LIFE CYCLE ASSESSMENT OF CLAY BRICK WALLING IN SOUTH AFRICA

THE CLAY BRICK ASSOCIATION OF SOUTH AFRICA: TECHNICAL REPORT 7A

VOLUME 1

Prepared by the Department of Architecture, University of Pretoria

for the Clay Brick Association of South Africa

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Disclaimer

The authors and any participant in this study cannot be held liable for any claim of damages of any nature whatsoever, to any person or entity, arising from this study. The data used herein to develop the Life Cycle Assessment model are based on information that was received from the participants in this study.

Data provided by the respondents in the questionnaire survey were used to identify and quantify the environmental impacts associated with the different clay brick firing technologies employed in South Africa. The data used in this study have not been reviewed or audited by a third party. Where data were uncertain, the participant was contacted by the authors in order to verify such data.

Where the authors were restricted from accessing a particular clay brick manufacturer's factory, the data from these sites were used as received from the nominated representative of that factory.

This Life Cycle Assessment is intended to assess the environmental impacts resulting from the manufacturing, use, demolition, waste and recycling of clay bricks and does not purport to compare the assessment results with any other wall construction method employed in South Africa. The associated report titled *A Thermal Performance comparison between six wall construction methods frequently used in South Africa: CBA Technical Report 7B* should be used in any comparative study of alternative wall construction methods in South Africa.

Acknowledgements

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Abstract

Quantified environmental impacts associated with clay brick production are not very well known within the South African context. This report is based on research undertaken for the Clay Brick Association of South Africa, where clay bricks are still the predominant wall construction material. It identified, amongst other, processes within the various firing techniques of clay bricks where environmental impacts are the most severe, with the intention to make producers aware of where they may improve production processes and reduce adverse environmental impacts. The report investigated the cradle to gate, gate to end of operational life and demolition, waste and recycle phases of the life cycle of clay bricks.

Environmental impacts that were assessed in this Life Cycle Assessment (LCA) include climate change, terrestrial acidification, freshwater eutrophication, particulate matter formation (affecting air quality), natural land transformation, water depletion, mineral resource depletion and fossil fuel depletion.

For the cradle to gate phase of the LCA data collection was done by means of a full population survey, with acceptable data being recorded for 85% of the population, which represents 95% of the clay brick manufacturers in South Africa. By applying the *SimaPro* software and additional data from the *EcoInvent* database, survey data were used to identify and model the environmental impacts associated with the various clay firing techniques employed in South Africa. These techniques are employed in the clamp kiln, tunnel kiln, transverse arch kiln, Hoffman kiln, vertical shaft brick kiln and the zigzag kiln. The research also covered the manufacturing processes of clay bricks, i.e. clay mining, clay preparation, brick extrusion, drying and firing.

The findings for this phase suggest that when the different firing technologies are compared to each other, the Hoffman kilns perform the worst on average across all the environmental impact categories, as opposed to the tunnel kilns which have the lowest average impact across all the environmental categories. In terms of functional aspects, kilns which utilise a continuous firing process generally have lower environmental impacts.

When the environmental impacts of the different firing technologies are compared, bearing in mind their contribution to the total clay brick production in South Africa, the clamp kilns are the biggest contributor to adverse environmental impacts on average across all the categories. Overall, the findings suggest that there is great potential to improve the clay brick manufacturing industry in terms of reducing their environmental impacts.

For the gate to end of operational life phase of the LCA, the environmental impacts associated with the transport of bricks to the building site, the building in of the bricks, the maintenance of the wall over its expected life span as well as the energy required to keep the structure within a specified thermal comfort range were investigated. For the South African climatic zones 1, 2, 3, 4, and 6 (as specified in SANS 10400) the wall type with the lowest environmental impact overall is the 280mm insulated cavity wall. For climatic zone 5 the wall type with the lowest environmental impact overall is the 220mm double brick wall.

For the demolition, waste and recycle and re-use phase of the life cycle of clay bricks data were collected by means of a desk-top study of available literature on the extent of generated and recycled or re-used construction and demolition waste in South Africa. Since the recycling and re-use of construction demolition waste is not a formalised or regulated industry in this country, it proved difficult to obtain accurate data and the findings from this study are therefore primarily based on estimates and extrapolated data. They nonetheless suggest that significant amounts of construction and demolition waste, of which clay bricks make up a large proportion, are recycled (mainly crushed and used as aggregate fill) or re-used by the informal building sector.

Ekserp

Lewensiklusassessering van kleibaksteenmure in Suid Afrika

Gekwantifiseerde omgewingsimpakte wat met kleibaksteenproduksie verband hou is nie alombekend in die Suid-Afrikaanse konteks nie. Hierdie verslag is gebaseer op navorsing wat onderneem is vir die Kleibaksteenvereniging van Suid-Afrika, waar kleibakstene steeds die mees algemeen gebruikte muurkonstruksiemateriaal is. Die verslag het, onder andere, prosesse binne die verskeie baktegnieke vir kleibakstene identifiseer waar omgewingsimpakte die ernstigste is, met die doel om baksteenvervaardigers bewus te maak van waar hulle vervaardigingsprosesse verbeter kan word en om nadelige omgewingsimpakte te verminder. Die verslag behels ‘n ondersoek wat strek van die wieg- tot fabriekshekfase, hek- tot einde van bedryfsleeftydfase, asook die sloping, storting en herwinningsfases van die lewensiklus van kleibakstene.

Omgewingsimpakte wat in hierdie lewensiklusassessering (LSA) evalueer is sluit klimaatsverandering, aardsversuring, varswatereutrofikasie, deeltjievorming (wat lugkwaliteit beïnvloed), natuurlike gebiedsomvorming, wateruitputting, minerale hulpbronuitputting asook fossielbrandstofuitputting in.

Vir die wieg- tot fabriekshekfase van die LSA is data deur middel van ‘n opname by alle kleibaksteenvervaardigers wat by die Kleibaksteenvereniging van Suid-Afrika geregistreer is en wat 95% van kleibaksteenvervaardigers in Suid-Afrika verteenwoordig, ingesamel. Aanvaarbare data is vir 85% van die populasie aangeteken. *SimaPro* programmatuur, bykomende data vanaf die *EcoInvent* databasis, asook die aangetekende data is gebruik om omgewingsimpakte wat verband hou met die verskillende baktegnieke wat in Suid-Afrika gebruik word, te identifiseer en te modelleer. Hierdie baktegnieke sluit die veldoond, tonneloond, dwarsoond, die Hoffmanoond, vertikale skagoond, en die meervoudige kamerbaksteenoond in. Die navorsing het ook die vervaardigingsprosesse van kleibakstene, tewete kleiontginning, kleivoorbereiding, steenekstrusie, droging en bak van die stene aangespreek.

Die bevindings van hierdie fase van die LSA dui daarop dat wanneer die verskillende baktegnieke as sulks met mekaar vergelyk word, die Hoffman-oonde die swakste presteer, gemiddeld gemeet oor al die impakkategorieë. Daarteenoor het die tonneloonde die laagste gemiddelde impak gemeet oor al die omgewingsimpakkategorieë. In terme van funksionele aspekte het oonde wat ‘n ononderbroke bakproses gebruik, algemeen gesproke laer omgewingsimpakte.

Vir die fabriekshek- tot einde van bedryfsleeftydfase van die LSA is die omgewingsimpakte ondersoek wat verband hou met die vervoer van bakstene na die bouterrein, die inbou van die stene, die onderhoud van die muur oor die verwagte leeftyd asook die energie wat benodig word om die gebou binne ’n gespesifiseerde termiese gemaksreeks te hou. Vir Suid-Afrikaanse klimaatsones 1, 2, 3, 4 en 6 (soos in SANS 10400 beskryf) het die 280mm isoleerde spoumuur algeheel die laagste omgewingsimpak. In klimaatsone 5 het die 220mm dubbelbaksteenmuur algeheel die laagste omgewingsimpak.

Vir die sloping-, storting- en herwinningsfases van die LSA van kleibakstene is data deur middel van ‘n lessenaar-studie van beskikbare literatuur oor die omvang van gegenereerde en herwinde of hergebruikte bou- en slopingsrommel in Suid-Afrika versamel. Aangesien die herwinning en hergebruik van sodanige rommel nie ‘n geformaliseerde of gereguleerde bedryf in Suid-Afrika is nie, is min data hieroor beskikbaar. Om hierdie rede word die bevindings van hierdie studie hoofsaaklik op beramings en afgeleide data gebaseer. Die bevindings dui nietemin daarop dat beduidende hoeveelhede bou- en slopingsrommel, waarvan kleibakstene ‘n groot gedeelte uitmaak, enersyds herwin word (hoofsaaklik as vergruisde material wat as aggregaatvulling gebruik word) of andersyds hergebruik word deur die informele bousektor.

Critical Review: Final Statement

"... This final version of the report is compliant with the ISO 14’044ff. standard for Life Cycle Assessment. The Report is extensively documented which allows the detailed analysis of the results. Part of the documentation is in confidential annexes, which have been disclosed to the reviewer in accordance to the ISO-standard.

Overall, I found no critical issues in this report. It is an impressive piece of LCA work and it represents the standard for measuring environmental impacts of clay brick production in South Africa. I can state that it fulfils the ISO 14’044ff standard..."

- Quantis International

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PLEASE NOTE THAT THE APPENDICES REFERRED TO IN THIS REPORT (VOLUME 1) CAN BE FOUND IN THE ACCOMPANYING VOLUME 2

Definition of terms and abbreviations

Cradle to gate phase	Refers to the manufacturing process of clay bricks from clay extraction and the sourcing of other ingredients, through the forming and firing stages and ends with the clay bricks ready to leave the manufacturing plant.
Gate to end of operational life phase	Refers to the stages where the bricks leave the manufacturing plant, are transported to a building site, are built into a building and where the brick walls are maintained during the building's lifespan.
Demolition, waste and recycle phase	Refers to the stages where the building is demolished and the demolition waste is either landfilled or recycled or reused.
LCA	Life Cycle Assessment.
LCI	Life Cycle Inventory.
LCIA	Life Cycle Impact Assessment.
SBE	Standard brick equivalent. For the purposes of this project, a standard brick equivalent is considered as 2.75kg of fired clay.
DEA	The National Department of Environmental Affairs (Previously the Department of Environmental Affairs and Tourism (DEAT)

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1. CHAPTER 1 - INTRODUCTION

1.1 BACKGROUND

The issue of sustainability has become increasingly critical in the current climatic and economic environment. In the 1987 Bruntland Report, the UN's World Commission on Environment and Development defined sustainability as:

> *…meeting the needs of the present generation without compromising the ability of future generations to meet their needs.* (Morris 2004:1)

Kulman and Farrington (2010:3436) define sustainability as the balance needed between the gratification of present needs and the concern for the well-being of future generations. They also allude to the fact that although we deplete natural resources at the expense of future generations, we also generate capital and knowledge which raise the well-being of future generations.

The greatest modification to achieve sustainability is to reduce the global environmental changes earth is experiencing due to anthropogenic climate change. Man has evolved in such a way that little consideration is placed on earth's finite resources and the impacts development has had on the environment.

Building is a major source of global greenhouse gas emissions, both during the manufacturing stages of materials such brick, cement, glass, steel, and in the operational phase of the building (Zipplies 2008:192). The building sector consumes between 30% and 45% of global energy production, with about 20% of that on the construction of the building and 80% during the operational phase of the building (UNEP 2007).

One of the most important considerations in achieving sustainable development in the construction sector is to understand the roles that building materials play, including the manufacturing, building in, use up to the end of life and then the wasting and or recycling or reuse phases.

South Africa produced 450 million tonnes of CO_2 in 2009, placing it as the 12th largest CO_2 emitter globally (McCormick & Scruton 2010). Figure 1.1 is an extract from their 2009 emissions study and shows a perspective on African countries' emissions in terms of global CO_2 emissions of that year.

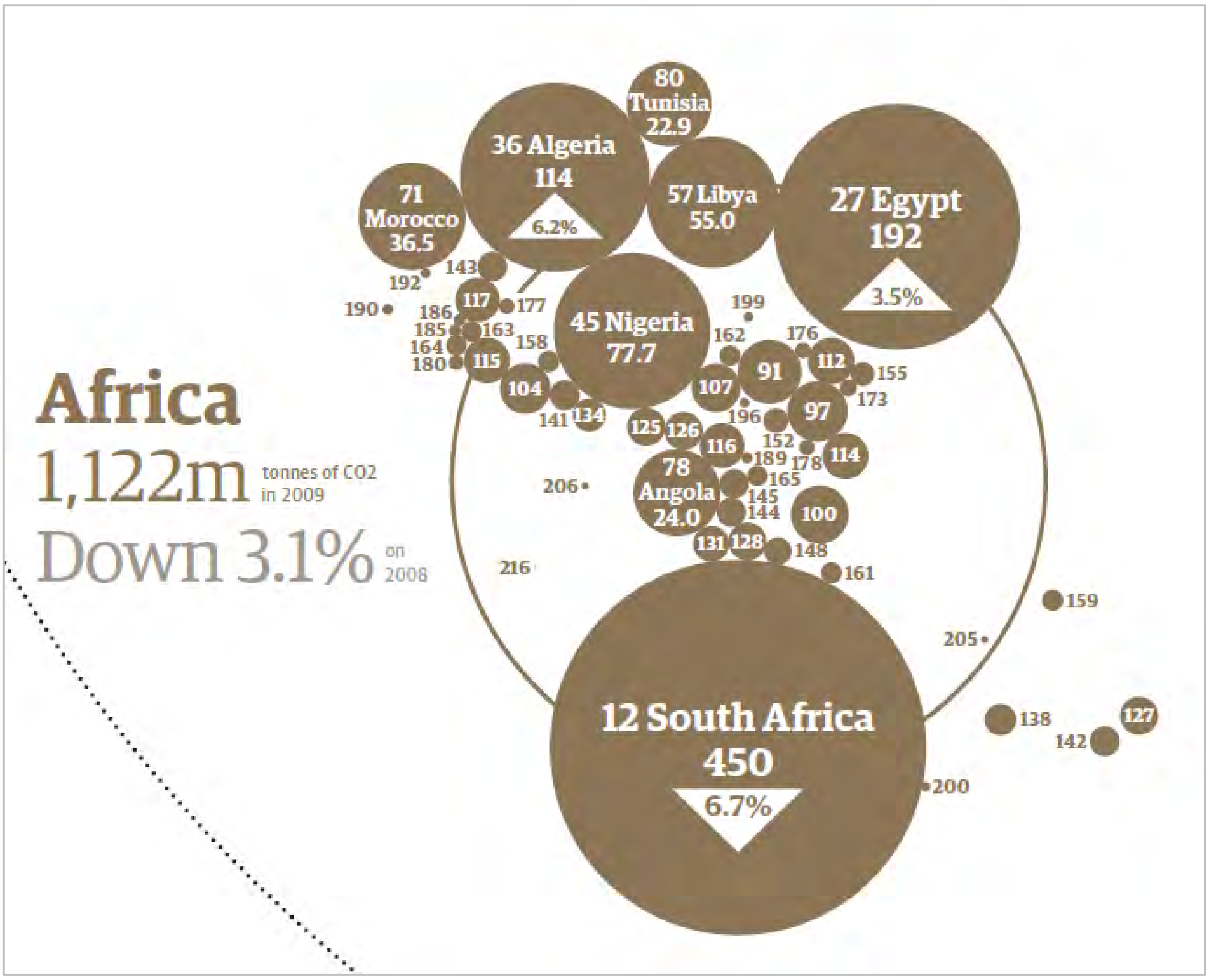

Figure 1.1: African CO_2 Emissions (McCormick & Scruton 2010)

As Africa's greatest emitter of CO_2 it is a matter of urgency to investigate and provide scientific data to reduce the harmful emissions South Africa is producing. South Africa's CO_2 emission breakdown is dominated by transport at 16% and manufacturing at 40% (Milford 2007). Manufacturing includes the production of building materials, which contributes 18 mt CO_2 p.a. to South Africa's total emissions.

Table 1.1 shows the breakdown according to major building materials.

Table 1.1: CO_2 emissions for major building materials in South Africa (Milford 2007)

CO_2 Emissions for Major Building Products ($mtCO_2$ p.a.)					
	Volume: Building and Civil Engineering	Volume: Building	Unit	Emission Factor tCO_2/t [1]	$mtCO_2$
Cement	14 193 911	9 226 525	Tonnes	1.1	10.1
Reinforcing Steel and Sections	700 000	70 000	Tonnes	1.2	0.1
Roofing and Vertical Cladding					
Roofing	57 451	54 579	m^2*1000	1.2	0.1
Vertical Cladding	32 005	30 405	m^2*1000	1.2	0.0
Walling					
Facebricks	1 157 193	1 099 333	BE*1000	0.9	1.0
Faceblocks	202 073	191 969	BE*1000	0.9	0.2
Stockbricks	2 464 479	2 341 255	BE*1000	0.9	2.1
Stockblocks	4 589 969	4 360 471	BE*1000	0.9	3.9
Total (major building products)					18

It can be determined from Table 1.1 that the production of face bricks and stock bricks, together contribute significantly to the annual CO_2 emissions. Therefore, the first phase of this study will assess the environmental impacts associated with the production and manufacture of clay bricks in South Africa through the implementation of a Life Cycle Assessment (LCA).

When focussing on clay bricks as a construction material in South Africa, a first step in providing scientific data on the effects and impacts of buildings on the environment would be an assessment of the various manufacturing techniques of clay bricks.

As a second step the construction of clay brick masonry buildings and their maintenance up to the end of their "first" or operational life are assessed.

As the third and final step an investigation is made into the demolition, waste and recycling or re-use potential of clay bricks in South Africa.

1.2 SCOPE OF THE STUDY

The study has been divided into 3 components, this due to different stakeholder interest in the 3 life cycle stages, these stages follow:

1.2.1 Cradle to gate phase

Now that the background to the study has been established, the scope needs to be identified. The South African construction industry is dominated by two construction typologies, i.e. concrete frame and brick infill construction and secondly load-bearing brick construction; whether clay bricks or concrete bricks and blocks. Other technologies such as cladded light steel frame construction, cladded timber frame construction and combinations hereof are less used, but do still form part of the construction industry in South Africa.

1.2.2 Gate to end of life phase

The second phase of this research project is to assess the environmental impacts associated with the gate to end of operational life phase of clay brick walling in South Africa. This phase encompasses the transport to site of bricks, the construction of clay brick walls and the operational stage of a clay brick structure in South Africa.

1.2.3 Demolition, waste and recycle phase

The final phase of this research project is to assess the environmental impacts associated with the demolition of clay brick structures, waste generation and recycling or re-use of clay bricks.

1.3 PROBLEM STATEMENT

The following problematic issues have been identified and are addressed in this study:

1.3.1 Brick production phase

The environmental impacts associated with the production of clay bricks (face and stock bricks) for the South African construction industry are not known; there is currently no published comprehensive research on the clay brick manufacturing sector which assesses the following environmental impacts associated with the production of clay bricks:

- The release of carcinogenic substances
- The release of non-carcinogenic substances
- The release of respiratory inorganics
- The release of substances causing ionizing radiation
- The release of substances contributing to ozone layer depletion
- The release of substances that increase aquatic eco-toxicity
- The release of substances that increase terrestrial eco-toxicity
- The release of substances that increase terrestrial acidification
- The use of land for the production of clay bricks.
- Emissions that contribute to global warming
- The consumption of non-renewable energy, and
- Energy consumed during mineral extraction.

From an industry perspective, the desire to understand the energy and emissions associated with the manufacture of clay bricks is evident. The study will reveal pertinent information that may be referenced for the anticipated Carbon Tax, due to become active in South Africa in the near future.

1.3.2 The building-in, use and maintenance phases of clay bricks

The building-in, use and maintenance phases of clay bricks in South Africa also have environmental impacts, and as with the brick production phase referred to above, little research on this phase has been done for South African conditions.

1.3.3 The demolition, waste and recycle phases of clay bricks

The reuse and recycling of clay bricks in South Africa is not a formalised industry and as such very little information on the extent of these activities is available. From casual observation the reuse and recycling of clay bricks do however take place, but the extent thereof needs to be investigated as part of a life cycle assessment.

1.4 GOAL AND OBJECTIVES

The goal of the report is to present the research which has been conducted in accordance with the applicable ISO standards 14040 and 14044.

The objectives of the LCA study are stated per life cycle phase and for the overall life cycle, i.e.:

1.4.1 Cradle to gate phase

- To gain an understanding of different manufacturing techniques for clay bricks in South Africa.
- To determine the aspects within the manufacturing process of clay bricks that contribute to adverse environmental impacts.
- To use generally accepted and recommended assessment techniques to determine the extent of environmental impacts associated with clay brick manufacturing in South Africa.
- To understand the differences in environmental impacts between different kiln types.

1.4.2 Gate to end of operational life phase

- To gain an understanding of the required materials and quantities thereof to construct $1m^2$ of 3 different clay brick wall types in South Africa.
- To determine the environmental impacts associated with the construction of $1m^2$ of 3 different clay brick wall types in South Africa.
- To develop an understanding of the environmental impacts associated with the operation and maintenance of $1m^2$ of 3 different clay brick wall types over its expected lifespan.

1.4.3 Demolition, waste and recycle phase

- To determine the extent to which clay bricks are wasted, recycled or re-used after the brick structure has been demolished in South Africa and other similar countries.
- To develop a model, based on practices in other countries, which can be applied to the South African context to determine estimates of the demolition, waste and recycle potential of clay brick in South Africa.
- To identify opportunities and present recommendations for the reuse and recycling of construction and demolition waste in South Africa.
- To understand the extent of which the end of life contributes to the overall life cycle impacts.

1.5 RESEARCH METHODOLOGY

The research methodologies that were considered and employed for the various phases of this study are:

1.5.1 Cradle to gate phase

1.5.1.1 RESEARCH DESIGN

The study took on the form of non-experimental research. Welman, Kruger & Mitchell (2005:92) suggest that if there is a great degree of regularity and orderliness in the phenomenon being studied, satisfactory results may be obtained by means of non-experimental research. The four basic types of research design are:

- Laboratory experiments
- Field experiments
- Laboratory surveys
- Field surveys.

A field survey based on a questionnaire was used in the first part of this phase of the study. The second part of this phase modelled the survey data in the *SimaPro* life cycle assessment software.

1.5.1.2 WHAT IS A SURVEY QUESTIONNAIRE?

Survey questionnaires are lists of questions used to collect data for further research into a topic (Barrett 2000). Survey questionnaires have the ability to be completed away from the researcher in the form of a self-administered or postal questionnaire. Another method of collecting data through the use of a survey questionnaire is to visit the research respondent and have a face-to-face question and answer session in order for the researcher or respondent to complete the questions. Welman *et al.* (2005:153) suggest that when a researcher develops a survey questionnaire, conceptualisation and operationalization variables are set into questions.

1.5.1.3 ADVANTAGES OF SURVEY QUESTIONNAIRES

The University of Surrey (2013) finds that:

- Survey questionnaires are a practical way of obtaining quantitative data in this case.
- Relatively large amounts of information can be collected from a large population of respondents in a short period of time.
- The survey can be carried out by the researcher or by a number of parties, this has no limitation on the validity and reliability of the data so collected.
- The results of questionnaires can be easily and objectively quantified through statistical coding and analysis.

1.5.1.4 DISADVANTAGES OF SURVEY QUESTIONNAIRES

The University of Surrey (2013) suggests that:

- Survey questionnaires may sometimes be perceived to collect information under the subjectivity of emotions, behaviour and social norms.

- A phenomenologist considers quantitative survey questionnaires to be an artificial creation by the researcher who asks for a limited amount of information with little explanations.
- There is no way to tell how truthful the respondent has been whilst completing the questionnaire.
- The respondent may be forgetful or simply not interested in the value of research, so data may be unreliable.

1.5.1.5 DESIGNING A QUESTIONNAIRE

The following items should be kept in mind when designing a questionnaire:

- Length of the questionnaire: Even though it may be advantageous for a researcher to have long questionnaires, it affects the reliability of the answers as respondents may find it tedious and exhausting filling in answers. Welman *et al.* (2005:177) find that the longer a question or questionnaire, the longer it will take to read, and therefore may lead to the possibility of resistance in respondents. The recommended limit of a questionnaire is 15 pages (*ibid.*). The questionnaire used for this research study is 13 pages long and is attached as Appendix 2 in Volume 2.
- Question sequence: The order of questions in a questionnaire should relate to the context within which the questionnaire is being answered. Grouping of associated questions is advisable (*ibid.* 2005:179).
- Response rate: Although the response rate to a questionnaire can rarely be comprehensive, to ensure a good response is to target the full population if possible. Another consideration would be to build a rapport with the respondents prior to collecting the data (*ibid.*). Sensitive issues such as biographical and trade information should be kept anonymous after data collection has been completed; respondents should have trust in the researcher to keep to this agreement prior to providing the data.
- Open ended or closed questions: Open ended questions do not provide options as expected answers, while closed questions offer a range of options to choose from (*ibid.* 2005:174). Closed questions may limit the respondent in answering the questions (*ibid.* 2005:175) however if enough planning and prior knowledge of the respondents and the research scenario are in place, this can be avoided.
- Design method: Obtaining useful outcomes from a questionnaire is important, and should be explained as such to respondents prior to collecting data. If respondents know the value of the research they will find it difficult to turn down the opportunity to contribute.

1.5.1.6 PRE-TESTING THE QUESTIONNAIRE

In this research, the authors pre-tested the questionnaire on three unrelated respondents who are part of the population to be surveyed. This pre-testing resulted in numerous changes to the questionnaire with regard to the question and answer layout, expected answers and industry terminology used.

1.5.1.7 SELECTING A TARGET POPULATION

Welman *et al.* (2005:125) suggest that if a total population is inaccessible due to location, size or other factors, a representative sample population may be used. The sample should consist of at least 25 units but not exceed 500. The degree of population validity achieved is dependent on the population under research; where the full population is less than the recommended sample (25) then the validity of results may be unrepresentative unless the full population is targeted. The complete population of clay brick manufacturers who are members of the Clay Brick Association of South Africa was accessible and was used as the target population for this study.

1.5.1.8 SUMMARY OF THE RESEARCH DESIGN

The research design for the cradle to gate phase may be summarised as follows:

- Literature reviews in order to identify pertinent issues in the clay brick production methodologies and similar studies.
- The research design was adapted and added to in order to obtain the recommended layout for the first part of LCA – goal and scope definition.
- The data collection phase was done through compilation, pre-testing and a final survey questionnaire targeting the full population of clay brick manufacturers in South Africa. All accessible production plants were visited while inaccessible plants were surveyed by using electronic media.
- The development of a flow chart which identifies sections within the manufacturing process to allocate the collected data to each specific process and firing technique.
- Data capturing and statistical analysis were undertaken by the University of Pretoria's Statistics Department.
- Undeterminable data from the population were collected from literature sources and the *EcoInvent* database v2.0.
- Data calculations and functions were developed by the authors to configure the collected data into the necessary format for input into the *SimaPro* modelling software.
- A LCA model was developed based on *SimaPro* software into which the collected data were inserted.
- The results of the model were interpreted and conclusions drawn from the model results.

1.5.2 Gate to end of operational life phase

The research design for this phase of the project is divided into three parts. The first part relates to the transport of bricks to the construction site for which data were collected from the database developed during phase one of this project. Respondents were questioned on the "transport-to-site" data of their products. These data were used to develop unit processes within *SimaPro* to determine the environmental impacts associated with the transport to site stage of the life cycle.

The second part of this phase relates to the actual construction of the clay brick wall. The data used to develop the model in *SimaPro* were obtained through interpretation and calculations of the required materials as recommended as best practice by cement manufacturers in South Africa.

The third part of this phase relates to the operational life of the clay brick structure. The data used to determine the environmental impacts associated with this stage of the life cycle of the clay brick structure were obtained from a study by the University of Pretoria's Department of Architecture, commissioned by the Clay Brick Association of South Africa, and titled *A thermal performance comparison between six wall construction methods frequently used in South Africa* (Vosloo, Harris, Holm, van Rooyen & Rice 2016).

1.5.3 Demolition, waste and recycle phase

The research for this phase can be described as a descriptive study, in which the demolition (transport, fuels, energy), waste, reuse and recycling of clay bricks in South Africa were investigated. The specific objective was to identify the extent of reuse and recycling of clay bricks in South Africa. The study also investigated opportunities and strategies for recycling construction and demolition waste in South Africa.

Data were collected through a review of literature such as of government reports, academic reports and national construction and demolition waste reports.

1.6 DELIMITATIONS

1.6.1 Cradle to gate phase

The following delimitations apply to this phase of the study:

- The scope of this phase is delimited to the manufacturing processes from raw material extraction to the clay bricks leaving the gate of manufacturing plant.
- The target population is delimited to the South African Clay Brick Association members and non-members who produce clay bricks.
- The study does not consider manufacturers outside of the borders of South Africa.
- Infrastructure is excluded from the study, only the product under consideration is investigated in terms of environmental inputs and outputs.

1.6.2 Gate to end of operational life phase

The following delimitations apply to this phase of the study:

- Environmental impacts associated with the transport of bricks to a building site.
- The building in of bricks into a building.
- The operational (heating and cooling energy) or maintenance requirements of a clay brick structure in South Africa over its expected lifespan.

1.6.3 Demolition, waste and recycle phase

The following delimitations apply to this phase of the study:

- This study is delimited to desktop research on demolition, waste, reuse and recycling of clay bricks in South Africa and other similar countries.
- The desktop research used for the South African context will be delimited to published research/findings presented by national or other governmental organisations.

1.7 IMPORTANCE OF STUDY

For the cradle to gate phase the study researches the full population of clay brick manufacturers in South Africa. Through an analysis and modelling of the collected data, the respondents will be able to identify aspects of their manufacturing process which contribute to adverse environmental impacts and take appropriate steps to reduce such impacts.

For the gate to end of operational life phase of the study the issues involved with the transport of clay bricks to site, building in and building maintenance over its lifespan will be identified and quantified to determine their environmental impacts. This will allow designers and specifiers to make informed decisions regarding the sustainability and maintenance costs of the building over its lifetime.

For the demolition, waste and recycling phase of the study the extent of demolition and wasting, reuse and recycling of bricks in South Africa will be investigated to determine its economic viability and if this sector, currently largely informal, could be formalised.

1.8 INTENDED APPLICATION OF THE STUDY

The intended application of the study is to support responsible decision making within the construction industry. It is hoped that in the future further research will be done, using the same or a similar methodology to allow for comparison between the life cycle analyses of building materials and methods most often used in the construction industry in South Africa.

The target audience of this study comprises of, but is not limited to:

- Clay brick manufacturers: to be able to assess the advantages of the various firing technologies
- manufacturers of other building materials: to provide a data baseline on clay bricks which they can use to compare their own products against
- Built environment professionals: to enable these professionals to make informed decisions when designing and specifying walling materials such as clay bricks
- Academics: to provide substantiated information on clay bricks as a walling material
- All other parties with vested interest in the environmental impacts associated with clay bricks in South Africa.

2. CHAPTER 2 – PROJECT SCOPE

2.1 INTRODUCTION

The Department of Environmental Affairs (DEA) defines LCA as …*the calculation and evaluation of the environmentally relevant inputs and outputs and the potential environmental impacts of the life cycle of a product, material or source* (DEAT 2004). The DEA also stresses that LCA is an iterative approach to identify the potential environmental impacts a product, material, method or system may have.

Environmental inputs and outputs refer to the demand for natural resources and to emissions into the environment. The life cycle also refers to the system of processes and distances the product, material or source needs to be transported. These processes typically include the following stages: raw material extraction, production, use and after-use. The process of LCA is guided by ISO standards, e.g. ISO 14040:2006 and 14044:2006.

2.2 COMPONENTS OF A LCA

A LCA is generally divided into four steps. These are:

- Goal and scope definition.
- Inventory of applicable data, also known as the Life Cycle Inventory (LCI).
- Impact assessment of the processes involved, also known as the Life Cycle Impact Assessment (LCIA),
- Environmental performance improvement assessment.

These steps can be briefly explained as follows:

2.2.1 Goal and scope definition

The goal and scope definition part of LCA is the first step. In this part the purpose of the study is described, i.e. the intended application and target audience (DEAT 2004). The scope of the study includes a description of the limitations and delimitations, the systems and their functions, the functional unit, the system boundaries, the approach to data allocation, the data requirements, the data quality requirements, the key assumptions, the impact assessment method, the interpretation method and the type of reporting to be used in the study (*ibid.*).

2.2.1.1 PRODUCT SYSTEM DESCRIPTION

The ISO 14040 (SANS 2006a:4) standard defines a product system as the collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product. In order to further understand the product system definition, the ISO 14040 (2006a:9) adds:

> *The product system is subdivided into a set of unit processes, which are linked to each other by flows of intermediate products and/or waste for treatment, to other product system by-product flows, and to the environment by elementary flows...A unit process generates products, elementary flows or waste (outputs). Elementary flows include the use of resources and releases*

to air, water and land associated with the system (ISO 14044 in SANS 2006b:9).

The product system for the cradle to gate phase of the study starts at raw material extraction and ends at the production plant gate. Clay brick manufacturers in South Africa are directly responsible for these stages. More specifically the product system covers the following steps:

- Raw material extraction
- Raw material processing
- Clay preparation
- Extrusion and forming
- Brick drying
- Brick firing
- Off-packing.

Figure 1.2 is a diagrammatic representation of the product system.

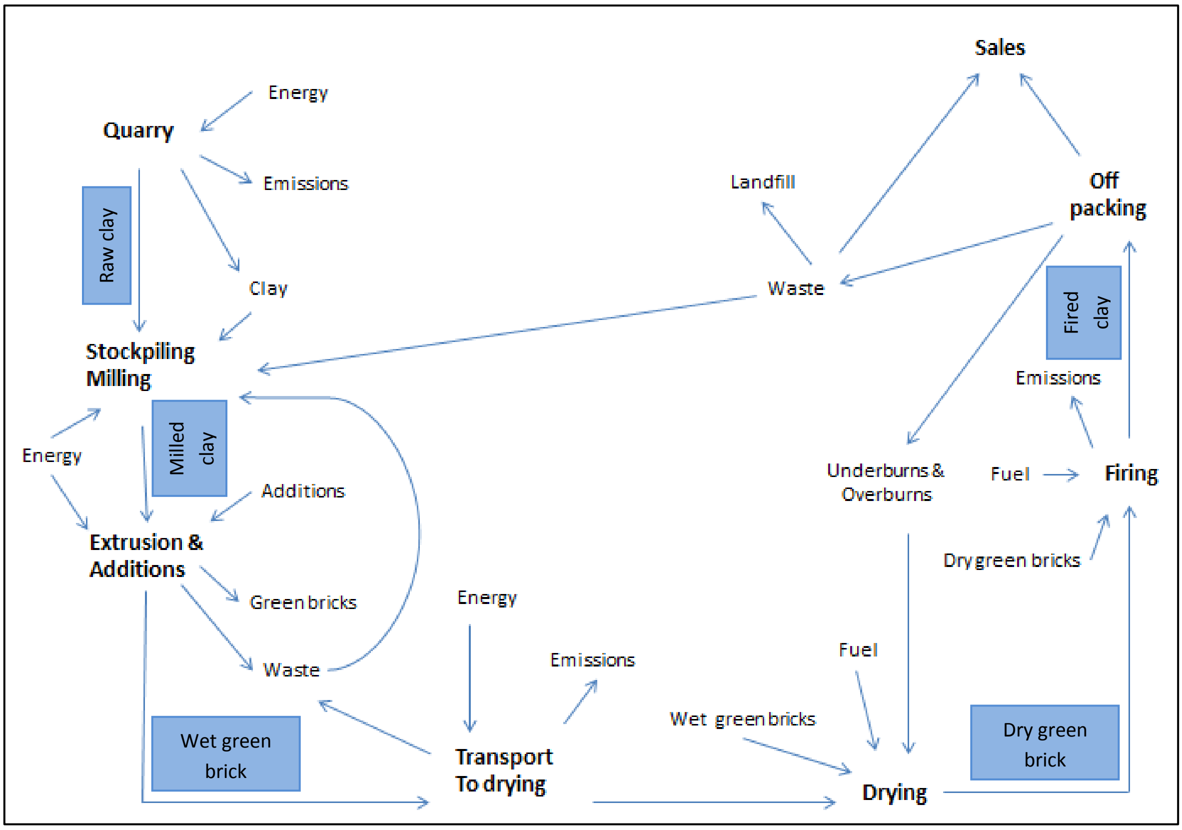

Figure 2.1: Product system of the cradle to gate phase of the LCA

2.2.1.2 FUNCTION OF THE PRODUCT SYSTEM

The primary function of clay bricks is to provide a construction material component with a defined set of thermal and structural properties and which can be used in conjunction with other bricks and materials to construct a wall or barrier between indoor and outdoor environments. Additional functions of bricks include protecting the indoor environment against weather influences as well as providing a safe living environment for the occupants of such an indoor space.

2.2.1.3 REFERENCE FLOW AND FUNCTIONAL UNITS

The reference flow for this product system defined in 2.2.1.1 above is one kilogram of fired clay brick.

The functional unit for this product system is one Standard Brick Equivalent (SBE) which may be used as a construction provision.

All comparative systems (various clay brick firing technologies) have exactly the same functionality; therefore the detail regarding performance characteristics and additional functions is not required.

2.2.1.4 SYSTEM BOUNDARY

The system boundary is defined by the ISO 14040 (SANS 2006a:12) as

> *…a definition of the unit processes to be included in the system. The ideal system boundary should be modelled in such a way that inputs and outputs at its boundary are elementary flows*.

The system boundary of the cradle-to-gate life cycle phase of clay brick production in South Africa is shown in Figure 1.3.

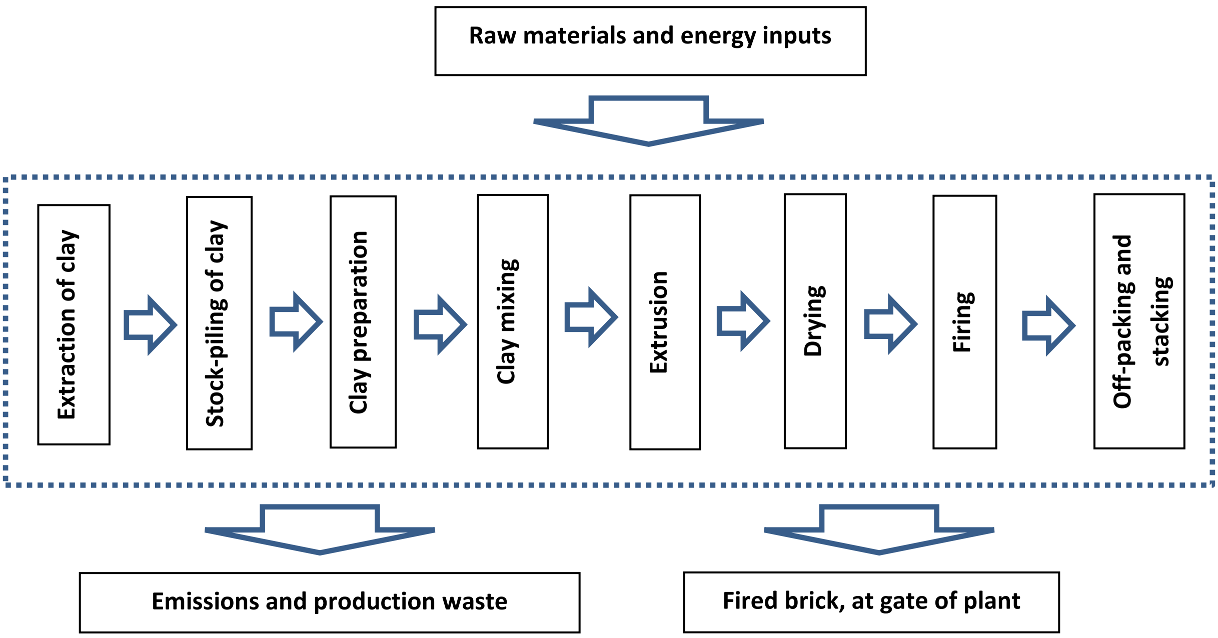

Figure 2.2: System boundary of the cradle to gate phase of the LCA

2.2.1.5 ALLOCATION APPROACH

Allocation is the process followed to define the division of data for production processes that produce more than one product. ISO 14040 (SANS 2006a:13) emphasises the importance of allocation when doing LCA. Few industrial processes yield a single output or are based on a linear system of raw material inputs and outputs. Most industrial processes yield more than one product, one of which may be recycled intermediately or discarded at the end of the process.

For this study it was assumed that none of the sampled fired clay product manufacturers in South Africa produce products other than clay bricks. For this reason, it was found unnecessary to define allocation procedures due to the limited number of multi-output production plants in the study. Production plants which produce other fired clay products have a mass breakdown of all resources and elementary flows of each product; therefore, allocation was applied prior to the collection of data from these plants and can therefore be treated as single output plants.

The only multi-output processes which have been identified are the co-generation of electricity in South Africa, and the co-generation of fuels for firing. This is background data obtained from literature; therefore, allocation will be dealt with when assembling the model.

2.2.1.6 DATA REQUIREMENTS

The data requirements for the cradle to gate phase of the LCA are summarised in Table 2.1.

Table 2.1: Data requirements for the cradle to gate phase of the LCA

Component	Related data	Data source
Extraction of clay	Energy and material needed to extract clay	Clay brick manufacturers/ literature
Stockpiling on site	Energy and resources needed for stockpiling	Clay brick manufacturers/ literature
Milling of clay	Energy and resources needed for milling	Clay brick manufacturers/ literature
Clay preparation	Energy and resources needed for clay preparation	Clay brick manufacturers/ literature
Clay mixing	Water, additives and energy needed for mixing	Clay brick manufacturers/ literature
Extrusion	Energy and materials needed for extrusion	Clay brick manufacturers/ literature
Drying	Energy and materials needed for drying	Clay brick manufacturers/ literature
Firing	Energy, fuel and materials needed for firing	Clay brick manufacturers/ literature

2.2.1.7 DATA QUALITY REQUIREMENTS

It is expected that the data collected from clay brick manufacturers will be of the highest quality. The authors interrogated the data received from the brick manufacturers, and where data were suspected to be incorrect, i.e. expressed in the wrong unit of measure, it was verified by a third party by contacting the specific manufacturer to ensure that the LCA results reflect the industry accurately. Emissions, energy generation, fuel economy and fuel generation will be derived from literature sources and internationally accepted databases such as *EcoInvent*.

