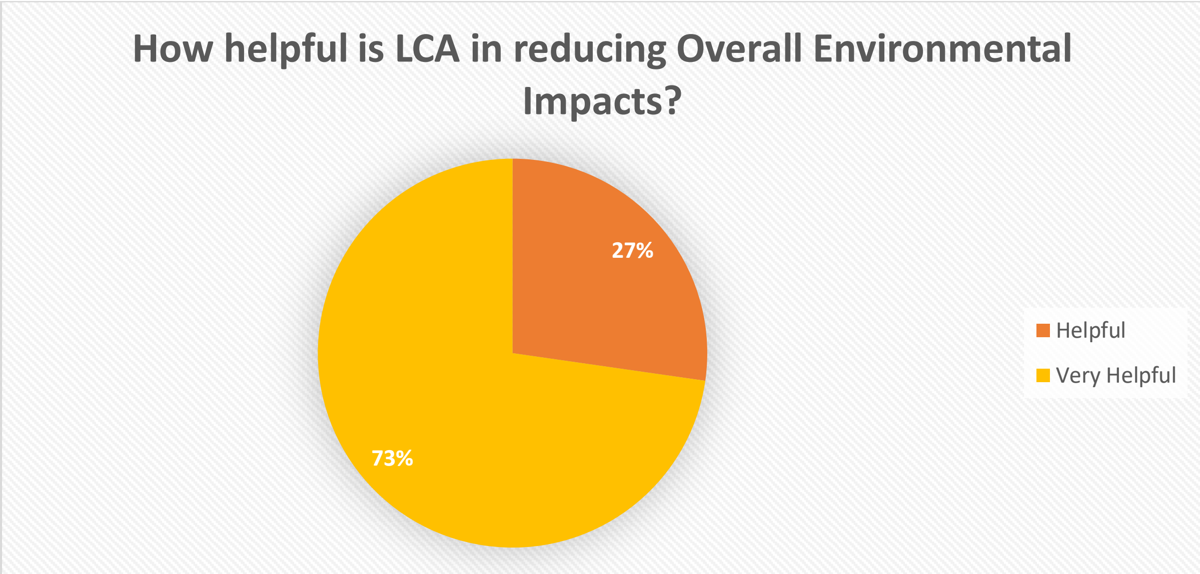


Figure 45: LCA Usefulness in reducing overall Environmental Impacts of Buildings

Source: Own Fieldwork

In Figure 46 below respondents were asked to state how helpful LCA is in helping them choose between alternative building designs that will be more sustainable. 45% of the respondents found LCA to be “very helpful” in this regard, 46% found it “helpful” and 9% were unsure how to respond.

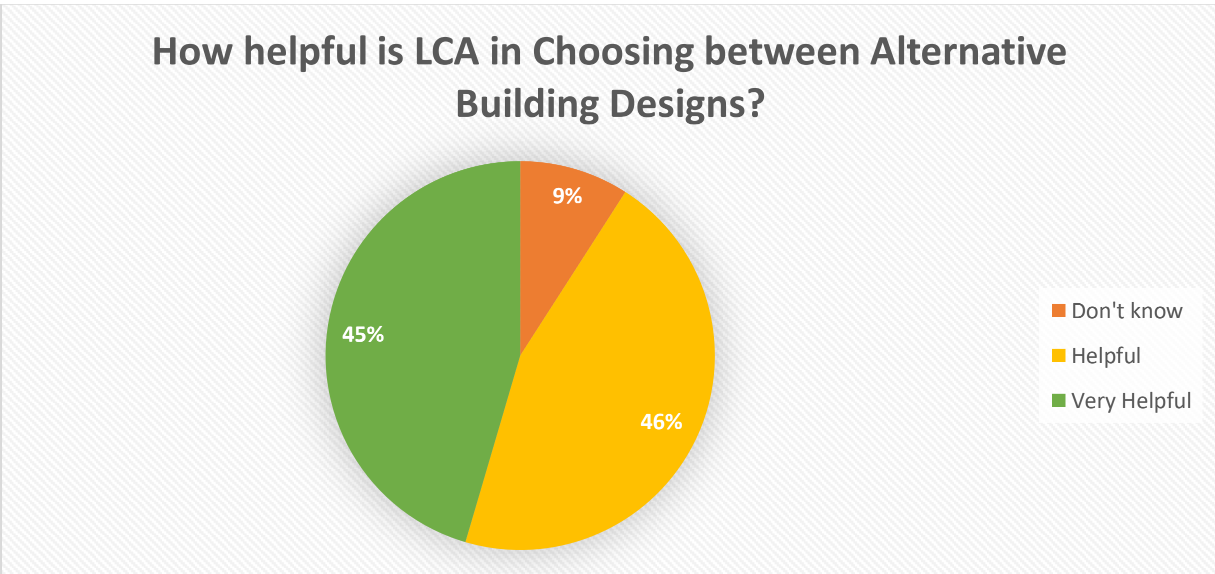


Figure 46: LCA Usefulness in Choosing between alternative Building designs

Source: Own Fieldwork

Similarly, in Fig.47 below, a total 95% of the respondents found LCA to be, at least, helpful in helping them even choose between alternative choices of construction that will enhance sustainability.

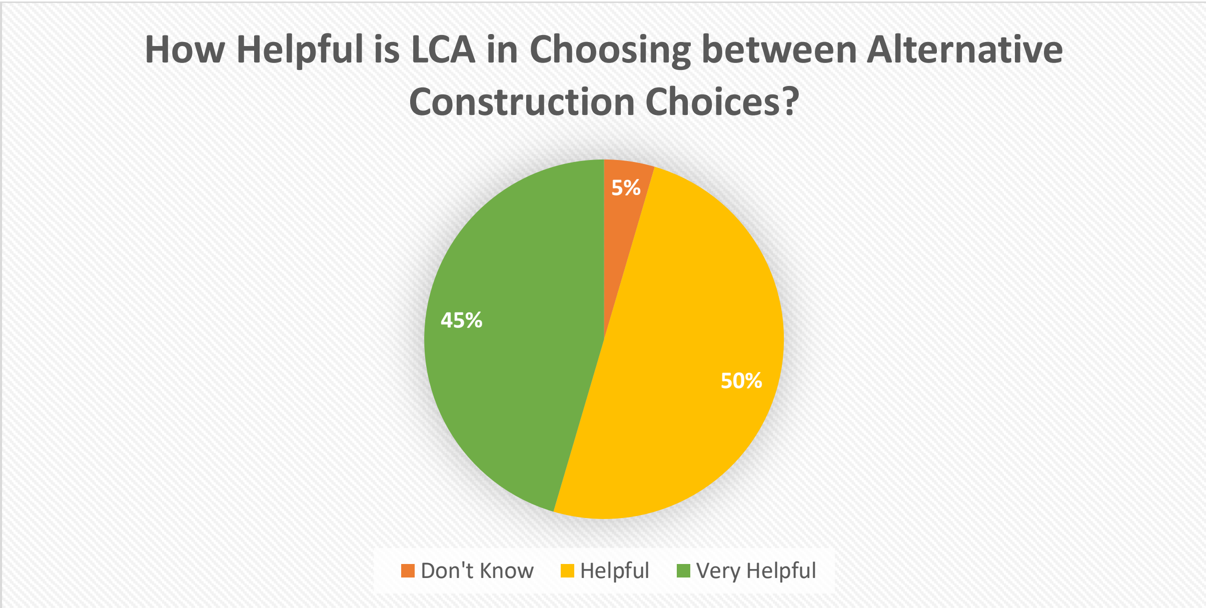


Figure 47: LCA Usefulness in choosing between alternative Construction choices

Source: Own Fieldwork

As it affects the likelihood of experiencing a reduction in energy consumption in a building on which LCA has been carried out, all the respondents opined that LCA would be useful in this regard. This is because the findings of the LCA study would have been applied into the construction of the building to make it more sustainable. See Figure 48below.