2.2.1.8 IMPACT ASSESSMENT APPROACH

In impact assessment, inventory items are linked to the environmental impacts which they generate. The main objective of the cradle to gate phase of the LCA is to understand how brick production affects the environment. The study therefore assesses all impact categories calculated by the impact assessment method *Impact 2002+*; these are (unit of measure as presented in this study):

- Carcinogens (kg C_2H_3Cl-eq)
- Non-carcinogens (kg C_2H_3Cl-eq)
- Respiratory inorganics (kg PM2.5-eq)
- Ionizing radiation (Bq C-14 eq)
- Ozone layer depletion (kg CFC-11 eq)
- Respiratory inorganics (kg C_2H_4-eq)
- Aquatic eco-toxicity (kg TEG water)
- Terrestrial eco-toxicity (kg TEG soil)
- Terrestrial acidification/nutrification (kg SO_2-eq)
- Land occupation (m^2org.arable)
- Global warming (kg CO_2-eq)
- Non-renewable energy (MJ primary), and
- Mineral extraction (MJ surplus).

The *Impact 2002+* method was selected as it proposes a feasible implementation of a combined midpoint/damage-orientated approach. The framework of *Impact 2002+* links all types of life cycle inventory results via several midpoint categories (mentioned above) to four overarching damage categories, i.e. human health, ecosystem quality, climate change and resources (Quantis 2012).

Of the available impact assessment methods, *Impact 2002+* is the most useful to the clay brick industry as it reveals specific elemental scientific results which are more appropriate for the industry to acknowledge.

2.2.1.9 INTERPRETATION TO BE EMPLOYED

As part of the LCA, an assessment was done of the main contributors to environmental impacts for each of the firing technologies researched. This will help the manufacturers identify the source of the greatest environmental impact from their production processes. Evaluations of the consistency, completeness and sensitivity of the data have also been undertaken.

2.2.2 Inventory of data

During the Life Cycle Inventory (LCI) analysis, data are collected and interpreted. Calculations are done and thereafter the inventory results are concluded and presented.

Emissions, energy requirements and material flows are calculated for each process of the product, material or source. This data will then be weighted according to the functional unit stipulated in the goal and scope of the study so that the whole life cycle can be taken into account (DEAT 2004).

2.2.3 Impact assessment of the processes involved

In the Life Cycle Impact Assessment (LCIA), the product or production system is evaluated from an environmental perspective using category indicators to compare results. There are four mandatory elements of LCIA for comparative assertions; these are (DEAT 2004):

- Selection of impact categories, category indicators and models.
- Assignment of the LCIA results, usually completed through a classification system.
- Calculation of category indicator results.
- Data quality analysis.

Apart from the mandatory elements, some optional actions can be undertaken:

- Calculation of the magnitude of category indicator results relative to a reference value, this process is called normalization.
- Grouping of impact categories into one or more predefined sets as stated in the goal and scope of the study.
- Weighting of category indicator results by using a numerical factor based on value-choices.

2.2.4 Environmental performance improvement assessment

In this phase of LCA results are analysed in relation to the goal and scope definitions. Where conclusions are reached, limitations and delimitations of the results are also presented. Recommendations on improving the environmental performance of the product, material or source are presented, based on the findings of the previous stages of the LCA (DEAT 2004).

In general, LCA can be viewed from two main perspectives:

- As a conceptual thought process which guides the selection of options in design and improvements, or
- methodically, as a way to build quantitative and qualitative inventories of environmental burdens or emissions, to evaluate the impact of these burdens or emissions and to identify alternative methodical approaches to improve environmental performance (Fava 1997).

2.3 TYPES OF LCA

Three types or levels of LCA are recognised, i.e. Conceptual LCA, Simplified LCA and Detailed LCA; these are used in different contexts and for different purposes.

2.3.1 Conceptual LCA

This level of LCA is the simplest form and is used to make a basic assessment of the environmental impacts of a product, material or source. Conceptual LCA is based upon a limited and qualitative inventory.

The results of a conceptual LCA can be presented in a qualitative statement, through the use of graphics, flow diagrams or simple scoring systems. The results of a conceptual LCA are not suitable for marketing purposes or for public dissemination; they may however aid the decision making process through identifying competitive advantages and elementary environmental impacts (DEAT 2004).

2.3.2 Simplified LCA

This level of LCA is based on the screening method, i.e. covering the whole life cycle. This is done through a superficial collection of generic data and standard modules for energy production. After this collection has been completed, a simple assessment that focuses on the most important environmental aspects, stages and a thorough assessment of the reliability of the results can be undertaken (DEAT 2004).

For a simplified LCA the following processes are usually followed:

- Screening: An identification process where parts of the life cycle are considered important or where data gaps occur.
- Simplifying: using the finding of screening in order to focus further research on parts of the life cycle.
- Assessing reliability: an evaluation which verifies that simplification does not reduce the overall reliability and validity of results.

2.3.3 Detailed LCA

This type of LCA is the most comprehensive of the three; it involves the full process of undertaking LCAs and is most reliable since it requires an in-depth study. The detailed LCA also involves reliable data collection which specifically focuses on the target or objective of the LCA, which if only available generically, is collected specifically for the product, material or source (DEAT 2004). For the purposes of this study, the Detailed LCA process was followed.

3. CHAPTER 3 – LCAs OF CLAY BRICKS IN SELECTED OTHER COUNTRIES

3.1 INTRODUCTION

A desk top review was undertaken of published LCAs of clay bricks and related aspects in selected other countries, i.e. from Canada, Greece and Australia to understand the environmental impacts associated with clay brick manufacturing, and end of life stages in other countries.

3.2 LCA OF BRICK AND MORTAR PRODUCTS IN CANADA

Brick manufacturing in Canada has developed extensively since the end of World War II. Even though the number of brick production plants has reduced from 2500 in the U.S.A. and Canada just after the War to around a combined 100 plants currently, Canada itself is still producing the largest proportion of the required bricks in that country (Venta 1998:2-2).

The Canadian study focuses on all the brick production plants currently operating in Canada, all of which use the same manufacturing process. Because of the little variation in manufacturing technologies, very few differences in the results were noted. Specific energy use and emissions data were not collected from brick manufacturers, but national averages for energy and emissions were used for the fuel utilised in brick firing and emissions therefrom were then calculated.

The study covers an average of 541 million bricks produced annually, with the nominal brick dimensions of 213x102x60mm. Firing fuel use varies across the manufacturers, primarily due to accessibility and cost of transport. Energy sources used as an external fuel are natural gas, propane, oils, sawdust and coal (*ibid.* 1998:2-8). 95% of all bricks produced in Canada are face brick, which means variability between site specific firing techniques is very low.

Clay used for brick production is usually mined on site, but at least one third of the clay used needs to be transported at least 20km to the production site (*ibid.* 1998:3-3).

The total energy required to produce one metric tonne of fired brick was found to be 4,5844 GJ. This, seen with Table 3.1, shows the evaluation of environmental impacts associated with clay brick production in Canada.

From the literature reviewed, several pertinent issues which are applicable to this study were identified. These are:

- The Canadian study is fairly old (1998); nevertheless, it did prove useful in developing the methodology required for the South African study. As far as representivity is concerned, the Canadian study targeted the full population of brick manufacturers in that country. When compared to the various different firing technologies used in the South African context, the data collected for the Canadian brick industry do not vary drastically from South African data. Emissions and energy use data were collected from national databases and then used in determining the environmental impacts. This approach is preferable, as generalised data for a specific region are always more accurate than generalised global data.

Table 3.1: Atmospheric emissions from natural gas fired kilns in Canada (Venta 1998)

emission	unit	grinding room	kiln	dryer	in-plant fuel use	subtotal processing
CO_2	kg/tonne		225.000		1.944	226.944
SO_2	g/tonne		250.000		2.805	252.805
NO_x	g/tonne		205.000		22.193	227.193
TOC	g/tonne		35.000	42.500		77.500
CH_4	g/tonne		20.500	14.000	0.597	35.097
VOC	g/tonne		14.500	28.500	2.390	45.390
CO	g/tonne		700.000		12.183	712.183
Filterable PM	*g/tonne*	*14.250*	*140.000*			154.250
Filterable PM-10	*g/tonne*	*1.311*	*105.000*			106.311
Condensible Inorganic PM	*g/tonne*		*265.000*			265.000
Condensible Organic PM	*g/tonne*		*55.000*			55.000
total PM	g/tonne	14.250	460.000			474.250
total PM-10	g/tonne	1.311	425.000			426.311
HF	g/tonne		190.000			190.000
HCl	g/tonne		105.000			105.000

- The standard brick dimensions of the Canadian brick resemble that of the South African paving brick, with a height dimension of 60mm. This variation has resulted in context specific results, which should be compared with caution to other studies with the same objectives.

3.3 ENVIRONMENTAL ASSESSMENT OF BRICK PRODUCTION IN GREECE

It was found useful to investigate the environmental impacts associated with brick production in Greece since it is also a major construction material used in that country. The purpose of the study by Koroneos & Dompros (2006) was to identify production processes in the total life cycle which contribute to the environmental impacts in that country.

The energy use of materials and stages of production was quantified along with emissions and the potential environmental impacts. In the assessed production plant, the main energy inputs are electricity, diesel and solid fuel. The environmental concerns that arise from this study are mainly the air emissions resulting from burning fossil fuel.

Data, including some measurements, were collected at the specific site. Data which were not accessible or unknown at the site were obtained from available literature sources. A summary of a number of stage inputs and outputs are given in Figure 3.1.

3.3.1 Raw material acquisition

The clay is transported to the factory by trucks. The basic ingredient of the clay is kaolin ($Al_2O_3 \cdot 2\ SiO_2 \cdot 2H_2O$). The percentage of kaolin affects the plasticity of clay. Clays with high kaolin content are called greasy clays while the ones with low content are called non-greasy clays. Greasy clays have high water absorption and when mixed with water have high plasticity, which makes them easier to process (Koroneos & Dompros 2006).

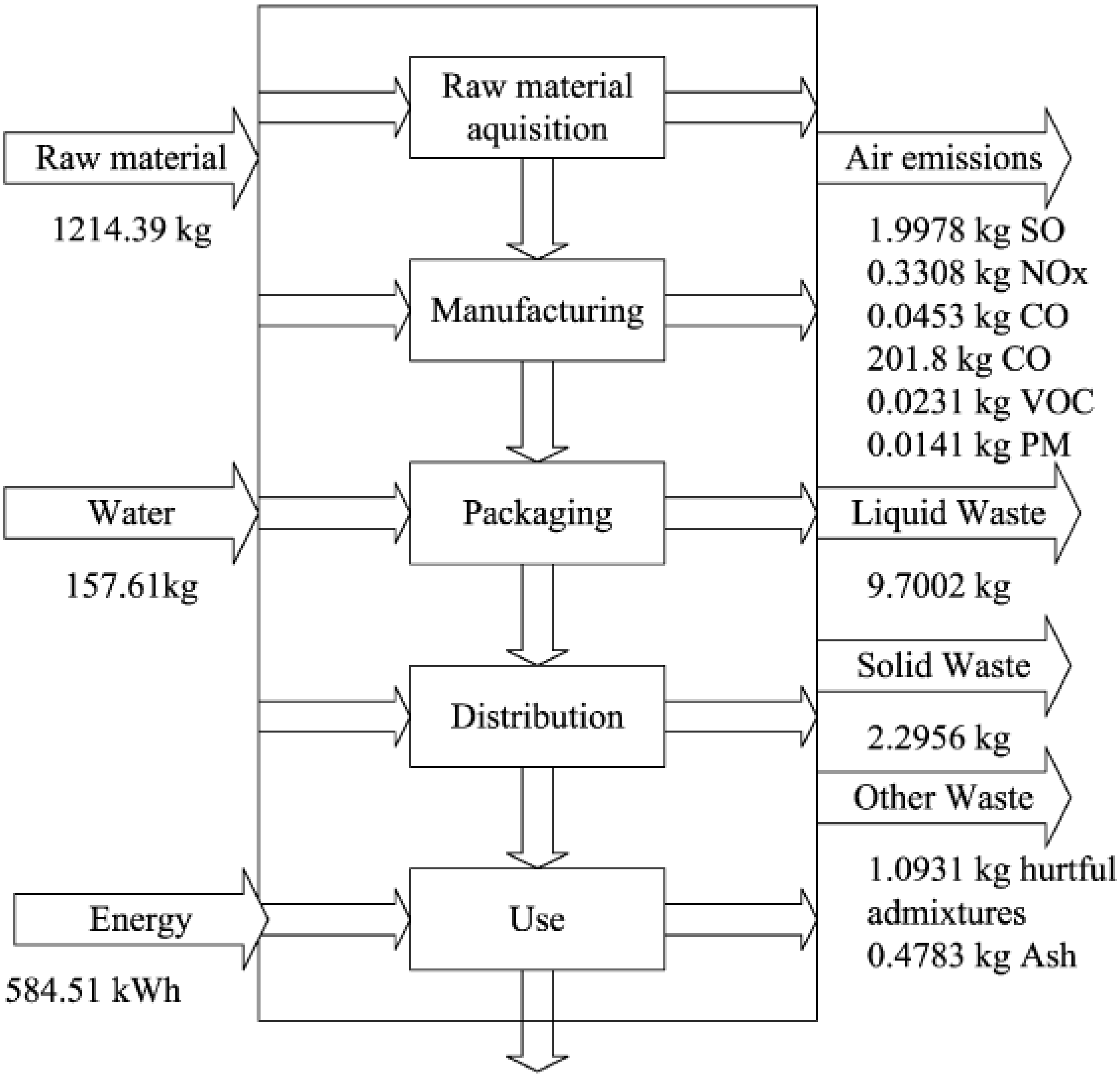

Figure 3.1: Inputs and outputs for the production of one metric tonne of bricks from a LCA in Greece (Koroneos & Dompros 2006).

3.3.2 Manufacturing process

The findings of the research show high energy use in the form of electricity, pet coke and diesel. The manufacturing process consists of the following subsystems (*ibid.*):

- Mixing and feeding: The clay arrives in the factory and it is stored in piles where it remains for 20 days before use. During this period the oxygen in the atmosphere destroys the anaerobic bacteria that exist in natural clays. It has been proven empirically that the existence of micro-organisms in the clay causes problems in the drying and firing processes. In order to take advantage of the properties of greasy and non-greasy clays, a mixture of the two is used. The mixing and feeding processes are carried out using earth moving machines (*ibid.*).
- Shaping: During this sub-process the clay is first milled to reduce the particle size to approximately 25mm and is cleaned. The clay is then mixed with water through a kneading process. The plasticity of the mixture depends on the amount of water added and the original mixture of greasy and non-greasy clays. This proportion varies

from 1.5:1 to 2.5:1. After the kneading process the clay passes between two rotating cylinders with a very small opening (2mm) in order to grind all large particles that still may occur in the clay. The processed clay then passes through a screw-like compressor where it is shaped and cut to form the bricks which are then placed on wooden pallets (*ibid.*).

- Drying: The green non-fired bricks are placed in hack lines for 4–5 days in order to dry (*ibid.*).
- Firing process: The dried bricks are then placed on rail trolleys and transported to a kiln that operates at 980–1030 C. The trolleys move slowly inside the kiln for an overall period of about 120 minutes. The fuel used in the furnace is pet-coke which is transported by trucks from a nearby harbour (*ibid.*).
- Recycling of bricks from production: Discarded bricks account for less than 1% of the total plant production. These bricks are collected and used as raw material for the next batch of clay bricks or for the production of clay tiles. The factory reports that up to 30% of the raw material used in producing brick may be recycled burnt bricks.

The study considers six categories of environmental impacts of the brick production plant. These categories are: global warming, acidification, eutrophication, winter smog formation, summer smog formation and solid waste. The impacts are summarized in Table 3.2.

Table 3.2: Categorization of the environmental impacts from the production of one metric tonne of bricks for a LCA in Greece (Koroneos & Dompros 2006)

Impact category	Equivalent mass
Greenhouse emissions	220.679 kg CO_2-eq
Acidification	2.229 kg SO_4-eq
Eutrophication	0.043 kg PO_4-eq
Winter-smog	2.012 kg SPM-eq
Summer-smog	0.009 kg C_2H_4-eq
Solid waste	2.788 kg

In the conclusion of the study, the authors found that the LCA conducted on the brick production plant shows a high energy intensive method of producing bricks. The summarized findings show that the majority of emissions are due to on-site burning of fossil fuels as the energy source. Acidification is the highest environmental impact; this is due to the factory using low grade fuel with a high sulphur content, which causes leaching of sulphuric acid into the ground water (Koroneos & Dompros 2006).

From the literature reviewed for this case study, the following pertinent issues which are applicable to this study were identified:

- This study was done on only one production plant, industry averages are therefore not known; this may have yielded results which would invalidate the study's title, i.e. *Brick production in Greece.* The study did no aggregating per brick, but of one tonne – limiting the information available to brick manufacturers. Presenting the results in a more applicable way, per brick or per kg of fired clay, would have allowed a larger audience to use results from the research.
- LCA's interpretation can be brought down to a single score, as environmental impacts vary across ecosystems. This reviewed study used the Eco-indicator method of weighting, which brought the impacts down to a single score. Bringing LCA results down to a single score involves weighting which uses a subjective value choice which

may impact on the credibility of the study. In the case of the Greek study, the environmental outputs were calculated for each process. For this study on brick production in South Africa it is unnecessary to disassemble the collected data and present it per process, what is of more importance is the total cradle-to-gate life cycle of bricks in South Africa.

- The reviewed study varies slightly from this research insofar as in-situ measurements were taken in the Greek study. The research for this report did not allow for measurements on site due to cost and resource constraints, the study is reliant on the validity of field data given to the authors by the brick manufacturers.
- It should be realised that in the Greek study the size and weight of a brick differ from the average South African case, resulting in different interpretation of environmental impacts at the end of the process. The values for outputs from the drying phase should be used with caution, as the drying process mentioned in the reviewed study is different from the typical processes employed in South Africa. Nevertheless, the Greek study is a useful example in assessing corresponding South African scenarios.

3.4 LCA FOR CLAY BRICK PRODUCTION IN AUSTRALIA

The publication reviewed for this study is on a LCA and thermal modelling exercise conducted by Energetics for ThinkBrick Australia. The main objective of the Australian study was to determine the environmental impacts associated with the production and operational phases of a brick built structure. Another objective was the identification of the areas with the greatest contribution to environmental impacts within the production process, to allow future environmental remedial decisions to be made within the production process (Energetics 2010). The study looked at several stages in the life cycle of a brick, from raw material extraction, brick manufacture, transport to site, construction of the brick building, use phase and demolition/disposal stages.

A subsection of the study was to determine the environmental impacts of the cradle-to-gate phases of brick manufacturing; this was the first stage in the study and was completed with data collected for the manufacturing stages from ThinkBrick Australia members (*ibid.*). The reference unit used for the cradle-to-gate study was one standard brick equivalent (SBE).

The study excluded the embodied energy associated with infrastructure and other capital goods – this ensures that the boundary of the system is limited to the actual product under observation. Cut-off flow was set at 1% (mass and expected environmental impacts). This means that the Australian study either omitted or estimated the environmental impacts, instead of collecting the information for these small contributors.

Data collected from ThinkBrick members were for the financial year 2007/08 (*ibid.*). The data collected were averaged to production volumes for the population surveyed. The target population was the full population, but as can be commonly expected in such studies, responses were not received from the full population. A response rate of 67% was achieved for the clay extraction life cycle stage and 73% for manufacturing of bricks life cycle stage (*ibid.*).

Energetics found that 10% of the total Australian energy generation is used in the production of bricks. Production plants which produce other fired clay products such as tiles and pavers were excluded from the population (*ibid.*).

The study found that one SBE generates 0.61 kg CO_2–eq over the cradle-to-gate life cycle. Cumulative energy demand was found to be 9.5 MJ per SBE (*ibid.*). Figure 3.2 shows the contributing energy sources for the production of one SBE.

From the literature reviewed for this case study, several pertinent issues which are applicable to this study were identified, these are:

- Relatively little research was presented on the cradle-to-gate stage of the life cycle of brick production in Australia since the project focussed mostly on the thermal performance of clay brick compared to other materials in the operational phase of a brick's life cycle.

- Factories which produced clay pavers (which are smaller than the average SBE) were excluded from the Australian study. This may not represent a true reflection of the population; more care could perhaps have been taken to develop rational proportional calculations in order to include these factories in the population. Multiple product output factories in the reviewed study were also excluded. This is questionable since the Australian study purports to assess brick products, and not specifically only clay brick units used for construction of walls. In the case of the South African study, there are few factories which produce multiple clay products, and where factories do produce clay products other than bricks, proportional data collection was employed to prevent skewed data being presented for the model. A valuable approach to background information, or information which was not accessible in the field survey conducted by Energetics was used in the Australian study. Reputable national literature sources were first pursued, after which global averages or European averages were used.

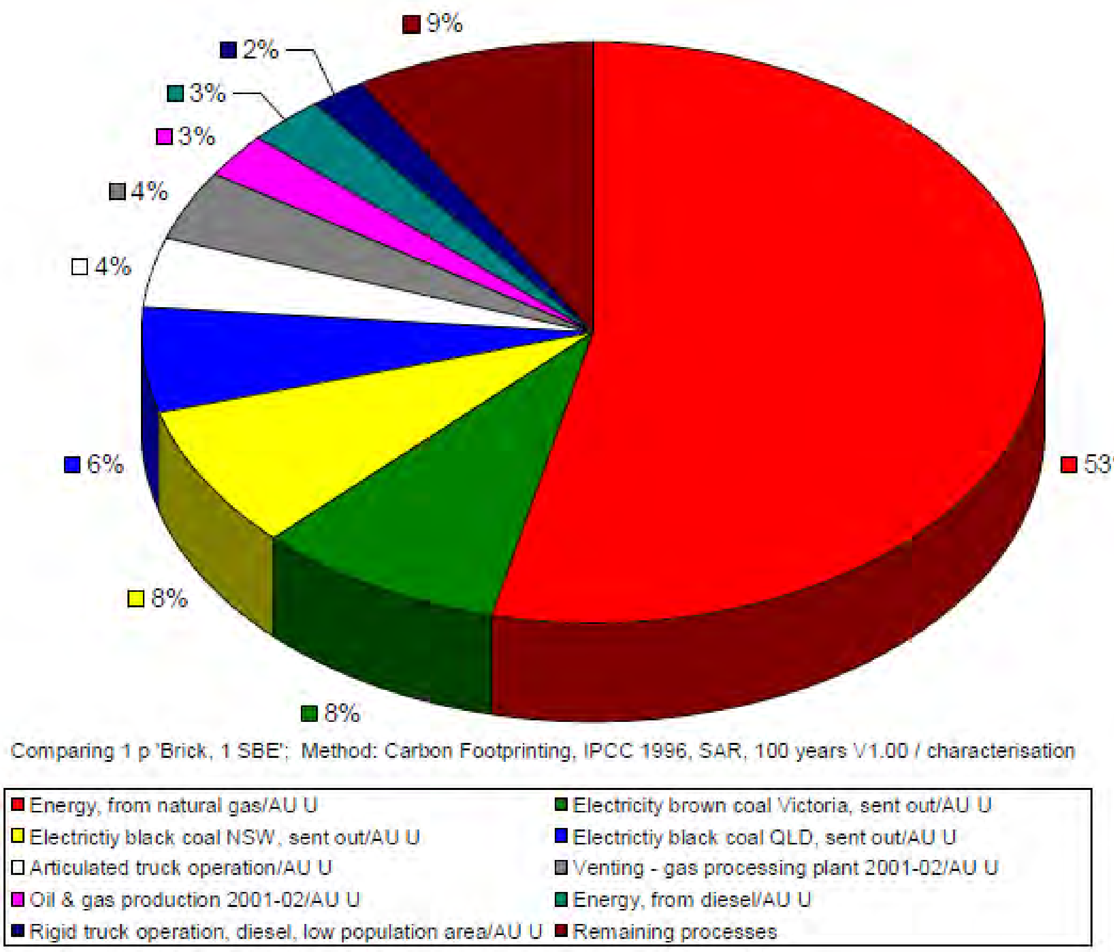

Figure 3.2: Contributing energy sources for the production of one SBE in Australia. (Energetics 2010:19)

3.5 CONSTRUCTION AND DEMOLITION WASTE

Fatta *et al.* (2003) point to the fact that in Greece, field data on C & DW are very difficult to obtain. The reason for this is that up until their research date (2001) construction and demolition companies were not required to quantify their waste generation (*ibid.* 2003:84). In addition to the difficulty of obtaining data, much uncontrolled and illegal dumping also occurs in Greece (*ibid.* 2003:84).

Nevertheless, the following assumptions were made in the Greek study to determine the quantities associated with C & DW:

- 1000m² of building activity produces 50m³ of solid waste.
- Converting m³ to tonnes was done through the assumed density of C & DW, i.e. 1.5 tonnes/m³.
- Estimates were based on the number of demolition licenses issued in Greece.

The results of the estimates suggest that in Greece, the average annual quantity of C & DW was 1 953 064 tonnes (Fatta *et al*. 2003:86). Further estimates by the Hellenic Solid Waste Management Association suggest that in Greece the average annual percentage of recycling solid waste was 17% (*ibid.*). Fatta *et al*. (*ibid.*) found that of the total municipal solid waste collected in Greece in 2011, just 3% was inert material (which can be considered to be brick and concrete).

Ghosh *et al.* (2013) find that of the total 48 million tonnes of solid waste generated in India per year, C & DW accounts for 25%; this amounts to 12 million tonnes per year. The research shows that nearly 50% of C & DW is being reused and recycled before it reached landfill sites (*ibid.*). In New Delhi alone nearly 6500 tonnes of municipal solid waste is generated per day (*ibid*.).

In India the average recovery rate of materials from demolished buildings is 25% while that figure rises to 75% from new building construction. The total quantity of bricks and masonry (tiles and other fired products) C & DW is 4 million tonnes per year (*ibid*.). In a similar research project conducted by IL&FS Ecosmart Ltd (2005) for the Government of Delhi, it was found that 31% of municipal solid waste was made up of bricks and masonry.

Kartam *et al.* (2004) found that in Kuwait, C & DW accounts for a considerable portion of the total municipal solid waste, at around 15-30% of the total mass, with a mere 10% of that being recycled and reused and 90% being sent to landfills. The study also found that the composition of C & DW is comprised of 30% brick which typically comes from renovations, left over from new constructions and demolition of old buildings.

Nunes *et al*. (2007) of the University of Rio de Janeiro found that of the total C & DW generated by Brazilians 14% are ceramics (which includes brick, tile and other fired products). The estimated generated quantity of C & DW is 2 877 tonnes per day which amounts to just over 1 million tonnes per year (*ibid*. 2007:5). Only 2% of the generated solid waste is sent to recycling sorting plants (Chagas 2011:2).

In Australia, where the waste management plans and policies are geared towards a carbon reduced future, a study of recycling companies in the Sydney region found that 471 000 metric tonnes of bricks are being recycled annually. The study was completed in 2003, and with a suggested economic and population growth of around 1.75% annually (Gambin *et al*. 2003:1) the estimated annual amount of recycled bricks for 2011 was 550 000 tonnes.

Reid (2003:9) found that in 2001 England and Wales generated 93.91 million tonnes of C & DW (with a confidence level of 90%). The study suggested that even though the figures are estimates and extrapolated quantities of regional C & DW generation, the results still indicate the scale of the material stream for waste generation in England and Wales (*ibid.*).

Kofoworola and Gheewala (2008) estimated that of the total waste disposed of in landfills in Thailand, 7.7% of this is C & DW. This amounts to approximately 1.1 million tonnes per year.

Bester *et al*. (2004) found that in developed countries, 45% of C & DW consists of bricks.

3.5.1 Pertinent aspects from the literature review on the demolition, waste and recycle phase

The following conclusions can be drawn from the above literature review, which will form the basis for assumptions for the conditions in South Africa:

- Bricks make up 45% of C & DW in developed countries.
- Bricks make up 31% of C & DW in India where there is a 50% reuse/recycle rate.
- Bricks make up 30% of C & DW in Kuwait with a 10% reuse/recycle rate.
- Ceramics make up approximately 14% of C & DW in Brazil with a low reuse/recycle rate. This can be further interpreted as bricks being roughly 7% of C & DW.
- Bricks make up 3% of municipal solid waste in Greece with an estimated 17% reuse/recycle rate.
- In Sydney, 550 000 metric tonnes of bricks are recycled annually.
- Annual C & DW in England and Wales is calculated at 93.91 million tonnes.
- Annual C & DW in Thailand is estimated at 1.1 million tonnes.
- Durban collects 219 000 tonnes of C & DW per year which are sent to landfills.
- The City of Johannesburg processes and recycles 835 000 tonnes of C & DW per year (based on data from private demolition companies and recyclers).
- 4 725 542 tonnes of C & DW were collected and landfilled in South Africa in 2011, while 756 087 tonnes were reused/recycled from the landfill sites, this accounts for a 16% recycle rate of C & DW.

Literature reviewed in this chapter appears to contradict each other, it appears that South Africa in totality recycles roughly 756 087 tonnes of C & DW annually (DEA 2012a) while the City of Johannesburg recycles 835 000 tonnes of C & DW annually (CoJ 2011). The contradiction may be due to the population/sources that were approached or cited in each of these studies.

The National Waste Information Baseline Report assessed municipal records and sources that monitor landfill sites, while the City of Johannesburg Integrated Waste Management Plan approached private demolition and recycling companies that work with C & DW. The latter addresses the stage prior to the waste being recorded at landfill sites, while the former addresses waste that has already passed through the stage where private recyclers and demolition companies source and sort possible recycling opportunities before the waste has arrived at landfill sites. The NWIBR does not however address the possibility that private recyclers and demolition companies may have reduced the amount of waste reaching landfill sites.

3.6 CONCLUSION

The case study reviews were beneficial in developing an appropriate research methodology and manner in which the problem statement of this study may be addressed. The ISO 14000 series of International Standards, e.g. ISO 14040 and ISO 14044, provide the guidelines and recommendations for carrying out LCAs with a suggested format of presentation. This study will be presented in the recommended format with close correlation with the generic research project guidelines which include chapters on research design, data collection, data modelling and conclusion.

4. CHAPTER 4 – LCA INVENTORY ASSESSMENT

4.1 INTRODUCTION TO THE THREE PHASES

The full life cycle of clay brick, i.e.: 'cradle to cradle' is covered in this chapter. Chapter 4 is divided into three parts, i.e. cradle to gate phase, the gate to end of operational life phase and the demolition, waste and recycling phase. A more detailed description of the required information is provided within each part to provide an understanding of the three phases within this project.

4.2 CRADLE TO GATE PHASE

4.2.1 Status of brick production in South Africa

As a large contributor to the building industry in South Africa, clay bricks are well-known and an often used building material. It is manufactured from four natural elements; earth, air, water and fire (CBA 2005:1). Clay brick can be considered to be the most solid and reliable structural building element of all time, and is widely recognised for durability, compressive strength, acoustic insulation and fire-resistant properties (*ibid.*).

4.2.2 Generic manufacturing sequence

Although every clay brick manufacturing plant has a specific sequence and method of producing bricks, the following generic sequence of events is followed to produce a fired clay brick:

4.2.2.1 STEP 1: CLAY MINING

Clay is mined from an on-site or off-site open cast mine. Clay mining is usually confined to certain periods of the year when rainfall is low, therefore some manufacturing plants will mine heavily during the dry season to make provision for non-production during the wet season – this scenario is typical of the Cape winter rainfall region of South Africa. Mined clay has an inherent moisture content which differs from location to location.

4.2.2.2 STEP 2: CLAY STOCKPILING

Mined clay is then stored for a number of days or weeks in large stock piles near the production plant. The purpose of stockpiling is to allow the clay to weather (also known in the industry as souring-in). Weathering ensures ease of milling later in the process, therefore helping to save energy.

4.2.2.3 STEP 3: CLAY MILLING

Weathered clay is then milled in a crushing plant. The purpose of milling is to reduce the clay particles to the required size for brick production. The correct size has a direct correlation with the ability to later mould and shape the clay.

4.2.2.4 STEP 4: ADDITIONS TO DRY MIX

This step is not part of a generic process, but may be included in some manufacturing plants. Internal body fuel, such as fly ash or coal grains are added to the dry clay mix. The mixing of various clays to achieve specific colours is completed in this stage, which may include the addition of chemicals and other additives to lower salinity or to increase plasticity.

4.2.2.5 STEP 5: ADDITION OF WATER

Water is then added to the dry mix and mixed in large tubs. This ensures that an even spread of materials is achieved. The water is sourced mostly from harvested rain water, borehole water or municipal supplied water. Each manufacturing plant has an identified water source for which annual records are maintained.

4.2.2.6 STEP 6: PROCESS OF DE-AIRING

The next step in the process involves de-airing, this is to ensure all air entrapped from prior mixing processes is removed. If air bubbles remain in the wet clay mix, it is likely that fractures and breakages will occur during the firing process.

4.2.2.7 STEP 7: EXTRUSION

The next step in the clay brick manufacturing process is extrusion. The wet clay mix is extruded through a die in long blocks, known as slugs. The dimensions of a slug are slightly larger than the average brick size; this is to allow for shrinkage in the firing process.

4.2.2.8 STEP 8: BRICK CUTTING

The wet clay slug is then wire-cut into separate bricks; once again, dimensions are slightly larger in order to account for moisture loss during firing.

4.2.2.9 STEP 9: DRYING

The cut bricks are then packed onto pallets or racks which are transported to be dried. Drying is either done naturally through solar and air drying, or through mechanical means in a tunnel dryer equipped with fans.

4.2.2.10 STEP 10: FIRING

Once the bricks have dried to a specified moisture content (this may take up to 90 days) they are ready to be fired in a kiln. In South Africa there are a number of different firing kiln techniques, i.e. clamp kilns, tunnel kilns, transverse arch kilns, Hoffman kilns, vertical shaft brick kilns and zigzag kilns. The basic purpose of a kiln is to fire the bricks into a vitrified state through the input of energy from an external firing fuel, which may be coal particles, natural gas or wood. The different kiln typologies are explained in Section 4.2.3 hereafter.

4.2.2.11 STEP 11: OFF-PACKING

After the bricks have reached the adequate state of vitrification, they are off-packed onto pallets for sale and sorting of the unburnt bricks for landfill or reuse in the manufacturing process. Mechanical off-packing is also used in the more technologically advanced manufacturing plants. Waste from the firing process varies for each firing methodology, however it is well known that minimal wastage allows for better economic gains, therefore manufacturing plants attempt to reduce wastage by constantly improving firing techniques and waste re-use.

4.2.3 Firing technologies employed in South Africa

4.2.3.1 CLAMP KILN

The clamp kiln is the most widely used firing technology in South Africa. Clamp kiln fired bricks are typically stock bricks, used for construction where plaster and other coverings will cover the wall. Clamp kilns are packed by hand; up to one million bricks per clamp kiln are packed in a length-extended pyramid shape as can be seen in Figure 4.1. Coal is placed between the bottom three layers, built with under-burnt or over-burnt bricks from a previous clamp kiln. Once the clamp is completely built with dry green bricks, a cover of previously under-burnt or over-burnt bricks protects the new unburnt bricks from the elements. Upon completion of the clamp construction, the coal is fired up. The clamp kiln burns for up to two weeks, reaching a maximum temperature of approximately 1300°C.

Figure 4.1: Clamp kiln packing (Rice 2012)

4.2.3.2 TUNNEL KILN

Tunnel kiln technology is probably one of the most advanced firing techniques employed in South Africa. Tunnel kilns are typically used to ensure consistency between brick batches and high quality standards are met. Most face bricks used in South Africa are produced in tunnel kilns, as the quality of the brick is high and the variation in colour is very low. Tunnel kilns are typically fired with natural gas, fuel oil or a specific quality of coal particles. Firing in tunnel kilns takes up to 48 hours and is set at a constant temperature (which implies that tunnel kilns are constantly fired with bricks moving through them) of 1100°C. Figure 4.2 shows a typical tunnel kiln.

Figure 4.2: Dry bricks entering gas fired tunnel kiln (Rice 2012)

4.2.3.3 TRANSVERSE ARCH KILN

The transverse arch (TVA) kilns are fired continuously. Green bricks are placed in cleared chambers in front of fires. Fired bricks are removed from behind the fire. When a chamber has been completely packed, the entrance is bricked up after which fuel (coal, oil or gas) is inserted in between bricks through holes in the roof of the arch. The fire is then moved through the stacked bricks by opening and closing holes in front of and behind the fire in the roof of the arch. This process occurs every two to four hours. The complete firing and vitrification process takes up to two weeks. Heat from the firing zone are drawn forward to dry the newly inserted green bricks while fired bricks are cooled down by air passing through the openings in the arch ends (CBA 2005). Figure 4.3 shows the entrance to a TVA kiln. Typically, several TVA kilns are placed next to each other; the fire is moved by the insertion of fuel into the adjoining arch.

Figure 4.3: Transverse arch kiln after firing (Birch 2011)

4.2.3.4 HOFFMAN KILN

In the Hoffman kiln, a circular tunnel is constructed out of refractory bricks. This continuous tunnel has numerous openings around the outside into which the dry green bricks are usually packed by hand (Volsteedt *et al*. 2013). Similar to other continuous kilns, fuel is dropped into the tunnel via holes in the roof in a timed sequence which allows the bricks enough time to vitrify before the fire is drawn to the next batch of bricks in the tunnel. Typical fuels used for the Hoffman kiln are coal and different density fuel oils. Figure 4.4 indicates the direction of air flow, which is opposite to the firing direction. This aids the drying and cooling process which occurs prior to firing and after firing respectively. The Hoffman kiln has had numerous developments, one of which is the TVA kiln (*ibid*.).

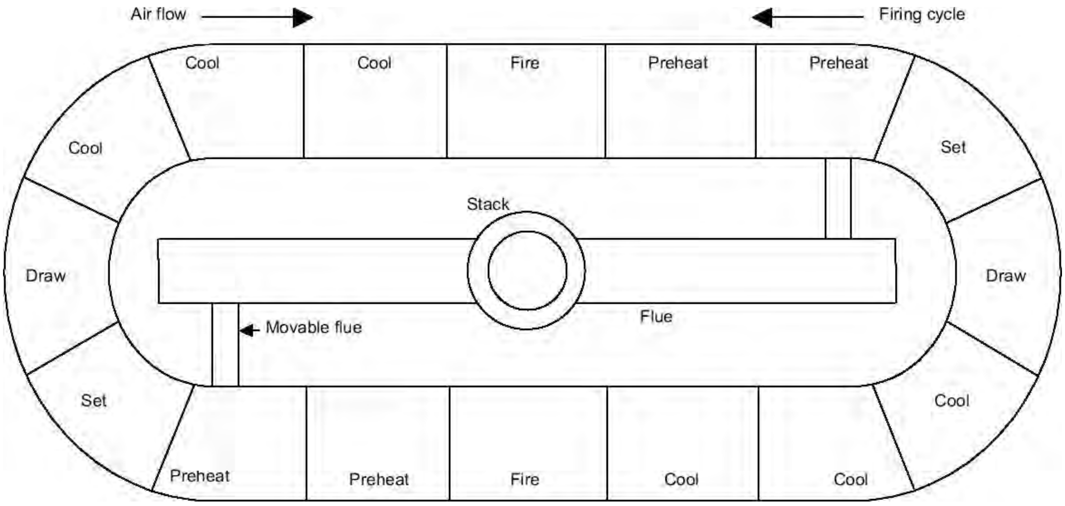

Figure 4.4: Hoffman kiln basic construction and firing process (Laefer, Boggs & Cooper 2004:268)

4.2.3.5 VERTICAL SHAFT BRICK KILN (VSBK)

The VSBK consists of one or more shafts located inside a rectangular brick structure. Shaft dimensions differ at each plant. The inside surface of the shaft is an insulated brick wall. The shaft is loaded with dry green bricks at the top, which move down the shaft through the central firing location. Figure 4.5 shows the VSBK construction. The firing of a VSBK is done by wood or coal, and is a continuous process ensuring there is no energy loss in start-up and cooling down. Bricks move down the shaft and are then off-packed at the base of the shaft. The firing process takes only 24 hours (De Giovanetti & Volsteedt 2012:3) which allows for faster production of fired bricks.

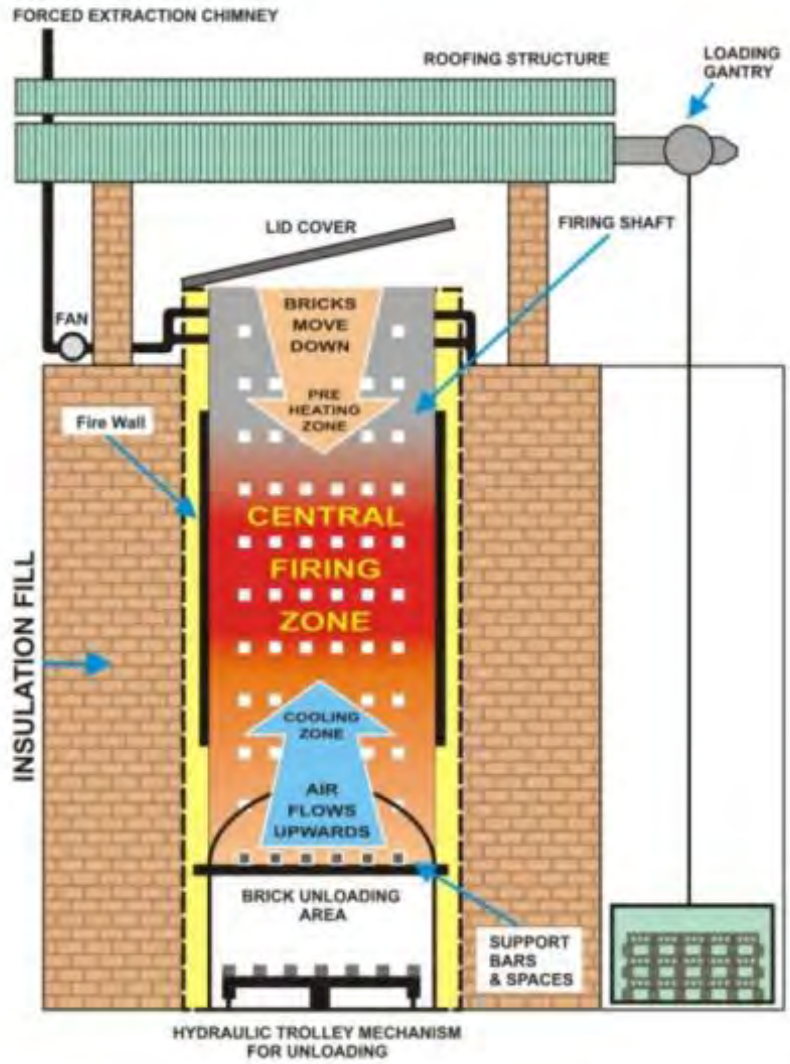

Figure 4.5: Diagrammatic operation of a VSBK (De Giovanetti & Volsteedt 2012:3)

4.2.3.6 ZIGZAG KILN

The zigzag kiln is one of the least used firing technologies in South Africa; only two manufacturing plants employ this technology. Nevertheless, an explanation of the working of a zigzag kiln is necessary for completeness in this study. What is unique about a zigzag kiln is the long fire zone which is advanced by suction fans. The typical firing process of a zigzag kiln can be seen in Figure 4.6. The fire is said to “move” around the kiln. Suction fans draw the fire from one batch of dry green bricks to another batch. The internal fuel added to the clay mix is the firing fuel for this type of kiln. Once bricks are burnt, the heat is reclaimed and used for drying the newly inserted brick batch. The greatest advantage of a zigzag kiln is the even distribution of heat in a specific location of the kiln, as well as the ability to control the fire through movement.

Figure 4.6: Zigzag general firing process (Habla Zigzag Kilns 2013)

4.3 GATE TO END OF OPERATIONAL LIFE PHASE

4.3.1 Transport to site

The data for the transport to building site stage of the gate to end of operational life phase of this project were collected as part of the field survey completed for the cradle to gate phase. The data reflect the number of bricks sold and the average distances they are transported to the building site. In South Africa it is typical of clay brick manufacturers to outsource the transport of bricks to avoid the capital and operational costs associated with heavy vehicles.

The transport process of face bricks differ slightly from that of non-face bricks as the aesthetic quality of the bricks is important in the former. It is for this reason that non-face or stock bricks are often loaded and purchased by weight while face bricks are palleted, loaded and purchased by unit, e.g. per 1000 bricks.

4.3.2 Building-in

The data required for the building-in stage for the gate to end of operational life phase of the project were collected by means of a desktop study and literature review. The unit under consideration was 1m² of brick walling. All materials required for the construction of 1m² of walling were taken into account. Three brick wall typologies were considered:

- 220mm double brick wall, either face brick externally or plaster and paint both externally and internally.

- 280mm cavity brick wall, either face brick externally or plaster and paint both externally and internally.
- 280mm insulated cavity brick wall, either face brick externally or plaster and paint both externally and internally.

4.3.3 Brick wall maintenance

For the purpose of this study it is assumed that a face brick wall or skin will require no maintenance over its lifespan. It is further assumed that a brick wall which has a plastered and painted finish on one or both sides will require repainting every few years – estimated at every 10 years for the purposes of this study.

4.4 DEMOLITION, WASTE AND RECYCLE PHASE

4.4.1 Introduction

This section addresses relevant literature for this phase of the study's objectives, i.e. the demolition of a building at the end of its life, the issues regarding the volume and quality of construction and demolition waste, as well as the potential to recycle and reuse clay bricks in South Africa. The literature study consists of reviews of publications on the following issues:

- Construction and demolition waste (C & DW) in South Africa.
- National reporting on waste generation in South Africa.
- C & DW aspects in countries similar to South Africa.

4.4.2 C & DW in South Africa

The construction industry is responsible for close to half of all the resources consumed in the world (van Wyk 2010:291). Although it may be very difficult to quantify the actual consumption of resources associated with the construction industry, it has been shown that of all the resources used in the construction process, up to 15% of all budgeted-for-materials will end up as waste (*ibid.*).

The waste generated from the construction phase of a building is rarely recycled, even though up to 80% of this waste has the potential to be recycled (Macozoma 2006:31). As a result of the poorly formalised construction waste recycling industry in South Africa, most of the C & DW ends up on landfill sites which can be accounted for by local authorities, or illegally dumped which is usually unaccounted for by any authority) (van Wyk 2010:291).

The end of life phase of a material is determined by either reuse of the material – as it is, without any further processing; recycling or reuse of the material in another form after some processing; or disposal at a landfill site (*ibid.*).

Case studies researched by the CSIR found that there are opportunities for recycling materials from a demolished building and that the recovery rate of materials of some demolition-to-rebuild scenarios could be as high as 80% (*ibid.* 2010:295).

The University of Johannesburg (2004) published a paper titled: *Construction and Demolition Waste in South Africa* in which an assessment was made of the 2002 conditions in South Africa. The authors found that even though recycling C & DW may not be the cheapest, quickest or easiest method of transforming a material into something other than common solid waste, the choice to do so makes the most sense environmentally (Bester, Kruger & Hinks 2004:63).

4.4.3 National reporting on waste in South Africa

The South African National Waste Information Baseline Report (NWIBR) published in 2012 (DEA 2012a) gives a quantitative assessment of the generated waste and uses 2011 as the baseline year. The report refers to a number of data sources and although some concerns may be expressed about the objectivity within this report, it does present important information concerning C & DW in South Africa.

The definition of "general waste" in the NWIBR categorizes building and demolition waste as not posing an immediate hazard or threat to health of the environment (DEA 2012a:3). The C & DW portion of the general waste generated in South Africa in 2011 is calculated at 20% (*ibid.*); this amounts to 4 725 542 tonnes/yr. The known recycled C & DW from landfilled sites is 756 087 tonnes/yr (*ibid*.) with the rest being disposed of in landfills across the country. These figures amount to a national C & DW recycle rate of 16% (*ibid*. 2012a:15). The NWIBR cited the Department of Trade and Industry as the source of this data, who claims that 630 000 tonnes of C & DW was recycled in 2007 (DEA 2012b:11). The two sources correlate with the growth in population and economy and therefore the rise in recycling of C & DW can be considered proportional to the growth in generation of C & DW.

4.4.4 Regional and municipal C & DW in South Africa

The NWIBR of 2012 found that in 2011, the percentage of C & DW in municipal waste was 20%. This figure was then examined and used to calculate the C & DW composition of municipal waste for Gauteng. A previous study, completed in 2004 (DEA 2012a:9), found that the C & DW portion of the total municipal waste was 15% for Cape Town and 14% for Gauteng. These figures reflect the growth in population of the country as well as the construction industry changes occurring between these two stages for which the studies were completed.

In a review of the data which were collected for the NWIBR, it is suggested that 33% of C & DW generated during the construction phase in the Western Cape province is made up of concrete and masonry (DEA 2012b:11).

Macozoma (2006) found that in 2002 the landfilled C & DW in Gauteng (which includes the metropolitan councils of Tshwane, Johannesburg and Ekurhuleni) was approximately 700 000 tonnes; however, no detailed classification of the composition of this C & DW was available. Macozoma found that there was extensive reuse of building materials on site for filling and as aggregates. Although the study concluded that there is a fairly large incidence of reuse and recycle within the informal second-hand building material market, the extent thereof is not recorded formally (see Figure 4.7). The research also found that there is extensive illegal dumping of C & DW, which makes it extremely difficult to accurately quantify C & DW in South Africa (Macozoma 2006:50).

The City of Johannesburg's Integrated Waste Management Plan (CoJ 2011) found that in 2007, the city estimated its annual C & DW processing and recycling (identified as "not going to landfill") to be 835 000 tonnes. These data were collected from well-established and municipally-recognised private companies who estimated their respective recycling and processing efforts (CoJ 2011:36).

In an attempt to salvage waste and generate building materials for low cost housing, USE-IT (a Durban based recycling company) found that 6 000 tonnes of waste are generated daily in Durban, of which 10-12% is C & DW (Unilever 2013:1). This amounts to 219 000 tonnes of C & DW going to landfill sites around Durban each year.

Figure 4.7: Typical construction and demolition waste in South Africa, with the concrete either landfilled or crushed for aggregate and bricks being recycled

5. CHAPTER 5 – LIFE CYCLE INVENTORY: DATA COLLECTION

5.1 CRADLE TO GATE PHASE

5.1.1 Introduction

In this chapter the processes associated with the production of clay bricks in South Africa that have the potential to contribute to the identified environmental impacts will be evaluated by means of data gathered by appropriate research methods.

A number of methods were considered to gather the quantitative data required to achieve the objectives of this study. Several initial investigations were made into the expected validity and variability of results from each of the manufacturers. These investigations were conducted using interviews and discussions with the relevant members of the Clay Brick Association of South Africa.

After the validity and variability of results from the manufacturers were established, it became possible to develop a logistically practical data collection process. The data collection process was undertaken by the authors and assistants who visited the brick production sites. The majority of brick manufacturers were visited in person but due to logistical constraints, some were targeted digitally using the same questionnaire.

In the section on Research Methodology (Chapter 1 Section 1.5) the motivation for the use of the field survey technique to gather data, particularly for quantitative research, was discussed. The methodology to be used in compiling and pre-testing the survey questionnaire was also investigated.

These quantitative data together with the qualitative data gathered in Chapters 2 and 4 will be used to formulate recommendations in Chapter 7.

The information required to compile the questions in the field survey questionnaire was gathered from the following processes and sources:

- An analysis of the different firing technologies used in the clay brick manufacturing industry in South Africa to determine the variability in processes and potential challenges within each to answer the set questions. Consultations with Clay Brick Association members were held to complete this analysis.
- Two site visits to clay brick manufacturers who employ the most often used firing technologies in South Africa.
- A review of publications on the different firing technologies and the differences between them to identify questions that ask for data which may be difficult to retrieve otherwise.
- An assessment of the necessary information to model and formulate an LCA in the *SimaPro* software.
- Multiple discussions with key role players who are familiar with the clay brick manufacturing industry in South Africa.

5.1.2 The survey

5.1.2.1 ISSUES ADDRESSED IN THE SURVEY

The questionnaires were aimed at gathering quantitative data necessary for developing an LCA in *SimaPro* which would evaluate the environmental impacts of the clay brick manufacturing industry in South Africa. The main impact categories investigated are:

- Land use.
- Water use.
- Energy use.
- Waste created (emissions, landfill, pollution, etc.).

Subsequently, the investigated categories were researched for the following manufacturing properties:

- Firing technology used.
- Quantities and dimensions of products produced.
- Mass of the products produced.
- Quantities of products sold compared to produced.
- Land usage.
- Clay mining statistics.
- Raw material extraction methods, quantities and fuel used.
- Clay stockpile statistics.
- Raw material preparation systems, quantities, energy, fuel, water, additives.
- Plant water source and quantity used per year.
- Wastage during production stages and end of life of waste.
- Type of drying used and associated energy requirements.
- Internal body fuel quantities, calorific value, fuel used to transport the internal body fuel.
- External body fuel quantities, calorific value, fuel used to transport the external body fuel.
- Gases expelled from firing process.
- Yield percentage of the production.
- End of life of firing waste.
- Energy consumption for the manufacturing plant.
- Electrical energy used by the manufacturing plant.

The consent form by respondents and the questionnaire used in the field survey of this study are shown in Appendix 2.

5.1.2.2 VARIABILITY OF THE QUESTIONNAIRE

One questionnaire was designed to be used for data collection at all the visited production plants. Differentiating between questionnaires for the different firing technologies was found to be unnecessary as the manufacturing processes employed by each firing technology are known to be somewhat similar, yet with some difference in the type of fuel, water usage, land, electrical energy and green brick drying employed. It was therefore found appropriate to address all the issues within one generic questionnaire, which would later, during data capturing, be separated into the different firing technologies. Where questions are not applicable to particular respondents they were requested to write *n/a* in the provided answer blocks, in order to be disregarded when formulating averages and counts across the industry.

5.1.2.3 SURVEY TARGET POPULATIONS

The Clay Bick Association of South Africa is mostly aware of all the clay brick manufacturers in South Africa, since most of these manufacturers are members of the Association. It was therefore decided to use the full list of clay brick manufacturers provided by the CBA to determine the target population. Table 5.1 shows the breakdown of the population. Non-operational plants and plants not in South Africa were not targeted in this study.

Table 5.1: Breakdown of the population targeted for the survey

Category	Number
Total population of known manufacturers	112
Operational manufacturers in South Africa	102
Non-operational manufacturers	10
Manufacturers out of South Africa	4
Manufacturers who employ two firing technologies *	3
Target population for study	**Operational manufacturers in SA: 102**

*Manufacturers who employ more than one firing technologies were treated as separate entities, with proportional allocation of all inputs and outputs; ultimately adding a manufacturing plant per additional firing technology. The target population is made up of 68% of manufacturers that employ clamp kilns, 20% tunnel kilns, 6% TVA kilns, and 2% each of Hoffman, VSBK and zigzag kilns.

The following process was followed for data collection:

- An introductory letter was sent digitally to respondents alerting them of the LCA and a brief background
- A digital copy of the questionnaire with instructions on what to expect (see Appendix 2) was sent to all respondents
- Logistically accessible manufacturers were identified, after which an itinerary was set up to visit the selected manufacturing plants.
- Data collection took place from 15 June 2013 to 15 August 2013.
- Data were then collated and inputted into a statistically suitable framework in Microsoft Excel.
- Data was separated and aggregated into the different firing technologies, and into the required format for input into a *SimaPro* model.

5.1.2.4 OVERALL RESPONSE

The target population of 102 yielded 86 responses (84.3%), which can be regarded as a high response rate.

5.1.3 Data collection and data quality

The authors collected and compiled data for the various identified stages of the brick production as part of the cradle to gate phase of the LCA. This resulted in primary data for clay extraction and brick manufacturing. These data have been combined with literature data where there were data gaps to build the necessary inventory for a *SimaPro* model. Table 5.2 describes the data sources and quality.

Table 5.2: Data source and quality for the cradle to gate phase

Life Cycle stage	Description of processes	Related data	Data source	Indicative data quality
Extraction of raw material	Mining of clay from quarry, energy requirements for mining clay	Energy, material, water, fuel	CBA members and other brick manufacturers	Good (primary data)
Manufacturing of brick products	Crushing of clay mix, addition of water, fuel and additives, drying of wet green bricks, firing of dry green bricks, transport of wet green bricks, dry green bricks, fired bricks	Energy, material, water, fuel	CBA members and other brick manufacturers	Good (primary data)
Emissions from burning fuels	Harmful emissions which contribute to greenhouse gases and other harmful substances in the atmosphere	Air emissions due to burning fossil fuels (Preferably in RSA)	CBA members, literature, *EcoInvent* database	Good (primary data) and Reasonable (secondary data)
Type and production of fuels	Generated in RSA	Environmental impacts associated with generation of electricity in SA	*EcoInvent* database – new addition of RSA electricity	Good (primary data)

5.1.4 Representation of the data

The clay extraction and brick manufacturing data represent the most recent 12-month period of operation of the manufacturers. Data were collected during the middle of 2013, with data representing 1 January 2012 to 31 December 2012 in most cases. The data are representative of the technologies used in the country, manufacturers who did not respond are all using a technology which had been covered in the other responses received. Geographically the study covers 83% of all manufacturers in South Africa. Table 5.3 represents these data.

Table 5.3: Representation of the data for the clay extraction and brick manufacturing stages

Component	Total yearly production of respondents (kg)	Equivalent standard brick equivalents (n)	Percentage of national production (full population)
Manufactured bricks	9 611 178 437 kg fired clay	3 494 973 977 SBE	95% * estimate

*this figure is an estimate provided by the Clay Brick Association

5.1.5 Averaging the data

The respondents in the survey provided data particular to their plants, such as the various energy inputs, e.g. litres of diesel, MJ of natural gas, kWh of electricity, etc. These data were then averaged according to production volume to create a profile for each firing technology.

5.1.6 Validation of the data

Validation of data for the cradle to gate phase was done by performing a mass balance check.

The mass balance check (see Table 5.4) over the brick manufacturing life cycle indicated a 95.5% correlation. The difference between the mass of material mined and imported and the mass of bricks manufactured (4.5%) is mainly due to the variation in clay densities across South Africa. Moisture content variations have been excluded since these cannot be averaged; clay densities can however be averaged.

Table 5.4: Mass balance check to validate the data

Description	Unit
Volume of material mined and imported	5 591 099m³
Average density of the material	1800kg/m³**
Mass of material mined and imported	10 063 978 200kg
Mass of bricks manufactured	9 611 178 437kg
Thus: Mass check percentage correlation	95.5%

(**Average density provided by Volsteedt *et al.* 2013)

Energy consumption data (electricity, natural gas, diesel and other fuels) related to clay extraction and brick production have been retrieved from invoices from the suppliers.

5.1.7 Data inventory for the cradle to gate phase

The data collected from the field survey were audited by the University of Pretoria Statistics Department. An integrated spread sheet was developed and populated with calculations of the primary data so collected.

5.1.8 Emissions inventory

As the data obtained for the emissions from burning coal were not satisfactory for inclusion in the *SimaPro* model, it was deemed acceptable to use emissions data obtained from the *EcoInvent* v2.2 databases for burning coal, translated from the “Hard Coal Coke, burned in stove” dataset, and expressed per MJ coal burnt. In Table 5.5 these emissions data are shown.

Since discarded tyres are burned in isolated cases as a fuel source (refer to appendices for fuels per kiln type), emissions data from burning tyres have been extracted from site specific emission studies (Langkloof Emissions Survey, April 2016, Lethabo Air Quality Specialists CC) for use in the *SimaPro* model. Table 5.6 shows the emissions data associated with tyre burning. The data received in the emissions study is deemed an acceptable proxy, as very limited data is available. Please refer to Appendix 12 for the emissions study, and permission from the manufacturer for use of this data.

Table 5.5: Emissions data used for burning 1kg coal (*EcoInvent* v2.2)

Emission	Quantity	Unit		Emission	Quantity	Unit
Heat, waste	1.01	MJ		Molybdenum	2.7E-09	kg
Aluminium	1.07E-05	kg		Nickel	2.97E-08	kg
Antimony	1.8E-09	kg		Nitrogen oxides	0.00006	kg
Arsenic	2.66E-08	kg		non-methane volatile organic compounds (unspecified origin)	7.5E-07	kg
Barium	9E-08	kg		Particulates, < 2.5 um	0.000005	kg
Benzene	2.5E-07	kg		Particulates, > 10 um	0.000035	kg
Benzo(a)pyrene	1E-10	kg		Particulates, > 2.5 um, and < 10um	0.00001	kg
Beryllium	1.26E-09	kg		Phenol	5E-08	kg
Boron	5.6E-07	kg		Phosphorus	6.32E-08	kg
Bromine	9.48E-09	kg		Polonium-210	0.000085	kBq
Calcium	1.26E-06	kg		Potassium	1.26E-06	kg
Cadmium	1.58E-09	kg		Potassium-40	1.35E-05	kBq
Carbon dioxide, fossil	0.095	kg		Propane	5E-07	kg
Carbon monoxide, fossil	0.005	kg		Propene	2.5E-07	kg
Chromium	8.91E-09	kg		Radium-226	0.000012	kBq
Chromium VI	9E-11	kg		Radium-228	0.000065	kBq
Cobalt	4.5E-09	kg		Radon-220	0.000001	kBq
Copper	1.55E-08	kg		Radon-222	0.000001	kBq
Dinitrogen monoxide	1.5E-06	kg		Scandium	1.26E-09	kg
Dioxins	5E-13	kg		Selenium	8.98E-09	kg
Ethane	7.5E-07	kg		Silicon	1.58E-05	kg
Ethene	1.5E-06	kg		Sodium	6.32E-07	kg
Ethyne	2.5E-07	kg		Strontium	1.35E-07	kg
Formaldehyde	1E-07	kg		Sulphur dioxide	0.00044	kg
Hydrocarbons, aliphatic, alkanes	2.5E-07	kg		Thallium	1.58E-09	kg
Hydrocarbons, aliphatic, unsaturated	2.5E-07	kg		Thorium	1.44E-09	kg
Hydrogen chloride	1.52E-05	kg		Thorium-228	5.5E-06	kBq
Hydrogen fluoride	1.77E-06	kg		Thorium-232	3.5E-06	kBq
Hydrogen sulphide	0.000001	kg		Tin	6.32E-10	kg
Iodine	1.14E-08	kg		Titanium	3.79E-07	kg
Iron	4.42E-06	kg		Toluene	5E-08	kg
Lead	1.08E-07	kg		Uranium	1.8E-09	kg
Lead-210	4.65E-05	kq		Uranium-238	0.00001	kBq
Magnesium	3.79E-06	kg		Vanadium	3.6E-08	kg
Manganese	3.15E-08	kg		Xylene	5E-08	kg
Mercury	3.36E-09	kg		Zinc	1.58E-07	kg
Methane, fossil	0.000015	kg				

Table 5.6: Emissions data used for burning tyres from external emissions study (per MJ fuel burnt)

Emission	Quantity	Unit		Emission	Quantity	Unit
Carbon monoxide	2.02	mg		Hydrogen fluoride	0.015	mg
Sulphur dioxide	64.9	mg		TOC, Total Organic Carbon	0.030	mg
Nitrogen dioxide	8.8	mg		Ammonia	0.013	mg
Hydrogen chloride	0.368	mg		Dioxins/furans	0.15	ng

5.2 GATE TO END OF OPERATIONAL LIFE PHASE

5.2.1 Introduction

For this phase the processes associated with the construction of clay brick walls in South Africa that have the potential to contribute to the identified environmental impacts were evaluated by means of qualitative data gathered by appropriate research methods.
It was deemed appropriate to assess the materials required for the construction of $1m^2$ of clay brick wall, i.e. the cement mortar, plaster and paint, in accordance with recommended best practise methods provided by the Cement and Concrete Institute of South Africa.

5.2.2 Data collection

The following aspects regarding data collection for the gate to end of operational life phase were considered:

5.2.2.1 RESEARCH METHOD

Qualitative data were obtained by means of a desktop study as well as an assessment of the available data in the *EcoInvent* database.

5.2.2.2 ISSUES ADDRESSED IN THE DATA COLLECTION

The following issues were addressed during the research for the gate to end of operational life phase of the LCA:

- The average distance the number of bricks for $1m^2$ of clay brick walling is transported to site.
- The quantity of binding material (cement mortar, and associated input materials) required to build in clay bricks in $1m^2$ of walling.
- The quantity of water required for wetting clay bricks before building in to the wall.
- The quantity of materials required to plaster $1m^2$ of clay brick wall.
- The quantity of material required to paint $1m^2$ of plastered wall.
- The quantity of material required for wall ties when constructing cavity walls.
- The quantity of material required for insulation typically installed in South Africa in accordance with SANS 10400 Part XA.

5.2.2.3 VARIABILITY OF THE DATA

Since different building contractors may use different ratios or mixes of the materials used for building in clay bricks to what is recommended by the Cement and Concrete Institute of South Africa, it was deemed acceptable to ignore such possible variations and to only apply the best practice ratio of quantities as recommended by the Cement and Concrete Institute.

5.2.3 Data sources and quality

In Table 5.7 the source and an indication of the quality of such data collected for this phase of the LCA are given.

Table 5.7: Data source and quality for the gate to end of life phase of the LCA

Life Cycle stage	Description of processes	Related data	Data source	Indicative data quality
Transport to site	Distance to site, weight of bricks required for brick wall	Environmental impacts associated with transporting bricks to site	Field survey	Good (primary data)
Building in components	Mortar, plaster, paint, wall ties, insulation	Environmental impacts associated with the production of building in components	Cement and Concrete Institute and *EcoInvent* database	Good (primary data)
Operational energy	Annual operational energy required to retain thermal comfort within clay brick buildings in South Africa	Environmental impacts associated with the operation of clay brick structures	Thermal Performance Study by the University of Pretoria (unpublished)	Good (primary data)
Electricity used during manufacturing and operational stage	Generated in RSA	Environmental impacts associated with generation of electricity in SA	*EcoInvent* database – new addition of RSA electricity generation data	Good (primary data)

5.2.4 Averaging the data

Averaging of the collected data was done for the first step (gate to building site) in this phase of the LCA. It was considered acceptable to average the transport to site distance for the average clay brick manufactured in South Africa as it is obvious that the further the distance a product is transported, the greater the environmental impact of the transport component will be.

5.2.5 Validation of the data

Validation of the data for this stage is unnecessary as the stage is singular and is considered as an assembly and not a life cycle on its own. An assembly is a summation of processes for a specific stage and no mass can be lost between stages as there is only one stage.

5.2.6 Data inventory for the gate to end of operational life phase

The collected data is summarised in Appendix 6 as inputs into each unit process. For the purposes of this LCA, the data for this stage have been presented in its elementary form rather than in the summation of each walling type.

5.3 DEMOLITION, WASTE AND RECYCLE PHASE

5.3.1 Introduction

This phase of the LCA deals with the processes associated with the demolition, waste generation and recycling of clay brick walls that have the potential to contribute to the identified environmental impacts and will be evaluated by means of qualitative data gathered by appropriate research methods.

In South Africa, brick recycling is not a formalised industry sector and is therefore very difficult to obtain reliable and representative data on the extent of recycling.
The desktop study did nonetheless indicate that a significant quantity of clay brick is recycled either prior to arriving at, or from landfill sites.

5.3.2 Data collection

The following aspects regarding data collection for the demolition, waste and recycle life phase were considered:

5.3.2.1 RESEARCH METHOD

Qualitative data were obtained by means of a desktop study as well as an assessment of the available data in the *EcoInvent* database.

5.3.2.2 ISSUES ADDRESSED IN THE DATA COLLECTION

The following issues were addressed during the data collection for the demolition, waste and recycle phase of the LCA:

- The average distance the number of bricks for 1m² of clay brick walling is transported to landfill.
- The quantity of binding material (cement mortar, and associated input materials) required to build in clay bricks in 1m² of walling going to landfill.
- The quantity of materials required to plaster 1m² of clay brick wall going to landfill.
- The quantity of material required to paint 1m² of plastered wall going to landfill.
- The quantity of material required for wall ties when constructing cavity walls going to landfill.
- The quantity of material required for insulation typically installed in South Africa in accordance with SANS 10400 Part XA and going to landfill.

5.3.2.3 VARIABILITY OF THE DATA

Since different contractors may use different modes to transport bricks to landfill sites it was deemed appropriate to assess this phase primarily based on the transport data available on the *EcoInvent* database.

5.3.3 Data sources and quality

In Table 5.8 the source and an indication of the quality of such data collected for this phase of the LCA are given.

Table 5.8: Data source and quality for the demolition waste and recycle phase of the LCA

Life Cycle stage	Description of processes	Related data	Data source	Indicative data quality
Transport to landfill	Distance bricks and other materials travel to landfill sites	Environmental impacts associated with transporting bricks to landfill site	*EcoInvent* database	Average (secondary data)
Demolition energy	Energy required in the demolition process	Environmental impacts associated with the production of demolition energy	*EcoInvent* database	Average (secondary data)
Emissions due to demolition	Emissions emitted during the demolition phase	Environmental impacts associated with emissions from the demolition of structures	*EcoInvent* database	Average (secondary data)
National recycling quantities	Percentage of bricks currently being recycled in South Africa	Environmental impacts associated with the recycling of clay bricks	Department of Environmental Affairs	Average (secondary data)

5.3.4 Validation of the data

Validation of the data for this stage is unnecessary as the stage is singular and is considered as an assembly and not a life cycle on its own. An assembly is a summation of processes for a specific stage and no mass can be lost between stages as there is only one stage.

5.3.5 Data inventory for the demolition, waste and recycle phase

The collected data is summarised in Appendix 10 as inputs into each unit process. For the purposes of this LCA, the data for this stage have been presented in quantities when reaching the end of life of 1m² clay brick walling.

6. CHAPTER 6 – LIFE CYCLE IMPACT ASSESSMENT: RESULTS

6.1 INTRODUCTION

In this chapter, the *SimaPro* model will be used to identify and quantify the environmental impacts associated with the life cycle of clay bricks in South Africa. Typically, in LCA, this stage in the complete process is called Life Cycle Impact Assessment (LCIA) which is aimed at evaluating the significance of potential environmental impacts using the inventory results (SANS 2006a:14). The process of LCIA involves associating inventory data with specific environmental impact categories and category indicators, thereby attempting to understand these impacts by providing information for the interpretation phase of the process which will be done in Chapter 7 (*ibid*.).

The selected impact assessment method is *Impact 2002+.* This method addresses the objectives of the study and calculates the results required to achieve the stated objectives.

6.2 METHODOLOGY FOR DATA MODELLING (PROCEDURE)

The guidelines for the methodology to be followed when conducting a LCA are given in ISO 14040 (SANS 2006a) and ISO 14044 (SANS 2006b). These were followed to ensure that accuracy and completeness have been achieved throughout the LCA process.

The following methodology was used for modelling of the data for the LCA process:

- Step 1: Re-assessment of the unit processes within the product system.
- Step 2: Allocation of inventory data to the unit processes.
- Step 3: Identification of reference products for each unit process.
- Step 4: Configuration and calculation of allocated inventory data into the necessary SI units relating to the LCA functional units.
- Step 5: Input of data into the *SimaPro* model (See Appendix 3).
- Step 6: Calculation of environmental impacts
- Step 7: Analysis and discussion of the results

6.3 SUMMARY OF UNIT PROCESSES

Steps 1 to 3 have been summarised in Appendix 4 which reassesses the unit processes for the identified product system, categorises the unit processes into the different phases as well as identifies the stage at which the unit process stops elementary flows.

Appendix 4 shows what data have been allocated to the unit processes to ensure all data collected have been used within the product system. A reference product has also been identified for each unit process.

6.4 TECHNICAL PROCESS OF LCA MODELLING

The description below is a summary of the steps taken to develop the *SimaPro* model for this study.

In *SimaPro* unit processes are material based, energy based, transport based, processing based or use based. The waste type and waste scenario should be selected when developing unit processes.

Once it has been established what type of unit process is going to be inputted into the library, the category within the type has to be chosen, often it is more practical to create a new category specific to the project which allows for easier navigation within the libraries.

The next step in developing the model in *SimaPro* involves the input of all the elementary and product flows as well as the outputs associated with the unit process being modelled.

Firstly, a known output to the technosphere needs to be inserted, it is best to consider having a suitable name which identifies the product, location in the life cycle, and the regional location of the product. An example could be: Glass bottle, at cleaning, ZA.

The next step is selecting the amount and unit of the product that will be modelled. Allocation (if there is more than one product for this unit process) and waste type need to be selected before moving on to the elementary flows.

The following step is inserting the known inputs from nature; this covers all items which can be found naturally in the environment, water, wood, air, gases, plants etc. The quantity of the input required to produce the amount of stipulated “output to technosphere” must also be inserted. Multiple inputs from nature can be inserted.

The same process is followed for inputs from the technosphere; these are items which have undergone processing by man, such as mined clay, manufactured concrete, manufactured steel, etc. Quantities need to be inserted as well.

Outputs are inserted in a similar way, although it is the responsibility of the modeller to know whether these emissions are to air, water, land or waste emissions (for which a waste treatment process is selected).

Multiple unit processes can be inserted. The next step is to assemble the unit processes into specific assemblies that occur in the life cycle. When creating assemblies, the process is similar to the above, with selection of the unit processes recently created, or from a library of data and then adding processes to this assembly if necessary.

Once the assembly has been modelled, the network can be viewed; this will show the relative contributions of the inputs of the unit processes within the assembly.

6.5 IMPACT RESULTS – CRADLE TO GATE PHASE

The Life Cycle Inventory Assessment results have been calculated for the reference flow indicated in Chapter 2 of the study. The results for six types of firing technologies are summarised in Table 6.1 and are presented per kg of fired clay brick.

Table 6.1: Impact category results for all firing technologies per kg of fired clay brick

Impact category	Unit	Clamp kiln_final rev1	Tunnel kiln_final rev1	VSBK kiln_final rev2	TVA kiln_final rev1	Zigzag kiln_final rev1	Hoffman kiln_final rev1	Weighted Average
Carcinogens	kg C2H3Cl eq	0.00217491	0.00177026	0.00225322	0.00224575	0.00190803	0.00427089	0.002123
Non-carcinogens	kg C2H3Cl eq	0.01092622	0.00535910	0.01137527	0.01139917	0.00920686	0.02193616	0.010039
Respiratory inorganics	kg PM2.5 eq	0.00016065	0.00014634	0.00029380	0.00023817	0.00015477	0.00029462	0.000169
Ionizing radiation	Bq C-14 eq	0.42093342	0.54806516	0.38893235	0.75018383	0.42877667	0.60425785	0.478998
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000	0.000000
Respiratory organics	kg C2H4 eq	0.00002614	0.00003168	0.00002327	0.00002409	0.00003086	0.00003714	0.000027
Aquatic ecotoxicity	kg TEG water	34.27989118	16.44613402	27.86532683	31.23583169	23.11512871	53.78178809	30.706005
Terrestrial ecotoxicity	kg TEG soil	9.30269052	4.50354896	7.77553166	8.47720434	6.78523946	14.94202440	8.347988
Terrestrial acid/nutri	kg SO2 eq	0.00348232	0.00342582	0.00584721	0.00531728	0.00348903	0.00592364	0.003720
Land occupation	m2org.arable	0.00085851	0.00035120	0.00058972	0.00055148	0.00059941	0.00187126	0.000735
Aquatic acidification	kg SO2 eq	0.00146539	0.00123979	0.00301916	0.00219968	0.00131888	0.00278059	0.001536
Aquatic eutrophication	kg PO4 P-lim	0.00008107	0.00002727	0.00005271	0.00005289	0.00004408	0.00010156	0.000068
Global warming	kg CO2 eq	0.26554181	0.24426787	0.28045177	0.33417085	0.23733932	0.51526328	0.270608
Non-renewable energy	MJ primary	3.58058319	3.19801007	2.52821803	3.28309681	2.26506805	4.53792822	3.463484
Mineral extraction	MJ surplus	0.00023532	0.00018969	0.00019122	0.00016711	0.00028370	0.00030648	0.000220

The results presented in Table 6.1 show the overall contribution of each firing technology to impact categories. The average across all firing technologies gives an overall view of the clay brick manufacturing industry in South Africa in terms of the impact categories assessed. The results shown have been subjected to characterization, which means numerical values for each have been subjected to factors which are used to quantitatively model the impact from each emission/resource that comes from the life cycle inventory (LC-Impact 2012).

6.5.1 Results of environmental impact contributions for all firing technologies

Figure 6.1 below shows the results of comparing impact categories under normalization.

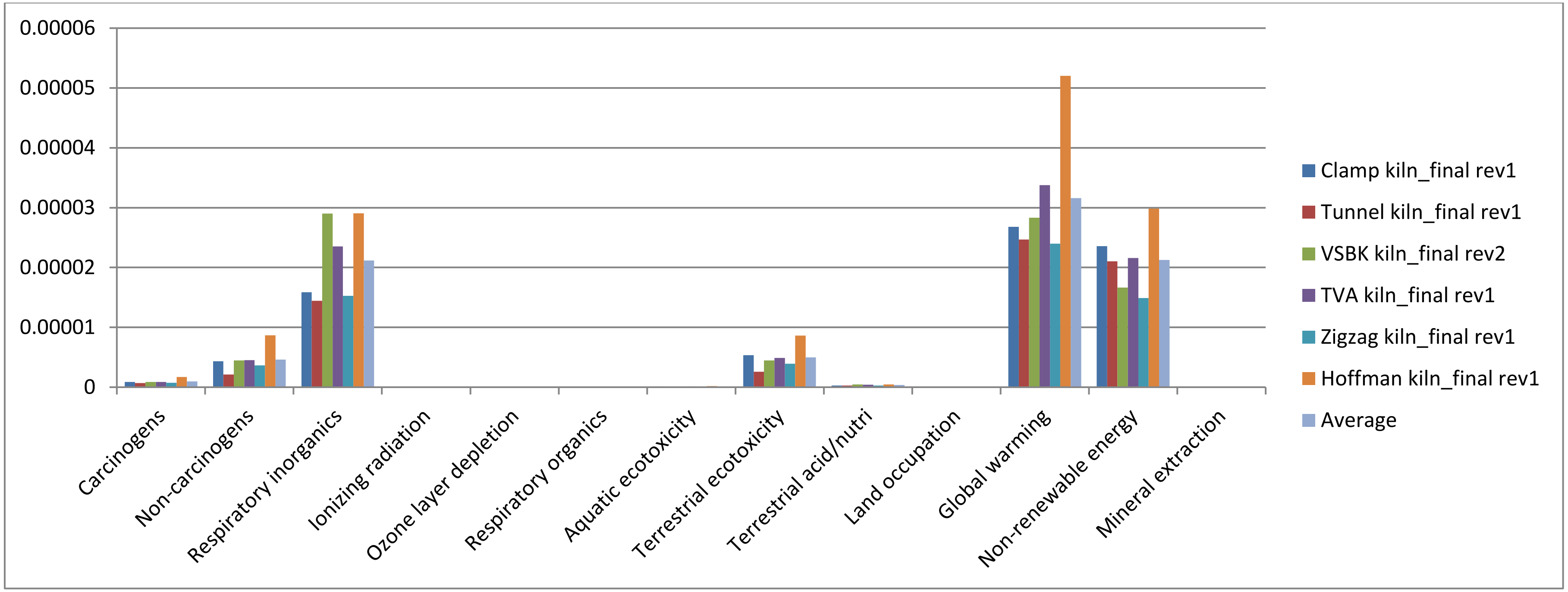

Figure 6.1: Comparison of normalization results for all firing technologies across impact categories (Normalized per person per year in Europe)

The purpose of normalization is to analyse the respective share of each impact to the overall damage to the environment. Normalization facilitates interpretation of results by comparing the different impact categories on the same graph with the same units. In normalization, results are subjected to normalization factors, which are designed to compare impacts for an overall view of the environmental impact of the assessed LCA (Impact 2002+). The full inventory of emitted substances for all firing technologies can be found in Appendix 5. Items 6.5.2 onwards will present more in-depth results for the different firing technologies. The subsequent sections should be read in conjunction with Appendix 4 in order to understand the inventory behind each unit process for each firing technology.

6.5.2 Results for clamp kiln firing technology

Table 6.2 below shows the contributions of each predefined unit process of clamp kilns towards the environmental impacts assessed. The full inventory of emitted substances for the clamp kiln firing technology can be found in Appendix 5.1. The total contribution of the unit processes within Table 6.2 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process C7 is unit process C5 and subsequently C3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.2: Clamp kiln characterization results per kg fired clay brick

Impact category	Unit	Total	C7, Clamp, brick firing, fired brick, ZA rev1	C0, Clamp, transport of fuels, at plant, ZA	C2, Clamp, mining fuel, stockpiled clay, ZA	C4, Clamp, wet green brick transport, wet bricks ready for drying, ZA	C6, Clamp, dry green brick transport, at firing location, ZA	C8, Clamp, fired brick transport, at sales bay, ZA	C9, Clamp, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.002174908	0.002120912	0.000018690	0.000017289	0.000006580	0.000006605	0.000004785	0.000000048
Non-carcinogens	kg C2H3Cl eq	0.010926216	0.010879259	0.000028074	0.000009168	0.000003490	0.000003503	0.000002538	0.000000185
Respiratory inorganics	kg PM2.5 eq	0.000160648	0.000143126	0.000003521	0.000006729	0.000002561	0.000002571	0.000001863	0.000000277
Ionizing radiation	Bq C-14 eq	0.420933419	0.377434467	0.026607847	0.007533687	0.002867340	0.002878049	0.002085169	0.001526860
Ozone layer depletion	kg CFC-11 eq	0.000000002	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000	0.000000000
Respiratory organics	kg C2H4 eq	0.000026135	0.000018922	0.000001844	0.000002628	0.000001000	0.000001004	0.000000727	0.000000010
Aquatic ecotoxicity	kg TEG water	34.279891176	33.873926290	0.182083228	0.103329881	0.039327604	0.039474493	0.028599576	0.013150103
Terrestrial ecotoxicity	kg TEG soil	9.302690524	9.130472126	0.119588058	0.024197791	0.009209738	0.009244137	0.006697448	0.003281226
Terrestrial acid/nutri	kg SO2 eq	0.003482319	0.003021260	0.000118091	0.000164633	0.000062660	0.000062894	0.000045567	0.000007215
Land occupation	m2org.arable	0.000858509	0.000826996	0.000024869	0.000003255	0.000001239	0.000001244	0.000000901	0.000000005
Aquatic acidification	kg SO2 eq	0.001465392	0.001395815	0.000017698	0.000024215	0.000009216	0.000009251	0.000006702	0.000002495
Aquatic eutrophication	kg PO4 P-lim	0.000081073	0.000080239	0.000000288	0.000000267	0.000000102	0.000000102	0.000000074	0.000000000
Global warming	kg CO2 eq	0.265541806	0.257454142	0.002853347	0.002460987	0.000936658	0.000940156	0.000681150	0.000215365
Non-renewable energy	MJ primary	3.580583188	3.453605467	0.047628498	0.037429201	0.014245645	0.014298852	0.010359629	0.003015896
Mineral extraction	MJ surplus	0.000235317	0.000180337	0.000022544	0.000015891	0.000006048	0.000006071	0.000004398	0.000000029

Figure 6.2 below shows the normalization results for the numerical values presented in Table 6.2 above.