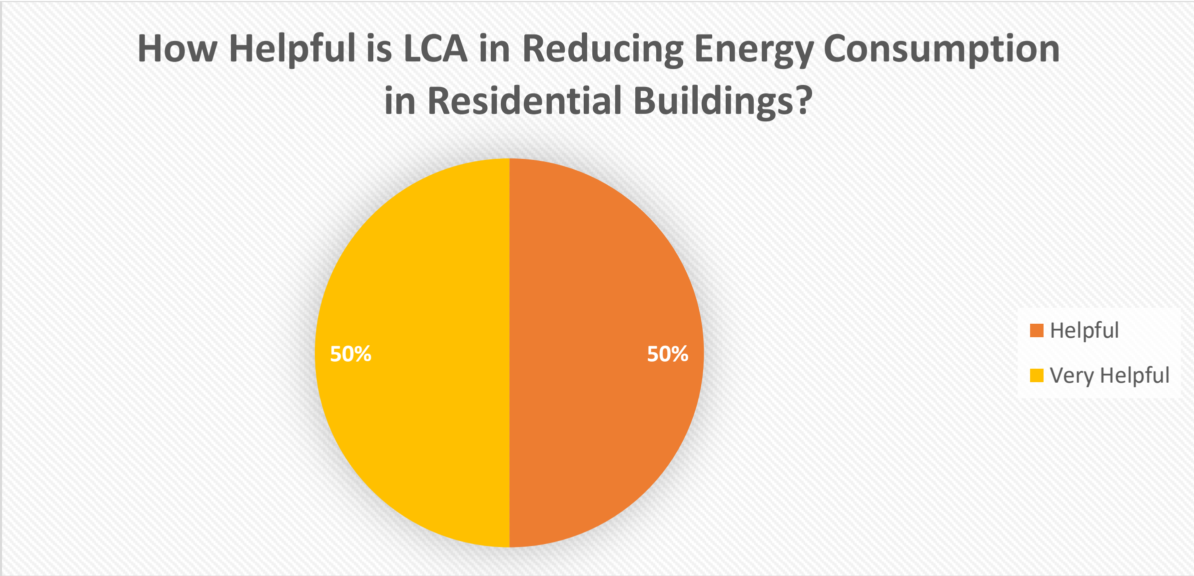


Figure 48: LCA Usefulness in Reducing Energy Consumption in Residential Buildings

Source: Own Fieldwork

Since design plays a role in modifying the behavior of residents in the building, it is understood that a sustainable building (that attained that status through LCA) will encourage its residents to cultivate environment friendly lifestyles. It is in this light that 64% of the respondents found LCA to be "very helpful" in encouraging environmental friendly lifestyle, and 36% of the respondents found it "helpful". See Fig. 49below

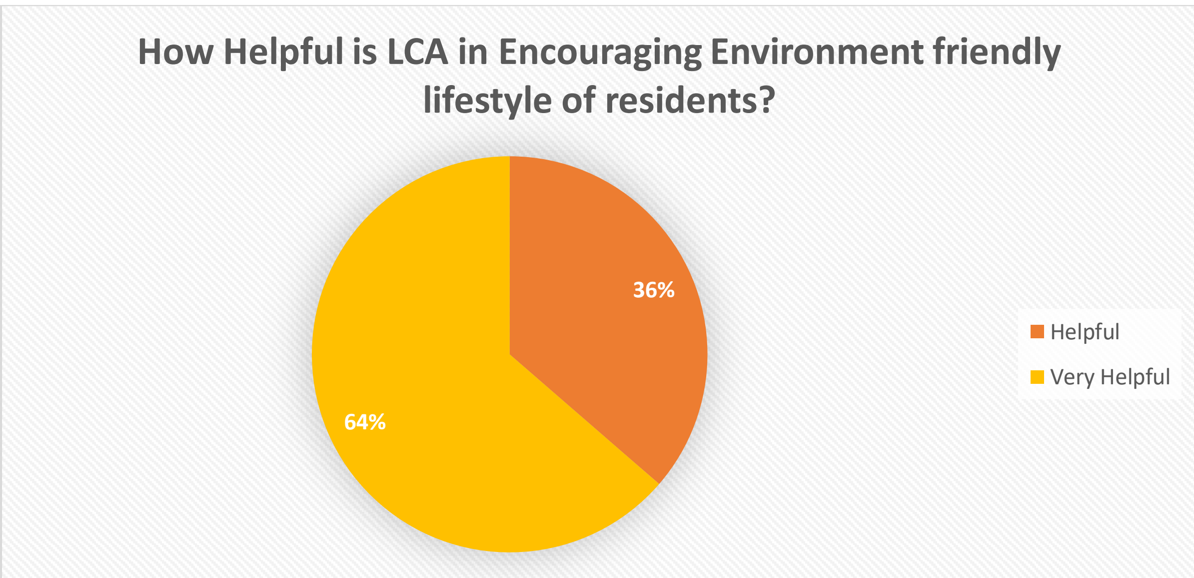


Figure 49: LCA Usefulness in Encouraging environment friendly lifestyle of residents

Source: Own Fieldwork

Thus, LCA can be helpful in attainingsustainable construction by putting the results of LCA of previous buildings into consideration when designing new buildings and when specifying materials to be used in the design. Moreover, LCA considers the life span of each material used on the building as a factor for determining the long-term environmental impact of that building material (Ramesh, et al., 2013).

4.8.2 Which of the stages of a building LCA consumes the most energy?

Answers to this question were obtained from desk review and the questionnaires issued out. There seemed to be some agreement among researchers in this subject matter that the “Operation” or “Use” stage of the building life cycle consumes the most energy over time in the long run. From literature review carried out, it is concluded that operation stage of the building is the stage where the building consume more energy than the other stages, mainly because of the length of this phase in the building life cycle. Petroche, et al. (2015) found out that this stage of the building life cycle accounts for 70% to 91% of the total life-cycle energy impact of the building. Oviir (2016) even opines that the Use Stage of the building makes up 62-98% of the total life-cycle energy of a building.

However, the responses to this question on the questionnaire showed that the respondents actually consider “building construction” stage to be the highest consumer of energy, making up41% of the total responses obtained. This is followed by the “pre-construction stage” at 32%, the “use stage” at 18% and the “end-of-life stage” at 9%. See Fig. 50below. One logic behind this consideration may be the length of operation is not that long as buildings are not built as per standards and they do not last long. Another consideration might be the only use of electricity in the use phase and no heating etc.

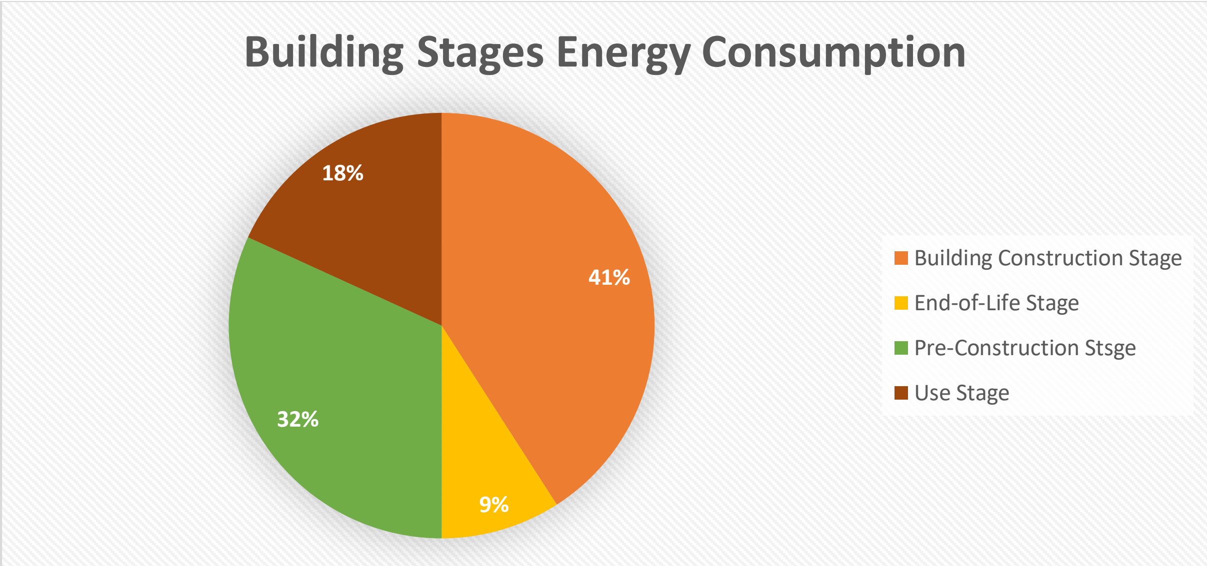


Figure 50: Energy Consumption of the various Building Stages

Source: Own Fieldwork

4.8.3 Which construction material is suitable for designing a sustainable residential building?

In answering this question, first it must be explained what exactly is meant by a "sustainable residential building". Form the various previous studies reviewed, a sustainable residential building refers to a house or building in which an individual or a family reside and that the said building is built with materials that cause very little damage to the global ecosystem while also satisfying human needs.

Since buildings are made from several different component parts, and these parts are also made up of different materials, it follows that a sustainable residential building is one that is built with materials that do not harm the environment or life generally.

The findings from the fieldwork revealed that for a standard size residential building the material that effect the environment less are Glass, Bricks and Tiles, Plastics and Oil Products and Wood. Visually, Figures 51 and 52 show the relative environmental impact of these building materials. The more area of the bar a material occupies, the greater the environmental impact of the material. Hence, the materials which take up less parts of the bar are less damaging the environment.

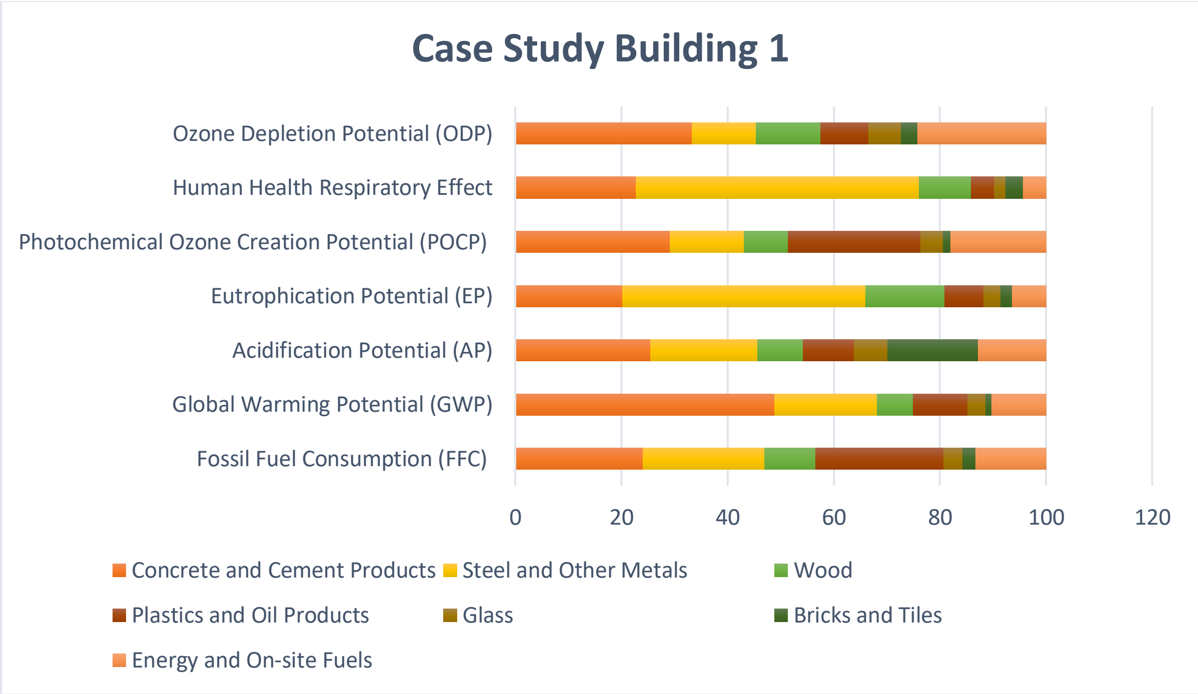


Figure 51: Construction Material Environmental Impact in Case Study 1

Source: Own Fieldwork

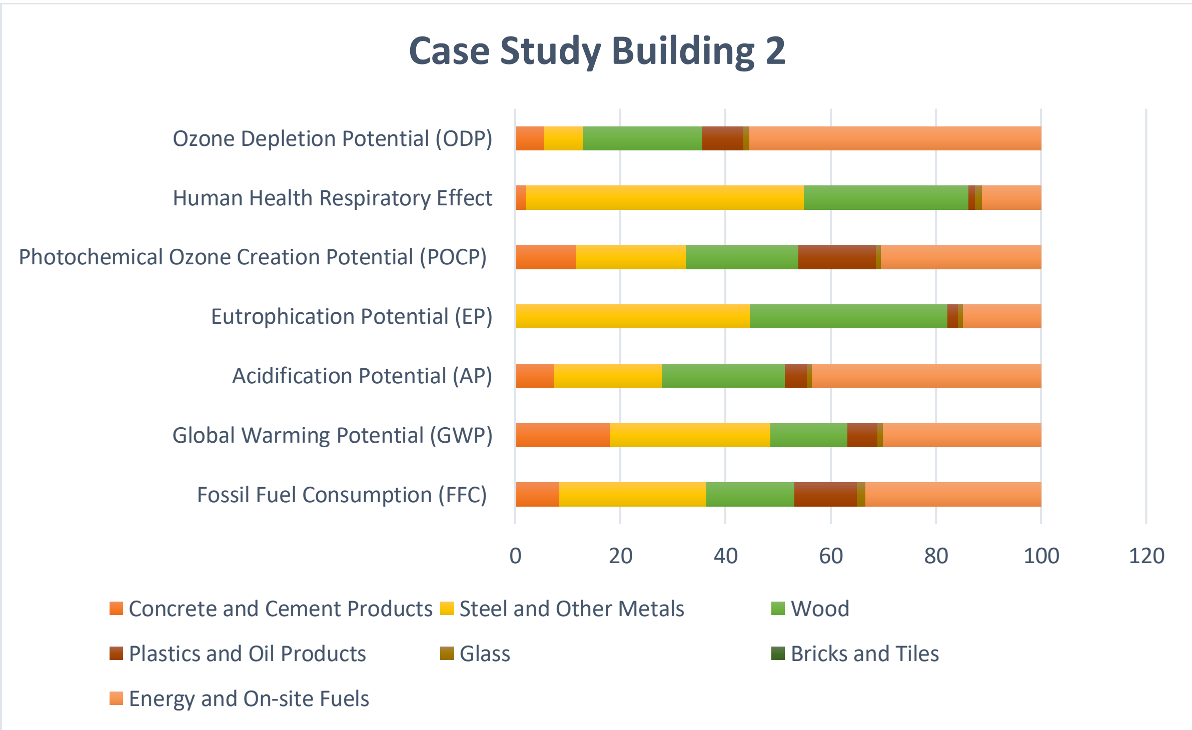


Figure 52: Construction Material Environmental Impact in Case Study 1

Source: Own Fieldwork

In Figure 51 where the building material impacts in Case Study 1 are presented, it can be seen that Concrete and Cement Products and Steel and Other Metals occupied the most areas in every impact category studied. This simply shows the emission potential of these building materials. On the other hand, Glass and Bricks and Tiles occupied the smallest areas on the bars and therefore are less damaging.

In Figure 52, the building materials used in Case Study 2 are presented. First observation shows that, asides the contributions of Energy and On-site Fuels, Steel and Other Metals and Wood contributed the most to environmental impact. Glass once again, proved to be the construction material with the least environmental impact.

The result of the both case studies are based on real life scenario where concrete is used in large quantity in buildings compared to glass and plastic, and therefore concrete is the one in the building construction that harm the environment more than glass and is term as less sustainable or more environmental damaging material for construction of residential building. Glass, here in real scenario is term as sustainable.

Going further, the per unit environmental impact of each building construction material gives an even clearer indication of what materials are truly sustainable in that the values obtained are not as a result of the quantity or volume of material used up. Thus, in figure 53 below where the building material environmental impact per unit of material is shown. It is clear that bricks and tiles, glass and wood (which took up the least spaces on the stacked bar chart) are the most sustainable building materials considered in this study. For the least sustainable building materials, plastics and oil products and steel and other metals rank highest.

In case study 2, the findings show very similar results to that of case study 1. This is shown in figure 54 below