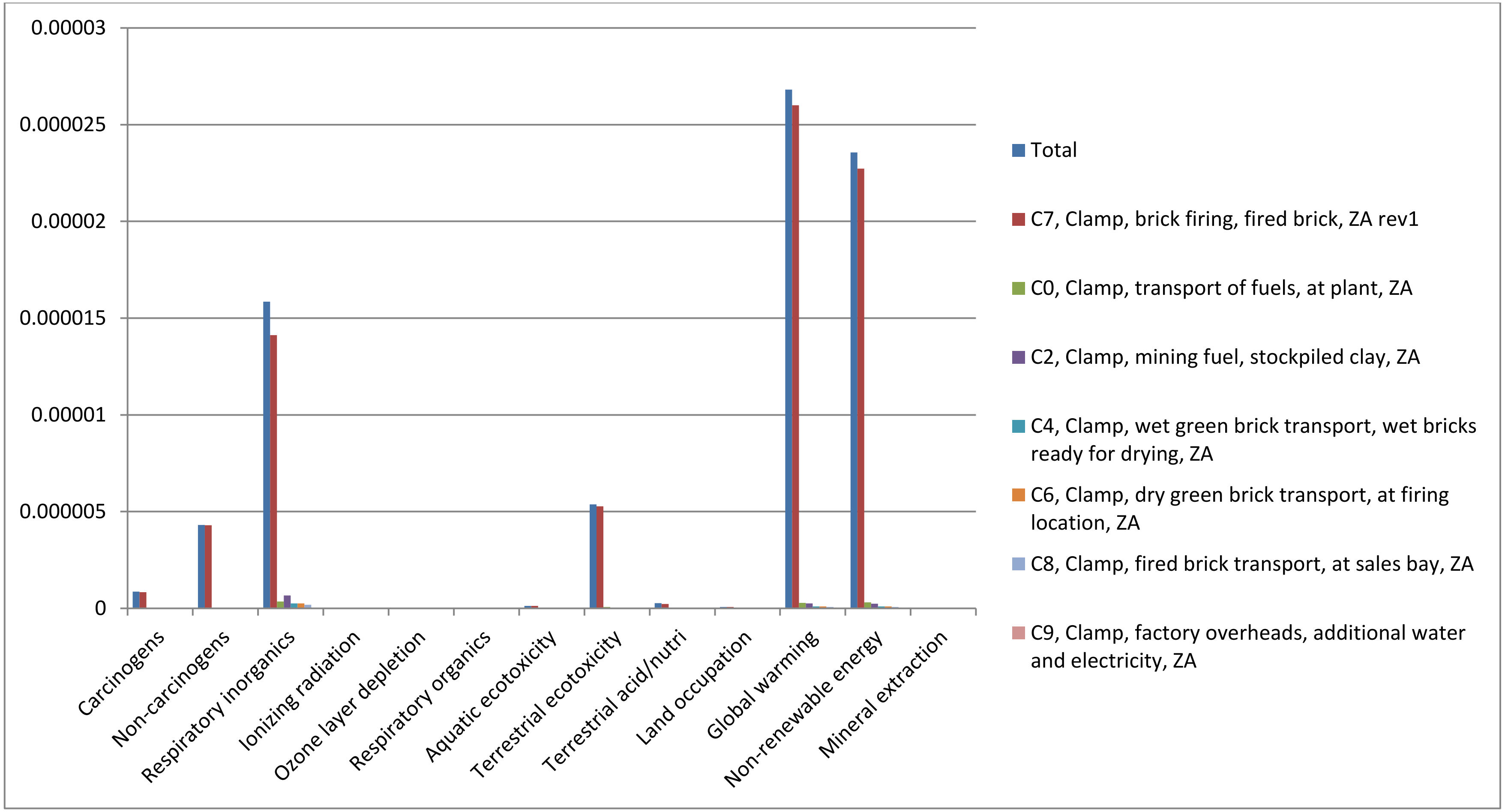

Figure 6.2: Normalization results for contributions to the environmental impacts assessed for the clamp kiln firing technology for predefined unit processes (Normalized per person per year in Europe)

6.5.3 Results for tunnel kiln firing technology

Table 6.3 below shows the contributions of each predefined unit process of tunnel kilns towards the environmental impacts assessed. The full inventory of emitted substances for the tunnel kiln firing technology can be found in Appendix 5.2. The total contribution of the unit processes within Table 6.3 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process T7 is unit process T5 and subsequently T3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.3: Tunnel kiln characterization results per kg fired clay brick

Impact category	Unit	Total	T7 Tunnel, brick firing, fired brick, ZA rev1	T0, Tunnel, transport of fuel, at plant, ZA	T2 Tunnel, mining fuel, stockpiled clay, ZA	T4 Tunnel, wet green brick transport, wet bricks ready for drying, ZA	T6 Tunnel, dry green brick transport, at firing location, ZA	T8 Tunnel, fired brick transport, at saled bay, ZA	T9 Tunnel, factory overheads, additional water and electricity, ZA rev1
Carcinogens	kg C2H3Cl eq	0.0017702577	0.0016934374	0.0000344745	0.0000357772	0.0000014235	0.0000007345	0.0000040201	0.0000003905
Non-carcinogens	kg C2H3Cl eq	0.0053591037	0.0052925232	0.0000428141	0.0000189728	0.0000007549	0.0000003895	0.0000021319	0.0000015174
Respiratory inorganics	kg PM2.5 eq	0.0001463432	0.0001227415	0.0000050005	0.0000139254	0.0000005541	0.0000002859	0.0000015647	0.0000022710
Ionizing radiation	Bq C-14 eq	0.5480651582	0.4683344652	0.0489421653	0.0155900196	0.0006202945	0.0003200559	0.0017517748	0.0125063829
Ozone layer depletion	kg CFC-11 eq	0.0000000140	0.0000000111	0.0000000022	0.0000000006	0.0000000000	0.0000000000	0.0000000001	0.0000000000
Respiratory organics	kg C2H4 eq	0.0000316832	0.0000224373	0.0000027874	0.0000054387	0.0000002164	0.0000001117	0.0000006111	0.0000000805
Aquatic ecotoxicity	kg TEG water	16.4461340200	15.8152095726	0.2724604505	0.2138282118	0.0085077799	0.0043897947	0.0240268381	0.1077113724
Terrestrial ecotoxicity	kg TEG soil	4.5035489614	4.2471050720	0.1708463984	0.0500742888	0.0019923518	0.0010280021	0.0056266047	0.0268762434
Terrestrial acid/nutri	kg SO2 eq	0.0034258177	0.0028068168	0.0001603884	0.0003406864	0.0000135552	0.0000069941	0.0000382813	0.0000590954
Land occupation	m2org.arable	0.0003512043	0.0002923707	0.0000508943	0.0000067360	0.0000002680	0.0000001383	0.0000007569	0.0000000400
Aquatic acidification	kg SO2 eq	0.0012397873	0.0011361900	0.0000243996	0.0000501089	0.0000019937	0.0000010287	0.0000056305	0.0000204359
Aquatic eutrophication	kg PO4 P-lim	0.0000272730	0.0000262017	0.0000004216	0.0000005535	0.0000000220	0.0000000114	0.0000000622	0.0000000007
Global warming	kg CO2 eq	0.2442678738	0.2320865797	0.0044451362	0.0050927040	0.0002026281	0.0001045509	0.0005722424	0.0017640326
Non-renewable energy	MJ primary	3.1980100681	3.0061502344	0.0763267172	0.0774550295	0.0030817746	0.0015901161	0.0087032456	0.0247029508
Mineral extraction	MJ surplus	0.0001896937	0.0001156646	0.0000352331	0.0000328839	0.0000013084	0.0000006751	0.0000036950	0.0000002336

Figure 6.3 below shows the normalization results for the numerical values presented in Table 6.3 above.

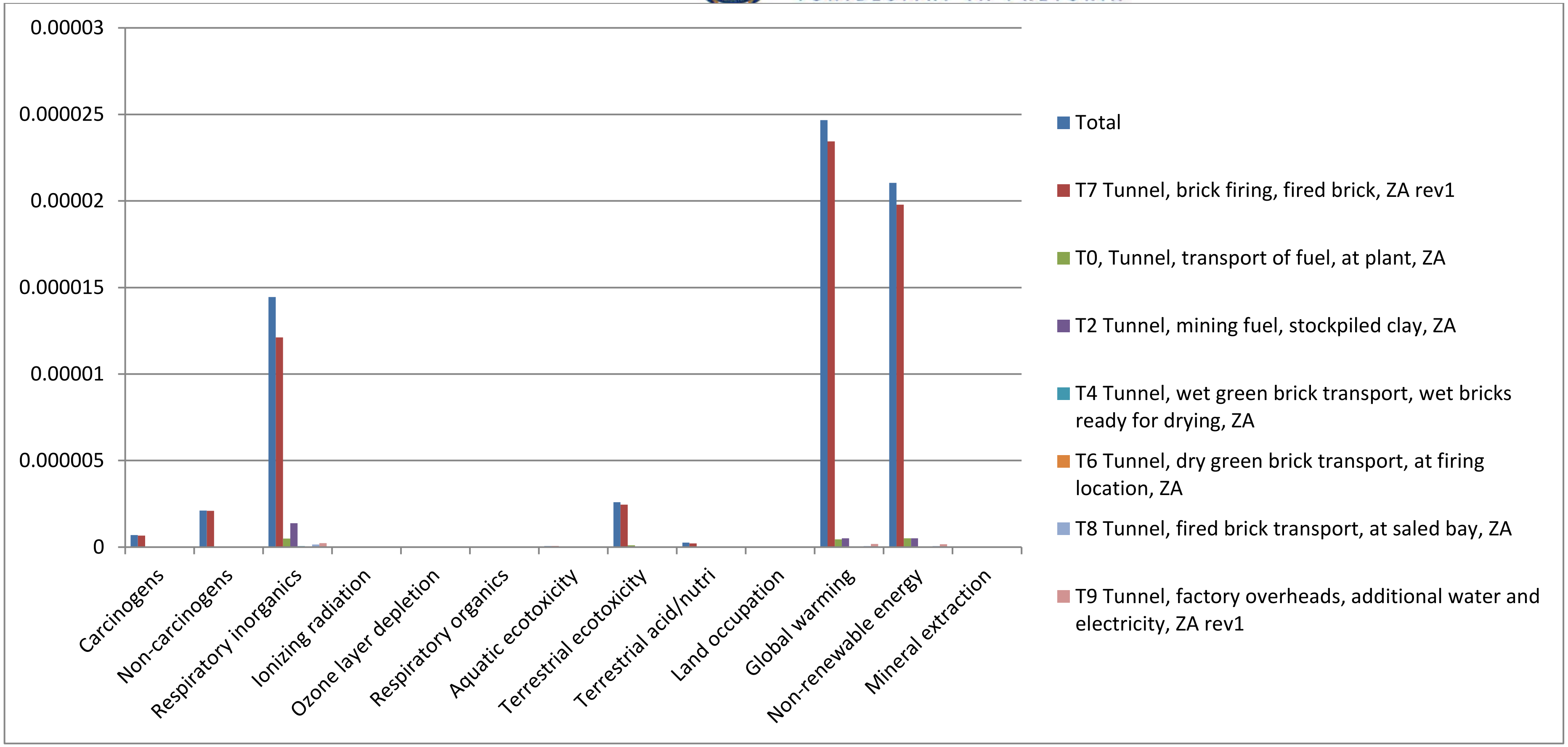

Figure 6.3: Normalization results for contributions to the environmental impacts assessed for the tunnel kiln firing technology for predefined unit processes (Normalized per person per year in Europe)

6.5.4 Results for TVA kiln firing technology

Table 6.4 below shows the contributions of each predefined unit process of TVA kilns towards the environmental impacts assessed. The full inventory of emitted substances for the TVA kiln firing technology can be found in Appendix 5.3. The total contribution of the unit processes within Table 6.4 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process TVA7 is unit process TVA5 and subsequently TVA3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.4: TVA kiln characterization results per kg fired clay brick

Impact category	Unit	Total	TVA7, brick firing, fired brick, ZA rev1	TVA0, transport of fuel, at plant, ZA	TVA2, mining fuel, stockpiled clay, ZA	TVA4, wet green brick transport, wet green brick ready for drying, ZA	TVA6, dry green brick transport, at firing location, ZA	TVA8, fired brick transport, at sales bay, ZA	TVA9, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00224575094	0.00220136891	0.00000541859	0.00002507277	0.00000193272	0.00000250033	0.00000835200	0.00000110563
Non-carcinogens	kg C2H3Cl eq	0.01139916587	0.01136679107	0.00000800228	0.00001329620	0.00000102493	0.00000132593	0.00000442910	0.00000429636
Respiratory inorganics	kg PM2.5 eq	0.00023817061	0.00021599934	0.00000100567	0.00000975899	0.00000075227	0.00000097319	0.00000325082	0.00000643032
Ionizing radiation	Bq C-14 eq	0.75018382834	0.69070503957	0.00757073646	0.01092553047	0.00084218758	0.00108952499	0.00363940653	0.03541140275
Ozone layer depletion	kg CFC-11 eq	0.00000000126	0.00000000041	0.00000000016	0.00000000045	0.00000000003	0.00000000004	0.00000000015	0.00000000001
Respiratory organics	kg C2H4 eq	0.00002409298	0.00001758365	0.00000052628	0.00000381147	0.00000029381	0.00000038009	0.00000126964	0.00000022804
Aquatic ecotoxicity	kg TEG water	31.23583168603	30.65271357250	0.05187369524	0.14985142470	0.01155120194	0.01494361053	0.04991705031	0.30498113082
Terrestrial ecotoxicity	kg TEG soil	8.47720433627	8.31410194036	0.03401688123	0.03509220532	0.00270506037	0.00349949458	0.01168957440	0.07609918000
Terrestrial acid/nutri	kg SO2 eq	0.00531728007	0.00475570308	0.00003375157	0.00023875403	0.00001840420	0.00002380923	0.00007953142	0.00016732653
Land occupation	m2org.arable	0.00055148415	0.00053716995	0.00000707312	0.00000472063	0.00000036389	0.00000047075	0.00000157249	0.00000011333
Aquatic acidification	kg SO2 eq	0.00219968499	0.00208374046	0.00000505800	0.00003511644	0.00000270693	0.00000350191	0.00001169765	0.00005786361
Aquatic eutrophication	kg PO4 P-lim	0.00005288629	0.00005221661	0.00000008207	0.00000038787	0.00000002990	0.00000003868	0.00000012920	0.00000000197
Global warming	kg CO2 eq	0.33417084628	0.32296603152	0.00082114808	0.00356898155	0.00027511268	0.00035590900	0.00118886445	0.00499479900
Non-renewable energy	MJ primary	3.28309680789	3.11746732230	0.01372452164	0.05428070706	0.00418419385	0.00541302659	0.01808146162	0.06994557484
Mineral extraction	MJ surplus	0.00016710734	0.00012520623	0.00000644355	0.00002304510	0.00000177642	0.00000229812	0.00000767656	0.00000066137

Figure 6.4 below shows the normalization results for the numerical values presented in Table 6.4 above.

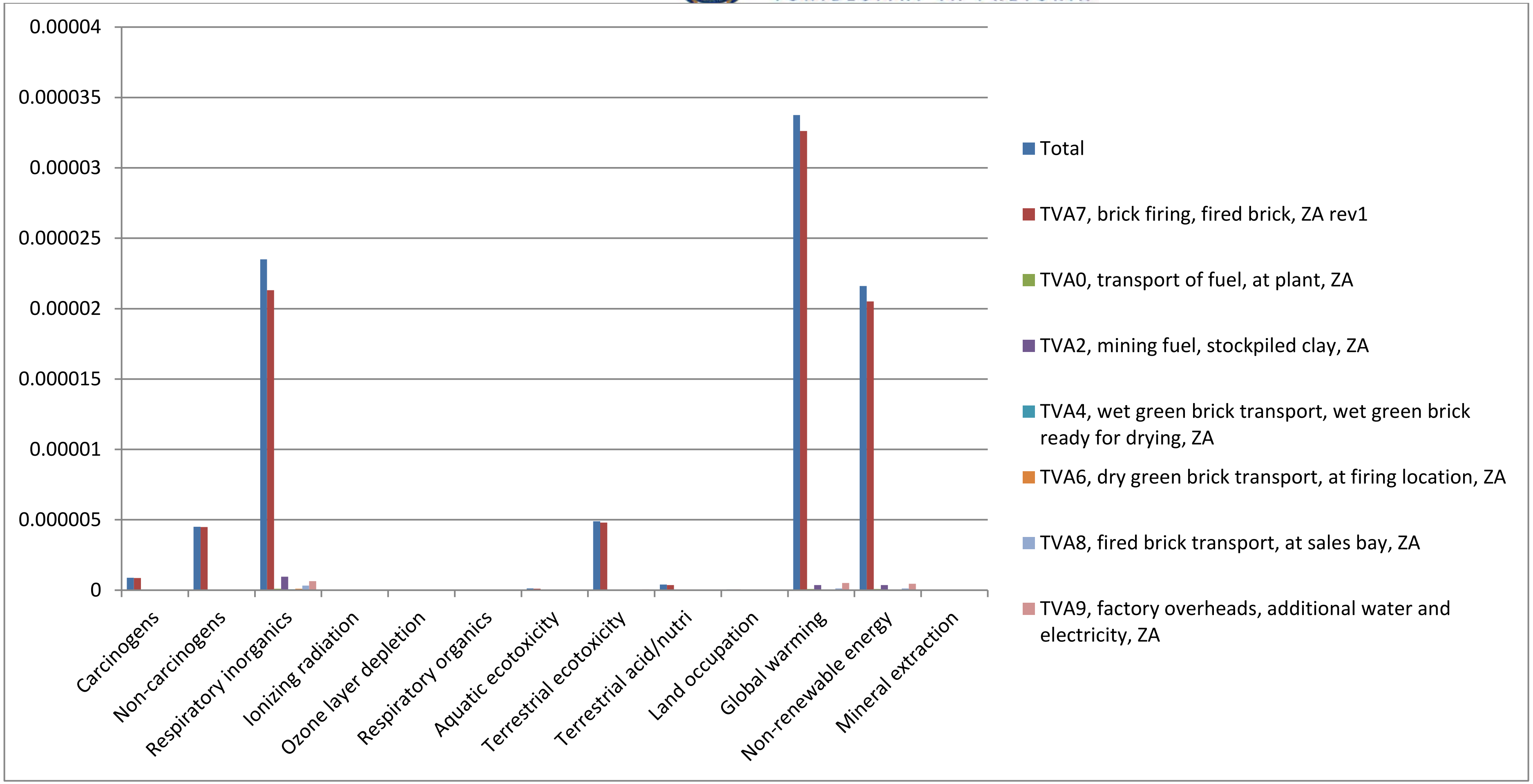

Figure 6.4: Normalization results for contributions to the environmental impacts assessed for the TVA kiln firing technology for predefined unit processes

(Normalized per person per year in Europe)

6.5.5 Results for the Hoffman kiln firing technology

Table 6.5 below shows the contributions of each predefined unit process of Hoffman kilns towards the environmental impacts assessed. The full inventory of emitted substances for the Hoffman kiln firing technology can be found in Appendix 5.4. The total contribution of the unit processes within Table 6.5 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process H7 is unit process H5 and subsequently H3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.5: Hoffman kiln characterization results per kg fired clay brick

Impact category	Unit	Total	H7, Hoffman, brick firing, fired brick, ZA rev1	H0, Hoffman, transport of fuel, at plant, ZA	H2, Hoffman, mining fuel, stockpiled clay, ZA	H4, Hoffman, wet green brick transport, wet green bricks ready for drying, ZA	H6, Hoffman, dry green brick transport, at firing location, ZA	H8, Hoffman, fired brick transport, at sales bay, ZA	H9, Hoffman, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.0042708876	0.0042186335	0.0000137640	0.0000298924	0.0000007611	0.0000007611	0.0000070447	0.0000000307
Non-carcinogens	kg C2H3Cl eq	0.0219361578	0.0218949688	0.0000206745	0.0000158521	0.0000004036	0.0000004036	0.0000037358	0.0000001194
Respiratory inorganics	kg PM2.5 eq	0.0002946158	0.0002768749	0.0000025928	0.0000116349	0.0000002962	0.0000002962	0.0000027420	0.0000001786
Ionizing radiation	Bq C-14 eq	0.6042578494	0.5669202634	0.0195950487	0.0130257114	0.0003316589	0.0003316589	0.0030697542	0.0009837539
Ozone layer depletion	kg CFC-11 eq	0.0000000016	0.0000000006	0.0000000003	0.0000000005	0.0000000000	0.0000000000	0.0000000001	0.0000000000
Respiratory organics	kg C2H4 eq	0.0000371353	0.0000299249	0.0000013576	0.0000045441	0.0000001157	0.0000001157	0.0000010709	0.0000000063
Aquatic ecotoxicity	kg TEG water	53.7817880854	53.4093636408	0.1340932141	0.1786569002	0.0045489371	0.0045489371	0.0421038635	0.0084725925
Terrestrial ecotoxicity	kg TEG soil	14.9420244047	14.7980126907	0.0880693309	0.0418378713	0.0010652701	0.0010652701	0.0098598824	0.0021140893
Terrestrial acid/nutri	kg SO2 eq	0.0059236406	0.0054657979	0.0000869670	0.0002846490	0.0000072477	0.0000072477	0.0000670829	0.0000046484
Land occupation	m2org.arable	0.0018712639	0.0018457050	0.0000183148	0.0000056281	0.0000001433	0.0000001433	0.0000013264	0.0000000031
Aquatic acidification	kg SO2 eq	0.0027805909	0.0027120843	0.0000130336	0.0000418668	0.0000010660	0.0000010660	0.0000098667	0.0000016075
Aquatic eutrophication	kg PO4 P-lim	0.0001015559	0.0001007485	0.0000002124	0.0000004624	0.0000000118	0.0000000118	0.0000001090	0.0000000001
Global warming	kg CO2 eq	0.5152632833	0.5075487098	0.0021013169	0.0042550358	0.0001083411	0.0001083411	0.0010027793	0.0001387591
Non-renewable energy	MJ primary	4.5379282234	4.4176478576	0.0350754946	0.0647149193	0.0016477623	0.0016477623	0.0152512896	0.0019431378
Mineral extraction	MJ surplus	0.0003064837	0.0002545140	0.0000166022	0.0000274750	0.0000006996	0.0000006996	0.0000064750	0.0000000184

Figure 6.5 below shows the normalization results for the numerical values presented in Table 6.5 above.

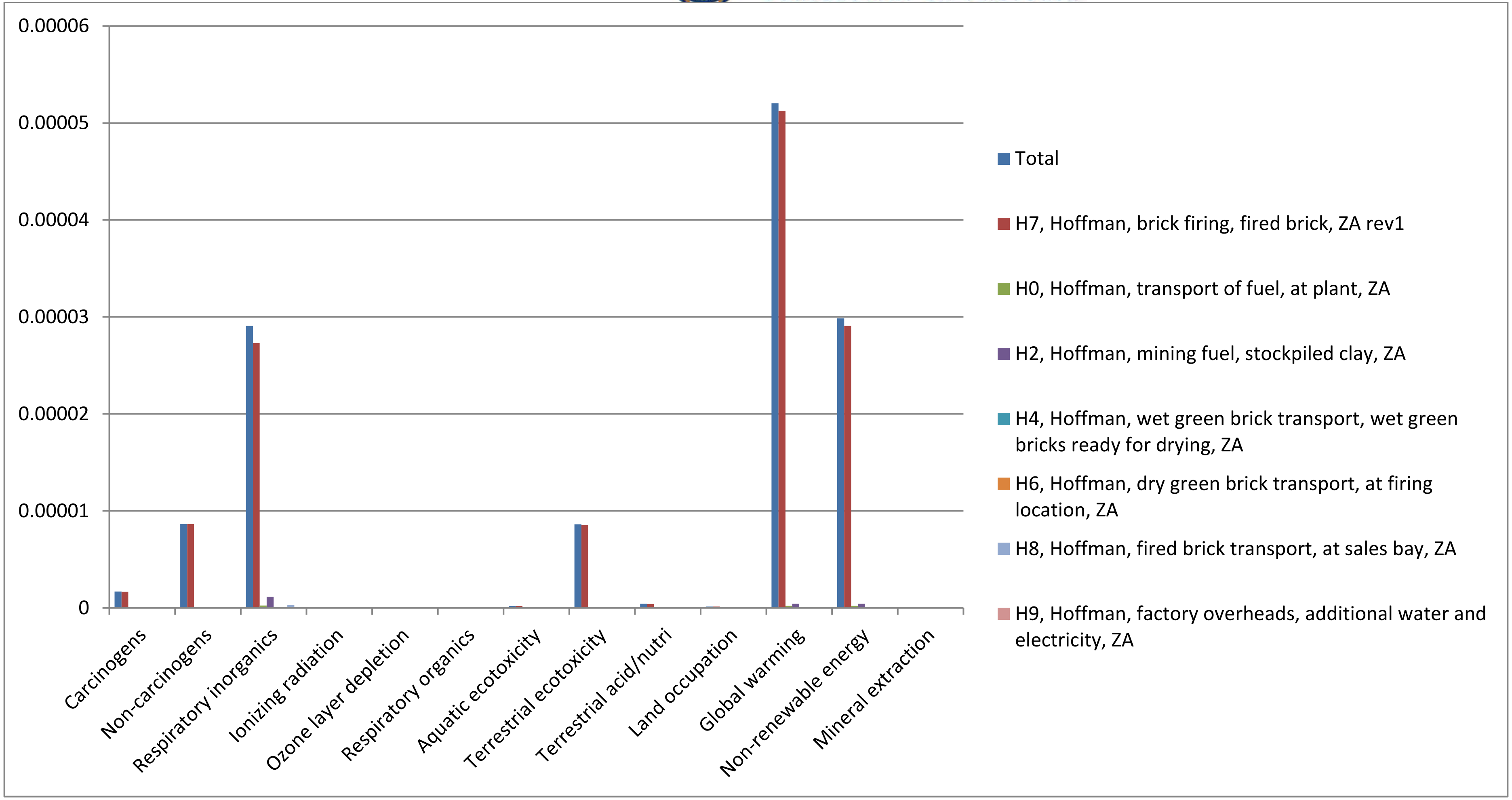

Figure 6.5: Normalization results for contributions to the environmental impacts assessed for the Hoffman kiln firing technology for predefined unit processes (Normalized per person per year in Europe)

6.5.6 Results for the VSBK firing technology

Table 6.6 below shows the contributions of each predefined unit process of VSBKs towards the environmental impacts assessed. The full inventory of emitted substances for the VSBK firing technology can be found in Appendix 5.5. The total contribution of the unit processes within Table 6.6 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process V7 is unit process V5 and subsequently V3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.6: VSBK characterization results per kg fired clay brick

Impact category	Unit	Total	V7, VSBK, brick firing, fired brick, ZA rev1	V0, VSBK, transport of fuel, at plant, ZA	V2, VSBK, mining fuel, stockpiled clay, ZA	V4, VSBK, wet green brick transport, wet green brick ready for drying, ZA	V6, VSBK, dry green brick transport, at firing location, ZA	V8, VSBK, fired brick transport, at sales bay, ZA	V9, VSBK, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.002253	0.0021850	0.0000407	0.0000092	0.0000073	0.0000071	0.0000037	0.0000003
Non-carcinogens	kg C2H3Cl eq	0.011375	0.0112985	0.0000611	0.0000049	0.0000038	0.0000037	0.0000020	0.0000013
Respiratory inorganics	kg PM2.5 eq	0.000294	0.0002736	0.0000077	0.0000036	0.0000028	0.0000027	0.0000015	0.0000019
Ionizing radiation	Bq C-14 eq	0.388932	0.3086639	0.0578745	0.0040255	0.0031597	0.0030772	0.0016250	0.0105066
Ozone layer depletion	kg CFC-11 eq	1.8E-09	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000	0.0000000
Respiratory organics	kg C2H4 eq	2.33E-05	0.0000150	0.0000040	0.0000014	0.0000011	0.0000011	0.0000006	0.0000001
Aquatic ecotoxicity	kg TEG water	27.86533	27.2157471	0.3960478	0.0552120	0.0433381	0.0422054	0.0222885	0.0904878
Terrestrial ecotoxicity	kg TEG soil	7.775532	7.4546563	0.2601151	0.0129295	0.0101489	0.0098837	0.0052195	0.0225786
Terrestrial acid/nutri	kg SO2 eq	0.005847	0.0052809	0.0002569	0.0000880	0.0000690	0.0000672	0.0000355	0.0000496
Land occupation	m2org.arable	0.00059	0.0005305	0.0000541	0.0000017	0.0000014	0.0000013	0.0000007	0.0000000
Aquatic acidification	kg SO2 eq	0.003019	0.0029253	0.0000385	0.0000129	0.0000102	0.0000099	0.0000052	0.0000172
Aquatic eutrophication	kg PO4 P-lim	5.27E-05	0.0000517	0.0000006	0.0000001	0.0000001	0.0000001	0.0000001	0.0000000
Global warming	kg CO2 eq	0.280452	0.2688803	0.0062063	0.0013150	0.0010322	0.0010052	0.0005308	0.0014820
Non-renewable energy	MJ primary	2.528218	2.3448093	0.1035964	0.0199994	0.0156984	0.0152881	0.0080736	0.0207528
Mineral extraction	MJ surplus	0.000191	0.0001169	0.0000490	0.0000085	0.0000067	0.0000065	0.0000034	0.0000002

Figure 6.6 below shows the normalization results for the numerical values presented in Table 6.6 above.

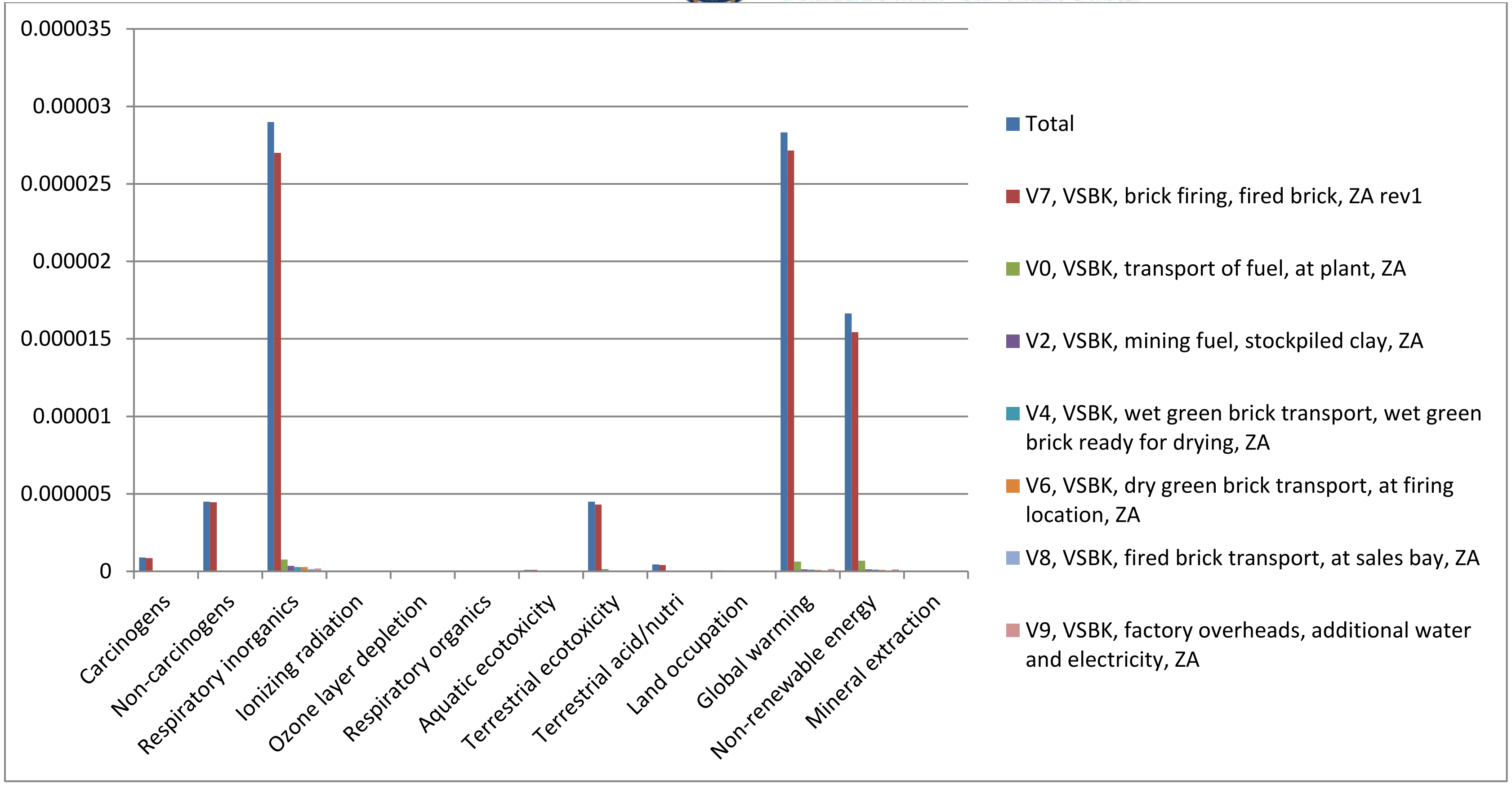

Figure 6.6: Normalization results for contributions to the environmental impacts assessed for the VSBK firing technology for predefined unit processes (Normalized per person per year in Europe)

6.5.7 Results for the Zigzag firing technology

Table 6.7 below shows the contributions of each predefined unit process of zigzag kilns towards the environmental impacts assessed. The full inventory of emitted substances for the zigzag kiln firing technology can be found in Appendix 5.6. The total contribution of the unit processes within Table 6.7 below cannot be compared to the total for the kiln in Table 6.1 as the input into unit process Z7 is unit process Z5 and subsequently Z3 (please refer to Appendix 4 for the inputs into the unit processes).

Table 6.7: Zigzag kiln characterization results per kg fired clay brick

Impact category	Unit	Total	Z7, Zigzag, brick firing, fired brick, ZA rev1	Z0, Zigzag, transport of fuel, at plant, ZA	Z2, Zigzag, mining fuel, stockpiled clay, ZA	Z4, Zigzag, wet green brick transport, wet green brick ready for drying, ZA	Z6, Zigzag, dry green brick transport, at firing location, ZA	Z8, Zigzag, fired brick transport, at sales bay, ZA	Z9, Zigzag, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00190803	0.00173991	0.00012412	0.00001297	0.00001031	0.00001031	0.00001031	0.00000009
Non-carcinogens	kg C2H3Cl eq	0.00920686	0.00899678	0.00018644	0.00000688	0.00000547	0.00000547	0.00000547	0.00000036
Respiratory inorganics	kg PM2.5 eq	0.00015477	0.00011375	0.00002338	0.00000505	0.00000401	0.00000401	0.00000401	0.00000054
Ionizing radiation	Bq C-14 eq	0.42877667	0.22994533	0.17670370	0.00565295	0.00449337	0.00449341	0.00449341	0.00299450
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00003086	0.00001192	0.00001224	0.00000197	0.00000157	0.00000157	0.00000157	0.00000002
Aquatic ecotoxicity	kg TEG water	23.11512871	21.61769173	1.20922218	0.07753417	0.06162979	0.06163035	0.06163035	0.02579014
Terrestrial ecotoxicity	kg TEG soil	6.78523946	5.92316043	0.79418924	0.01815695	0.01443246	0.01443260	0.01443260	0.00643518
Terrestrial acid/nutri	kg SO2 eq	0.00348903	0.00227251	0.00078425	0.00012353	0.00009819	0.00009819	0.00009819	0.00001415
Land occupation	m2org.arable	0.00059941	0.00042598	0.00016516	0.00000244	0.00000194	0.00000194	0.00000194	0.00000001
Aquatic acidification	kg SO2 eq	0.00131888	0.00113495	0.00011753	0.00001817	0.00001444	0.00001444	0.00001444	0.00000489
Aquatic eutrophication	kg PO4 P-lim	0.00004408	0.00004149	0.00000192	0.00000020	0.00000016	0.00000016	0.00000016	0.00000000
Global warming	kg CO2 eq	0.23733932	0.21171763	0.01894920	0.00184662	0.00146782	0.00146784	0.00146784	0.00042238
Non-renewable energy	MJ primary	2.26506805	1.84779226	0.31630285	0.02808522	0.02232417	0.02232437	0.02232437	0.00591481
Mineral extraction	MJ surplus	0.00028370	0.00009357	0.00014972	0.00001192	0.00000948	0.00000948	0.00000948	0.00000006

Figure 6.7 below shows the normalization results for the numerical values presented in Table 6.7 above.

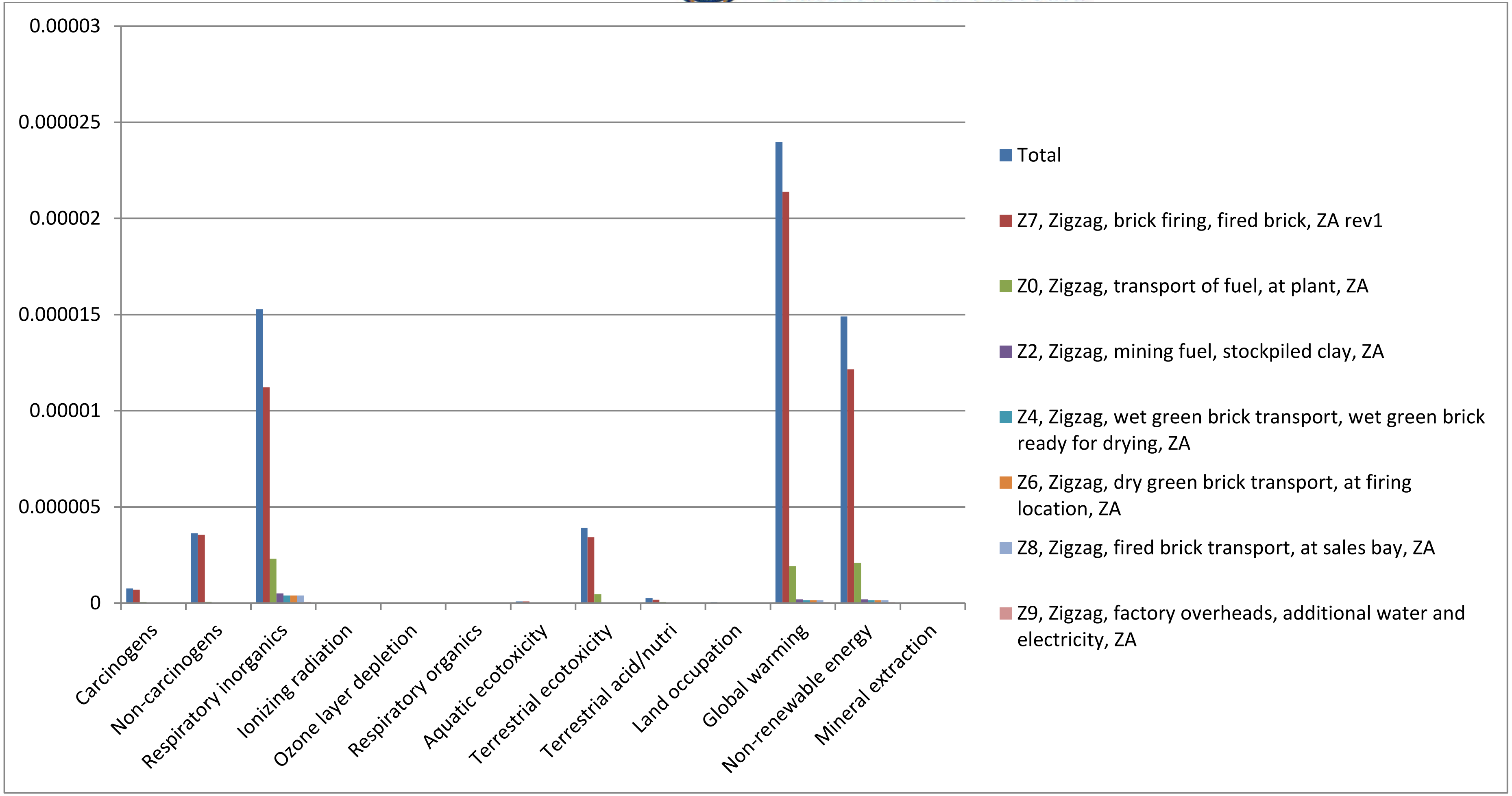

Figure 6.7: Normalization results for contributions to the environmental impacts assessed for the zigzag kiln firing technology for predefined unit processes (Normalized per person per year in Europe)

6.6 IMPACT RESULTS – GATE TO END OF OPERATIONAL LIFE PHASE

6.6.1 Results for the transport of bricks to the building site

Table 6.8 below shows the contribution of the transport to building site stage towards the environmental impacts assessed. The full inventory of emitted substances for the transport to building site stage can be found in Appendix 7.

Table 6.8: Characterization results for the transport to building site of 1m² of clay brick walling

Impact category	Unit	Transport, lorry >32t, EURO3/RER U
Carcinogens	kg C2H3Cl eq	0.00644291911
Non-carcinogens	kg C2H3Cl eq	0.00846695722
Respiratory inorganics	kg PM2.5 eq	0.00108981410
Ionizing radiation	Bq C-14 eq	7.47782241768
Ozone layer depletion	kg CFC-11 eq	0.00000014049
Respiratory organics	kg C2H4 eq	0.00065107110
Aquatic ecotoxicity	kg TEG water	52.32407572144
Terrestrial ecotoxicity	kg TEG soil	32.57589059880
Terrestrial acid/nutri	kg SO2 eq	0.03497791619
Land occupation	m2org.arable	0.00604703865
Aquatic acidification	kg SO2 eq	0.00526251685
Aquatic eutrophication	kg PO4 P-lim	0.00008906822
Global warming	kg CO2 eq	0.84366362827
Non-renewable energy	MJ primary	14.49861661077
Mineral extraction	MJ surplus	0.00815794951

Figure 6.8 below shows the normalization results for the numerical values presented in Table 6.8 above.