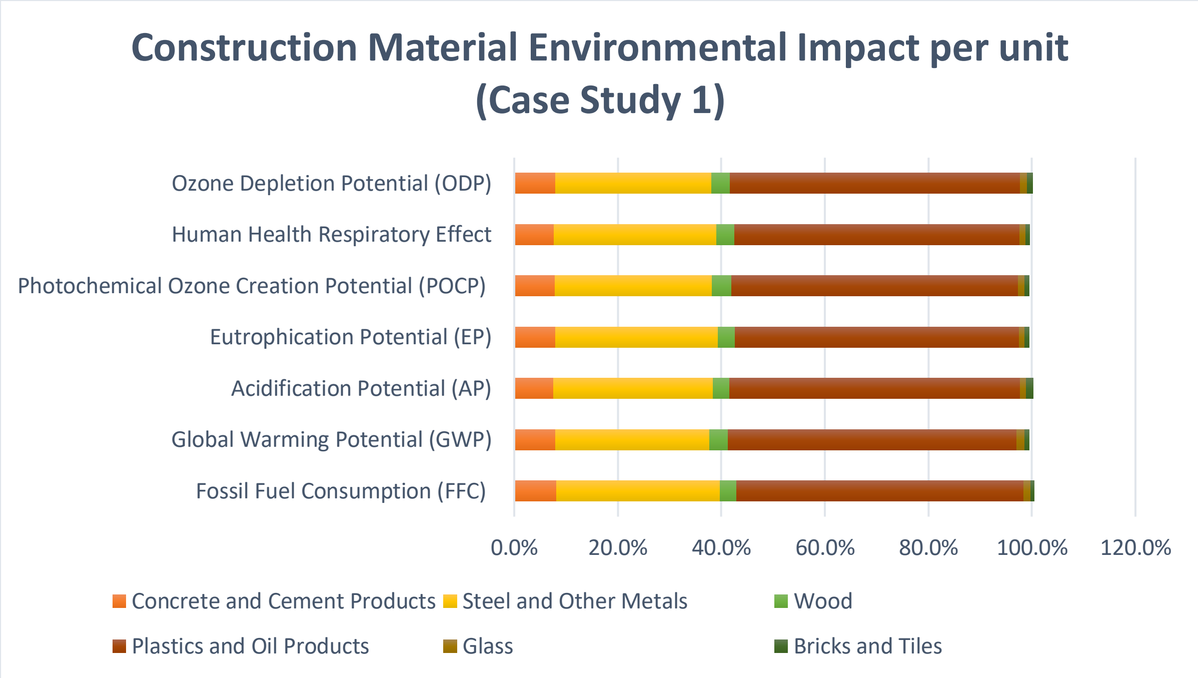


Figure 53: Construction Material Environmental Impact per unit in Case Study 1

Source: Own Fieldwork

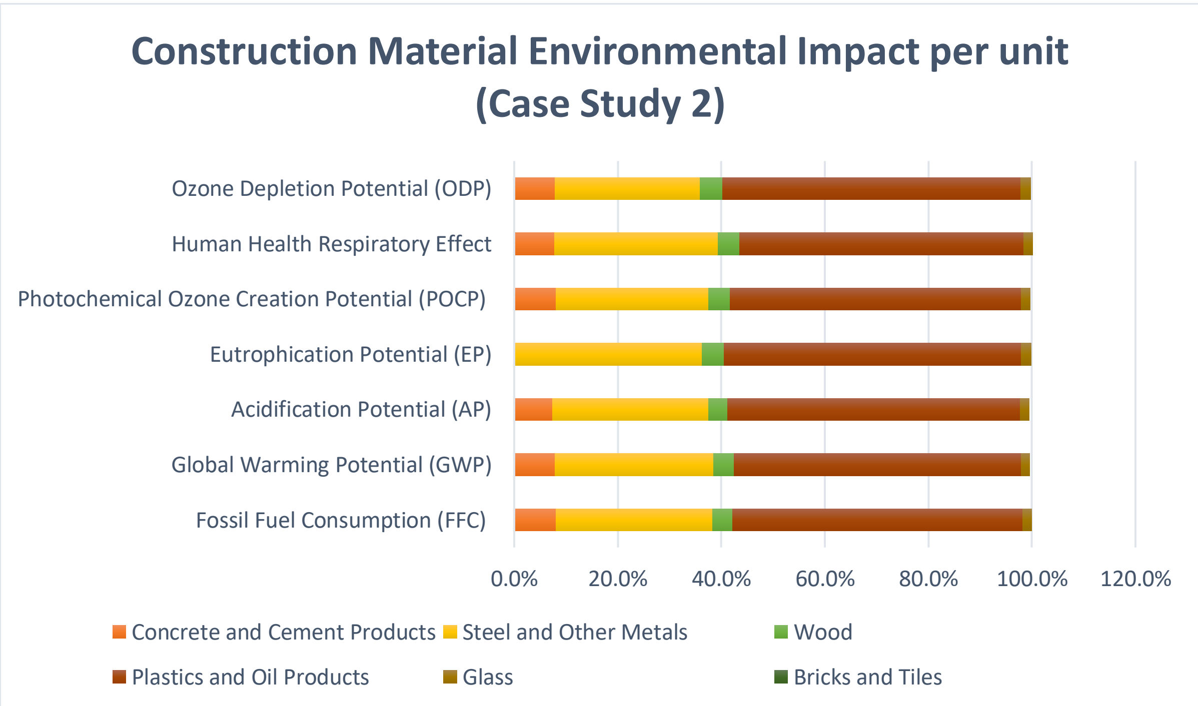


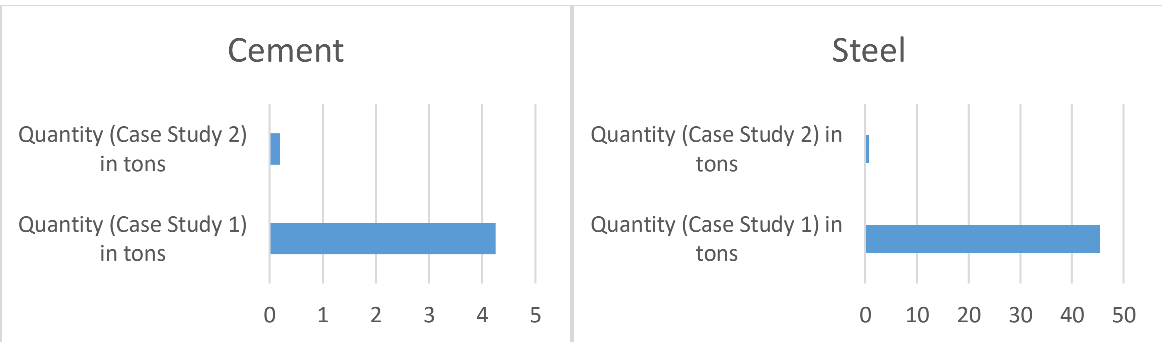
Figure 54: Construction Material Environmental Impact per unit in Case Study

Source: Own Fieldwork

4.8.4 Does the region of a building, size of a building, and number of residents have an impact on the GHG emissions from a residential building?

From the case studies carried out, it is unclear whether the region where a building is located really has an impact on the GHG emissions from that residential building as both the buildings are located in the same temperature zone. However from literature review and research studies and from the research questionnaire we find that region of the building does have impact on GHG emission. Studies carried out by (Rossi, et al., 2012) in which they carried out LCA on buildings in three (3) different countries – Belgium, Portugal and Sweden – showed that regions of different climatic classification will have to handle heating and cooling loads differently. Since GHGs are emitted during these processes, it can be understood that the region of a building play some roles in determining the GHGs emissions in a building. 36 of the respondents, representing 54.4%, opined that the region of a building have an impact on the GHG emissions from a residential building. So based on these two results I would like to rely on those findings.

Without much debate, the size of a building definitely impacts on the greenhouse gas (GHG) emissions from that building. The reason for this is quite simple: it lies in the quantity of materials used up to construct the building. A small building need less amount of building materials than a bigger building and as a result of this fact, the smaller building emits less GHGs than the bigger residential building. A look at Tables 6 and 7 which have been presented earlier in this chapter shows the quantity of the materials used in the buildings. Table 8 specifically compares the quantities of some major construction materials used in both case study buildings. An extract from Table 8 was worked upon in a spreadsheet and presented below as simple comparable figures in figure 55.



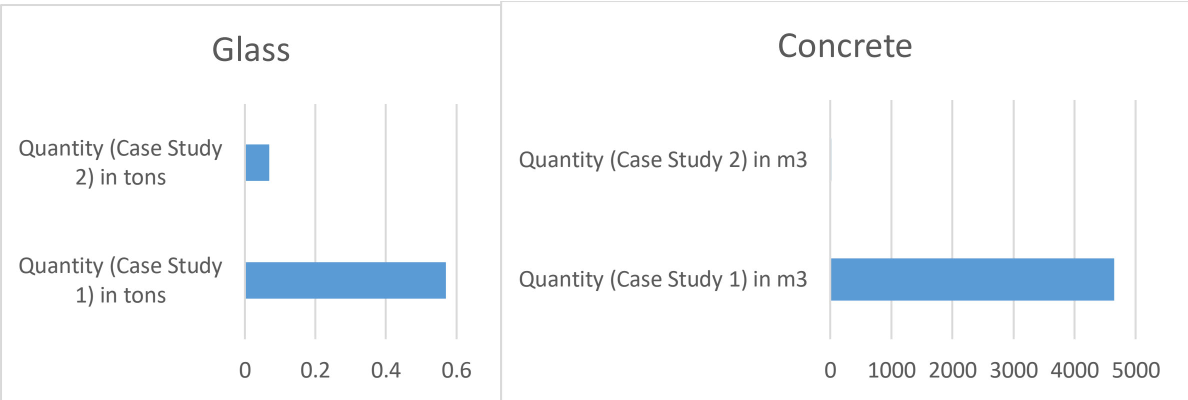


Figure 55: Quantity of some Materials used in both buildings

Source: Own Fieldwork

The materials used in Case Study 1 were clearly more than the materials used in Case Study 2.

More importantly, the impact category that deals with GHGs emissions is Global Warming Potential. From figures 21 and 22 earlier presented in this work, it is clear how the huge quantity of materials used, especially concrete, contributed to the GWP of case study 1 building.