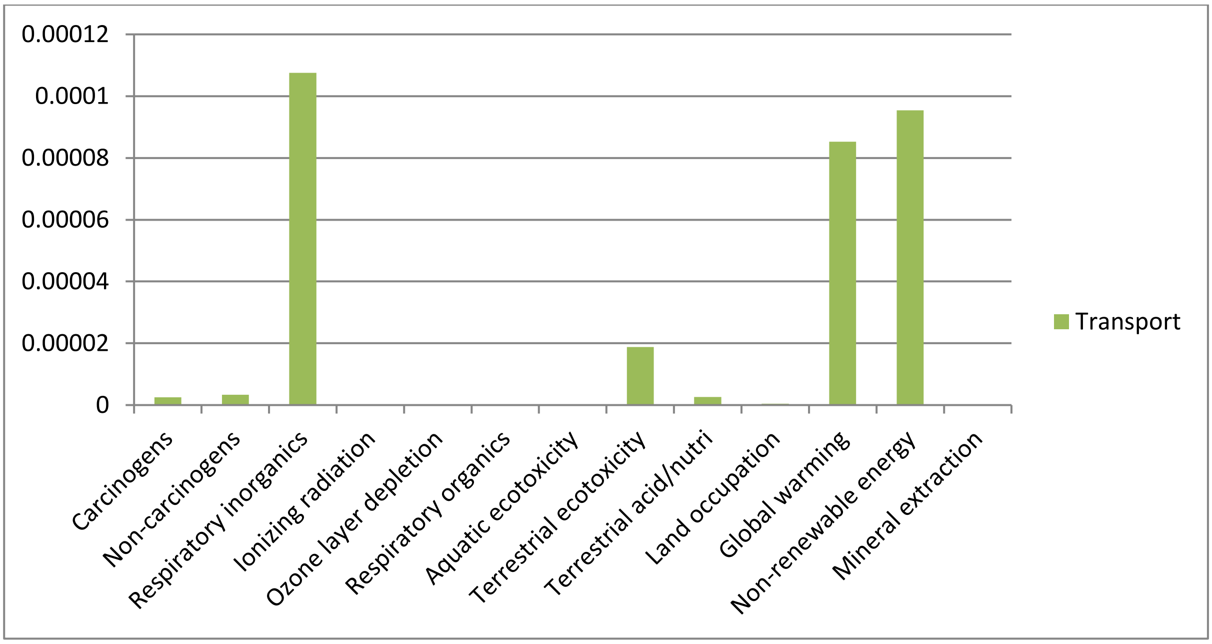

Figure 6.8: Normalization results for contributions to the transport to building site stage of 1m² of clay brick walling (normalized per person per year in Europe)

6.6.2 Results for the materials used to construct 1m² of 220mm double brick wall with face brick externally and plaster and paint internally

Table 6.9 below shows the contribution of the materials used to construct 1m² of 220mm double bricks wall with face brick externally and plaster and paint internally, towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.2.

Table 6.9: Characterization results for the materials used to construct 1m² of 220mm double brick wall with face brick externally and plaster and paint internally

Impact category	Unit	Total	Building in components - Bricks	Building in components - Mortar	Building in component - Plaster	Building in components - paint
Carcinogens	kg C2H3Cl eq	0.704104	0.607123	0.018621	0.014902	0.063457
Non-carcinogens	kg C2H3Cl eq	3.078238	2.871225	0.075378	0.060051	0.071584
Respiratory inorganics	kg PM2.5 eq	0.056964	0.048412	0.002277	0.001825	0.004450
Ionizing radiation	Bq C-14 eq	390.065787	136.993450	73.432874	59.035579	120.603884
Ozone layer depletion	kg CFC-11 eq	0.000002	0.000001	0.000000	0.000000	0.000001
Respiratory organics	kg C2H4 eq	0.012150	0.007712	0.000922	0.000738	0.002778
Aquatic ecotoxicity	kg TEG water	9378.096438	8781.917303	181.696723	136.811435	277.670977
Terrestrial ecotoxicity	kg TEG soil	2537.051185	2387.524537	30.706860	24.566955	94.252834
Terrestrial acid/nutri	kg SO2 eq	1.298313	1.063905	0.069153	0.055342	0.109913
Land occupation	m2org.arable	1.427133	0.210350	0.013971	0.011467	1.191344
Aquatic acidification	kg SO2 eq	0.495034	0.439226	0.012436	0.009946	0.033425
Aquatic eutrophication	kg PO4 P-lim	0.020931	0.019418	0.000179	0.000143	0.001191
Global warming	kg CO2 eq	95.786322	77.393856	7.248675	5.772791	5.371000
Non-renewable energy	MJ primary	1166.442268	990.556297	33.755409	27.008563	115.121999
Mineral extraction	MJ surplus	0.192501	0.062865	0.019886	0.016191	0.093560

Figure 6.9 below shows the normalization results for the numerical values presented above.

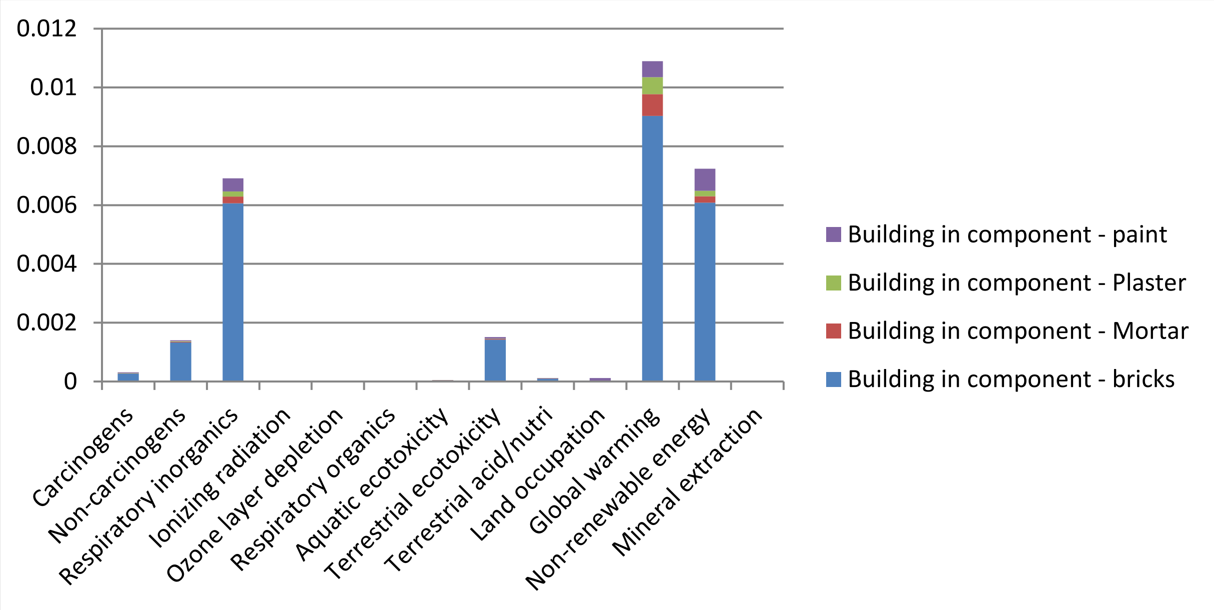

Figure 6.9: Normalization results for the contributions of the materials used for constructing 1m² of 220mm double brick wall with face brick externally and plaster and paint internally (normalized per person per year in Europe)

6.6.3 Results for the materials used to construct 1m² of 220mm double brick wall with both sides plastered and painted

Table 6.10 below shows the contribution of the materials used to construct 1m² of 220mm double brick wall with both sides plastered and painted towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.3.

Table 6.10: Characterization results for the materials used to construct 1m² of 220mm double brick wall with both sides plastered and painted

Impact category	Unit	Total	220mm Double brick wall face external	Building in component - Plaster	Building in components - paint
Carcinogens	kg C2H3Cl eq	0.782464	0.704104	0.014902	0.063457
Non-carcinogens	kg C2H3Cl eq	3.209873	3.078238	0.060051	0.071584
Respiratory inorganics	kg PM2.5 eq	0.063239	0.056964	0.001825	0.004450
Ionizing radiation	Bq C-14 eq	569.705250	390.065787	59.035579	120.603884
Ozone layer depletion	kg CFC-11 eq	0.000003	0.000002	0.000000	0.000001
Respiratory organics	kg C2H4 eq	0.015667	0.012150	0.000738	0.002778
Aquatic ecotoxicity	kg TEG water	9792.578850	9378.096438	136.811435	277.670977
Terrestrial ecotoxicity	kg TEG soil	2655.870973	2537.051185	24.566955	94.252834
Terrestrial acid/nutri	kg SO2 eq	1.463569	1.298313	0.055342	0.109913
Land occupation	m2org.arable	2.629943	1.427133	0.011467	1.191344
Aquatic acidification	kg SO2 eq	0.538405	0.495034	0.009946	0.033425
Aquatic eutrophication	kg PO4 P-lim	0.022265	0.020931	0.000143	0.001191
Global warming	kg CO2 eq	106.930112	95.786322	5.772791	5.371000
Non-renewable energy	MJ primary	1308.572831	1166.442268	27.008563	115.121999
Mineral extraction	MJ surplus	0.302252	0.192501	0.016191	0.093560

Figure 6.10 below shows the normalization results for the numerical values presented above.

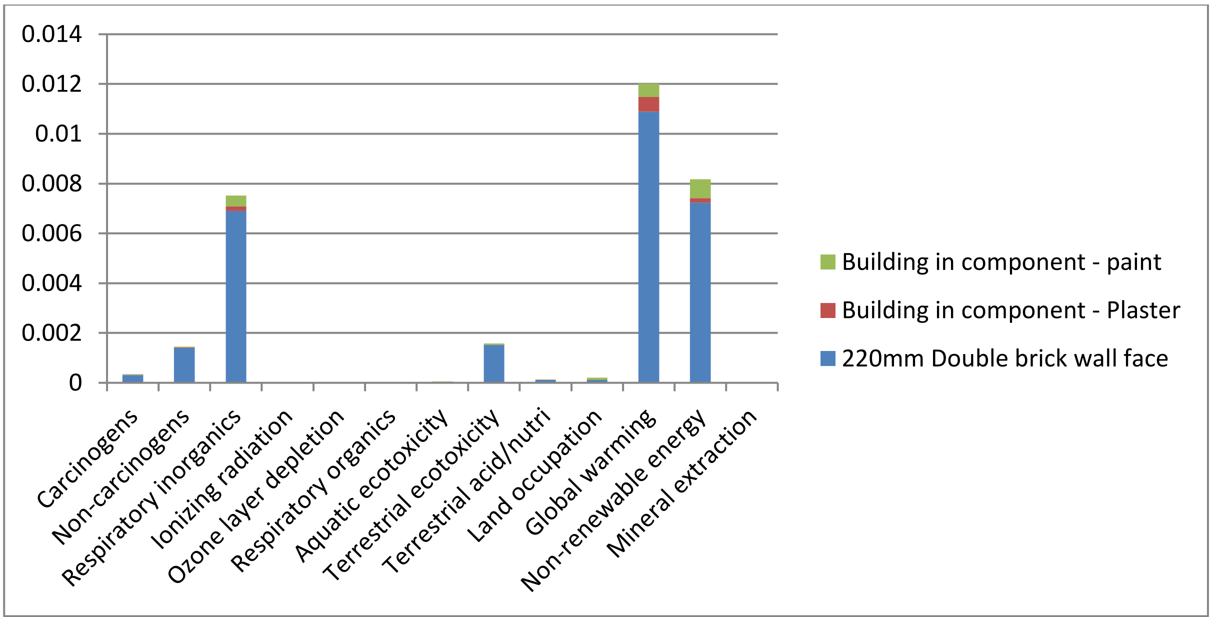

Figure 6.10: Normalization results for the contributions of the materials used to construct 1m²of 220mm double brick wall with both sides plastered and painted (normalized per person per year in Europe)

6.6.4 Results for the materials used to construct 1m² of 280mm double brick cavity wall with face brick externally and plaster and paint internally

Table 6.11 below shows the contribution of the materials used to construct 1m² of 280mm double brick cavity wall with face brick externally and plaster and paint internally, towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.4.

Table 6.11: Characterization results for the materials used to construct 1m² of 280mm double brick cavity wall with face brick externally and plaster and paint internally

Impact category	Unit	Total	Double brick wall face	Building in component - wall ties
Carcinogens	kg C2H3Cl eq	0.711644	0.704104	0.007540
Non-carcinogens	kg C2H3Cl eq	3.083969	3.078238	0.005732
Respiratory inorganics	kg PM2.5 eq	0.057103	0.056964	0.000139
Ionizing radiation	Bq C-14 eq	391.820550	390.065787	1.754763
Ozone layer depletion	kg CFC-11 eq	0.000002	0.000002	0.000000
Respiratory organics	kg C2H4 eq	0.012182	0.012150	0.000032
Aquatic ecotoxicity	kg TEG water	9389.128674	9378.096438	11.032236
Terrestrial ecotoxicity	kg TEG soil	2541.789396	2537.051185	4.738211
Terrestrial acid/nutri	kg SO2 eq	1.299785	1.298313	0.001471
Land occupation	m2org.arable	1.427789	1.427133	0.000656
Aquatic acidification	kg SO2 eq	0.495429	0.495034	0.000396
Aquatic eutrophication	kg PO4 P-lim	0.020957	0.020931	0.000026
Global warming	kg CO2 eq	95.883006	95.786322	0.096685
Non-renewable energy	MJ primary	1167.961463	1166.442268	1.519195
Mineral extraction	MJ surplus	0.243464	0.192501	0.050963

Figure 6.11 below shows the normalization results for the numerical values above.

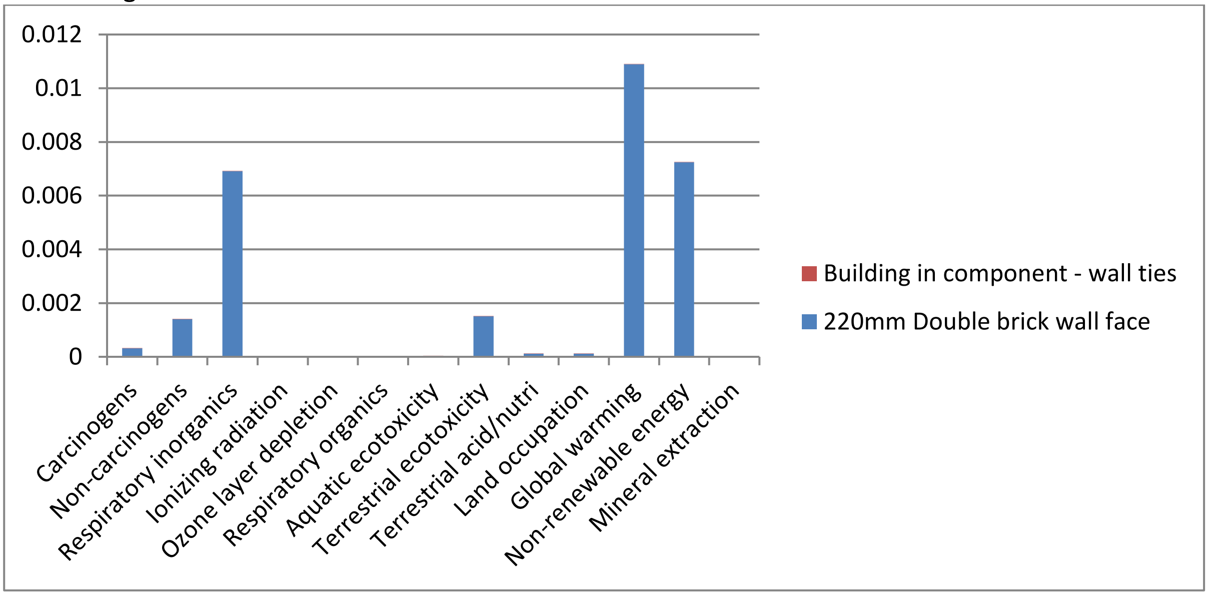

Figure 6.11: Normalization results for the contributions of the materials used to construct 1m² of 280mm double brick cavity wall with face brick externally and plaster and paint internally (normalized per person per year in Europe)

6.6.5 Results for the materials used to construct 1m² of 280mm double brick cavity wall with both sides plastered and painted

Table 6.12 below shows the contribution of the materials used to construct 1m² of 280mm double brick cavity wall with both sides plastered and painted towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.5.

Table 6.12: Characterization results for the materials used to construct 1m² of 280mm double brick cavity wall with both sides plastered and painted

Impact category	Unit	Total	280mm double brick cavity paint	Building in component - Plaster	Building in components - paint
Carcinogens	kg C2H3Cl eq	0.790004	0.711644	0.014902	0.063457444
Non-carcinogens	kg C2H3Cl eq	3.215604	3.083969	0.060051	0.071583846
Respiratory inorganics	kg PM2.5 eq	0.063378	0.057103	0.001825	0.004450332
Ionizing radiation	Bq C-14 eq	571.460013	391.820550	59.035579	120.6038838
Ozone layer depletion	kg CFC-11 eq	0.000003	0.000002	0.000000	7.53434E-07
Respiratory organics	kg C2H4 eq	0.015699	0.012182	0.000738	0.002777951
Aquatic ecotoxicity	kg TEG water	9803.611087	9389.128674	136.811435	277.670977
Terrestrial ecotoxicity	kg TEG soil	2660.609184	2541.789396	24.566955	94.25283372
Terrestrial acid/nutri	kg SO2 eq	1.465041	1.299785	0.055342	0.109913414
Land occupation	m2org.arable	2.630599	1.427789	0.011467	1.191343551
Aquatic acidification	kg SO2 eq	0.538801	0.495429	0.009946	0.033425206
Aquatic eutrophication	kg PO4 P-lim	0.022291	0.020957	0.000143	0.00119109
Global warming	kg CO2 eq	107.026797	95.883006	5.772791	5.371000004
Non-renewable energy	MJ primary	1310.092026	1167.961463	27.008563	115.1219991
Mineral extraction	MJ surplus	0.353215	0.243464	0.016191	9.36E-02

Figure 6.12 below shows the normalization results of the numerical values presented above.

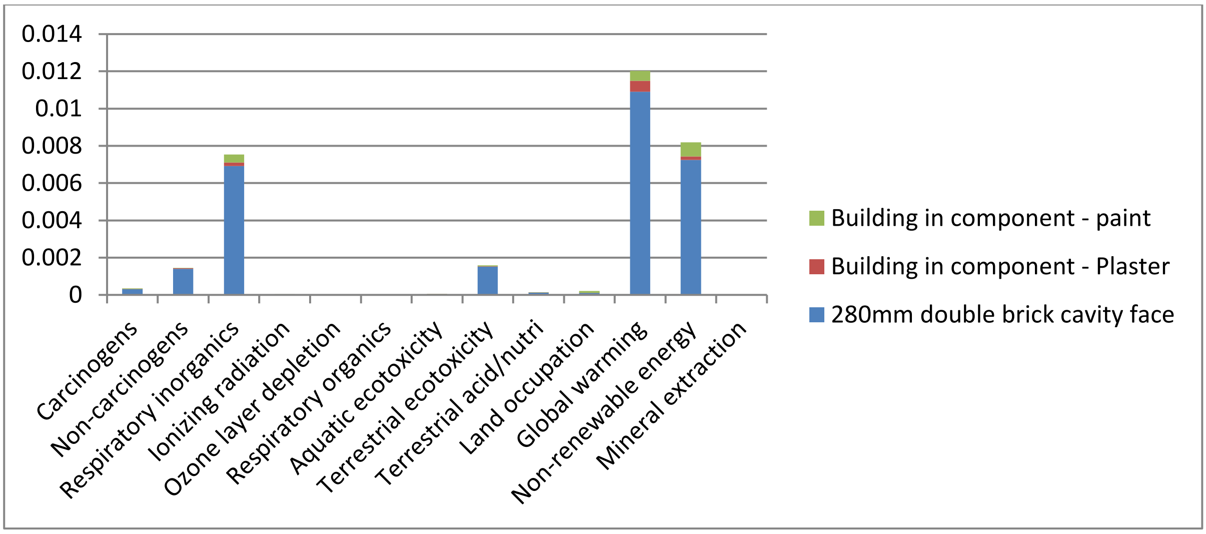

Figure 6.12: Normalization results for the contributions of the materials used to construct 1m² of 280mm double brick cavity wall with both sides plastered and painted (normalized per person per year in Europe)

6.6.6 Results for the materials used to construct 1m² of 280mm double brick insulated cavity wall with face brick externally and plaster and paint internally

Table 6.13 below shows the contribution of the materials used to construct 1m² of 280mm double brick insulated cavity wall with face brick externally and plaster and paint internally, towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.6.

Table 6.13: Characterization results for the materials used to construct 1m² of 280mm double brick insulated cavity wall with face brick externally and plaster and paint internally

Impact category	Unit	Total	220mm Double brick wall face	Building in component - wall ties	Building in component - insulation
Carcinogens	kg C2H3Cl eq	0.714838	0.704104	0.007540	0.00319397
Non-carcinogens	kg C2H3Cl eq	3.084359	3.078238	0.005732	0.000389377
Respiratory inorganics	kg PM2.5 eq	0.057149	0.056964	0.000139	4.62649E-05
Ionizing radiation	Bq C-14 eq	392.425784	390.065787	1.754763	0.605233931
Ozone layer depletion	kg CFC-11 eq	0.000002	0.000002	0.000000	6.27102E-09
Respiratory organics	kg C2H4 eq	0.012430	0.012150	0.000032	0.000247489
Aquatic ecotoxicity	kg TEG water	9390.814987	9378.096438	11.032237	1.686312538
Terrestrial ecotoxicity	kg TEG soil	2542.144385	2537.051185	4.738211	0.354988972
Terrestrial acid/nutri	kg SO2 eq	1.300935	1.298313	0.001471	0.001150692
Land occupation	m2org.arable	1.427815	1.427133	0.000656	2.61429E-05
Aquatic acidification	kg SO2 eq	0.495769	0.495034	0.000396	0.000339816
Aquatic eutrophication	kg PO4 P-lim	0.020965	0.020931	0.000026	7.91696E-06
Global warming	kg CO2 eq	95.998078	95.786322	0.096685	0.115071245
Non-renewable energy	MJ primary	1171.215727	1166.442268	1.519195	3.254263696
Mineral extraction	MJ surplus	0.243750	0.192501	0.050963	2.86E-04

Figure 6.13 below shows the normalization results of the numerical values presented above.

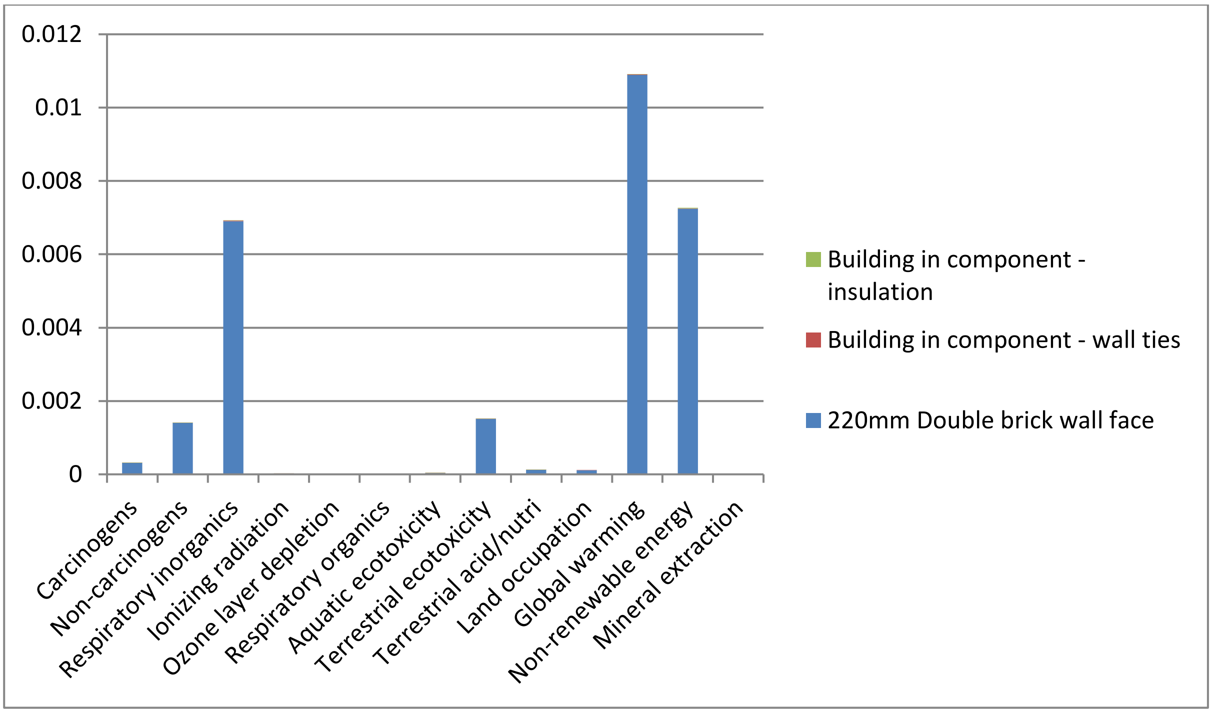

Figure 6.13: Normalization results for the contributions of the materials used to construct 1m² of 280mm double brick insulated cavity wall with face brick externally and plaster and paint internally (normalized per person per year in Europe)

6.6.7 Results for the materials used to construct 1m² of 280mm double brick insulated cavity wall with both sides plastered and painted

Table 6.14 below shows the contribution of the materials used to construct 1m² of 280mm double brick insulated cavity wall with both sides plastered and painted towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 7.7.

Impact category	Unit	Total	220mm Double Brick Face	Building in component - wall ties	Building in component - insulation	Building in component - Plaster	Building in components - paint
Carcinogens	kg C2H3Cl eq	0.793198	0.704104	0.007540	0.00319397	0.014902396	0.063457444
Non-carcinogens	kg C2H3Cl eq	3.215993	3.078238	0.005732	0.000389377	0.060050821	0.071583846
Respiratory inorganics	kg PM2.5 eq	0.063424	0.056964	0.000139	4.62649E-05	0.001824837	0.004450332
Ionizing radiation	Bq C-14 eq	572.065247	390.065787	1.754763	0.605233931	59.03557906	120.6038839
Ozone layer depletion	kg CFC-11 eq	0.000003	0.000002	0.000000	6.27102E-09	1.73181E-07	7.53434E-07
Respiratory organics	kg C2H4 eq	0.015946	0.012150	0.000032	0.000247489	0.000738495	0.002777951
Aquatic ecotoxicity	kg TEG water	9805.297399	9378.096438	11.032237	1.686312538	136.8114348	277.670977
Terrestrial ecotoxicity	kg TEG soil	2660.964173	2537.051185	4.738211	0.354988972	24.56695437	94.25283374
Terrestrial acid/nutri	kg SO2 eq	1.466191	1.298313	0.001471	0.001150692	0.055342474	0.109913414
Land occupation	m2org.arable	2.630626	1.427133	0.000656	2.61429E-05	0.011467171	1.191343551
Aquatic acidification	kg SO2 eq	0.539141	0.495034	0.000396	0.000339816	0.009946186	0.033425206
Aquatic eutrophication	kg PO4 P-lim	0.022299	0.020931	0.000026	7.91696E-06	0.000143323	0.00119109
Global warming	kg CO2 eq	107.141868	95.786322	0.096685	0.115071245	5.772790524	5.371000004
Non-renewable energy	MJ primary	1313.346289	1166.442268	1.519195	3.254263696	27.00856339	115.1219991
Mineral extraction	MJ surplus	0.353501	0.192501	0.050963	0.000286106	0.016190635	0.093559939

Table 6.14: Characterization results for the materials used to construct 1m² of 280mm double brick insulated cavity wall with both sides plastered and painted

Figure 6.14 below shows the normalization results of the numerical values presented above.

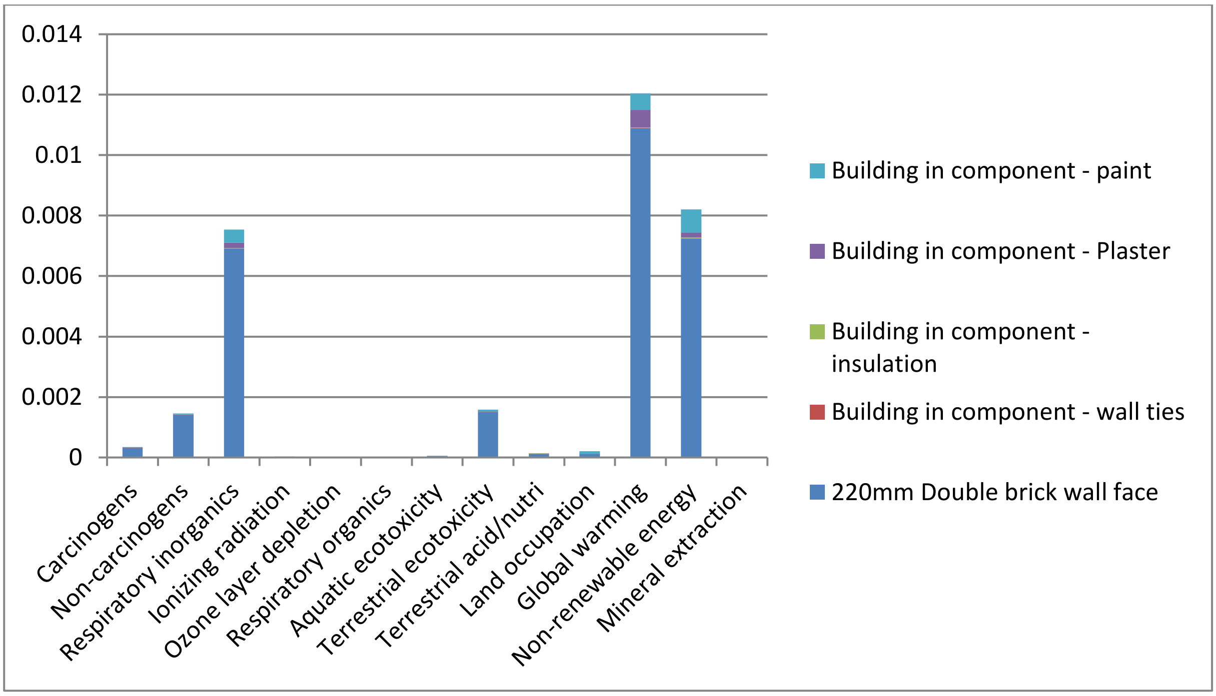

Figure 6.14: Normalization results for the contributions of the materials used to construct 1m² of 280mm double brick insulated cavity wall with both sides plastered and painted (normalized per person per year in Europe)

6.6.8 Results from the generation of 1kWh electricity for the South African grid

Table 6.15 below shows the contributions made by the generation of 1kWh of South African electricity towards the environmental impacts assessed. The full inventory of emitted substances can be found in Appendix 8.

Table 6.15: Characterization results for the generation of 1kWh electricity for the South African grid

Impact category	Unit	South African medium voltage electricity production (at grid)
Carcinogens	kg C2H3Cl eq	0.000207
Non-carcinogens	kg C2H3Cl eq	0.000804
Respiratory inorganics	kg PM2.5 eq	0.001204
Ionizing radiation	Bq C-14 eq	6.629070
Ozone layer depletion	kg CFC-11 eq	0.000000
Respiratory organics	kg C2H4 eq	0.000043
Aquatic ecotoxicity	kg TEG water	57.092942
Terrestrial ecotoxicity	kg TEG soil	14.245885
Terrestrial acid/nutri	kg SO2 eq	0.031324
Land occupation	m2org.arable	0.000021
Aquatic acidification	kg SO2 eq	0.010832
Aquatic eutrophication	kg PO4 P-lim	0.000000
Global warming	kg CO2 eq	0.935034
Non-renewable energy	MJ primary	13.093920
Mineral extraction	MJ surplus	0.000124

Figure 6.15 below shows the normalisation results of the numerical values presented above.

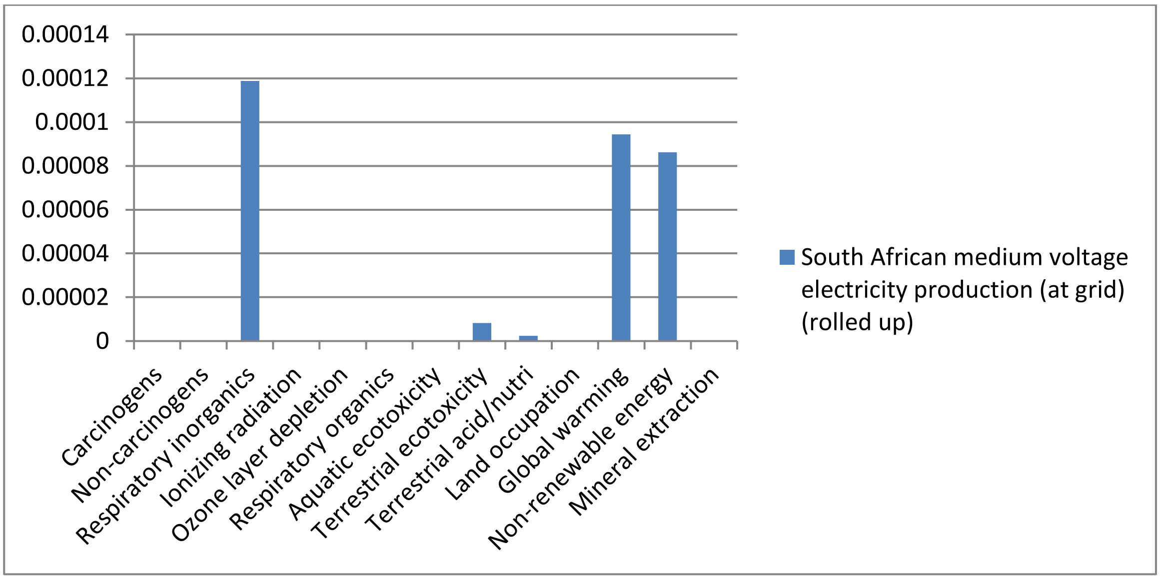

Figure 6.15: Normalisation results for the generation of 1kWh electricity for the South African grid

6.6.9 Results for the generation of operational energy of three different clay brick walling types in six South African climatic zones

Table 6.16 below shows the environmental impact contributions towards the environmental impacts assessed of the operational energy required per annum per m² walling to achieve a specified thermal range throughout the year in accordance with the Thermal Performance Study which forms the second part of this research project (refer to *A thermal performance comparison between six wall construction methods frequently used in South Africa* by Vosloo *et al*. 2016)

The full inventory of emitted substances for each clay brick walling type for each climatic zone can be found in Appendix 9.

Table 6.16: Characterization results for the annual operational energy per m² walling for three clay brick wall types in six different South African climatic zones required to achieve a specified thermal comfort range within the building

Impact category	Unit	Zone 1			Zone 2			Zone 3			Zone 4			Zone 5			Zone 6		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity
Carcinogens	kg C2H3Cl eq	0.008	0.007	0.006	0.009	0.008	0.008	0.018	0.017	0.017	0.008	0.007	0.006	0.011	0.011	0.012	0.019	0.018	0.017
Non-carcinogens	kg C2H3Cl eq	0.031	0.027	0.022	0.034	0.032	0.030	0.069	0.068	0.065	0.031	0.026	0.025	0.044	0.044	0.046	0.075	0.071	0.066
Respiratory inorganics	kg PM2.5 eq	0.047	0.040	0.033	0.051	0.048	0.045	0.104	0.102	0.097	0.047	0.038	0.037	0.065	0.067	0.069	0.113	0.107	0.099
Ionizing radiation	Bq C-14 eq	257.620	222.483	182.570	282.828	266.160	250.035	572.718	559.052	535.151	257.620	211.596	203.767	359.362	366.736	377.845	620.544	587.620	543.130
Ozone layer depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Respiratory organics	kg C2H4 eq	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003
Aquatic ecotoxicity	kg TEG water	2218.756	1916.135	1572.389	2435.863	2292.303	2153.429	4932.538	4814.843	4608.998	2218.756	1822.371	1754.946	3095.007	3158.516	3254.199	5344.442	5060.889	4677.711
Terrestrial ecotoxicity	kg TEG soil	553.626	478.116	392.344	607.799	571.978	537.326	1230.771	1201.404	1150.042	553.626	454.720	437.896	772.269	788.116	811.991	1333.550	1262.798	1167.187
Terrestrial acid/nutri	kg SO2 eq	1.217	1.051	0.863	1.336	1.258	1.181	2.706	2.642	2.529	1.217	1.000	0.963	1.698	1.733	1.785	2.932	2.777	2.566
Land occupation	m2org.arable	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Aquatic acidification	kg SO2 eq	0.421	0.364	0.298	0.462	0.435	0.409	0.936	0.914	0.874	0.421	0.346	0.333	0.587	0.599	0.617	1.014	0.960	0.887
Aquatic eutrophication	kg PO4 P-lim	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Global warming	kg CO2 eq	36.337	31.381	25.752	39.893	37.542	35.268	80.782	78.855	75.483	36.337	29.846	28.741	50.688	51.728	53.295	87.528	82.884	76.609
Non-renewable energy	MJ primary	508.858	439.454	360.618	558.650	525.726	493.876	1131.248	1104.255	1057.046	508.858	417.950	402.486	709.821	724.387	746.331	1225.715	1160.684	1072.805
Mineral extraction	MJ surplus	0.005	0.004	0.003	0.005	0.005	0.005	0.011	0.010	0.010	0.005	0.004	0.004	0.007	0.007	0.007	0.012	0.011	0.010

6.7 IMPACT RESULTS - DEMOLITION, WASTE AND RECYCLE PHASE

6.7.1 Introduction

This section refers to some of the reviewed case studies of LCAs in other countries presented in Chapter 3 to evaluate and present a possible construction and demolition waste (C & DW) model for South Africa. The data obtained from the case studies and other literature on C & DW is used to make estimates of the magnitude of C & DW in SA.

Chapter 7 will address the possible improvements which can be made to reduce the amount of C & DW with specific focus on clay bricks going to landfill sites around South Africa and suggest possible opportunities for recycling and re-use of wasted clay bricks.

6.7.2 Construction and demolition waste management in selected other countries

Table 6.17 indicates C & DW management statistics from selected other countries.

Table 6.17: C & DW management statistic from selected other countries

Country	Annual Income per person #	Population*	C & DW generated per year	C & DW diverted from landfill per year	Ratio of diverted to generated C & DW
Brazil	$ 12 000	193 364 000	1 000 000 t (1)	20 000 t (2)	2%
Kuwait	$ 43 800	3 051 000	600 000 t (3)	60 000 t (4)	10%
South Africa	$ 11 300	51 190 000	4 725 542 t (5)	756 087 t (6)	16%
Greece	$ 25 100	11 306 183	6 828 051 (7)	341 402 t (8)	5%
Thailand	$ 10 000	63 525 062	1 100 000 t (9)	242 000 t (10)	24%
India	$ 3 900	1 084 630 000	12 000 000 t (11)	6 000 000 t (12)	50%
England	$ 36 700	58 977 708	38 938 000 t (13)	34 714 000 t (14)	89%

References:

# World Fact Book, 2013	7 Sofia *et al*, 2009
* World Atlas, 2014	8 Sofia *et al*, 2009
1 Nunes, 2007	9 Kofoworola & Gheewala, 2009
2 Nunes, 2007	10 Kofoworola & Gheewala, 2009
3 Aljassar *et al*. 2005	11 Ponnada & Kameswari, 2015
4 Aljassar *et al*. 2005	12 Ponnada & Kameswari, 2015
5 DEA, 2012	13 Karfoot, 2016
6 DEA, 2012	14 Karfoot, 2016

From the above figures it can be deduced that developed countries such as England have a higher rate of recycling C & DW than developing countries such as Kuwait, Brazil and South Africa. Since it can be seen that India recycles proportionally much more C & DW than any of the other listed developing nations, it could be concluded that the data presented in the source document may not be primary data but estimates only.

The relatively high percentage of C & DW diverted from landfill sites, presumably for recycling or re-use, in the listed developed countries may be ascribed to an awareness in those countries of the sustainability imperative and/or amore formalised and regulated recycling industry for which there is better reporting and available data. In developing countries such as SA and from casual observation it may be found that higher value C & DW components such as metal and timber are most often recycled and re-used whereas bulk C & DW such as masonry and concrete are often difficult to move or be transported away easily from demolition or landfill sites. From casual observation in SA and many other sub-Saharan African countries it would seem that where wasted clay bricks are re-used, it is often by individuals on an informal basis; see Figure 6.16.

6.7.3 Building a South African model for construction and demolition waste

It is suggested that clay bricks make up at least 25% (a conservative estimate) of all C & DW in South Africa. This can be deduced as India, a developing country, generates C & DW that consists of 30% bricks, and Kuwait, a developing country as well, generates C & DW made up of 31% bricks.

The total quantity of C & DW generated annually in South Africa is estimated at 4 725 542 tonnes. Of this, and assuming 25% consists of brick, this then amounts to 1 181 385 tonnes of brick that are collected annually and sent to landfills.

This estimate can be further interpreted to achieve a number of wasted bricks; where the standard brick equivalent (SBE) is 2.75 kg (Volsteedt *et al*. 2013), the total number of wasted bricks amounts to 429 594 545 SBEs.

The national recycle rate for C & DW in SA is 16% (DEA 2012a:15). The balance of 84% of C & DW which is not immediately recycled is mostly landfilled, but a portion of this is re-used by the informal sector through salvage and resell entrepreneurial ventures. These ventures are neither recorded nor quantified and therefore cannot be used in this estimate but should not be overlooked when assessing a recycling/re-use model for South Africa.

Recycling accounted for by municipalities from their landfill sites is 16% of the landfilled C & DW; therefore, it can be calculated that 16% of 1 181 385 tonnes (=189 021 tonnes or about 68.7m SBEs) of brick are recycled from municipal landfills annually.

Private companies in the City of Johannesburg recycle 835 000 tonnes of C & DW per year (over and above the municipal recycling stated above) (CoJ 2011:36). It can then be assumed that bricks, which make up 25% of the privately recycled C & DW account for 208 750 tonnes or about 75.9m SBEs annually being recycled by private companies in Johannesburg.

A distinction needs however to be drawn between the recycling of bricks (often crushed and re-used as aggregate or fill by larger companies and salvaging, cleaning and re-use by of bricks by individuals.

If the above figure is extrapolated for the full population of South Africa, of which Johannesburg accounts for 8%, then brick recycling in all South Africa by private companies, i.e. recycling of bricks before C & DW is recorded by municipalities at landfill sites, amounts to 2 609 375 tonnes of brick being privately recycled annually. This is probably not a correct assumption since the extent of building demolition in

Johannesburg is probably much higher than in smaller municipalities and the rural areas of South Africa.

However, should the figures estimated above be used, it can be postulated that annually in South Africa recycling of brick occurs in the following quantities:

- Privately: 2 609 375 tonnes of brick
- Publically: 189 021 tonnes of brick

The large difference in recycling rates between the private and public sectors in South Africa could be explained since clay brick is one of the easiest building materials to remove from the landfill chain as it is easily handled, may be transported by private vehicles and retain structural integrity after the demolition of the building.

It can therefore be concluded that in South Africa, the annual quantity of bricks recycled is 2 798 396 tonnes, which amounts to about 1 017m SBEs. According to a study done which targeted the full population of brick manufacturers in South Africa (Rice 2014) a total number of 3 688m SBEs is produced annually.

Figure 6.16: Typical small scale informal and unregulated salvaging of clay bricks for re-use on a demolished building site

Although the data used in this particular phase of the study may be secondary and to an extent unverifiable, it is suggested the data are sufficient to use in a model to calculate the extent of the recycling and re-use of bricks in South Africa. The model uses conservative figures from similarly developed countries in order to relate the known figures from these countries to the South African context. In South Africa it is very difficult to account accurately for extent of the demolition, waste and recycle/re-use of clay bricks which occur informally without any regulatory measures that control the recycling of demolished building materials. This phase is therefore an attempt to develop a model which can be used to analyse and quantify the phenomenon of recycling C & DW.

6.7.4 Results for the demolition, waste and recycle phase of the LCA

Table 6.18 below shows the contribution of the various elements which are disposed of for 1m² of clay brick wall when the wall has reached the end of its life. The components reflected in the table below may not necessarily be present in all wall types; Chapter 7 assesses the impact of this phase with regard to the various wall types. The full inventory of emitted substances can be found in Appendix 11.

Table 6.18: Characterization results for the demolition waste and recycle phase of the various elements from the various researched wall types

Impact category	Unit	Brick Landfill 63,3 %	Brick Recycled 36,7 %	Mortar Landfill 100 %	Plaster Landfill 100 %	Paint Landfill 100 %	Wall ties 100 %	Insulation 100 %
Carcinogens	kg C2H3Cl eq	0.021827	0.002402	0.005924	0.001066	0.001026	0.000029	0.000705
Non-carcinogens	kg C2H3Cl eq	0.016042	0.001274	0.004306	0.000775	0.000803	0.000017	0.004349
Respiratory inorganics	kg PM2.5 eq	0.007761	0.002677	0.002114	0.000380	0.000182	0.000010	0.000003
Ionizing radiation	Bq C-14 eq	18.936528	1.046828	5.038264	0.906439	0.993562	0.015441	0.013311
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Respiratory organics	kg C2H4 eq	0.002769	0.000365	0.000757	0.000136	0.000124	0.000004	0.000002
Aquatic ecotoxicity	kg TEG water	128.445853	14.357992	34.883324	6.275894	6.013284	0.170087	1.761602
Terrestrial ecotoxicity	kg TEG soil	53.423186	3.362355	14.253767	2.564409	2.762086	0.047245	0.015977
Terrestrial acid/nutri	kg SO2 eq	0.127453	0.022876	0.035457	0.006379	0.005104	0.000246	0.000126
Land occupation	m2org.arable	0.071706	0.000452	0.018735	0.003371	0.004114	0.000027	0.000008
Aquatic acidification	kg SO2 eq	0.019018	0.003365	0.005286	0.000951	0.000766	0.000036	0.000017
Aquatic eutrophication	kg PO4 P-lim	0.000251	0.000037	0.000069	0.000012	0.000011	0.000000	0.000000
Global warming	kg CO2 eq	2.343896	0.341961	0.644366	0.115928	0.101733	0.003824	0.157465
Non-renewable energy	MJ primary	53.576952	5.200898	14.473448	2.603933	2.587080	0.063850	0.013378
Mineral extraction	MJ surplus	0.018493	0.002208	0.005036	0.000906	0.000852	0.000026	0.000023

7. CHAPTER 7 – INTERPRETATION: FINDINGS, DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

The interpretation stage of a LCA addresses several aspects, such as:

- Identification of significant issues.
- Conclusions, limiting conditions and recommendations.
- Evaluation of the report in terms of completeness, consistency and sensitivity checks.

In this chapter the findings and conclusions for each of the three phases will be discussed; the meeting of stated objectives will be evaluated and where applicable recommendations will be made.

7.2 ASSUMPTIONS, CHOICES, AND LIMITATIONS

The pertinent assumptions, choices and limitations pertaining to the data reported on in this section are given in Table 7.1 below.

Table 7.1: Assumptions, delimitations and limitations in respect of the data interpretation

Assumptions and delimitations For the purposes of this study it is assumed that**:**	
1	the entire land area used for brick production will be used for the entire lifespan of the manufacturing plant. This assumption is necessary as there are no practical means of calculating the land area use changes over the life span of a manufacturing plant.
2	the data provided by respondents to the authors and research assistants are as accurate as possible. Data collected in the data collection process were used as is in the LCA model development. During the data collection process there was no practical means of verifying this data.
3	once mineral extraction sites reach the end of their production life span, half of the land will be rehabilitated to its previous state, while the other half will be transformed into an artificial water storage facility such as a dam or part of a river system.
4	the internal face of clay brick walls is plastered and painted for all brick wall types assessed in this study.
5	for 1m² of walling there are 52 units per leaf of walling, therefore the total mass of clay bricks for a double leaf wall is 291 kg (2.8 x 52 x 2)
6	for maintenance purposes a plastered and painted wall has to be repainted once every 10 years of its 50-year lifespan
7	The distance to landfill site was taken as 7.15 Tons based on calculations of collected data.
8	Transport to landfill sites is completed by diesel fuelled heavy duty transport
9	The data collected for clay extraction from the various respondents may not be for the same 12-month period. Mined clay is sometimes stored on site for a period of time before it is used to manufacture bricks.
10	Seasonal rainfall will have an effect on the ability for clay to be mined; some factories only extract clay during the dry season and overload their stockpiles in order to account for production losses during the wet season.
11	An average clay type although it is noted that clays differ geographically, and these differences may have an effect on the energy and water usage.
12	An average coal energy value but it is noted from the responses that coal quality and carbon content varies. The coal used for firing in the various manufacturing plants may possess different properties with regard to carbon content, firing temperature, emissions data and fuel grade.
13	The assumptions for the annual energy usage and model used for generating this can be sourced from CBA Technical Report 7B, as referenced in the references of this report.

14	The use of proxy data for the substances emitted from burning coal was done as no overall comprehensive air quality emissions studies were completed at any of the manufacturing plants in this study.
15	Transport for each stage of the manufacturing process was treated as a separate unit process, this enables the results for transport emissions to be calculated separately from each stage of manufacturing.
16	It was found necessary to develop a unit process for clay extraction and fuel used for mining for each firing technology as each technology is typically associated with a different quality of clay and availability within the vicinity of the manufacturing plant.
17	The decision to average data over each firing technology was implemented as this would be the only means of obtaining an overall view of the industry, although it is possible to complete a LCA for each manufacturing plant, it was not the objective of this study to consider each plant, but rather the different firing technologies.
18	It is well evidenced that the life span of clay brick structures can exceed 500 years, but for the purpose of this study the average lifespan is taken at 50 years.
Limitations	
1	The target population of this study was limited to CBA members whereas it is known that there are a number of clay brick manufacturers who are not registered or members of the CBA.

7.3 SENSITIVITY, COMPLETENESS AND UNCERTAINTY

7.3.1 Sensitivity analyses

Sensitivity analyses have been completed and modelled with defined parameters in the LCA model to address areas of data uncertainty and to better understand process relationships.

The areas of uncertain data are emissions from burning coal, water additions during the preparation of the wet clay mix, the mass of clay, electricity consumption split between unit processes, transport of firing fuel to manufacturing plant, transport of material to landfill and operational lifespan of a brick structure. Data obtained from literature are estimates for the South African context; these include emissions from burning coal. Analyses showed little variation. This is due to the fact that the full population was surveyed and actual figures were recorded in the field survey. It can therefore be concluded that the data represented in the LCA model are accurate and a true reflection of the clay brick industry in South Africa.

7.3.2 Completeness and consistency check

An overview of the data completeness for the LCA is presented in Table 7.2.

Table 7.2: Overview of data completeness

Component	Data completeness
General	Data collected from 86 sites representing almost 10 000 000 000 kg of brick (84% of clay brick manufacturers in South Africa).
Transport of fuel to plant	Data collected for distance, quantity
Clay extraction	Data collected for land area, use, time
Mining fuel	Data collected for fuel used
Clay preparation	Data collected for water used, energy used, fuel additions, and additives
Wet green brick transport	Data collected for fuel used
Drying of wet green brick	Data collected for fuel used for drying
Emissions from drying	Where appropriate, used from other suitable studies
Dry green brick transport	Data collected for fuel used, energy
Firing	Data collected for fuel used, energy
Fired brick transport	Data collected for fuel used
Factory overheads	Data collected for overheads such as electricity and water.
Material for building in	Data collected for quantity material required for $1m^2$ walling
Operational lifespan	Data collected for various lifespans
Operational energy	Data collected for production of electricity in South Africa
Maintenance	Data collected and calculated for maintenance on clay brick walls
Demolition	Data calculated for demolition component of End of Life
Reuse	Data calculated for reuse component of End of Life
Recycle	Data calculated for recycle component of End of Life
Transport to landfill	Data calculated for transport to landfill

To ensure consistency in the data that have been used, the following steps were followed:

- Energy consumption data at the various sites were obtained from energy suppliers' invoices to the manufacturers.
- Infrastructure processes such as roads, electricity pylons, administration buildings, transport of staff and factory construction have been excluded from data collection.
- Literature data used for modelling have been sourced from a single database, *EcoInvent* and used as a proxy for this study, where possible their electricity data were substituted with South African electricity data obtained from *The Green House*, a LCA consultancy in South Africa.

7.3.3 Uncertainty

Every LCA is a complex model of data, calculations, choices made and assumptions. By definition, each data point – although not always quantified – carries a degree of uncertainty. It is important to recognise how this uncertainty will affect the results of the study.

The main aspects for uncertainty in this study are:

- Quantification of all the materials, including natural resources, used for manufacturing the clay bricks.
- Division of energy usage across unit processes.
- Quantification of energy used in the firing process.
- Availability of data on process specific emissions.
- Availability of data on the specific emissions of the fuels used.
- Direct material and direct energy use data are accurate; however, process emissions other than that of the actual brick firing process are somewhat uncertain.
- Components of End of Life phase

This study can however be seen as sufficiently accurate, comprehensive and representative of the South African clay brick manufacturing industry since the collected data are for 84.3% of the full population. Multiple sources of information were collected for the calculated data components of the study.

7.4 FINDINGS AND DISCUSSIONS FOR THE CRADLE TO GATE PHASE OF THE LCA

7.4.1 Identification of significant issues

The various life cycle stages of clay brick production in South Africa have been modelled and assessed using the internationally recognized *SimaPro* LCA software. Figure 7.1 and Tables 7.3 to 7.5 below show the significance of the firing technology/unit process upon the assessed environmental impacts. The contributions of each firing technology/unit process within each firing technology are rated on a colour scale, with the greatest contributor to the impact category being red and the lowest contributor to the impact category highlighted in green. Average contributions are a combination of red and green, refer to Table 7.3 below.

Table 7.3: The emission values of each firing technology of the assessed environmental impact categories (Highest contribution = red, lowest contribution = green)

Impact category	Unit	Clamp kiln_final rev1	Tunnel kiln_final rev1	VSBK kiln_final rev2	TVA kiln_final rev1	Zigzag kiln_final rev1	Hoffman kiln_final rev1
Carcinogens	kg C2H3Cl eq	0.00217491	0.00177026	0.00225322	0.00224575	0.00190803	0.00427089
Non-carcinogens	kg C2H3Cl eq	0.01092622	0.00535910	0.01137527	0.01139917	0.00920686	0.02193616
Respiratory inorganics	kg PM2.5 eq	0.00016065	0.00014634	0.00029380	0.00023817	0.00015477	0.00029462
Ionizing radiation	Bq C-14 eq	0.42093342	0.54806516	0.38893235	0.75018383	0.42877667	0.60425785
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000001	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00002614	0.00003168	0.00002327	0.00002409	0.00003086	0.00003714
Aquatic ecotoxicity	kg TEG water	34.27989118	16.44613402	27.86532683	31.23583169	23.11512871	53.78178809
Terrestrial ecotoxicity	kg TEG soil	9.30269052	4.50354896	7.77553166	8.47720434	6.78523946	14.94202440
Terrestrial acid/nutri	kg SO2 eq	0.00348232	0.00342582	0.00584721	0.00531728	0.00348903	0.00592364
Land occupation	m2org.arable	0.00085851	0.00035120	0.00058972	0.00055148	0.00059941	0.00187126
Aquatic acidification	kg SO2 eq	0.00146539	0.00123979	0.00301916	0.00219968	0.00131888	0.00278059
Aquatic eutrophication	kg PO4 P-lim	0.00008107	0.00002727	0.00005271	0.00005289	0.00004408	0.00010156
Global warming	kg CO2 eq	0.26554181	0.24426787	0.28045177	0.33417085	0.23733932	0.51526328
Non-renewable energy	MJ primary	3.58058319	3.19801007	2.52821803	3.28309681	2.26506805	4.53792822
Mineral extraction	MJ surplus	0.00023532	0.00018969	0.00019122	0.00016711	0.00028370	0.00030648

The environmental impacts associated with manufacturing clay bricks in South Africa are presented in Table 7.4. These results encompass the production of clay bricks in 2012 for the country (9 661 915 937 kg fired clay brick) relating to the population breakdown found in section 5.1.2.3 of this report. The results show that the

Hoffman kiln process has the largest environmental overall impact across firing technologies employed in South Africa.

Table 7.4: Industry severity scale in terms of full industry production (Highest contribution = red, lowest contribution = green)

Impact category	Unit	Clamp kiln_final rev1	Tunnel kiln_final rev1	VSBK kiln_final rev2	TVA kiln_final rev1	Zigzag kiln_final rev1	Hoffman kiln_final rev1	Total
Carcinogens	kg C_2H_3Cl eq	14 441 253.90	3 097 767.37	373 431.70	2 266 074.07	67 582.54	264 286.78	20 510 396.36
Non-carcinogens	kg C_2H_3Cl eq	72 549 384.22	9 377 875.70	1 885 249.58	11 502 323.66	326 107.16	1 357 431.33	96 998 371.66
Respiratory inorganics	kg PM2.5 eq	1 066 692.30	256 085.37	48 692.47	240 325.96	5 481.93	18 231.12	1 635 509.15
Ionizing radiation	Bq C-14 eq	2 794 971 270.51	959 057 184.09	64 458 665.38	756 972 685.16	15 187 269.70	37 392 078.62	4 628 039 153.45
Ozone layer depletion	kg CFC-11 eq	10.273000592	24.564638037	0.298254498	1.267938609	0.144497949	0.101841655	36.650171340
Respiratory organics	kg C_2H_4 eq	173 535.16	55 442.30	3 856.10	24 311.01	1 093.04	2 297.97	260 535.57
Aquatic ecotoxicity	kg TEG water	227 616 308 587.21	28 779 028 785.87	4 618 185 631.76	31 518 503 187.27	818 737 858.88	3 328 070 707.52	296 678 834 758.50
Terrestrial ecotoxicity	kg TEG soil	61 769 276 517.67	7 880 743 585.69	1 288 657 004.00	8 553 919 568.31	240 333 181.55	924 627 378.58	80 657 557 235.80
Terrestrial acid/nutri	kg SO_2 eq	23 122 375.82	5 994 825.60	969 072.16	5 365 399.28	123 581.31	366 560.79	35 941 814.94
Land occupation	m^2org.arable	5 700 444.32	614 571.03	97 736.04	556 474.86	21 231.17	115 795.68	7 106 253.10
Aquatic acidification	kg SO_2 eq	9 730 107.34	2 169 499.23	500 372.62	2 219 591.24	46 714.62	172 065.74	14 838 350.80
Aquatic eutrophication	kg PO_4 P-lim	538 316.65	47 724.98	8 736.37	53 364.89	1 561.45	6 284.38	655 988.70
Global warming	kg CO_2 eq	1 763 180 789.44	427 443 444.41	46 479 926.40	337 194 955.76	8 406 558.89	31 885 006.07	2 614 590 680.97
Non-renewable energy	MJ primary	23 774 845 833.58	5 596 185 930.62	419 007 472.81	3 312 807 491.21	80 228 710.49	280 811 526.18	33 463 886 964.89
Mineral extraction	MJ surplus	1 562 491.55	331 944.22	31 691.94	168 619.59	10 048.49	18 965.52	2 123 761.31

Each of the impact categories is discussed below using the results from averaged data for the full industry. The averaged results used in the discussion are presented in Table 7.5.

Table 7.5: Average results for the clay brick industry

Impact category	Unit	per kg, weighted average (total emission / total produced)	per brick (2.75kg)	per m2 (104 kg's)
Carcinogens	kg C_2H_3Cl eq	0.002123	0.005837723	0.607123204
Non-carcinogens	kg C_2H_3Cl eq	0.010039	0.027607932	2.87122497
Respiratory inorganics	kg PM2.5 eq	0.000169	0.000465503	0.048412305
Ionizing radiation	Bq C-14 eq	0.478998	1.317244712	136.99345
Ozone layer depletion	kg CFC-11 eq	0.000000	1.04315E-08	1.08487E-06
Respiratory organics	kg C_2H_4 eq	0.000027	7.41543E-05	0.007712049
Aquatic ecotoxicity	kg TEG water	30.706005	84.44151252	8781.917303
Terrestrial ecotoxicity	kg TEG soil	8.347988	22.9569667	2387.524537
Terrestrial acid/nutri	kg SO_2 eq	0.003720	0.010229854	1.063904834
Land occupation	m^2org.arable	0.000735	0.002022601	0.210350452
Aquatic acidification	kg SO_2 eq	0.001536	0.004223331	0.439226377
Aquatic eutrophication	kg PO_4 P-lim	0.000068	0.000186709	0.01941776
Global warming	kg CO_2 eq	0.270608	0.744171696	77.39385642
Non-renewable energy	MJ primary	3.463484	9.524579779	990.556297
Mineral extraction	MJ surplus	0.000220	0.000604471	0.062864937

Typically, to facilitate interpretation of the impact results, normalization is completed in order to compare impact categories in the same unit. Figure 6.1 presented in Chapter 6 shows the results for the full industry which has been subjected to normalization and therefore facilitates interpretation in this chapter.

Figure 7.1 below presents the same results as Figure 6.1, with the addition of an "average" kiln.

The normalized results presented in Figure 7.1 show that the environmental impact categories most affected are respiratory inorganics, terrestrial eco-toxicity, global warming and non-renewable energy. A discussion of every impact category assessed in this model is presented in item 7.4.2 for the full industry which is followed by a discussion of each firing technology in terms of the assessed environmental impacts in item 7.4.3.

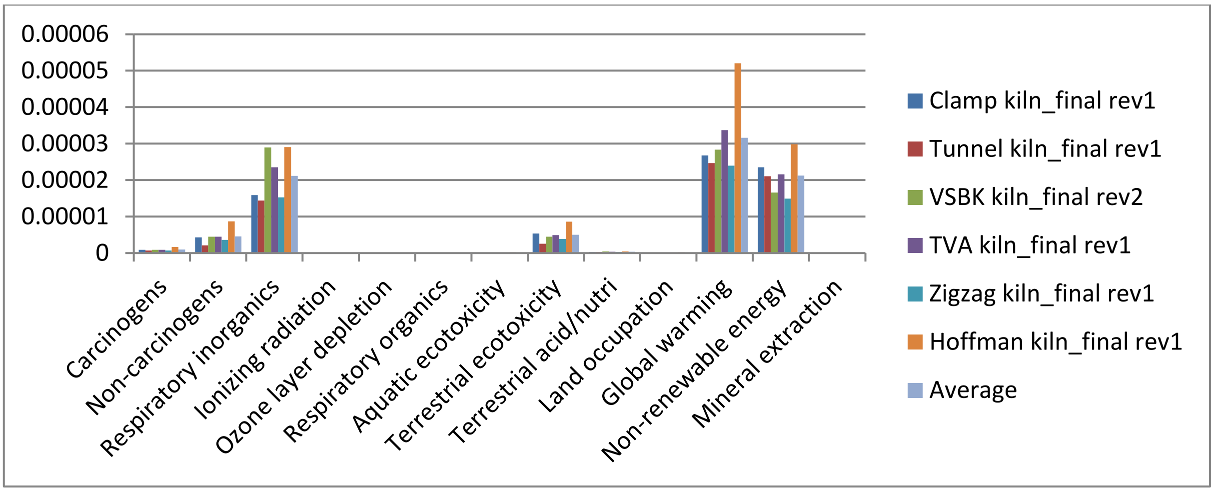

Figure 7.1: Comparison of normalization results for all firing technologies across impact categories (Normalized per person per year in Europe)

Figure 7.1 above reveals that overall; the manufacture of clay bricks in South Africa has high environmental impacts. The most severe impacts, when compared under normalization conditions as presented in Figure 7.1 are global warming, non-renewable energy and respiratory inorganics.

This is largely due to the use of fossil fuels, largely coal, for the firing of the bricks. Every producer makes use of fossil fuels for the firing process whether it is coal, natural gas, or oils. The major (but not only) environmental impact from burning fossil fuels is the release of carbon dioxide into the atmosphere. Carbon dioxide is a gas that traps heat in the earth's atmosphere. The combustion of fossil fuels is also implicated in increasing levels of atmospheric methane and nitrous oxide. Heating up of the atmosphere contributes to the increase in global temperature.

The second largest environmental impact from manufacturing clay bricks is the use of non-renewable energy. Similarly, to the contribution to global warming, the use of non-renewable energy sources (fossil fuels) contributes to the depletion of the fossil fuels, valuable limited natural resources.

The third largest environmental impact associated with the manufacture of clay bricks is the release of respiratory inorganics. These are harmful particulate matter which contributes to the health of humans. As the environmental impact suggest, these particulate matter particles affect the respiratory tract. Burning fossil fuels release respiratory inorganics.

Firing technologies whose results are higher than the industry average and whose respective processes therefore contribute most severely to environmental impacts and which have the most potential to be reduced will be discussed in more detail.

7.4.2 Industry results discussions

7.4.2.1 CARCINOGENS

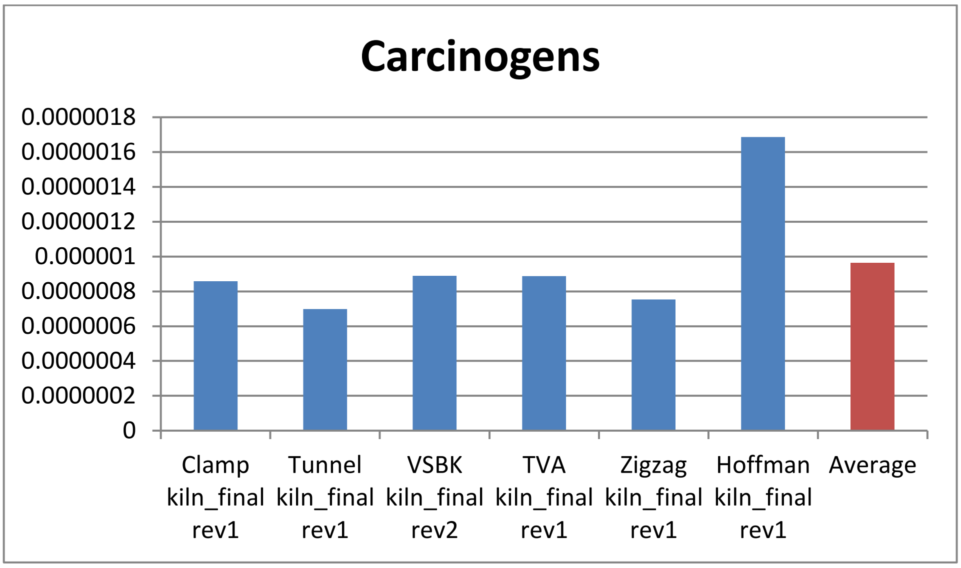

Figure 7.2: Characterization results for the impact category "carcinogens" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

The impact category "carcinogens" addresses the effects of cancer causing substances. The Hoffman kiln emits the largest quantity of carcinogens per kg of fired clay brick amongst the firing technologies used in South Africa. These impacts arise from the firing of bricks using large quantities of fossil fuels which, in South Africa, on average, is higher than other kiln types.

7.4.2.2 NON-CARCINOGENS

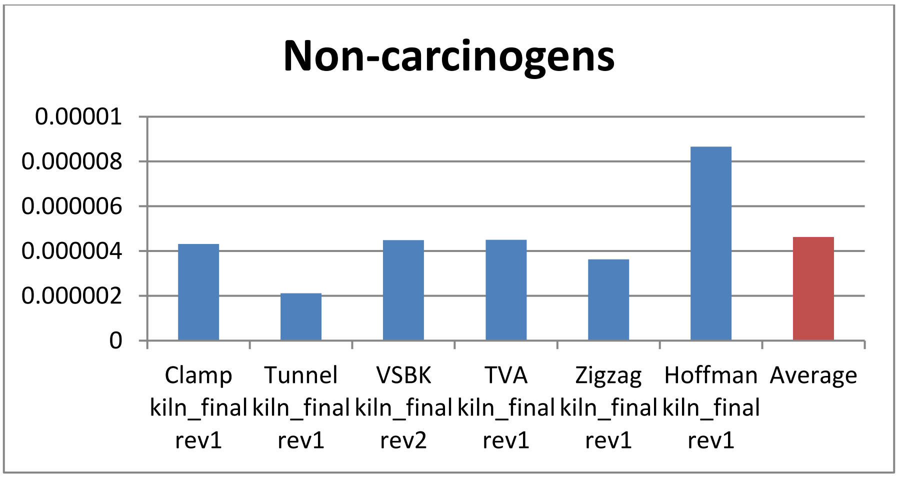

Figure 7.3: Characterization results for the impact category "non-carcinogens" for the full industry of clay brick

Non-carcinogenic emissions pose no cancer risks to human health. The results show a large difference between all firing technologies; this is due to all the firing technologies using varying quantities of coal as an internal or external fuel or both. The emissions associated with non-carcinogens are emitted from the mining phase of coal and from the transport of this coal to the various production plants. The tunnel kiln is lowest for this impact category as a smaller quantity of coal is generally used during the firing process.

7.4.2.3 RESPIRATORY INORGANICS

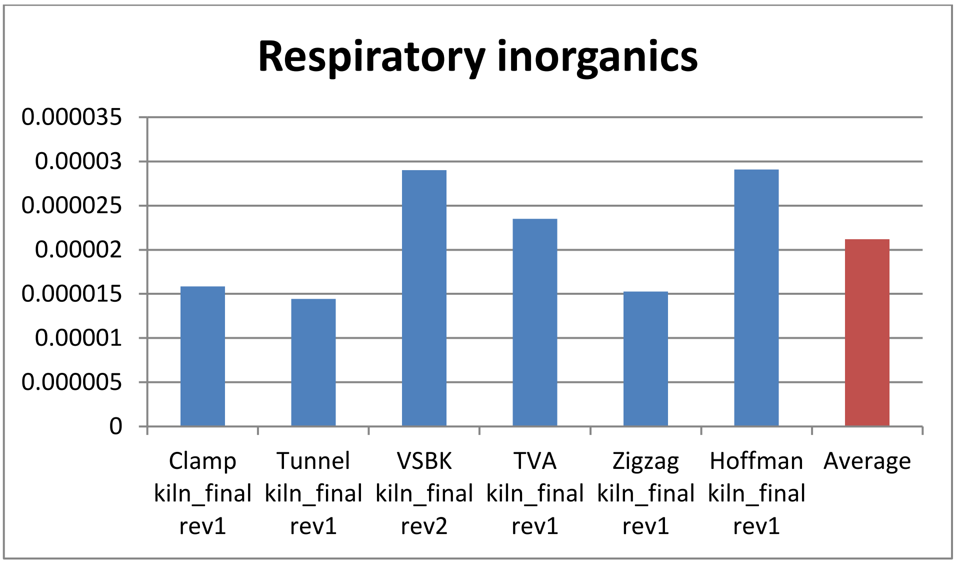

Figure 7.4: Characterization results for the impact category "respiratory inorganics" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Respiratory inorganics affect the respiratory systems of humans and animals resulting from winter smog caused by the release of dust, sulphur and nitrogen oxides to the air. For this impact category it was found that the Hoffman and VSBK kilns have the highest respiratory inorganic emissions per kg of fired clay bricks. These emissions are released from the burning of fuels (tyres in the case of VSBK), the quantity added as an internal fuel and the electricity used from the South African electricity grid. The results show some variation amongst the other firing technologies which too are attributed to the combination of coal burning emissions, addition of internal body fuel and electricity used from the South African electricity grid. Natural gas used for firing in tunnel kilns (which result in the lowest impact) contributes to this impact category.

7.4.2.4 IONIZING RADIATION

The impact category "ionizing radiation" covers the impacts arising from releases of radioactive substances as well as direct exposure to radioactive substances. Exposure to ionizing radiation is harmful to both humans and animals. The highest contributor per kg fired clay bricks in South Africa is the TVA kiln.

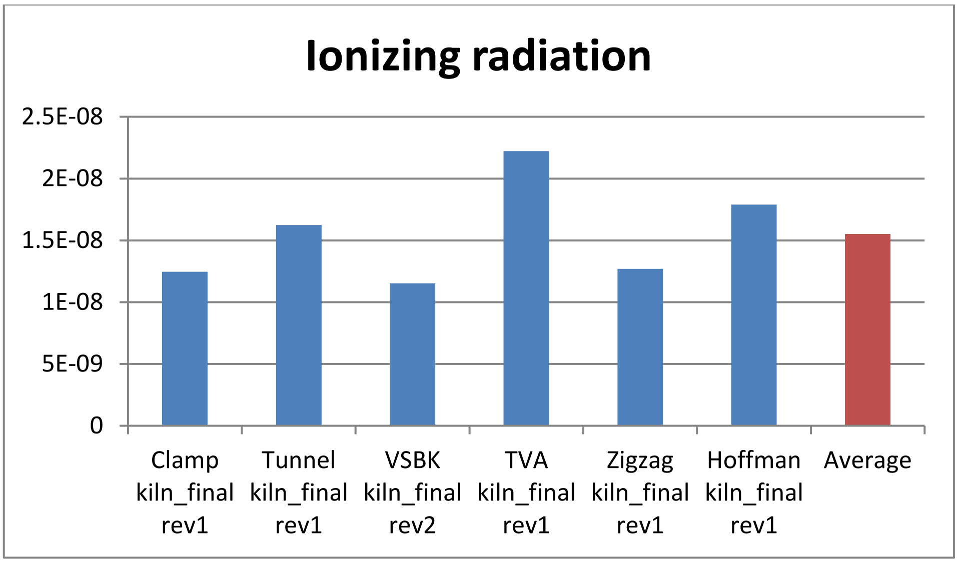

Figure 7.5: Characterization results for the impact category "ionizing radiation" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

7.4.2.5 OZONE LAYER DEPLETION

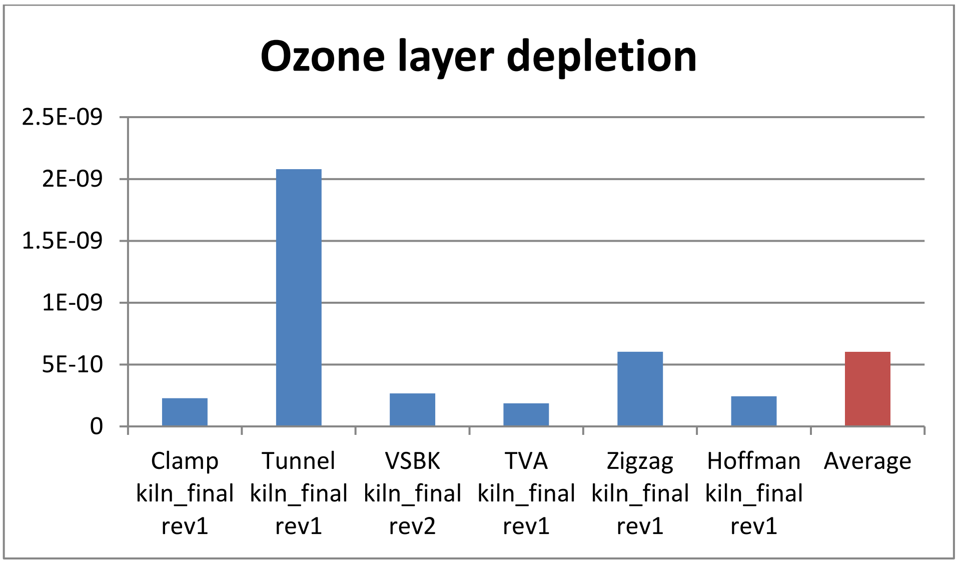

Figure 7.6: Characterization results for the impact category "ozone layer depletion" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Stratospheric ozone depletion refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions of greenhouse gases. For this impact category, the highest contributor of ozone layer depleting substances per kg fired clay bricks is the tunnel kiln. Natural gas is made up mostly of methane, some natural gas leaks into the atmosphere from oil and natural gas wells, storage tanks, pipelines, and processing plants. Methane is a potent greenhouse gas.

7.4.2.6 RESPIRATORY ORGANICS

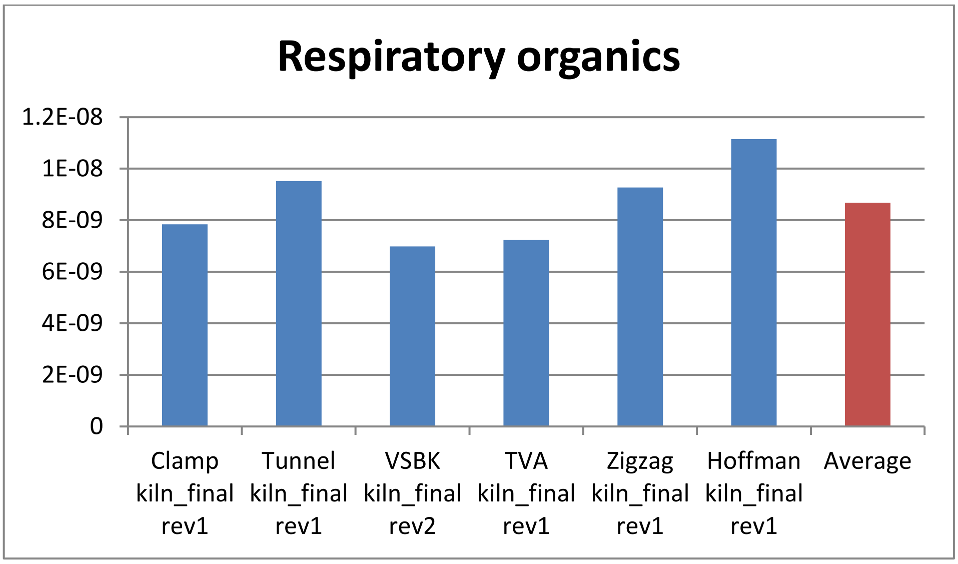

Figure 7.7: Characterization results for the impact category "respiratory organics" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

The impacts, primarily respiratory effects, in the category of respiratory organics result from summer smog caused by the emissions of organic substances to air. The highest contributor of respiratory organics is Hoffman kiln. The heavy use of coal due to multiple start-up fires required in clamp kiln plants also contribute to this impact category. Coal used as the internal and external firing fuels for clamp operations contribute heavily from upstream emissions as a result of coal mining.

7.4.2.7 AQUATIC ECO-TOXICITY

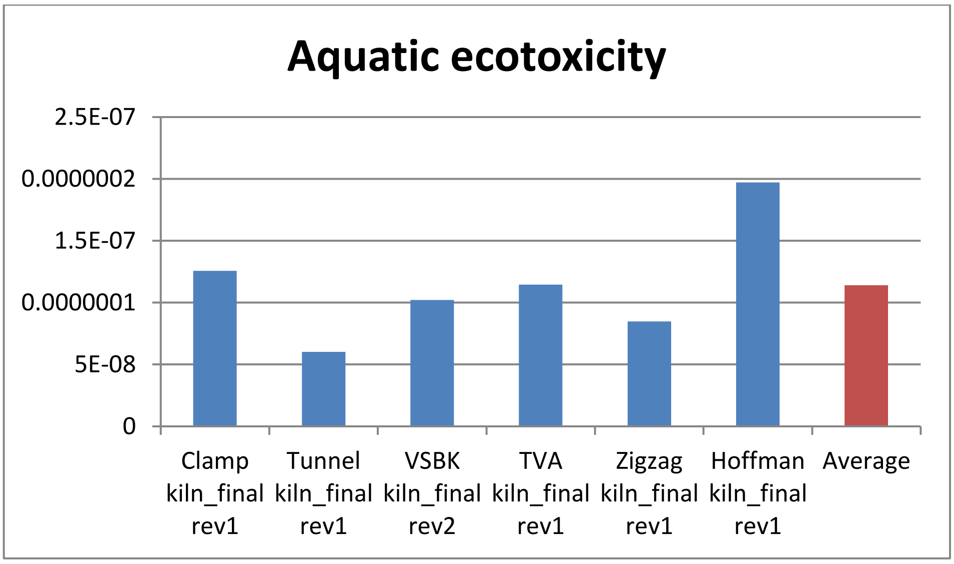

Figure 7.8: Characterization results for the impact category "aquatic eco-toxicity" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Aquatic eco-toxicity refers to the impact of toxic substances on aquatic systems released from the analysed system. Hoffman kiln operations contribute the highest per kg fired clay brick to this impact category. The emissions for Hoffman kilns are attributed to the use of coal as internal and external firing fuels. Although emissions from mining coal is evident in all firing technologies, the quantity of coal sourced and added as an internal and/or external firing fuel contributes to this impact category.

7.4.2.8 TERRESTRIAL ECO-TOXICITY

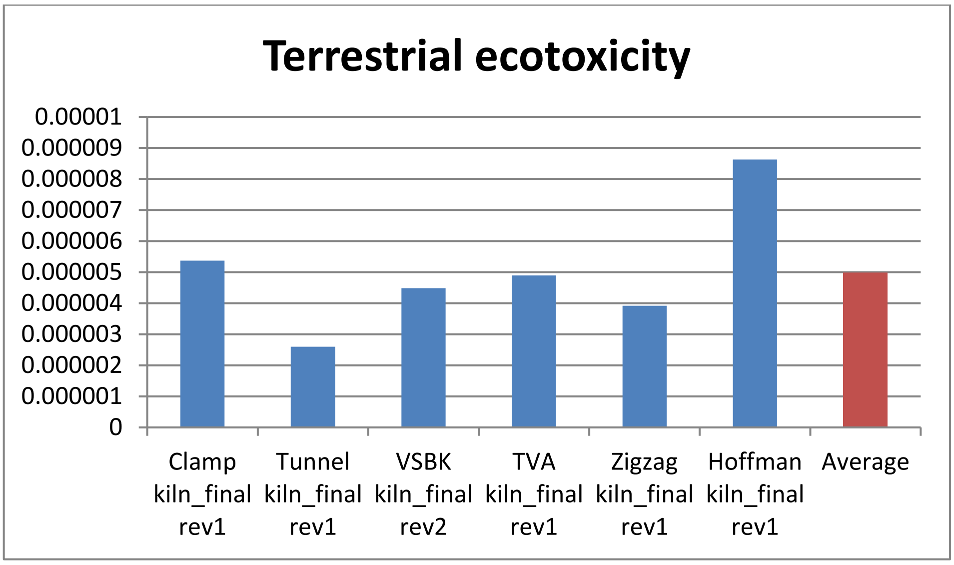

Figure 7.9: Characterization results for the impact category "terrestrial eco-toxicity" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Terrestrial eco-toxicity refers to the impact of toxic substances on terrestrial systems released from the analysed system. Hoffman kiln operations contribute the highest per kg fired clay brick to this impact category. The emissions for clamp kilns are attributed to the use of coal as internal and external firing fuels. Although emissions from mining coal is evident in all firing technologies, the quantity of coal sourced and added as an internal and/or external firing fuel contributes to this impact category.

7.4.2.9 TERRESTRIAL ACIDIFICATION/NUTRIFICATION

Terrestrial acidification is generally considered to be caused by nitrogen and sulphur. The sources of nitrogen and sulphur are fossil fuel combustion amongst other processes. The effect of acidification is the decrease of species richness and diversity. The contribution made by Hoffman and VSBK kilns per kg fired clay brick are the highest for this impact category. These emissions from VSBK kilns are attributed to the use of coal as internal firing fuel and the burning of tyres for drying the wet green bricks. Although emissions from mining coal is evident in all firing technologies, the quantity of coal sourced and added as an internal and/or external firing fuel contributes to this impact category.