As if in agreement with the deductions above, 57 respondents (86.4%) actually stated that the size of a building is a major factor affecting the level of GHGs emissions in buildings. (See figure 56 below)

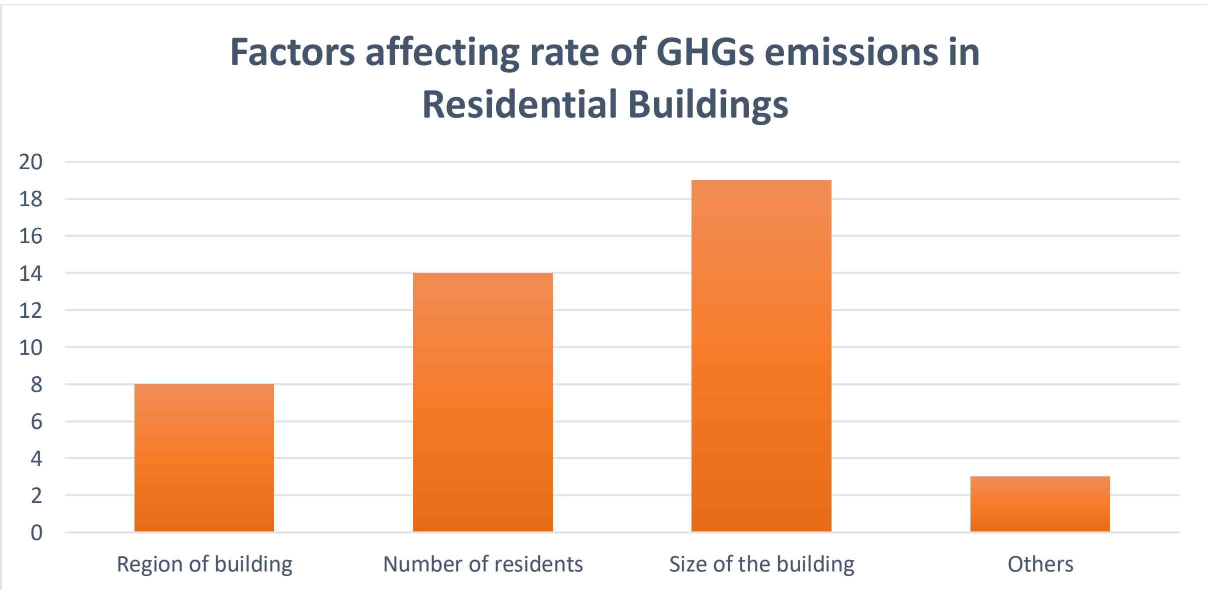


Figure 56: Factors affecting GHGs emissions in Pakistani residential houses

Source: Own Fieldwork

Lastly, the number of residents in the house does not necessarily lead to GHG emissions. Rather, it is the harmful behavior of occupants that could lead to high GHGs emission in a house. Hence, a household of five (5) persons with a lifestyle that encourages prudent use of resources and chemical products will have a lower GHG emission potential that a household of two (2) persons with a harmful lifestyle wherein CFCs and other GHGs are freely emitted. In this breadth, 42 respondents (63.6%) opined that the number of residents in a house could significantly affect the amount of GHGs emitted from that house. See figure 56 above.

A few respondents also went on to identify other factors that might lead to GHGs emissions in residential buildings such as quality of construction material, use of synthetic construction material and improper disposal of toxic waste during construction. Others suggested that the kind of household activities carried out inside the building could predispose it to high emissions of GHGs.

4.8.5 What are the main hurdles for a full use of LCA construction approach in Pakistan?

In this aspect of the work, 10 number of hurdles were listed from which the respondents have to choose each as deemed most significant. The relative importance index was used as tool to rank the obstacle from 1 to 10. The relative importance index was calculated according to equation 1. The barrier with the higher relative importance index was ranked first followed by the lower rank with lower value subsequently. This is given by the table below.

Barriers to LCA Implementation	**RII**	**Rank**
Lack of Awareness	0.901	1
Unwillingness of investors to pay for LCA	0.845	2
Lack of Sustainable regulations and Policies	0.800	3
Lack of Skilled Professionals	0.778	4
Lack of Commitment and inspiration	0.775	5
LCA is considered Time Consuming	0.774	6
LCA Practitioners are not well paid	0.763	7
LCA Strange Proposition	0.721	8
LCA is considered complicated Process	0.706	9
LCA Software's and Database Quality issues	0.690	10

Table 11:Relative importance index (RII) and Rank of Barriers to LCA implementation in Pakistan

Source: Own Fieldwork

The higher value of RII means that high number of respondent agrees on a certain barrier to be most significant. So based on the relative importance index value the findings showed that the most significant hurdles to full use of LCA in Pakistan is "lack of awareness" with RII value 0.901, which mean 90 percent of the respondent think this is a barrier to LCA implementation in Pakistan. At rank 2 is "unwillingness of investors to pay for LCA" with RII 0.845.At rank 3 stands "Lack of Sustainable regulations and Policies" with RII 0.800.At rank 4 is "absence of skilled LCA practitioners" with RII 0.778.At rank 5 is "Lack of Commitment and inspiration" with RII 0.775.At rank 6 is "LCA is considered Time Consuming" with RII 0.774.At rank 7 is “LCA Practitioners are not well paid” with RII 0.763. At rank 8 is “LCA is a strange proposition” with RII 0.721.At rank 9 is “LCA a considered complicated Process” with RII 0.706. And at last rank is LCA softwares and quality of databases issue” with RII 0.690. LCA is not taken seriously because there are no strict regulations for it; and that plans are made according to client need and budget with little or no environmental concerns. This obstruction to LCA can be represented by a graph as below.

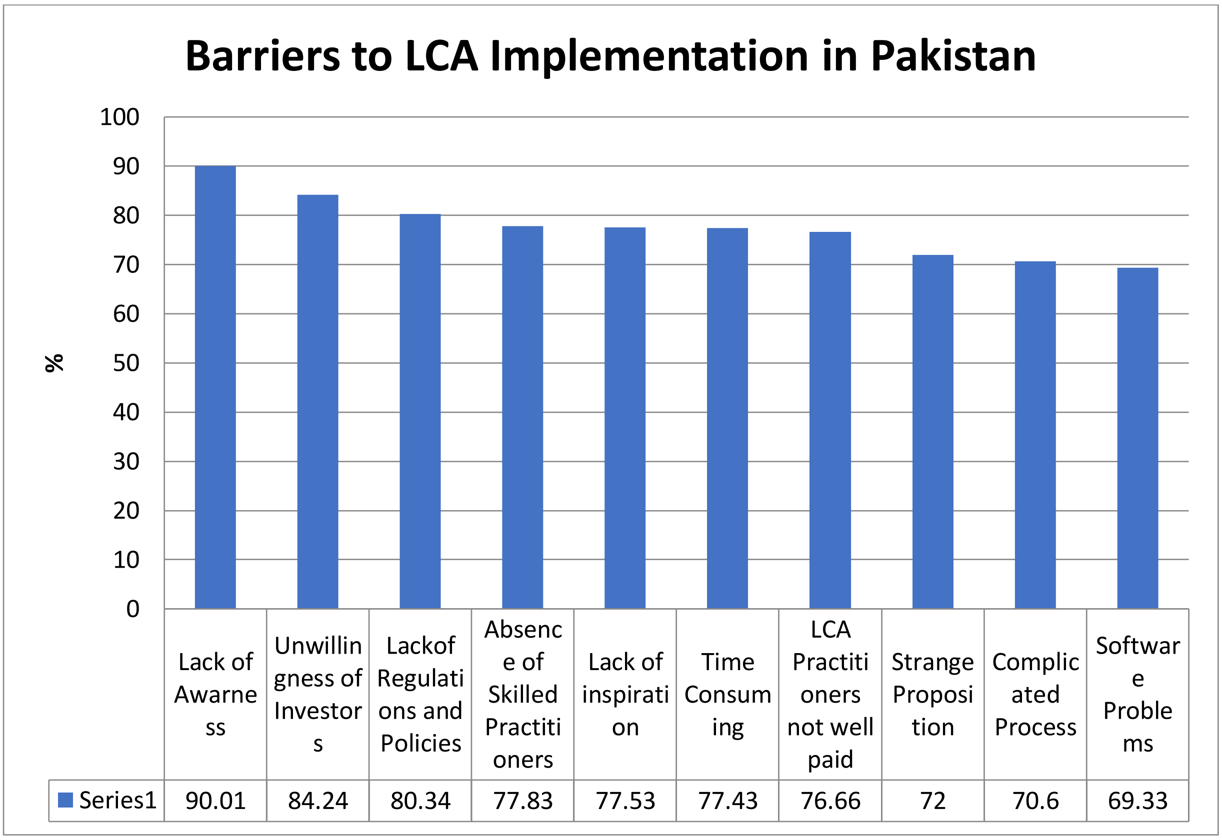


Figure 57: Barriers to use of LCA in Pakistan

Source: Own Fieldwork

4.8.6 What policies must be adopted to ensure green construction approach?

Based on the findings of this study, some recommendations will be provided to ensure green construction. These are articulated in Chapter 6 of this thesis in policies and recommendation section.

4.9 Chapter Summary

In Chapter 4, the findings of the study carried out have been copiously presented using simple tables, charts and descriptive texts. The two case study buildings have been studied and the results obtained from the analyses carried out have shown how the building materials impact on the environment. The chapter concludes by providing answers to the research questions developed for this study. In the next chapter, concluding discussions will be had on the findings of this study.

CHAPTER FIVE: DISCUSSIONS

5.1 Introduction

This chapter briefly discusses the result of analysis to articulate them for a clear appreciation of the efforts put in this thesis. The discussions will be articulated to show how the set aim and objectives of this study are achieved or otherwise show why they were unattained. It will give a brief idea to researchers about future research scope in LCA in Pakistan.