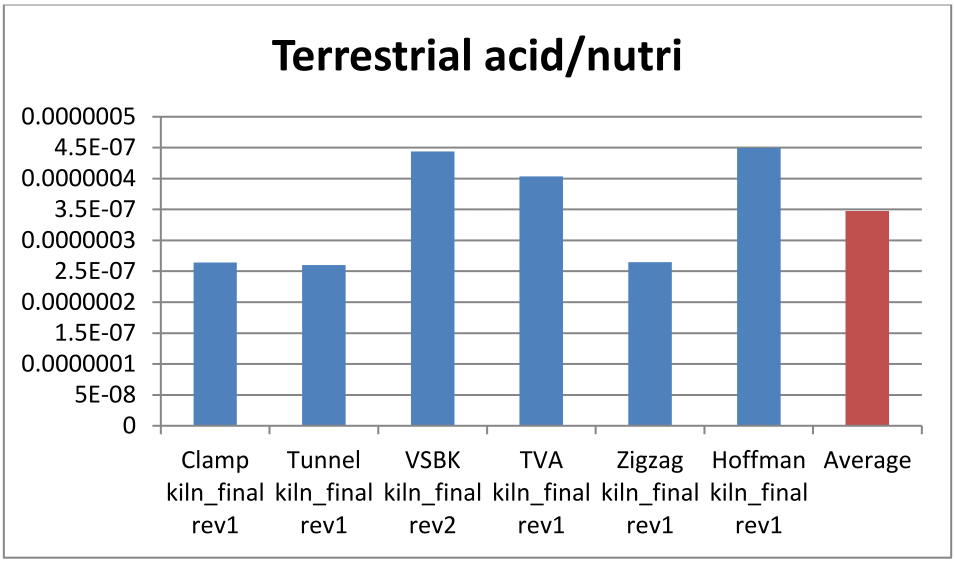

Figure 7.10: Characterization results for the impact category "terrestrial acidification/nutrification" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

7.4.2.10 LAND OCCUPATION

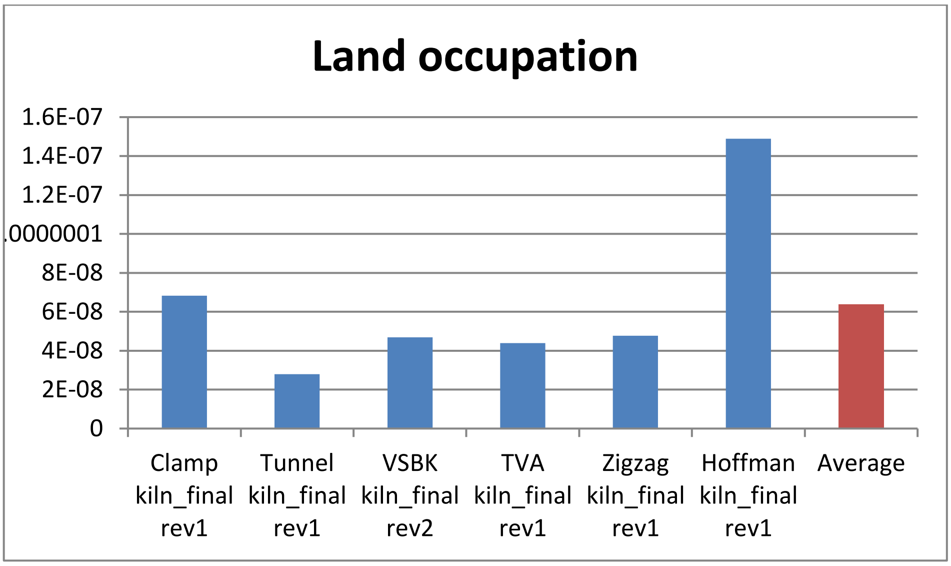

Figure 7.11: Characterization results for the impact category "land occupation" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

The "land occupation" impact category addresses land use changes which result in the transformation of land unsuited for the continued growth of diverse plant species. This impact category is dominated by the high contributions per kg fired clay bricks for Hoffman kilns and clamp kilns. The impacts associated with land occupation are evident in all firing technologies, as all firing technologies use coal as an internal and/or external fuel. The coal mining industry makes use of timber in the mining process. Such timber plantations occupy large tracts of land which are transformed into mono-culture use and results in a loss of biodiversity. The clamp and Hoffman kilns contribute the most in this impact category as these firing technologies utilise, on average, a higher land use per kg of fired clay brick.

7.4.2.11 GLOBAL WARMING

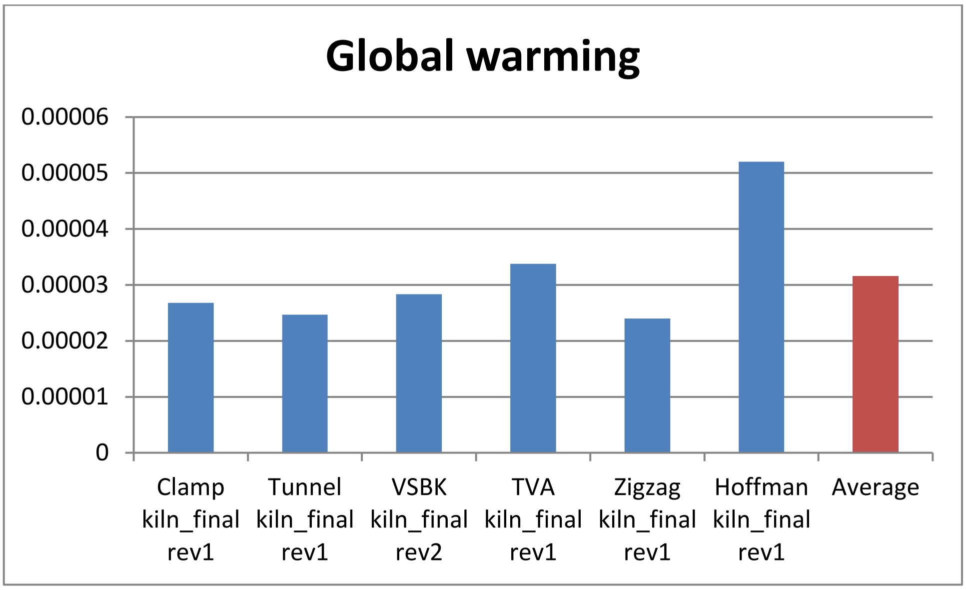

Figure 7.12: Characterization results for the impact category "global warming" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Greenhouse gases emitted into the atmosphere may have broad based adverse effects on all forms of life. The global warming impact category is expressed in carbon dioxide equivalents. The results for global warming show that the although the Hoffman kiln has the highest contribution to global warming per kg of fired clay brick, all firing technologies pose a risk to the environment as a result of combustion of fossil fuels in the firing process. When assessing the Global Warming impact of the industry, the population distribution of the various kiln types should be analysed.

7.4.2.12 NON-RENEWABLE ENERGY

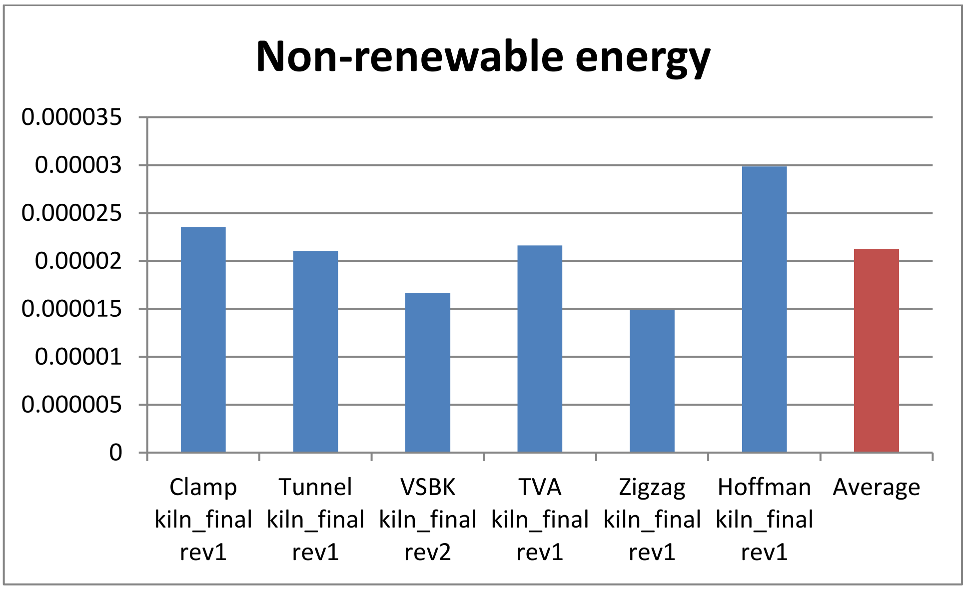

Figure 7.13: Characterization results for the impact category "non-renewable energy" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

Figure 7.13 shows the quantity of non-renewable energy used for manufacturing 1 kg of fired clay brick for each firing technology. The results show that the Hoffman firing technology uses the most non-renewable energy for manufacture of clay bricks, while VSBK and zigzag kilns use the least. The combination of coal burning emissions and the quantity of coal used as an internal body fuel contributes to the non-renewable energy result for Hoffman kilns. It cannot be ignored that all firing technologies utilise fossil fuels for firing bricks, therefore non-renewable energy consumption is expected for all firing technologies.

7.4.2.13 MINERAL EXTRACTION

For the mineral extraction impact category, it is assumed that a certain quantity of the mineral mined will lead to additional energy required for further mining of this resource in the future. The Hoffman kiln contributed the highest per kg fired clay brick for this impact category. The processes that attribute to this is the high use of coal in the drying process averaged over all the manufacturers, as well as coal burning emissions and the use of coal as a firing fuel.

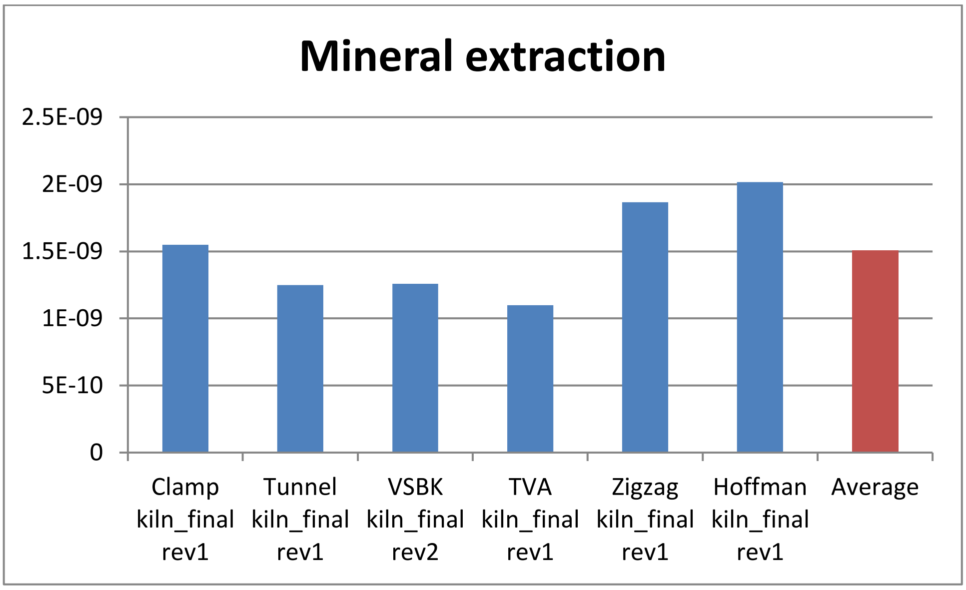

Figure 7.14: Characterization results for the impact category "mineral extraction" for the full industry of clay brick manufacturers (results presented per kg fired clay brick)

7.4.3 Clamp kiln results discussion

Table 7.6: Clamp kiln unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	C0, Clamp, transport of fuels, at plant, ZA	C1, Clamp, clay extraction, extracted clay, ZA	C2, Clamp, mining fuel, stockpiled clay, ZA	C3, Clamp, clay preparation, wet green brick, ZA rev1	C4, Clamp, wet green brick transport, wet bricks ready for drying, ZA	C5, Clamp, drying of wet green brick, dry green brick, ZA rev1	C6, Clamp, dry green brick transport, at firing location, ZA	C7, Clamp, brick firing, fired brick, ZA rev1	C8, Clamp, fired brick transport, at sales bay, ZA	C9, Clamp, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.000019	0.000000	0.000017	0.000042	0.000007	0.000076	0.000007	0.002121	0.000005	0.000000
Non-carcinogens	kg C2H3Cl eq	0.000028	0.000000	0.000009	0.000071	0.000003	0.000227	0.000004	0.010879	0.000003	0.000000
Respiratory inorganics	kg PM2.5 eq	0.000004	0.000000	0.000007	0.000024	0.000003	0.000030	0.000003	0.000143	0.000002	0.000000
Ionizing radiation	Bq C-14 eq	0.026608	0.000000	0.007534	0.242237	0.002867	0.279964	0.002878	0.377434	0.002085	0.001527
Ozone layer depletion	kg CFC-11 eq	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Respiratory organics	kg C2H4 eq	0.000002	0.000000	0.000003	0.000008	0.000001	0.000009	0.000001	0.000019	0.000001	0.000000
Aquatic ecotoxicity	kg TEG water	0.182083	0.000000	0.103330	13.297070	0.039328	15.470803	0.039474	33.873926	0.028600	0.013150
Terrestrial ecotoxicity	kg TEG soil	0.119588	0.000000	0.024198	3.383058	0.009210	3.943136	0.009244	9.130472	0.006697	0.003281
Terrestrial acid/nutri	kg SO2 eq	0.000118	0.000000	0.000165	0.000836	0.000063	0.000992	0.000063	0.003021	0.000046	0.000007
Land occupation	m2org.arable	0.000025	0.000000	0.000003	0.000505	0.000001	0.000581	0.000001	0.000827	0.000001	0.000000
Aquatic acidification	kg SO2 eq	0.000018	0.000000	0.000024	0.000177	0.000009	0.000221	0.000009	0.001396	0.000007	0.000002
Aquatic eutrophication	kg PO4 P-lim	0.000000	0.000000	0.000000	0.000049	0.000000	0.000056	0.000000	0.000080	0.000000	0.000000
Global warming	kg CO2 eq	0.002853	0.000000	0.002461	0.015122	0.000937	0.020764	0.000940	0.257454	0.000681	0.000215
Non-renewable energy	MJ primary	0.047628	0.000000	0.037429	2.136022	0.014246	2.459057	0.014299	3.453605	0.010360	0.003016
Mineral extraction	MJ surplus	0.000023	0.000000	0.000016	0.000110	0.000006	0.000127	0.000006	0.000180	0.000004	0.000000

Table 7.6 above shows the severity scale of the contributing unit processes to the total environmental impacts for the clamp kiln industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of the clamp kiln technology is the firing process (unit process C7) itself. Unit process C7 inherits the contributions from C5, which inherits from C3. Please refer to the appendices for explanations of the unlisted unit processes.

7.4.4 Tunnel kiln results discussion

Table 7.7: Tunnel kiln unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	T0, Tunnel, transport of fuel, at plant, ZA	T2 Tunnel, mining fuel, stockpiled clay, ZA	T3 Tunnel, clay preparation, wet green brick, ZA rev1	T4 Tunnel, wet green brick transport, wet bricks ready for drying, ZA	T5 Tunnel, drying of wet green brick, dry green brick, ZA rev1	T6 Tunnel, dry green brick transport, at firing location, ZA	T7 Tunnel, brick firing, fired brick, ZA rev1	T8 Tunnel, fired brick transport, at saled bay, ZA	T9 Tunnel, factory overheads, additional water and electricity, ZA rev1
Carcinogens	kg C2H3Cl eq	0.00003447	0.00003578	0.00001908	0.00000142	0.00008672	0.00000073	0.00169344	0.00000402	0.00000039
Non-carcinogens	kg C2H3Cl eq	0.00004281	0.00001897	0.00004354	0.00000075	0.00017989	0.00000039	0.00529252	0.00000213	0.00000152
Respiratory inorganics	kg PM2.5 eq	0.00000500	0.00001393	0.00003788	0.00000055	0.00005286	0.00000029	0.00012274	0.00000156	0.00000227
Ionizing radiation	Bq C-14 eq	0.04894217	0.01559002	0.24490117	0.00062029	0.31645916	0.00032006	0.46833447	0.00175177	0.01250638
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000001	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00000279	0.00000544	0.00000369	0.00000022	0.00000552	0.00000011	0.00002244	0.00000061	0.00000008
Aquatic ecotoxicity	kg TEG water	0.27246045	0.21382821	5.87546777	0.00850778	6.86574538	0.00438979	15.81520957	0.02402684	0.10771137
Terrestrial ecotoxicity	kg TEG soil	0.17084640	0.05007429	1.48794261	0.00199235	1.73209615	0.00102800	4.24710507	0.00562660	0.02687624
Terrestrial acid/nutri	kg SO2 eq	0.00016039	0.00034069	0.00105367	0.00001356	0.00140867	0.00000699	0.00280682	0.00003828	0.00005910
Land occupation	m2org.arable	0.00005089	0.00000674	0.00017008	0.00000027	0.00019605	0.00000014	0.00029237	0.00000076	0.00000004
Aquatic acidification	kg SO2 eq	0.00002440	0.00005011	0.00032669	0.00000199	0.00045271	0.00000103	0.00113619	0.00000563	0.00002044
Aquatic eutrophication	kg PO4 P-lim	0.00000042	0.00000055	0.00001638	0.00000002	0.00001732	0.00000001	0.00002620	0.00000006	0.00000000
Global warming	kg CO2 eq	0.00444514	0.00509270	0.02814490	0.00020263	0.04639378	0.00010455	0.23208658	0.00057224	0.00176403
Non-renewable energy	MJ primary	0.07632672	0.07745503	1.04058650	0.00308177	1.29729766	0.00159012	3.00615023	0.00870325	0.02470295
Mineral extraction	MJ surplus	0.00003523	0.00003288	0.00004013	0.00000131	0.00004837	0.00000068	0.00011566	0.00000369	0.00000023

Table 7.7 above shows the severity scale of the contributing unit processes to the total environmental impacts for the tunnel kiln industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of the tunnel technology is the firing process (unit process T7) itself. Other stages during the production of clay bricks using a tunnel kiln is the drying stage, and clay preparation stage. The clay preparation stage encompasses electrical energy for the crushing and formation of wet green bricks. Unit process T7 inherits the contributions from T5, which inherits from T3. Please refer to the appendices for explanations of the unlisted unit processes.

7.4.5 TVA kiln results discussion

Table 7.8: TVA kiln unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	TVA0, transport of fuel, at plant, ZA	TVA2, mining fuel, stockpiled clay, ZA	TVA3, clay preparation, wet green brick, ZA rev1	TVA4, wet green brick transport, wet green brick ready for drying, ZA	TVA5, drying of wet green brick, dry green brick, ZA rev1	TVA6, dry green brick transport, at firing location, ZA	TVA7, brick firing, fired brick, ZA rev1	TVA8, fired brick transport, at sales bay, ZA	TVA9, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00000542	0.00002507	0.00003110	0.00000193	0.00003414	0.00000250	0.00220137	0.00000835	0.00000111
Non-carcinogens	kg C2H3Cl eq	0.00000800	0.00001330	0.00007172	0.00000102	0.00008354	0.00000133	0.01136679	0.00000443	0.00000430
Respiratory inorganics	kg PM2.5 eq	0.00000101	0.00000976	0.00006357	0.00000075	0.00008126	0.00000097	0.00021600	0.00000325	0.00000643
Ionizing radiation	Bq C-14 eq	0.00757074	0.01092553	0.40827227	0.00084219	0.50571267	0.00108952	0.69070504	0.00363941	0.03541140
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00000053	0.00000381	0.00000602	0.00000029	0.00000665	0.00000038	0.00001758	0.00000127	0.00000023
Aquatic ecotoxicity	kg TEG water	0.05187370	0.14985142	9.55950278	0.01155120	10.39870936	0.01494361	30.65271357	0.04991705	0.30498113
Terrestrial ecotoxicity	kg TEG soil	0.03401688	0.03509221	2.42042152	0.00270506	2.62982114	0.00349949	8.31410194	0.01168957	0.07609918
Terrestrial acid/nutri	kg SO2 eq	0.00003375	0.00023875	0.00176304	0.00001840	0.00222346	0.00002381	0.00475570	0.00007953	0.00016733
Land occupation	m2org.arable	0.00000707	0.00000472	0.00027295	0.00000036	0.00027326	0.00000047	0.00053717	0.00000157	0.00000011
Aquatic acidification	kg SO2 eq	0.00000506	0.00003512	0.00054922	0.00000271	0.00070844	0.00000350	0.00208374	0.00001170	0.00005786
Aquatic eutrophication	kg PO4 P-lim	0.00000008	0.00000039	0.00002628	0.00000003	0.00002629	0.00000004	0.00005222	0.00000013	0.00000000
Global warming	kg CO2 eq	0.00082115	0.00356898	0.04732010	0.00027511	0.06106412	0.00035591	0.32296603	0.00118886	0.00499480
Non-renewable energy	MJ primary	0.01372452	0.05428071	1.69994273	0.00418419	1.89240968	0.00541303	3.11746732	0.01808146	0.06994557
Mineral extraction	MJ surplus	0.00000644	0.00002305	0.00006468	0.00000178	0.00006650	0.00000230	0.00012521	0.00000768	0.00000066

Table 7.8 above shows the severity scale of the contributing unit processes to the total environmental impacts for the TVA kiln industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of the TVA technology is the firing process (unit process TVA7) itself. Energy usage is attributed largely to the clay preparation and drying stages of the TVA kiln. Unit process TVA7 inherits the contributions from TVA5, which inherits from TVA3. Please refer to the appendices for explanations of the unlisted unit processes.

7.4.6 Hoffman kiln results discussion

Table 7.9: Hoffman kiln unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	H0, Hoffman, transport of fuel, at plant, ZA	H2, Hoffman, mining fuel, stockpiled clay, ZA	H3, Hoffman, clay preparation, wet green brick, ZA rev1	H4, Hoffman, wet green brick transport, wet green bricks ready for drying, ZA	H5, Hoffman, drying of wet green brick, dry green brick, ZA rev1	H6, Hoffman, dry green brick transport, at firing location, ZA	H7, Hoffman, brick firing, fired brick, ZA rev1	H8, Hoffman, fired brick transport, at sales bay, ZA	H9, Hoffman, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00001376	0.00002989	0.00004622	0.00000076	0.00007277	0.00000076	0.00421863	0.00000704	0.00000003
Non-carcinogens	kg C2H3Cl eq	0.00002067	0.00001585	0.00008273	0.00000040	0.00029939	0.00000040	0.02189497	0.00000374	0.00000012
Respiratory inorganics	kg PM2.5 eq	0.00000259	0.00001163	0.00003751	0.00000030	0.00004843	0.00000030	0.00027687	0.00000274	0.00000018
Ionizing radiation	Bq C-14 eq	0.01959505	0.01302571	0.32136707	0.00033166	0.37927452	0.00033166	0.56692026	0.00306975	0.00098375
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00000136	0.00000454	0.00000876	0.00000012	0.00001024	0.00000012	0.00002992	0.00000107	0.00000001
Aquatic ecotoxicity	kg TEG water	0.13409321	0.17865690	14.68390078	0.00454894	16.38013014	0.00454894	53.40936364	0.04210386	0.00847259
Terrestrial ecotoxicity	kg TEG soil	0.08806933	0.04183787	3.73320118	0.00106527	4.35249669	0.00106527	14.79801269	0.00985988	0.00211409
Terrestrial acid/nutri	kg SO2 eq	0.00008697	0.00028465	0.00119094	0.00000725	0.00139314	0.00000725	0.00546580	0.00006708	0.00000465
Land occupation	m2org.arable	0.00001831	0.00000563	0.00053665	0.00000014	0.00135583	0.00000014	0.00184570	0.00000133	0.00000000
Aquatic acidification	kg SO2 eq	0.00001303	0.00004187	0.00029262	0.00000107	0.00034312	0.00000107	0.00271208	0.00000987	0.00000161
Aquatic eutrophication	kg PO4 P-lim	0.00000021	0.00000046	0.00005180	0.00000001	0.00005255	0.00000001	0.00010075	0.00000011	0.00000000
Global warming	kg CO2 eq	0.00210132	0.00425504	0.02508459	0.00010834	0.02873197	0.00010834	0.50754871	0.00100278	0.00013876
Non-renewable energy	MJ primary	0.03507549	0.06471492	2.39660573	0.00164776	2.45002526	0.00164776	4.41764786	0.01525129	0.00194314
Mineral extraction	MJ surplus	0.00001660	0.00002747	0.00011851	0.00000070	0.00014835	0.00000070	0.00025451	0.00000647	0.00000002

Table 7.9 above shows the severity scale of the contributing unit processes to the total environmental impacts for the Hoffman kiln industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of the Hoffman kiln technology is the firing process (unit process H7) itself, followed closely by the drying and preparation stages. Transport associated with the Hoffman kiln is evidentially greater than other kilns, this due to the location of mines, stockpiles and production plant. Hoffman kilns also import clay, thereby contributing to the transport of minerals required for the production of clay bricks. Unit process H7 inherits the contributions from H5, which inherits from H3. Please refer to the appendices for explanations of the unlisted unit processes.

7.4.7 VSBK results discussion

Table 7.10: VSBK unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	V0, VSBK, transport of fuel, at plant, ZA	V2, VSBK, mining fuel, stockpiled clay, ZA	V3, VSBK, clay preparation, wet green brick, ZA rev1	V4, VSBK, wet green brick transport, wet green brick ready for drying, ZA	V5, VSBK, drying of wet green brick, dry green brick, ZA rev1	V6, VSBK, dry green brick transport, at firing location, ZA	V7, VSBK, brick firing, fired brick, ZA rev1	V8, VSBK, fired brick transport, at sales bay, ZA	V9, VSBK, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00004065	0.00000924	0.00004365	0.00000725	0.00004369	0.00000706	0.00218496	0.00000373	0.00000033
Non-carcinogens	kg C2H3Cl eq	0.00006106	0.00000490	0.00007597	0.00000385	0.00007694	0.00000374	0.01129846	0.00000198	0.00000127
Respiratory inorganics	kg PM2.5 eq	0.00000766	0.00000360	0.00003024	0.00000282	0.00015939	0.00000275	0.00027362	0.00000145	0.00000191
Ionizing radiation	Bq C-14 eq	0.05787449	0.00402546	0.27754565	0.00315974	0.28842038	0.00307716	0.30866391	0.00162504	0.01050655
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00000401	0.00000140	0.00000826	0.00000110	0.00000827	0.00000107	0.00001504	0.00000057	0.00000007
Aquatic ecotoxicity	kg TEG water	0.39604784	0.05521199	13.91233233	0.04333813	13.90657630	0.04220540	27.21574714	0.02228852	0.09048780
Terrestrial ecotoxicity	kg TEG soil	0.26011509	0.01292954	3.53838773	0.01014892	3.53637591	0.00988366	7.45465631	0.00521953	0.02257860
Terrestrial acid/nutri	kg SO2 eq	0.00025686	0.00008797	0.00099471	0.00006905	0.00337941	0.00006724	0.00528093	0.00003551	0.00004965
Land occupation	m2org.arable	0.00005409	0.00000174	0.00051880	0.00000137	0.00051436	0.00000133	0.00053046	0.00000070	0.00000003
Aquatic acidification	kg SO2 eq	0.00003850	0.00001294	0.00022870	0.00001016	0.00171412	0.00000989	0.00292529	0.00000522	0.00001717
Aquatic eutrophication	kg PO4 P-lim	0.00000063	0.00000014	0.00005008	0.00000011	0.00004965	0.00000011	0.00005166	0.00000006	0.00000000
Global warming	kg CO2 eq	0.00620629	0.00131497	0.01957319	0.00103218	0.02134099	0.00100520	0.26888033	0.00053084	0.00148196
Non-renewable energy	MJ primary	0.10359640	0.01999945	2.25177138	0.01569838	2.25855254	0.01528807	2.34480933	0.00807358	0.02075283
Mineral extraction	MJ surplus	0.00004904	0.00000849	0.00011397	0.00000666	0.00011323	0.00000649	0.00011692	0.00000343	0.00000020

Table 7.10 above shows the severity scale of the contributing unit processes to the total environmental impacts for the VSBK industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of clay bricks using a VSBK technology is the firing process (unit process V7) itself, followed closely by the drying process (V5) and the preparation process (V3). The field research conducted revealed that the average VSBK kiln burns discarded tyres in the drying process. Unit process V7 inherits the contributions from V5, which inherits from V3. Please refer to the appendices for explanations of the unlisted unit processes.

7.4.8 Zigzag kiln results discussion

Table 7.11: Zigzag kiln unit process impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	Z0, Zigzag, transport of fuel, at plant, ZA	Z2, Zigzag, mining fuel, stockpiled clay, ZA	Z3, Zigzag, clay preparation, wet green brick, ZA rev1	Z4, Zigzag, wet green brick transport, wet green brick ready for drying, ZA	Z5, Zigzag, drying of wet green brick, dry green brick, ZA re1	Z6, Zigzag, dry green brick transport, at firing location, ZA	Z7, Zigzag, brick firing, fired brick, ZA rev1	Z8, Zigzag, fired brick transport, at sales bay, ZA	Z9, Zigzag, factory overheads, additional water and electricity, ZA
Carcinogens	kg C2H3Cl eq	0.00012412	0.00001297	0.00003545	0.00001031	0.00003564	0.00001031	0.00173991	0.00001031	0.00000009
Non-carcinogens	kg C2H3Cl eq	0.00018644	0.00000688	0.00006085	0.00000547	0.00006158	0.00000547	0.00899678	0.00000547	0.00000036
Respiratory inorganics	kg PM2.5 eq	0.00002338	0.00000505	0.00002256	0.00000401	0.00002364	0.00000401	0.00011375	0.00000401	0.00000054
Ionizing radiation	Bq C-14 eq	0.17670370	0.00565295	0.21534754	0.00449337	0.22133654	0.00449341	0.22994533	0.00449341	0.00299450
Ozone layer depletion	kg CFC-11 eq	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000	0.00000000
Respiratory organics	kg C2H4 eq	0.00001224	0.00000197	0.00000670	0.00000157	0.00000674	0.00000157	0.00001192	0.00000157	0.00000002
Aquatic ecotoxicity	kg TEG water	1.20922218	0.07753417	11.31525677	0.06162979	11.36683704	0.06163035	21.61769173	0.06163035	0.02579014
Terrestrial ecotoxicity	kg TEG soil	0.79418924	0.01815695	2.87838149	0.01443246	2.89125185	0.01443260	5.92316043	0.01443260	0.00643518
Terrestrial acid/nutri	kg SO2 eq	0.00078425	0.00012353	0.00075748	0.00009819	0.00078578	0.00009819	0.00227251	0.00009819	0.00001415
Land occupation	m2org.arable	0.00016516	0.00000244	0.00042594	0.00000194	0.00042596	0.00000194	0.00042598	0.00000194	0.00000001
Aquatic acidification	kg SO2 eq	0.00011753	0.00001817	0.00016729	0.00001444	0.00017708	0.00001444	0.00113495	0.00001444	0.00000489
Aquatic eutrophication	kg PO4 P-lim	0.00000192	0.00000020	0.00004112	0.00000016	0.00004112	0.00000016	0.00004149	0.00000016	0.00000000
Global warming	kg CO2 eq	0.01894920	0.00184662	0.01430223	0.00146782	0.01514698	0.00146784	0.21171763	0.00146784	0.00042238
Non-renewable energy	MJ primary	0.31630285	0.02808522	1.82413307	0.02232417	1.83596269	0.02232437	1.84779226	0.02232437	0.00591481
Mineral extraction	MJ surplus	0.00014972	0.00001192	0.00009334	0.00000948	0.00009346	0.00000948	0.00009357	0.00000948	0.00000006

Table 7.11 above shows the severity scale of the contributing unit processes to the total environmental impacts for the zigzag kiln industry. The severity scale shows that the greatest contributing unit process within the manufacturing stages of clay bricks using the zigzag kiln technology is the firing process (unit process Z7), followed closely by the drying process (Z5) and the clay preparation process (Z3). The transport of fuel to plant processes (Z0), also shows a high contribution to overall environmental impacts. Unit process Z7 inherits the contributions from Z5, which inherits from Z3. Please refer to the appendices for explanations of the unlisted unit processes.

7.5 FINDINGS FOR THE GATE TO END OF OPERATIONAL LIFE PHASE OF THE LCA

7.5.1 Introduction

This section presents the findings of the gate to the end of operational life phase of the LCA. The significant issues are addressed in this section; results are given for the various clay brick wall types under consideration in this LCA.

7.5.2 Identification of significant issues

The various life cycle stages of constructing a clay brick wall in South Africa have been modelled and assessed using the *SimaPro* LCA software. Table 7.12 shows the impact significance in the assessed environmental impact categories of the materials required to build 1m² of clay brick wall of various construction methodologies.

The different wall construction methodologies investigated are:

- 220mm double brick wall with face brick externally and plaster and paint internally.
- 220mm double brick wall with both sides plastered and painted.
- 280mm double brick cavity wall with face brick externally and plaster and paint internally.
- 280mm double brick cavity wall with both sides plastered and painted.
- 280mm double brick insulated cavity wall with face brick externally and plaster and paint internally.
- 280mm double brick insulated cavity wall with both sides plastered and painted.

Table 7.12: Wall construction types: Impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	220mm Double Brick Wall (face external)	220mm Double Brick Wall (plastered external)	280mm Double Brick Cavity Wall (face external)	280mm Double Brick Cavity Wall (plastered external)	280mm Insulated Double Brick Wall (face external)	280mm Insulated Double Brick Wall (plastered external)
Carcinogens	kg C2H3Cl eq	0.704104	0.782463871	0.71164437	0.79000421	0.714838341	0.793198181
Non-carcinogens	kg C2H3Cl eq	3.078238	3.209872502	3.083969386	3.215604054	3.084358763	3.215993431
Respiratory inorganics	kg PM2.5 eq	0.056964	0.063239316	0.057102828	0.063377997	0.057149093	0.063424262
Ionizing radiation	Bq C-14 eq	390.065787	569.7052501	391.8205504	571.4600133	392.4257844	572.0652473
Ozone layer depletion	kg CFC-11 eq	0.000002	3.15475E-06	2.23243E-06	3.15904E-06	2.2387E-06	3.16531E-06
Respiratory organics	kg C2H4 eq	0.012150	0.015666502	0.012182131	0.015698576	0.01242962	0.015946066
Aquatic ecotoxicity	kg TEG water	9378.096438	9792.57885	9389.128674	9803.611087	9390.814987	9805.297399
Terrestrial ecotoxicity	kg TEG soil	2537.051185	2655.870973	2541.789396	2660.609184	2542.144385	2660.964173
Terrestrial acid/nutri	kg SO2 eq	1.298313	1.463569363	1.299784743	1.465040632	1.300935436	1.466191324
Land occupation	m2org.arable	1.427133	2.629943239	1.427788736	2.630599459	1.427814879	2.6306256
Aquatic acidification	kg SO2 eq	0.495034	0.538405028	0.495429407	0.5388008	0.495769223	0.539140616
Aquatic eutrophication	kg PO4 P-lim	0.020931	0.022265104	0.020956614	0.022291027	0.020964531	0.022298944
Global warming	kg CO2 eq	95.786322	106.930112	95.88300629	107.0267968	95.99807754	107.1418681
Non-renewable energy	MJ primary	1166.442268	1308.572831	1167.961463	1310.092026	1171.215727	1313.346289
Mineral extraction	MJ surplus	0.192501	0.302251996	0.243464166	0.353214742	0.243750274	0.353500848

The impact severity scale shows that plastered walls contribute the most severely to the assessed environmental impacts, while face brick walls contribute the least. This however should not be deemed as a decision making tool for the specification of the various brick wall construction types as the subsequent stage/s of the life cycle too contribute to the environmental impacts assessed. The build-up of a wall has an impact on its thermal properties, and therefore on the energy associated with the operational stage of a brick walled building. For all wall types, the environmental impacts associated with the mortar and/or plaster are attributed to the production of cementitious products.

7.5.3 Operational energy

Table 7.13: Operational energy vs. construction type and climatic zone: Impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	Zone 1			Zone 2			Zone 3			Zone 4			Zone 5			Zone 6		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity
Carcinogens	kg C2H3Cl eq	0.008	0.007	0.006	0.009	0.008	0.008	0.018	0.017	0.017	0.008	0.007	0.006	0.011	0.011	0.012	0.019	0.018	0.017
Non-carcinogens	kg C2H3Cl eq	0.031	0.027	0.022	0.034	0.032	0.030	0.069	0.068	0.065	0.031	0.026	0.025	0.044	0.044	0.046	0.075	0.071	0.066
Respiratory inorganics	kg PM2.5 eq	0.047	0.040	0.033	0.051	0.048	0.045	0.104	0.102	0.097	0.047	0.038	0.037	0.065	0.067	0.069	0.113	0.107	0.099
Ionizing radiation	Bq C-14 eq	257.620	222.483	182.570	282.828	266.160	250.035	572.718	559.052	535.151	257.620	211.596	203.767	359.362	366.736	377.845	620.544	587.620	543.130
Ozone layer depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Respiratory organics	kg C2H4 eq	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003
Aquatic ecotoxicity	kg TEG water	2218.756	1916.135	1572.389	2435.863	2292.303	2153.429	4932.538	4814.843	4608.998	2218.756	1822.371	1754.946	3095.007	3158.516	3254.199	5344.442	5060.889	4677.711
Terrestrial ecotoxicity	kg TEG soil	553.626	478.116	392.344	607.799	571.978	537.326	1230.771	1201.404	1150.042	553.626	454.720	437.896	772.269	788.116	811.991	1333.550	1262.798	1167.187
Terrestrial acid/nutri	kg SO2 eq	1.217	1.051	0.863	1.336	1.258	1.181	2.706	2.642	2.529	1.217	1.000	0.963	1.698	1.733	1.785	2.932	2.777	2.566
Land occupation	m2org.arable	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Aquatic acidification	kg SO2 eq	0.421	0.364	0.298	0.462	0.435	0.409	0.936	0.914	0.874	0.421	0.346	0.333	0.587	0.599	0.617	1.014	0.960	0.887
Aquatic eutrophication	kg PO4 P-lim	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Global warming	kg CO2 eq	36.337	31.381	25.752	39.893	37.542	35.268	80.782	78.855	75.483	36.337	29.846	28.741	50.688	51.728	53.295	87.528	82.884	76.609
Non-renewable energy	MJ primary	508.858	439.454	360.618	558.650	525.726	493.876	1131.248	1104.255	1057.046	508.858	417.950	402.486	709.821	724.387	746.331	1225.715	1160.684	1072.805
Mineral extraction	MJ surplus	0.005	0.004	0.003	0.005	0.005	0.005	0.011	0.010	0.010	0.005	0.004	0.004	0.007	0.007	0.007	0.012	0.011	0.010

Table 7.13 above shows that for climatic zones 1, 2, 3, 4, 6 the least operational energy is used, resulting in the lowest environmental impacts for those zones by constructing with a 280mm double brick insulated cavity wall. The results show that for Zone 5, the least environmental impactful wall type is the 220mm double brick wall. The operational stage of the building is 50 years.

7.6 FINDINGS FOR THE DEMOLITION, WASTE AND RECYCLE PHASE OF THE LCA

7.6.1 Introduction

This section presents the findings of the C & DW model developed in Section 6.7 of Chapter 6, as well as to assess the possible opportunities to employ an effective waste management policy in South Africa. In this section some techniques to reduce waste during the construction phase of a building will be discussed. This section will also demonstrate that the objectives stated in section 1.4.3 have been achieved.

7.6.2 Findings

The following findings can be made from the calculations presented in Chapter 6:

- An estimated 421.9m fired clay bricks are annually contained in C & DW for South Africa (recorded by municipalities at landfill sites before recycling takes place)
- An estimated 999.4m fired clay bricks are recycled annually in South Africa (both from before and after reaching landfill sites)
- An estimated 3 688.47m fired clay bricks are manufactured annually in South Africa (Rice 2014)

7.6.3 Conclusions

The central aim of this phase of the study was to investigate the extent of reuse and recycling of clay bricks that occurs in South Africa and the opportunities presented thereby. The three objectives stated in Chapter 1 have been achieved:

7.6.3.1 ACHIEVING OBJECTIVE 1

7.5.3 Operational energy

Table 7.13: Operational energy vs. construction type and climatic zone: Impact severity scale (Highest contribution = red, lowest contribution = green)

Impact category	Unit	Zone 1			Zone 2			Zone 3			Zone 4			Zone 5			Zone 6		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity	220mm Double Brick	280mm Double Brick with Cavity	280mm Double Brick with insulated cavity
Carcinogens	kg C2H3Cl eq	0.008	0.007	0.006	0.009	0.008	0.008	0.018	0.017	0.017	0.008	0.007	0.006	0.011	0.011	0.012	0.019	0.018	0.017
Non-carcinogens	kg C2H3Cl eq	0.031	0.027	0.022	0.034	0.032	0.030	0.069	0.068	0.065	0.031	0.026	0.025	0.044	0.044	0.046	0.075	0.071	0.066
Respiratory inorganics	kg PM2.5 eq	0.047	0.040	0.033	0.051	0.048	0.045	0.104	0.102	0.097	0.047	0.038	0.037	0.065	0.067	0.069	0.113	0.107	0.099
Ionizing radiation	Bq C-14 eq	257.620	222.483	182.570	282.828	266.160	250.035	572.718	559.052	535.151	257.620	211.596	203.767	359.362	366.736	377.845	620.544	587.620	543.130
Ozone layer depletion	kg CFC-11 eq	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Respiratory organics	kg C2H4 eq	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003	0.002	0.001	0.001	0.002	0.002	0.002	0.004	0.004	0.003
Aquatic ecotoxicity	kg TEG water	2218.756	1916.135	1572.389	2435.863	2292.303	2153.429	4932.538	4814.843	4608.998	2218.756	1822.371	1754.946	3095.007	3158.516	3254.199	5344.442	5060.889	4677.711
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Terrestrial acid/nutri	kg SO2 eq	1.217	1.051	0.863	1.336	1.258	1.181	2.706	2.642	2.529	1.217	1.000	0.963	1.698	1.733	1.785	2.932	2.777	2.566
Land occupation	m2org.arable	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.002	0.002
Aquatic acidification	kg SO2 eq	0.421	0.364	0.298	0.462	0.435	0.409	0.936	0.914	0.874	0.421	0.346	0.333	0.587	0.599	0.617	1.014	0.960	0.887
Aquatic eutrophication	kg PO4 P-lim	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Global warming	kg CO2 eq	36.337	31.381	25.752	39.893	37.542	35.268	80.782	78.855	75.483	36.337	29.846	28.741	50.688	51.728	53.295	87.528	82.884	76.609
Non-renewable energy	MJ primary	508.858	439.454	360.618	558.650	525.726	493.876	1131.248	1104.255	1057.046	508.858	417.950	402.486	709.821	724.387	746.331	1225.715	1160.684	1072.805
Mineral extraction	MJ surplus	0.005	0.004	0.003	0.005	0.005	0.005	0.011	0.010	0.010	0.005	0.004	0.004	0.007	0.007	0.007	0.012	0.011	0.010

Table 7.13 above shows that for climatic zones 1, 2, 3, 4, 6 the least operational energy is used, resulting in the lowest environmental impacts for those zones by constructing with a 280mm double brick insulated cavity wall. The results show that for Zone 5, the least environmental impactful wall type is the 220mm double brick wall. The operational stage of the building is 50 years.