5.2 Relevance of LCA in Achieving Sustainability in the Building Industry

In this work so far, I have shown that LCA is indeed unquantifiable relevant in achieving sustainability in the building industry. I have showed that right from the desk review; previous researchers have stated the huge potential that LCA had for the well-being of the environment. And in this study, the findings have also revealed that LCA provides a direction for environmental actors to follow in order for them to achieve sustainability.

The usefulness of LCA in achieving a sustainable built environment lies in the fact that LCA shows all the environmental impacts that would arise from the production, use and demolition of a building. Once these data are available, it is therefore a case of the building industry actors using that information to make better design decisions, use the right or alternative material and ensure the right practice. It is expected that once the sustainability of the materials is known, it will help building designers to propose more sustainable designs that will encourage green construction.

In one of the answers to the research questions earlier discussed, it is clearly stated how LCA helps practitioners to achieve sustainability such as helping to reduce to overall environmental impact of buildings, choosing between alternative building designs, choosing between alternative construction choices, reducing energy consumption in residential buildings, and encouraging environment friendly lifestyle of residents. In each of these areas, LCA is seen to be, at least, “helpful” in achieving sustainability by over 90%. (See figures 45 – 49 above).

5.3 Embodied Energy of Building Materials

On the set objective of calculating the embodied energy of the building materials used in the case study buildings, I achieved that by obtaining just two set of data: the quantity of material used and the embodied energy per unit of the material. By simply multiplying these figures, the figures obtained represented the total embodied energy of the construction materials used in the two projects.

In this effort, it was found out that assuming all materials had similar embodied energy per unit, materials that were in large quantities often reflected a higher total initial embodied energy compared with materials that are in lower quantity. Take concrete for example, although its embodied energy per unit is 5.44GJ, in case study 1 where the volume of concrete used was 4,650.7m^3, the total embodied energy of the material was calculated to be 25,299.8GJ whereas in case study 2 where the volume of concrete used was just 101.6.45m^3, the total embodied energy of concrete was calculated to be 552.70GJ.

It can therefore be appreciated how this aspect of the work impacts on the overall outlook of this study.

5.4 Building Materials for Sustainable Construction

Since one of the set objectives of this thesis is to determine the most suitable building material for the construction of sustainable residential buildings, one of the main focus of the field work was to show how building materials impact on the environment.

In this vein, the building materials were studied against the backdrop of specific environmental impacts i.e. fossil fuel consumption, global warming, eutrophication and acidification among others. The building material type categories studied include Concrete and Cement Products, Steel and Metals, Wood, Plastic and, Glass, Bricks and Tiles.

The findings revealed that the sustainability performance of the building materials for a complete standard building ranks glass, bricks and tiles as the less environment harming materials. On the other side, steel and other metals as well as concrete and cement products are the most environment harmfulmaterials. But when compared per unit of material Plastic, steel and metal s are more environment harmful while concrete, wood and brick tiles are less harmful and sustainable. From Table 10 and figures 17 – 44 earlier presented in this study, we can see the performance of the building materials as regards sustainability.

5.5 Factors Affecting GHGs Emission in Residential buildings

Another key objective of this thesis is to determine some of the factors affecting the level of GHGs emission in residential buildings. This was primarily achieved by research literature and obtaining responses to this question from Pakistani LCA practitioners via the use of the questionnaires. It was found out that size of the building, number of residents of the building and the region in which the building is located all affected the amount of GHGs emitted from residential buildings. See figures 41 and 42 above for more details.

5.6 Chapter Summary

In chapter five, a brief summary of the responses to the research objectives of this study was presented. It agreed that LCA is relevant to the drive to achieve sustainability in Pakistan even as it also agreed that the embodied energy of different building materials are useful indicators of the overall sustainability of the building. Further, it found out that some building materials are actually more sustainable for building construction than others. Lastly, some of the key factors affecting GHGs emission in residential buildings in Pakistan were mentioned.

CHAPTER SIX: CONCLUSION

6.1 Introduction

This chapter provides a summary of the thesis. It also pencil in conclusions from the result & discussions of analysis. Lastly, the main recommendations for future will be presented.

6.2 Summary

LCA has come a long way since the idea was first formalized in the 1990s in Europe. Over the years, there has been tremendous progress in this field with several researchers coming up with useful findings to improve the system. One notable evidence of these endeavors is found in the number software designed to carry out LCA operations in the environmental industry.

The sheer capability of LCA to provide a comprehensive analysis and environmental assessment of the entire production system from “cradle to grave” makes LCA a more preferred tool than EIA.

This thesis therefore set out to apply LCA to two (2) case study residential buildings in Pakistan with a view to using the findings to determine the sustainability of building materials commonly used in construction. It is expected that once the sustainability of the materials is known, it will help building designers to propose more sustainable designs that will encourage green construction in Pakistan.

Using the openLCA software, the processes and flows were created and analyzed with a focus on how the building materials and building systems actually impact the environment. Findings showed that for a full standard size residential building the building materials that create the most damage to the environment are Steel, Concrete and Cement; while the building materials with the least harmful impact on the environment are wood, Glass Brick and Tile. On the hand individually per unit Plastic and steel and metal are more damaging than Brick, Tiles and concrete.

Furthermore, structured questionnaires were sent out to some LCA practitioners in Pakistan. These questionnaires were distributed to obtain firsthand opinion of these LCA experts on their experience of LCA in Pakistan. Findings showed that LCA is still in its infancy in Pakistan and that even in areas where LCA is relatively popular, designers are all too quick to sacrifice the environment for the sake of the client's needs or budget. These are problems that need carefully thought-out solutions. It was also found out that Pakistani LCA experts use a variety of LCA software such as Gabi, openLCA, Umberto, OneClick LCA etc.

However, there are several hurdles impeding the practice of LCA in Pakistan. Some of the challenges identified include:

a) LCA is time consuming;
b) LCA Software are not affordable;
c) Poor Quality of databases;
d) Absence of skilled LCA practitioners;
e) Lack of awareness;
f) Unwillingness of investors to pay for LCA
g) Lack of proper regulation for sustainable development

Providing solutions to these challenges is absolutely necessary if LCA in Pakistan is to meet up with the standards already set in the Western world and Australia, and to provide step forward in the quest to gaining a higher consciousness for sustainable buildings.

The work done so far is indeed revealing. It has successfully put Pakistan at the center of the discussion on LCA and opened up the floor for healthy discussion to be and on this subject by environmental engineers, architects and project managers among other stakeholders in LCA.

6.3 Conclusion

The research explores LCA and uses it to calculate the total embodied energy of the building materials used in Pakistani residential houses. It goes further to analyze how these building materials impact on the environment in at least seven (7) areas including acidification, fossil fuel consumption, eutrophication, global warming, human toxicity etc. The results obtained showed how each building material contributed to environmental pollution. Whereas some building materials turn out a high acidification potential, other materials ranked higher in another category of environmental impact and so on.

From the literature reviewed, it could be seen that the results of this study are in line with similar studies earlier carried out in other parts of the world.

Without doubt, LCA can be used to ensure sustainable buildings in Pakistan that will have comfortable environments for residents as well as other building users. With some bold steps on environmental policies in Pakistan, LCA practice will develop rapidly and this will rebound in a sustainable environment for residents to dwell in and enjoy a full dose of a productive life.

6.4 Recommendation

As earlier mentioned, some recommendations will now be highlighted as a logical result of the findings from the field work carried out. These recommendations are also to serve as answers to one of the research questions stated in this thesis. The following recommendations are important for the full adoption of LCA in the design of sustainable residential buildings in Pakistan:

1. Architects and other environmental designers should be encouraged to incorporate LCA in their works or projects. As a step forward, these building professionals should be able to learn and make use of LCA software for their projects.
2. At policy level, every building owner should be made to submit results of the LCA carried out on his/her proposed structure before final approval is given to their construction projects. At a higher level, strict fines and punishments should be stipulated for infractions on this policy.
3. The use of natural and organic material in construction should be encouraged because they have less carbon footprint and are therefore more environmentally sustainable. Similarly, architects should always prioritize sustainability in their designs.
4. There should be carefully designed “LCA awareness campaigns” by way of seminars, workshops etc. targeted at building professionals in the academia

and in active practice. These should raise the level of environmental concern in these core professionals and students.

5. As part of the awareness, government should adopt measures to make people aware of benefits of LCA. This would increase the chances of a buy-in on the part of the people.
6. Pakistan should fully abide by the Kyoto Protocol so as to ensure sustainable development, by reducing CO_2 emissions in all aspects of building construction.
7. All materials with high toxicity such as lead should be banned. Use of lead in paints creates environmental issues and impact negatively on human health.
8. Construction materials with high embodied energy should only be used in small quantities when constructing buildings, while materials with low embodied energy should be utilized more for construction.
9. Efforts should be geared towards developing databases that have high local input. This is to increase the accuracy of LCA findings.
10. Government should keep a check on big national construction firms and these firms should be required to hire LCA experts.
11. Lastly, a comprehensive policy guideline on the practice of LCA in Pakistan should be developed. This will serve as a framework for the performance of LCA on any project in Pakistan. The policy should also cater for green construction, inspection and hazard assessment for buildings.

Declaration of Authorship

I affirm hereby that the delivered Master's thesis on the topic "Life Cycle Analysis and Comparison of Different Construction Materials of Residential Buildings for Sustainable Construction Choice" was delivered independently without any help from third party. No sources or assistance for the research was used other than those listed. Those content that belongs to other publication has been marked as such. Neither this thesis or any part or variant has been published or been submitted to any examination authority.

Date

Signature of the Student

Appendices

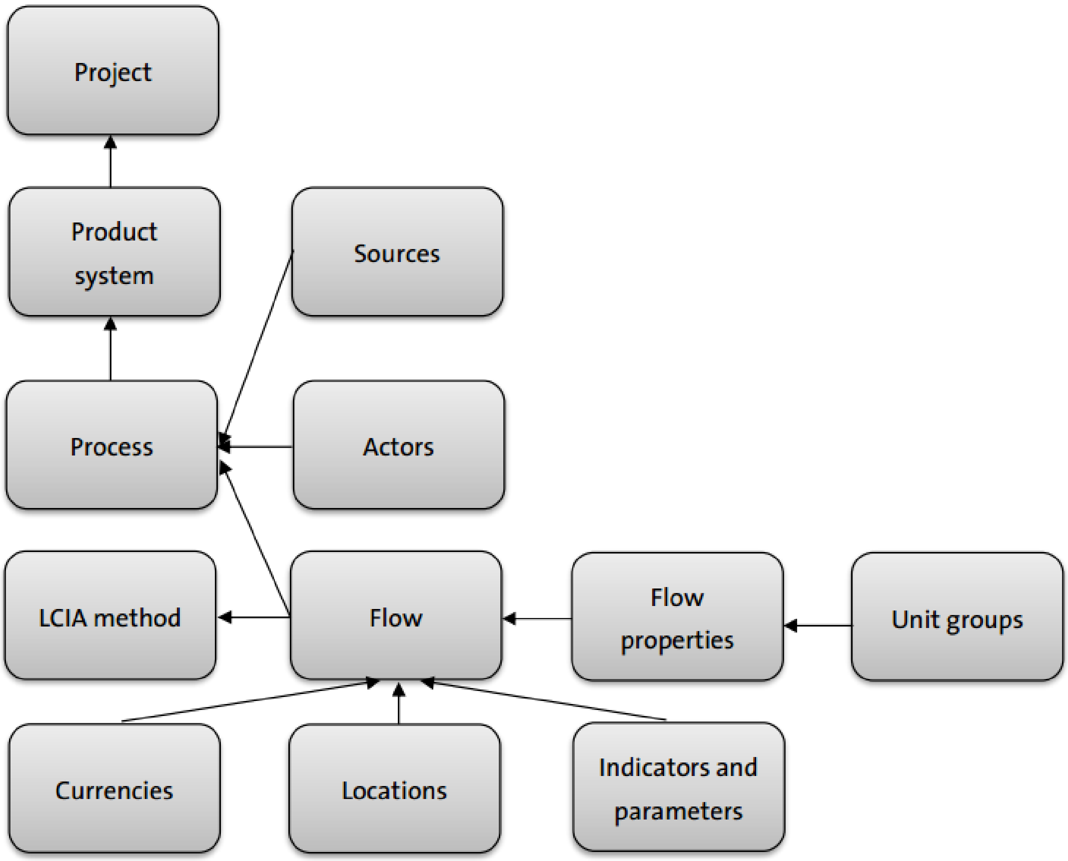
Appendix A: Material Embodied Energy Coefficients

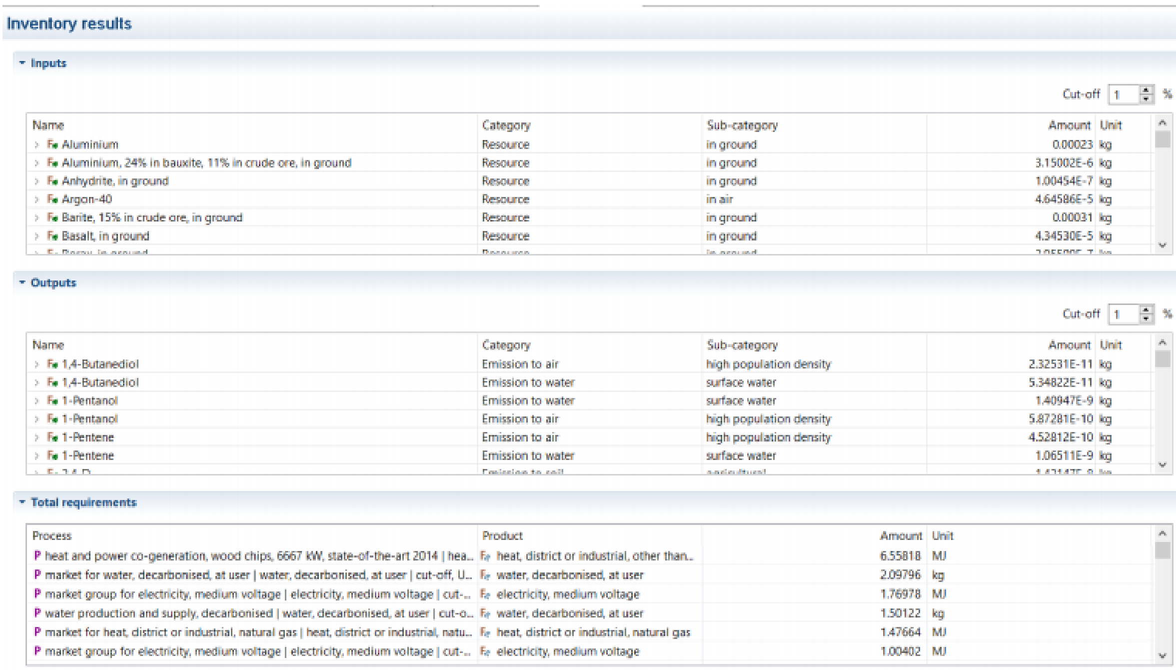
Material	Unit	Embodied energy coefficient (GJ/unit)
Aluminium		
Virgin	t	252.6
Reflective foil	m^2	0.137
Carpet	m^3	3.08
Wool	m^2	0.741
Nylon	m^2	0.683
Ceramics		
Clay brick (110mm)	m^2	0.56
Ceramic tiles	m^2	0.29
Concrete		
15 MPa	m^3	4.03
20 MPa	m^3	4.44
30 MPa	m^3	5.44
40 MPa	m^3	6.75
Cement	t	16.96
Concrete roof tiles	m^2	0.251
Glass		
Clear float (4mm)	m^2	1.73
Toughened glass (6mm)	m^2	3.66
Double glazing	m^2	3.46
Triple glazing	m^2	5.19
Insulation		
EPS R2	m^3	7.22
Fibreglass insulation R2	m^3	2
Straw	m^3	1.29
Paint		
Oil-based paint	m^2	0.101
Water-based paint	m^2	0.096
Plasterboard		
10mm	m^2	0.207
13mm	m^2	0.232
Plastics		
General (PVC)	t	156.9
Polyester	t	156.9
Polystyrene	m^3	7.04

Sand and stone		
Granite	t	0.087
Sand	m^3	0.617
Steel		
Stainless steel	t	445.2
Steel	t	85.46
Timber		
Hardwood	m^3	21.33
Softwood	m^3	10.93

Source: Schmidt, 2018

Appendix B: openLCA Database Elements Flow chart





Inventory results

Inputs

Cut-off 1 %

Name	Category	Sub-category	Amount	Unit
Aluminium	Resource	in ground	0.00023	kg
Aluminium, 24% in bauxite, 11% in crude ore, in ground	Resource	in ground	3.15002E-6	kg
Anhydrite, in ground	Resource	in ground	1.00454E-7	kg
Argon-40	Resource	in air	4.64586E-5	kg
Barite, 15% in crude ore, in ground	Resource	in ground	0.00031	kg
Basalt, in ground	Resource	in ground	4.34530E-5	kg

Outputs

Cut-off 1 %

Name	Category	Sub-category	Amount	Unit
1,4-Butanediol	Emission to air	high population density	2.32531E-11	kg
1,4-Butanediol	Emission to water	surface water	5.34822E-11	kg
1-Pentanol	Emission to water	surface water	1.40947E-9	kg
1-Pentanol	Emission to air	high population density	5.87281E-10	kg
1-Pentene	Emission to air	high population density	4.52812E-10	kg
1-Pentene	Emission to water	surface water	1.06511E-9	kg

Total requirements

Process	Product	Amount	Unit
heat and power co-generation, wood chips, 6667 kW, state-of-the-art 2014 | hea...	heat, district or industrial, other than...	6.55818	MJ
market for water, decarbonised, at user | water, decarbonised, at user | cut-off, U...	water, decarbonised, at user	2.09796	kg
market group for electricity, medium voltage | electricity, medium voltage | cut-...	electricity, medium voltage	1.76978	MJ
water production and supply, decarbonised | water, decarbonised, at user | cut-o...	water, decarbonised, at user	1.50122	kg
market for heat, district or industrial, natural gas | heat, district or industrial, natu...	heat, district or industrial, natural gas	1.47664	MJ
market group for electricity, medium voltage | electricity, medium voltage | cut-...	electricity, medium voltage	1.00402	MJ

Source: Field Work

Appendix C: Questionnaire

DEPARTMENT OF CONSTRUCTION AND REAL ESTATE MANAGEMENT IN A JOINT STUDY PROGRAMME OF METROPOLIA UAS AND HTW BERLIN

LIFE CYCLE ANALYSIS AND COMPARISON OF DIFFERENT CONSTRUCTION MATERIALS OF RESIDENTIAL BUILDINGS FOR SUSTAINABLE CONSTRUCTION CHOICE

Practitioner Questionnaire

To be filled in by LCA relevant Respondent in Pakistan

Dear Respondent,

In line with the requirements to complete my degree of Master of Science in Construction and Real Estate Management in a Joint Study Programme of Metropolia UAS and HTW Berlin, I am undertaking a research work on the above named topic. The information you provide in this questionnaire will be treated in confidence and will be used for academic purposes only. Thank you.

Please tick as appropriate to the following questions

A. SOCIO-DEMOGRAPHIC DATA

1. What is your gender?
   ☐Male ☐Female☐Other

2. What is your age range?
   ☐18-27 ☐28-37 ☐ 38-47 ☐ 48-57 ☐ Above 57

3. Where is your location of operation in Pakistan?
   ☐ Lahore ☐ Islamabad ☐ Karachi ☐Peshawar ☐ other …………….

4. What is your professional position?
   ☐ LCA Practitioner ☐Civil Engineer ☐Architect ☐Environmental Engineer
   ☐Sustainability Specialist ☐Other………

B. LCA-BASED DATA

5. Which LCA software(s) do you use in your firm?
   ☐ Gabi ☐OpenLCA ☐OneClickLca ☐SimaPro ☐ Traci ☐ Other
   ☐None……………

6. Have you personally performed LCA?
☐Yes I have participated in LCA ☐Yes I have personally led an LCA process ☐No I have not done LCA

7. Based on your experience with LCA, which of the life cycle stages of buildings consumes the most energy?
☐Pre-construction Stage ☐Building Construction Stage ☐Use Stage☐ End-of-life Stage

8. How is LCA helpful in achieving sustainable construction?

S/N	Parameters	Very Helpful	Helpful	Not Helpful	Don't Know
1.	Reducing overall environmental impacts				
2.	Choosing between alternative building designs				
3.	Choosing between alternative construction choices				
4.	Reducing energy consumption in residential buildings				
5.	Encouraging environmental friendly lifestyle of residents				

9. What are the significant factors leading to greenhouse gases emission in residential buildings in Pakistan?
☐Region of building ☐Number of residents ☐ Size of the building
☐Others
(specify)…...…………………………………………………………………………………….

C BARRIORS TO LCA IN PAKISTAN

10. Is LCA completely strange for people in Pakistan and is the cause of limiting LCA implementation in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

11. Is absence of Skilled LCA Practitioners is limiting application of LCA in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

12. Is lack of awareness about the benefits of LCA restricting LCA implementation?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

13. Is LCA software's affordability, Poor quality of Database and Inaccuracy of results adding barriers to LCA implementation in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

14. Is LCA Considered a time consuming process that is why in Pakistan it is least considered?

☐ Strongly agree ☐Agree ☐partially agree ☐Disagree ☐Strongly disagree

15. Is unwillingness of investors and Stakeholders to pay for LCA is leading to LCA barriers in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

16. Are engineers architect and LCA experts not well paid for LCA calculations?

☐Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

17. Are there lack of regulations and Policies for enforcing sustainable development and sustainable environment in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

18. Is LCA considered complicated process in Pakistan?

☐ Strongly agree ☐Agree ☐Partially agree ☐Disagree ☐Strongly disagree

19. Is there lack of inspiration and influence for those who have already performed LCA to reconsider it for future?

☐ Strongly agree ☐Agree ☐partially agree ☐Disagree ☐Strongly disagree

D POLICY REQUIRED

20.……………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………………………

Questionnaire for Barriers to LCA Implementation in Pakistan

What are the possible reasons and factors that hinder the LCA application in Pakistan?

1 (Strongly Disagree) 2(Disagree) 3(Neutral) 4 (Agree) 5 (Strongly Agree)

S.No	Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1.	Position					
2.	Is LCA completely strange for people in Pakistan?	1	2	3	4	5
3.	Is absence of Skilled LCA Practitioners limiting LCA implementation in Pakistan?	1	2	3	4	5
4.	Is lack of awareness regarding the benefits of LCA restricting LCA implementation in Pakistan?	1	2	3	4	5
5.	LCA software's affordability, Poor quality of Database and Inaccuracy of results adding barriers to LCA implementation in Pakistan?	1	2	3	4	5
6.	Is LCA considered a time consuming process that is why in Pakistan it is least considered?	1	2	3	4	5
7.	Is unwillingness of investors and stakeholders to pay for LCA is leading to LCA barriers in Pakistan?	1	2	3	4	5
8	Are Engineers Architect and LCA experts not well paid for LCA calculations?	1	2	3	4	5
9	Is there lack of regulations and Policies for enforcing sustainable development and sustainable environment in Pakistan?	1	2	3	4	5
10	Is LCA considered a complicated process in Pakistan?	1	2	3	4	5
11	Is there lack of inspiration and influence for those who have already performed LCA?	1	2	3	4	5

Frequency Tables

Is LCA completely strange for people in Pakistan and is the cause of limiting LCA implementation in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Disagree	8	12.1	12.1	15.2
	Partial	16	24.2	24.2	39.4
	Agree	26	39.4	39.4	78.8
	Strongly Agree	14	21.2	21.2	100.0
	Total	66	100.0	100.0	

Is absence of Skilled LCA Practitioners limiting implementation of LCA in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Disagree	12	18.2	18.2	21.2
	Partial	12	18.2	18.2	39.4
	Agree	15	22.7	22.7	62.1
	Strongly Agree	27	37.9	37.9	100.0
	Total	66	100.0	100.0	

Is lack of awareness restricting LCA implementation in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Agree	23	34.8	34.8	37.9
	Strongly Agree	41	62.1	62.1	100.0
	Total	66	100.0	100.0	

LCA software's affordability, poor quality of Database and Inaccuracy of results adding barriers to LCA implementation in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Disagree	4	6.1	6.1	9.1
	Partial	29	43.9	43.9	53.0
	Agree	23	34.8	34.8	87.9
	Strongly Agree	8	12.1	12.1	100.0
	Total	66	100.0	100.0	

Is LCA considered a complicated process in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	1	1.5	1.5	1.5
	Disagree	23	34.8	34.8	36.4
	Agree	24	36.4	36.4	72.7
	Strongly Agree	18	27.3	27.3	100.0
	Total	66	100.0	100.0	

Is LCA considered a time consuming process that is why in Pakistan it is least considered?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Disagree	2	3.0	3.0	6.1
	Partial	30	45.5	45.5	51.5
	Agree	32	48.5	48.5	100.0
	Total	66	100.0	100.0	

Is unwillingness of Investors, Stakeholders to pay for LCA is leading to LCA barriers in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	1	1.5	1.5	1.5
	Partial	11	16.7	16.7	18.2
	Agree	26	39.4	39.4	57.6
	Strongly Agree	28	42.4	42.4	100.0
	Total	66	100.0	100.0	

Are engineers or architect or LCA experts not well paid for LCA calculations?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	1	1.5	1.5	1.5
	Disagree	3	4.5	4.5	6.1
	Partial	20	30.3	30.3	36.4
	Agree	24	36.4	36.4	72.7
	Strongly Agree	18	27.3	27.3	100.0
	Total	66	100.0	100.0	

Is there lack of regulations and Policies for enforcing sustainable Development and sustainable environment in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	2	3.0	3.0	3.0
	Disagree	4	6.1	6.1	9.1
	Partial	15	22.7	22.7	31.8
	Agree	15	22.7	22.7	54.5
	Strongly Agree	30	45.5	45.5	100.0
	Total	66	100.0	100.0	

Is LCA considered a complicated process in Pakistan?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	1	1.5	1.5	1.5
	Disagree	23	34.8	34.8	36.4
	Agree	24	36.4	36.4	72.7
	Strongly Agree	18	27.3	27.3	100.0
	Total	66	100.0	100.0	

Is there lack of inspiration and influence for those who have already performed LCA to reconsider it for future?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Strongly Disagree	1	1.5	1.5	1.5
	Disagree	3	4.5	4.5	6.1
	Partial	16	24.2	24.2	30.3
	Agree	29	43.9	43.9	74.2
	Strongly Agree	17	25.8	25.8	100.0
	Total	66	100.0	100.0	

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