7.6 FINDINGS FOR THE DEMOLITION, WASTE AND RECYCLE PHASE OF THE LCA

7.6.1 Introduction

This section presents the findings of the C & DW model developed in Section 6.7 of Chapter 6, as well as to assess the possible opportunities to employ an effective waste management policy in South Africa. In this section some techniques to reduce waste during the construction phase of a building will be discussed. This section will also demonstrate that the objectives stated in section 1.4.3 have been achieved.

7.6.2 Findings

The following findings can be made from the calculations presented in Chapter 6:

- An estimated 421.9m fired clay bricks are annually contained in C & DW for South Africa (recorded by municipalities at landfill sites before recycling takes place)
- An estimated 999.4m fired clay bricks are recycled annually in South Africa (both from before and after reaching landfill sites)
- An estimated 3 688.47m fired clay bricks are manufactured annually in South Africa (Rice 2014)

7.6.3 Conclusions

The central aim of this phase of the study was to investigate the extent of reuse and recycling of clay bricks that occurs in South Africa and the opportunities presented thereby. The three objectives stated in Chapter 1 have been achieved:

7.6.3.1 ACHIEVING OBJECTIVE 1

To gain an understanding, through investigation, of the reuse and recycling of clay bricks in South Africa and other similar countries in the world.

An understanding of the reuse and recycling of clay bricks in South Africa has been developed through the investigation of national publications which present quantities of construction and demolition waste, and the known recycling efforts currently employed in South Africa. It was necessary to estimate the number of clay bricks in the quantities of C & DW provided as no known recorded specific quantities for clay bricks exist.

7.6.3.2 ACHIEVING OBJECTIVE 2

To develop a model from other countries which can be applied to the South African context in order to present estimates for the demolition, waste and recycle phases of clay brick in South Africa.

In Section 6.7.3 a model is proposed which can be applied to the South African context using data obtained from the literature review. The model consists of ratios of the generation of construction and demolition waste and waste which has been diverted from landfills to be utilised by the people of the country assessed. It was found that developed countries divert more waste from landfills than developing countries; this seems to be counter-intuitive. The model was used to calculate the estimated reuse and recycle phases for clay bricks in South Africa.

7.6.3.3 ACHIEVING OBJECTIVE 3

To identify opportunities and present recommendations for the reuse and recycling of construction and demolition waste in South Africa

Benefits of recycling waste have been highlighted in this section, opportunities and recommendations regarding the recycling of C & DW have also been presented, and a generic waste management plan has been proposed for the South African context to reduce the amount of waste going to landfill sites. The opportunities of identifying and developing suitable landfill sites are limited. Specific recommendations have been made regarding the reduction of waste being generated on construction sites across the country which in turn will reduce the amount waste going to landfill sites.

7.7 RESULTS FOR THE COMBINED PHASES OF THE LCA OF CLAY BRICK WALLING IN SOUTH AFRICA

In this section the combined calculations (averaged across all six firing technologies) of environmental impacts over all the assessed impact categories are presented using an average across all firing technologies for Phase 1, standard data for Phase 2 and Phase 3. The results are presented for all three identified clay brick wall construction methodologies. These data categories (Tables 7.13 to 7.49) are further presented for the six climatic zones of South Africa as per Appendix A of SANS 10400 Part XA. In the absence of reliable data, the operational lifespan for clay brick walls is assumed to be 50 years. Values under the "Operation" column of Tables 7.13 to 7.49 represent a 50-year life span.

Table 7.14: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 1

1m² 220mm Double Brick Wall - Exterior Face - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.402176	0.000000	0.030154	1.142877
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	1.562816	0.000000	0.021622	4.671143
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	2.339049	0.000000	0.012553	2.409656
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	12881.006036	0.000000	25.021620	13303.571266
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000003	0.000000	0.000001	0.000006
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.082950	0.000000	0.003892	0.099643
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	110937.818964	0.000000	177.687170	120545.926647
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	27681.309436	0.000000	71.039308	30321.975820
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	60.865537	0.000000	0.185785	62.384614
Land occupation	m2org.arable	0.210350	1.222829	0.041223	0.000000	0.090893	1.565296
Aquatic acidification	kg SO2 eq	0.439226	0.061070	21.048064	0.000000	0.027669	21.576029
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.000717	0.000000	0.000357	0.022094
Global warming	kg CO2 eq	77.393856	19.236129	1816.873409	0.000000	3.330223	1916.833618
Non-renewable energy	MJ primary	990.556297	190.384588	25442.916739	0.000000	73.251298	26697.108923
Mineral extraction	MJ surplus	0.062865	0.137794	0.240574	0.000000	0.025737	0.466970

Table 7.15: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 2.

1m² 220mm Double Brick Wall - Exterior Face - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.441529	0.000000	0.030154	1.182230
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	1.715738	0.000000	0.021622	4.824065
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	2.567927	0.000000	0.012553	2.638534
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	14141.419169	0.000000	25.021620	14563.984398
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000004	0.000000	0.000001	0.000007
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.091067	0.000000	0.003892	0.107760
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	121793.142182	0.000000	177.687170	131401.249865
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	30389.939945	0.000000	71.039308	33030.606329
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	66.821261	0.000000	0.185785	68.340338
Land occupation	m2org.arable	0.210350	1.222829	0.045257	0.000000	0.090893	1.569329
Aquatic acidification	kg SO2 eq	0.439226	0.061070	23.107628	0.000000	0.027669	23.635593
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.000787	0.000000	0.000357	0.022164
Global warming	kg CO2 eq	77.393856	19.236129	1994.655416	0.000000	3.330223	2094.615625
Non-renewable energy	MJ primary	990.556297	190.384588	27932.519360	0.000000	73.251298	29186.711543
Mineral extraction	MJ surplus	0.062865	0.137794	0.264114	0.000000	0.025737	0.490511

Table 7.16: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 3.

1m² 220mm Double Brick Wall - Exterior Face - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.894082	0.000000	0.030154	1.634782
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	3.474310	0.000000	0.021622	6.582637
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	5.199962	0.000000	0.012553	5.270569
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	28635.882029	0.000000	25.021620	29058.447259
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000008	0.000000	0.000001	0.000011
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.184407	0.000000	0.003892	0.201100
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	246626.877393	0.000000	177.687170	256234.985077
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	61538.571537	0.000000	71.039308	64179.237921
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	135.310730	0.000000	0.185785	136.829807
Land occupation	m2org.arable	0.210350	1.222829	0.091644	0.000000	0.090893	1.615716
Aquatic acidification	kg SO2 eq	0.439226	0.061070	46.792144	0.000000	0.027669	47.320108
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.001594	0.000000	0.000357	0.022971
Global warming	kg CO2 eq	77.393856	19.236129	4039.107851	0.000000	3.330223	4139.068059
Non-renewable energy	MJ primary	990.556297	190.384588	56562.380312	0.000000	73.251298	57816.572495
Mineral extraction	MJ surplus	0.062865	0.137794	0.534822	0.000000	0.025737	0.761218

Table 7.17: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 4.

1m² 220mm Double Brick Wall - Exterior Face - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.402176	0.000000	0.030154	1.142877
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	1.562816	0.000000	0.021622	4.671143
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	2.339049	0.000000	0.012553	2.409656
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	12881.006036	0.000000	25.021620	13303.571266
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000003	0.000000	0.000001	0.000006
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.082950	0.000000	0.003892	0.099643
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	110937.818964	0.000000	177.687170	120545.926647
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	27681.309436	0.000000	71.039308	30321.975820
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	60.865537	0.000000	0.185785	62.384614
Land occupation	m2org.arable	0.210350	1.222829	0.041223	0.000000	0.090893	1.565295
Aquatic acidification	kg SO2 eq	0.439226	0.061070	21.048064	0.000000	0.027669	21.576029
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.000717	0.000000	0.000357	0.022094
Global warming	kg CO2 eq	77.393856	19.236129	1816.873409	0.000000	3.330223	1916.833617
Non-renewable energy	MJ primary	990.556297	190.384588	25442.916739	0.000000	73.251298	26697.108922
Mineral extraction	MJ surplus	0.062865	0.137794	0.240574	0.000000	0.025737	0.466970

Table 7.18: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 5.

1m² 220mm Double Brick Wall - Exterior Face - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.561007	0.000000	0.030154	1.301708
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	2.180017	0.000000	0.021622	5.288344
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	3.262808	0.000000	0.012553	3.333415
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	17968.088024	0.000000	25.021620	18390.653254
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000005	0.000000	0.000001	0.000007
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.115710	0.000000	0.003892	0.132402
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	154750.373592	0.000000	177.687170	164358.481276
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	38613.459475	0.000000	71.039308	41254.125859
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	84.903098	0.000000	0.185785	86.422176
Land occupation	m2org.arable	0.210350	1.222829	0.057503	0.000000	0.090893	1.581575
Aquatic acidification	kg SO2 eq	0.439226	0.061070	29.360554	0.000000	0.027669	29.888518
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.001000	0.000000	0.000357	0.022377
Global warming	kg CO2 eq	77.393856	19.236129	2534.409289	0.000000	3.330223	2634.369497
Non-renewable energy	MJ primary	990.556297	190.384588	35491.060735	0.000000	73.251298	36745.252918
Mineral extraction	MJ surplus	0.062865	0.137794	0.335583	0.000000	0.025737	0.561980

Table 7.19: Impact category results for a 220 mm double brick wall with face brick externally and plaster and paint internally for climatic zone 6.

1m² 220mm Double Brick Wall - Exterior Face - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.103424	0.968744	0.000000	0.030154	1.709445
Non-carcinogens	kg C2H3Cl eq	2.871225	0.215480	3.764441	0.000000	0.021622	6.872768
Respiratory inorganics	kg PM2.5 eq	0.048412	0.009642	5.634198	0.000000	0.012553	5.704806
Ionizing radiation	Bq C-14 eq	136.993450	260.550160	31027.196620	0.000000	25.021620	31449.761850
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000001	0.000008	0.000000	0.000001	0.000011
Respiratory organics	kg C2H4 eq	0.007712	0.005089	0.199807	0.000000	0.003892	0.216499
Aquatic ecotoxicity	kg TEG water	8781.917303	648.503211	267222.102979	0.000000	177.687170	276830.210663
Terrestrial ecotoxicity	kg TEG soil	2387.524537	182.102539	66677.511690	0.000000	71.039308	69318.178074
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.269387	146.610208	0.000000	0.185785	148.129286
Land occupation	m2org.arable	0.210350	1.222829	0.099296	0.000000	0.090893	1.623369
Aquatic acidification	kg SO2 eq	0.439226	0.061070	50.699645	0.000000	0.027669	51.227609
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.001602	0.001727	0.000000	0.000357	0.023104
Global warming	kg CO2 eq	77.393856	19.236129	4376.404168	0.000000	3.330223	4476.364376
Non-renewable energy	MJ primary	990.556297	190.384588	61285.770538	0.000000	73.251298	62539.962721
Mineral extraction	MJ surplus	0.062865	0.137794	0.579483	0.000000	0.025737	0.805880

Table 7.20: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 1.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.402176	0.317287	0.032245	2.237716
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	1.562816	0.357919	0.023200	8.508609
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	2.339049	0.022252	0.013116	2.499220
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	12881.006036	603.019419	26.921621	14237.858265
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000003	0.000004	0.000001	0.000012
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.082950	0.013890	0.004152	0.125676
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	110937.818964	1388.354885	189.976348	131261.568583
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	27681.309436	471.264169	76.365803	33385.863576
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	60.865537	0.549567	0.197268	64.488251
Land occupation	m2org.arable	0.210350	2.655469	0.041223	5.956718	0.098377	8.962138
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	21.048064	0.167126	0.029386	140451.701116
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.000717	0.005955	0.000381	0.046547
Global warming	kg CO2 eq	77.393856	119.883734	1816.873409	26.855000	3.547884	2044.553884
Non-renewable energy	MJ primary	990.556297	1256.910259	25442.916739	575.609995	78.442311	28344.435602
Mineral extraction	MJ surplus	0.062865	0.313016	0.240574	0.467800	0.027495	1.111750

Table 7.21: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 2.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.441529	0.317287	0.032245	2.277069
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	1.715738	0.357919	0.023200	8.661531
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	2.567927	0.022252	0.013116	2.728096
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	14141.419169	603.019419	26.921621	15498.271397
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000004	0.000004	0.000001	0.000012
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.091067	0.013890	0.004152	0.133792
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	121793.142182	1388.354885	189.976348	142116.891802
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	30389.939945	471.264169	76.365803	36094.494085
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	66.821261	0.549567	0.197268	70.443975
Land occupation	m2org.arable	0.210350	2.655469	0.045257	5.956718	0.098377	8.966171
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	23.107628	0.167126	0.029386	140453.760679
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.000787	0.005955	0.000381	0.046618
Global warming	kg CO2 eq	77.393856	119.883734	1994.655416	26.855000	3.547884	2222.335891
Non-renewable energy	MJ primary	990.556297	1256.910259	27932.519360	575.609995	78.442311	30834.038222
Mineral extraction	MJ surplus	0.062865	0.313016	0.264114	0.467800	0.027495	1.135290

Table 7.22: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 3.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.894082	0.317287	0.032245	2.729621
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	3.474310	0.357919	0.023200	10.420103
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	5.199962	0.022252	0.013116	5.360131
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	28635.882029	603.019419	26.921621	29992.734258
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000008	0.000004	0.000001	0.000016
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.184407	0.013890	0.004152	0.227133
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	246626.877393	1388.354885	189.976348	266950.627013
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	61538.571537	471.264169	76.365803	67243.125677
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	135.310730	0.549567	0.197268	138.933444
Land occupation	m2org.arable	0.210350	2.655469	0.091644	5.956718	0.098377	9.012558
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	46.792144	0.167126	0.029386	140477.445195
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.001594	0.005955	0.000381	0.047425
Global warming	kg CO2 eq	77.393856	119.883734	4039.107851	26.855000	3.547884	4266.788325
Non-renewable energy	MJ primary	990.556297	1256.910259	56562.380312	575.609995	78.442311	59463.899174
Mineral extraction	MJ surplus	0.062865	0.313016	0.534822	0.467800	0.027495	1.405997

Table 7.23: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 4.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.402176	0.317287	0.032245	2.237715
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	1.562816	0.357919	0.023200	8.508609
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	2.339049	0.022252	0.013116	2.499219
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	12881.006036	603.019419	26.921621	14237.858265
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000003	0.000004	0.000001	0.000012
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.082950	0.013890	0.004152	0.125676
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	110937.818964	1388.354885	189.976348	131261.568583
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	27681.309436	471.264169	76.365803	33385.863576
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	60.865537	0.549567	0.197268	64.488251
Land occupation	m2org.arable	0.210350	2.655469	0.041223	5.956718	0.098377	8.962137
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	21.048064	0.167126	0.029386	140451.701115
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.000717	0.005955	0.000381	0.046548
Global warming	kg CO2 eq	77.393856	119.883734	1816.873409	26.855000	3.547884	2044.553884
Non-renewable energy	MJ primary	990.556297	1256.910259	25442.916739	575.609995	78.442311	28344.435602
Mineral extraction	MJ surplus	0.062865	0.313016	0.240574	0.467800	0.027495	1.111749

Table 7.24: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 5.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.561007	0.317287	0.032245	2.396547
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	2.180017	0.357919	0.023200	9.125810
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	3.262808	0.022252	0.013116	3.422977
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	17968.088024	603.019419	26.921621	19324.940253
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000005	0.000004	0.000001	0.000013
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.115710	0.013890	0.004152	0.158435
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	154750.373592	1388.354885	189.976348	175074.123212
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	38613.459475	471.264169	76.365803	44318.013615
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	84.903098	0.549567	0.197268	88.525812
Land occupation	m2org.arable	0.210350	2.655469	0.057503	5.956718	0.098377	8.978417
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	29.360554	0.167126	0.029386	140460.013605
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.001000	0.005955	0.000381	0.046831
Global warming	kg CO2 eq	77.393856	119.883734	2534.409289	26.855000	3.547884	2762.089763
Non-renewable energy	MJ primary	990.556297	1256.910259	35491.060735	575.609995	78.442311	38392.579598
Mineral extraction	MJ surplus	0.062865	0.313016	0.335583	0.467800	0.027495	1.206759

Table 7.25: Impact category results for a 220 mm double brick wall with both sides plastered and painted for climatic zone 6.

1m² 220mm Double Brick Wall - Exterior Plaster and Paint - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.878884	0.968744	0.317287	0.032245	2.804283
Non-carcinogens	kg C2H3Cl eq	2.871225	3.693449	3.764441	0.357919	0.023200	10.710234
Respiratory inorganics	kg PM2.5 eq	0.048412	0.076390	5.634198	0.022252	0.013116	5.794368
Ionizing radiation	Bq C-14 eq	136.993450	589.917738	31027.196620	603.019419	26.921621	32384.048848
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000003	0.000008	0.000004	0.000001	0.000017
Respiratory organics	kg C2H4 eq	0.007712	0.016972	0.199807	0.013890	0.004152	0.242532
Aquatic ecotoxicity	kg TEG water	8781.917303	9963.501084	267222.102979	1388.354885	189.976348	287545.852599
Terrestrial ecotoxicity	kg TEG soil	2387.524537	2769.399631	66677.511690	471.264169	76.365803	72382.065830
Terrestrial acid/nutri	kg SO2 eq	1.063905	1.811974	146.610208	0.549567	0.197268	150.232922
Land occupation	m2org.arable	0.210350	2.655469	0.099296	5.956718	0.098377	9.020210
Aquatic acidification	kg SO2 eq	0.439226	140430.017313	50.699645	0.167126	0.029386	140481.352696
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.020077	0.001727	0.005955	0.000381	0.047558
Global warming	kg CO2 eq	77.393856	119.883734	4376.404168	26.855000	3.547884	4604.084642
Non-renewable energy	MJ primary	990.556297	1256.910259	61285.770538	575.609995	78.442311	64187.289400
Mineral extraction	MJ surplus	0.062865	0.313016	0.579483	0.467800	0.027495	1.450659

Table 7.26: Impact category results for a 280 mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 1.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.347322	0.000000	0.030182	0.998611
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	1.349660	0.000000	0.021639	4.256722
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	2.020021	0.000000	0.012563	2.082225
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	11124.137056	0.000000	25.037061	11295.400152
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000003	0.000000	0.000001	0.000005
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.071636	0.000000	0.003896	0.083927
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	95806.763798	0.000000	177.857257	104829.894669
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	23905.794251	0.000000	71.086553	26401.719442
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	52.563951	0.000000	0.186032	53.850337
Land occupation	m2org.arable	0.210350	0.006703	0.035601	0.000000	0.090920	0.343574
Aquatic acidification	kg SO2 eq	0.439226	0.005658	18.177272	0.000000	0.027705	18.649862
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.000619	0.000000	0.000358	0.020510
Global warming	kg CO2 eq	77.393856	0.940348	1569.066016	0.000000	3.334047	1650.734267
Non-renewable energy	MJ primary	990.556297	16.017811	21972.700898	0.000000	73.315148	23052.590154
Mineral extraction	MJ surplus	0.062865	0.059121	0.207761	0.000000	0.025763	0.355510

Table 7.27: Impact category results for a 280 mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 2.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.415507	0.000000	0.030182	1.066796
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	1.614620	0.000000	0.021639	4.521682
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	2.416584	0.000000	0.012563	2.478787
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	13307.983207	0.000000	25.037061	13479.246304
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000003	0.000000	0.000001	0.000005
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.085700	0.000000	0.003896	0.097991
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	114615.164964	0.000000	177.857257	123638.295835
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	28598.884286	0.000000	71.086553	31094.809478
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	62.883096	0.000000	0.186032	64.169482
Land occupation	m2org.arable	0.210350	0.006703	0.042590	0.000000	0.090920	0.350563
Aquatic acidification	kg SO2 eq	0.439226	0.005658	21.745762	0.000000	0.027705	22.218351
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.000741	0.000000	0.000358	0.020631
Global warming	kg CO2 eq	77.393856	0.940348	1877.098788	0.000000	3.334047	1958.767039
Non-renewable energy	MJ primary	990.556297	16.017811	26286.293768	0.000000	73.315148	27366.183024
Mineral extraction	MJ surplus	0.062865	0.059121	0.248548	0.000000	0.025763	0.396297

Table 7.28: Impact category results for a 280mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 3.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.872748	0.000000	0.030182	1.524036
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	3.391410	0.000000	0.021639	6.298472
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	5.075886	0.000000	0.012563	5.138089
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	27952.603312	0.000000	25.037061	28123.866409
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000007	0.000000	0.000001	0.000009
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.180007	0.000000	0.003896	0.192298
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	240742.131250	0.000000	177.857257	249765.262121
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	60070.204117	0.000000	71.086553	62566.129309
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	132.082091	0.000000	0.186032	133.368476
Land occupation	m2org.arable	0.210350	0.006703	0.089457	0.000000	0.090920	0.397430
Aquatic acidification	kg SO2 eq	0.439226	0.005658	45.675640	0.000000	0.027705	46.148229
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.001556	0.000000	0.000358	0.021446
Global warming	kg CO2 eq	77.393856	0.940348	3942.730990	0.000000	3.334047	4024.399241
Non-renewable energy	MJ primary	990.556297	16.017811	55212.749432	0.000000	73.315148	56292.638688
Mineral extraction	MJ surplus	0.062865	0.059121	0.522060	0.000000	0.025763	0.669809

Table 7.29: Impact category results for a 280 mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 4.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.330327	0.000000	0.030182	0.981615
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	1.283616	0.000000	0.021639	4.190679
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	1.921174	0.000000	0.012563	1.983377
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	10579.790357	0.000000	25.037061	10751.053453
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000003	0.000000	0.000001	0.000005
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.068131	0.000000	0.003896	0.080422
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	91118.571324	0.000000	177.857257	100141.702195
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	22735.992034	0.000000	71.086553	25231.917226
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	49.991796	0.000000	0.186032	51.278181
Land occupation	m2org.arable	0.210350	0.006703	0.033859	0.000000	0.090920	0.341832
Aquatic acidification	kg SO2 eq	0.439226	0.005658	17.287788	0.000000	0.027705	17.760378
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.000589	0.000000	0.000358	0.020479
Global warming	kg CO2 eq	77.393856	0.940348	1492.285596	0.000000	3.334047	1573.953848
Non-renewable energy	MJ primary	990.556297	16.017811	20897.492354	0.000000	73.315148	21977.381610
Mineral extraction	MJ surplus	0.062865	0.059121	0.197595	0.000000	0.025763	0.345344

Table 7.30: Impact category results for a 280 mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 5.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.572519	0.000000	0.030182	1.223807
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	2.224750	0.000000	0.021639	5.131813
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	3.329759	0.000000	0.012563	3.391963
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	18336.787194	0.000000	25.037061	18508.050291
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000005	0.000000	0.000001	0.000007
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.118084	0.000000	0.003896	0.130375
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	157925.799611	0.000000	177.857257	166948.930482
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	39405.794776	0.000000	71.086553	41901.719968
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	86.645282	0.000000	0.186032	87.931667
Land occupation	m2org.arable	0.210350	0.006703	0.058683	0.000000	0.090920	0.366657
Aquatic acidification	kg SO2 eq	0.439226	0.005658	29.963023	0.000000	0.027705	30.435612
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.001020	0.000000	0.000358	0.020911
Global warming	kg CO2 eq	77.393856	0.940348	2586.414521	0.000000	3.334047	2668.082773
Non-renewable energy	MJ primary	990.556297	16.017811	36219.325456	0.000000	73.315148	37299.214712
Mineral extraction	MJ surplus	0.062865	0.059121	0.342469	0.000000	0.025763	0.490218

Table 7.31: Impact category results for a 280 mm double brick cavity wall with face brick externally and plaster and paint internally for climatic zone 6.

1m² 280mm Double Brick Cavity Wall - Exterior Face - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.013983	0.917347	0.000000	0.030182	1.568635
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014199	3.564716	0.000000	0.021639	6.471779
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001228	5.335272	0.000000	0.012563	5.397475
Ionizing radiation	Bq C-14 eq	136.993450	9.232586	29381.024975	0.000000	25.037061	29552.288072
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000008	0.000000	0.000001	0.000010
Respiratory organics	kg C2H4 eq	0.007712	0.000683	0.189206	0.000000	0.003896	0.201497
Aquatic ecotoxicity	kg TEG water	8781.917303	63.356312	253044.429949	0.000000	177.857257	262067.560820
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.314102	63139.885316	0.000000	71.086553	65635.810508
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.036449	138.831692	0.000000	0.186032	140.118077
Land occupation	m2org.arable	0.210350	0.006703	0.094028	0.000000	0.090920	0.402002
Aquatic acidification	kg SO2 eq	0.439226	0.005658	48.009736	0.000000	0.027705	48.482326
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000115	0.001635	0.000000	0.000358	0.021526
Global warming	kg CO2 eq	77.393856	0.940348	4144.210698	0.000000	3.334047	4225.878949
Non-renewable energy	MJ primary	990.556297	16.017811	58034.207114	0.000000	73.315148	59114.096370
Mineral extraction	MJ surplus	0.062865	0.059121	0.548739	0.000000	0.025763	0.696487

Table 7.32: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 1.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.347322	0.317287	0.032274	1.477903
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.349660	0.357919	0.023217	4.879877
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	2.020021	0.022252	0.013126	2.117635
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	11124.137056	603.019419	26.937062	12260.203732
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000003	0.000004	0.000001	0.000011
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.071636	0.013890	0.004156	0.105357
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	95806.763798	1388.354885	190.146435	107061.189869
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	23905.794251	471.264169	76.413048	27116.304672
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	52.563951	0.549567	0.197514	54.743050
Land occupation	m2org.arable	0.210350	2.412351	0.035601	5.956718	0.098404	8.713423
Aquatic acidification	kg SO2 eq	0.439226	0.092741	18.177272	0.167126	0.029422	18.905787
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000619	0.005955	0.000381	0.029166
Global warming	kg CO2 eq	77.393856	23.343001	1569.066016	26.855000	3.551708	1700.209580
Non-renewable energy	MJ primary	990.556297	303.533200	21972.700898	575.609995	78.506161	23920.906551
Mineral extraction	MJ surplus	0.062865	0.278908	0.207761	0.467800	0.027521	1.044855

Table 7.33: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 2.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.415507	0.317287	0.032274	1.546088
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.614620	0.357919	0.023217	5.144837
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	2.416584	0.022252	0.013126	2.514198
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	13307.983207	603.019419	26.937062	14444.049883
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000003	0.000004	0.000001	0.000011
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.085700	0.013890	0.004156	0.119421
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	114615.164964	1388.354885	190.146435	125869.591035
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	28598.884286	471.264169	76.413048	31809.394707
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	62.883096	0.549567	0.197514	65.062195
Land occupation	m2org.arable	0.210350	2.412351	0.042590	5.956718	0.098404	8.720412
Aquatic acidification	kg SO2 eq	0.439226	0.092741	21.745762	0.167126	0.029422	22.474277
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000741	0.005955	0.000381	0.029287
Global warming	kg CO2 eq	77.393856	23.343001	1877.098788	26.855000	3.551708	2008.242353
Non-renewable energy	MJ primary	990.556297	303.533200	26286.293768	575.609995	78.506161	28234.499421
Mineral extraction	MJ surplus	0.062865	0.278908	0.248548	0.467800	0.027521	1.085642

Table 7.34: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 3.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.872748	0.317287	0.032274	2.003329
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	3.391410	0.357919	0.023217	6.921627
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	5.075886	0.022252	0.013126	5.173500
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	27952.603312	603.019419	26.937062	29088.669989
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000007	0.000004	0.000001	0.000015
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.180007	0.013890	0.004156	0.213728
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	240742.131250	1388.354885	190.146435	251996.557321
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	60070.204117	471.264169	76.413048	63280.714539
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	132.082091	0.549567	0.197514	134.261189
Land occupation	m2org.arable	0.210350	2.412351	0.089457	5.956718	0.098404	8.767280
Aquatic acidification	kg SO2 eq	0.439226	0.092741	45.675640	0.167126	0.029422	46.404155
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001556	0.005955	0.000381	0.030102
Global warming	kg CO2 eq	77.393856	23.343001	3942.730990	26.855000	3.551708	4073.874555
Non-renewable energy	MJ primary	990.556297	303.533200	55212.749432	575.609995	78.506161	57160.955085
Mineral extraction	MJ surplus	0.062865	0.278908	0.522060	0.467800	0.027521	1.359154

Table 7.35: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 4.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.330327	0.317287	0.032274	1.460908
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.283616	0.357919	0.023217	4.813834
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	1.921174	0.022252	0.013126	2.018788
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	10579.790357	603.019419	26.937062	11715.857033
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000003	0.000004	0.000001	0.000010
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.068131	0.013890	0.004156	0.101852
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	91118.571324	1388.354885	190.146435	102372.997396
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	22735.992034	471.264169	76.413048	25946.502455
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	49.991796	0.549567	0.197514	52.170894
Land occupation	m2org.arable	0.210350	2.412351	0.033859	5.956718	0.098404	8.711681
Aquatic acidification	kg SO2 eq	0.439226	0.092741	17.287788	0.167126	0.029422	18.016304
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000589	0.005955	0.000381	0.029135
Global warming	kg CO2 eq	77.393856	23.343001	1492.285596	26.855000	3.551708	1623.429161
Non-renewable energy	MJ primary	990.556297	303.533200	20897.492354	575.609995	78.506161	22845.698008
Mineral extraction	MJ surplus	0.062865	0.278908	0.197595	0.467800	0.027521	1.034688

Table 7.36: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 5.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.572519	0.317287	0.032274	1.703100
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	2.224750	0.357919	0.023217	5.754968
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	3.329759	0.022252	0.013126	3.427374
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	18336.787194	603.019419	26.937062	19472.853870
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000005	0.000004	0.000001	0.000012
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.118084	0.013890	0.004156	0.151805
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	157925.799611	1388.354885	190.146435	169180.225682
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	39405.794776	471.264169	76.413048	42616.305198
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	86.645282	0.549567	0.197514	88.824380
Land occupation	m2org.arable	0.210350	2.412351	0.058683	5.956718	0.098404	8.736506
Aquatic acidification	kg SO2 eq	0.439226	0.092741	29.963023	0.167126	0.029422	30.691538
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001020	0.005955	0.000381	0.029567
Global warming	kg CO2 eq	77.393856	23.343001	2586.414521	26.855000	3.551708	2717.558087
Non-renewable energy	MJ primary	990.556297	303.533200	36219.325456	575.609995	78.506161	38167.531110
Mineral extraction	MJ surplus	0.062865	0.278908	0.342469	0.467800	0.027521	1.179563

Table 7.37: Impact category results for a 280 mm double brick cavity wall with both sides plastered and painted for climatic zone 6.

1m² 280mm Double Brick Cavity Wall - Exterior Plaster and Paint - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.917347	0.317287	0.032274	2.047928
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	3.564716	0.357919	0.023217	7.094934
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	5.335272	0.022252	0.013126	5.432886
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	29381.024975	603.019419	26.937062	30517.091651
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000008	0.000004	0.000001	0.000015
Respiratory organics	kg C2H4 eq	0.007712	0.007963	0.189206	0.013890	0.004156	0.222927
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	253044.429949	1388.354885	190.146435	264298.856020
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	63139.885316	471.264169	76.413048	66350.395737
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	138.831692	0.549567	0.197514	141.010790
Land occupation	m2org.arable	0.210350	2.412351	0.094028	5.956718	0.098404	8.771851
Aquatic acidification	kg SO2 eq	0.439226	0.092741	48.009736	0.167126	0.029422	48.738252
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001635	0.005955	0.000381	0.030182
Global warming	kg CO2 eq	77.393856	23.343001	4144.210698	26.855000	3.551708	4275.354263
Non-renewable energy	MJ primary	990.556297	303.533200	58034.207114	575.609995	78.506161	59982.412767
Mineral extraction	MJ surplus	0.062865	0.278908	0.548739	0.467800	0.027521	1.385832

Table 7.38: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 1.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.285014	0.000000	0.030887	0.940202
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	1.107537	0.000000	0.025988	4.019337
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	1.657638	0.000000	0.012566	1.719891
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	9128.514777	0.000000	25.050372	9300.396418
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000002	0.000000	0.000001	0.000004
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.058785	0.000000	0.003898	0.071326
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	78619.442989	0.000000	179.618858	87646.021775
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	19617.197719	0.000000	71.102530	22113.493876
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	43.134205	0.000000	0.186158	44.421868
Land occupation	m2org.arable	0.210350	0.006729	0.029214	0.000000	0.090928	0.337221
Aquatic acidification	kg SO2 eq	0.439226	0.005998	14.916348	0.000000	0.027722	15.389294
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.000508	0.000000	0.000358	0.020407
Global warming	kg CO2 eq	77.393856	1.055420	1287.582330	0.000000	3.491512	1369.523117
Non-renewable energy	MJ primary	990.556297	19.272075	18030.892988	0.000000	73.328527	19114.049886
Mineral extraction	MJ surplus	0.062865	0.059407	0.170490	0.000000	0.025786	0.318548

Table 7.39: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 2.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.390335	0.000000	0.030887	1.045522
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	1.516802	0.000000	0.025988	4.428602
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	2.270180	0.000000	0.012566	2.332434
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	12501.748977	0.000000	25.050372	12673.630618
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000003	0.000000	0.000001	0.000005
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.080508	0.000000	0.003898	0.093049
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	107671.462989	0.000000	179.618858	116698.041775
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	26866.285206	0.000000	71.102530	29362.581364
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	59.073465	0.000000	0.186158	60.361128
Land occupation	m2org.arable	0.210350	0.006729	0.040009	0.000000	0.090928	0.348016
Aquatic acidification	kg SO2 eq	0.439226	0.005998	20.428344	0.000000	0.027722	20.901290
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.000696	0.000000	0.000358	0.020595
Global warming	kg CO2 eq	77.393856	1.055420	1763.378980	0.000000	3.491512	1845.319768
Non-renewable energy	MJ primary	990.556297	19.272075	24693.797783	0.000000	73.328527	25776.954682
Mineral extraction	MJ surplus	0.062865	0.059407	0.233491	0.000000	0.025786	0.381548

Table 7.40: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 3.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.835436	0.000000	0.030887	1.490623
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	3.246420	0.000000	0.025988	6.158221
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	4.858882	0.000000	0.012566	4.921135
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	26757.572609	0.000000	25.050372	26929.454250
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000007	0.000000	0.000001	0.000009
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.172311	0.000000	0.003898	0.184852
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	230449.914982	0.000000	179.618858	239476.493769
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	57502.080587	0.000000	71.102530	59998.376745
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	126.435312	0.000000	0.186158	127.722975
Land occupation	m2org.arable	0.210350	0.006729	0.085632	0.000000	0.090928	0.393639
Aquatic acidification	kg SO2 eq	0.439226	0.005998	43.722913	0.000000	0.027722	44.195859
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.001489	0.000000	0.000358	0.021388
Global warming	kg CO2 eq	77.393856	1.055420	3774.171212	0.000000	3.491512	3856.112000
Non-renewable energy	MJ primary	990.556297	19.272075	52852.291980	0.000000	73.328527	53935.448878
Mineral extraction	MJ surplus	0.062865	0.059407	0.499741	0.000000	0.025786	0.647799

Table 7.41: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 4.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.318105	0.000000	0.030887	0.973292
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	1.236124	0.000000	0.025988	4.147924
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	1.850093	0.000000	0.012566	1.912346
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	10188.351738	0.000000	25.050372	10360.233380
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000003	0.000000	0.000001	0.000004
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.065610	0.000000	0.003898	0.078151
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	87747.301529	0.000000	179.618858	96773.880316
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	21894.789608	0.000000	71.102530	24391.085766
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	48.142163	0.000000	0.186158	49.429827
Land occupation	m2org.arable	0.210350	0.006729	0.032606	0.000000	0.090928	0.340613
Aquatic acidification	kg SO2 eq	0.439226	0.005998	16.648163	0.000000	0.027722	17.121109
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.000567	0.000000	0.000358	0.020466
Global warming	kg CO2 eq	77.393856	1.055420	1437.072951	0.000000	3.491512	1519.013739
Non-renewable energy	MJ primary	990.556297	19.272075	20124.312049	0.000000	73.328527	21207.468948
Mineral extraction	MJ surplus	0.062865	0.059407	0.190284	0.000000	0.025786	0.338342

Table 7.42: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 5.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.589862	0.000000	0.030887	1.245050
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	2.292146	0.000000	0.025988	5.203946
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	3.430629	0.000000	0.012566	3.492883
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	18892.273009	0.000000	25.050372	19064.154651
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000005	0.000000	0.000001	0.000007
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.121661	0.000000	0.003898	0.134202
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	162709.927857	0.000000	179.618858	171736.506644
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	40599.534978	0.000000	71.102530	43095.831136
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	89.270072	0.000000	0.186158	90.557735
Land occupation	m2org.arable	0.210350	0.006729	0.060461	0.000000	0.090928	0.368468
Aquatic acidification	kg SO2 eq	0.439226	0.005998	30.870708	0.000000	0.027722	31.343654
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.001051	0.000000	0.000358	0.020950
Global warming	kg CO2 eq	77.393856	1.055420	2664.766119	0.000000	3.491512	2746.706907
Non-renewable energy	MJ primary	990.556297	19.272075	37316.536288	0.000000	73.328527	38399.693187
Mineral extraction	MJ surplus	0.062865	0.059407	0.352844	0.000000	0.025786	0.500902

Table 7.43: Impact category results for a 280 mm double brick insulated cavity wall with face brick externally and plaster and paint internally for climatic zone 6.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Face - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.017177	0.847891	0.000000	0.030887	1.503078
Non-carcinogens	kg C2H3Cl eq	2.871225	0.014588	3.294818	0.000000	0.025988	6.206619
Respiratory inorganics	kg PM2.5 eq	0.048412	0.001275	4.931319	0.000000	0.012566	4.993573
Ionizing radiation	Bq C-14 eq	136.993450	9.837820	27156.482177	0.000000	25.050372	27328.363818
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000000	0.000007	0.000000	0.000001	0.000009
Respiratory organics	kg C2H4 eq	0.007712	0.000931	0.174880	0.000000	0.003898	0.187421
Aquatic ecotoxicity	kg TEG water	8781.917303	65.042625	233885.528422	0.000000	179.618858	242912.107209
Terrestrial ecotoxicity	kg TEG soil	2387.524537	37.669091	58359.338100	0.000000	71.102530	60855.634257
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.037600	128.320246	0.000000	0.186158	129.607909
Land occupation	m2org.arable	0.210350	0.006729	0.086909	0.000000	0.090928	0.394916
Aquatic acidification	kg SO2 eq	0.439226	0.005998	44.374747	0.000000	0.027722	44.847693
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.000123	0.001511	0.000000	0.000358	0.021410
Global warming	kg CO2 eq	77.393856	1.055420	3830.437639	0.000000	3.491512	3912.378427
Non-renewable energy	MJ primary	990.556297	19.272075	53640.229110	0.000000	73.328527	54723.386008
Mineral extraction	MJ surplus	0.062865	0.059407	0.507192	0.000000	0.025786	0.655249

Table 7.44: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 1.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 1							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.285014	0.317287	0.032979	1.416300
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.107537	0.357919	0.027565	4.642104
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	1.657638	0.022252	0.013129	1.755256
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	9128.514777	603.019419	26.950373	10264.594764
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000002	0.000004	0.000001	0.000010
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.058785	0.013890	0.004158	0.092509
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	78619.442989	1388.354885	191.908036	89875.630662
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	19617.197719	471.264169	76.429025	22827.724116
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	43.134205	0.549567	0.197641	45.313429
Land occupation	m2org.arable	0.210350	2.412351	0.029214	5.956718	0.098412	8.707045
Aquatic acidification	kg SO2 eq	0.439226	0.092741	14.916348	0.167126	0.029440	15.644880
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000508	0.005955	0.000381	0.029054
Global warming	kg CO2 eq	77.393856	23.343001	1287.582330	26.855000	3.709173	1418.883359
Non-renewable energy	MJ primary	990.556297	303.533200	18030.892988	575.609995	78.519539	19979.112020
Mineral extraction	MJ surplus	0.062865	0.278908	0.170490	0.467800	0.027544	1.007606

Table 7.45: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 2.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 2							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.390335	0.317287	0.032979	1.521621
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.516802	0.357919	0.027565	5.051368
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	2.270180	0.022252	0.013129	2.367798
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	12501.748977	603.019419	26.950373	13637.828964
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000003	0.000004	0.000001	0.000011
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.080508	0.013890	0.004158	0.114232
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	107671.462989	1388.354885	191.908036	118927.650662
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	26866.285206	471.264169	76.429025	30076.811604
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	59.073465	0.549567	0.197641	61.252690
Land occupation	m2org.arable	0.210350	2.412351	0.040009	5.956718	0.098412	8.717840
Aquatic acidification	kg SO2 eq	0.439226	0.092741	20.428344	0.167126	0.029440	21.156876
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000696	0.005955	0.000381	0.029242
Global warming	kg CO2 eq	77.393856	23.343001	1763.378980	26.855000	3.709173	1894.680010
Non-renewable energy	MJ primary	990.556297	303.533200	24693.797783	575.609995	78.519539	26642.016815
Mineral extraction	MJ surplus	0.062865	0.278908	0.233491	0.467800	0.027544	1.070607

Table 7.46: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 3.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 3							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.835436	0.317287	0.032979	1.966722
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	3.246420	0.357919	0.027565	6.780987
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	4.858882	0.022252	0.013129	4.956499
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	26757.572609	603.019419	26.950373	27893.652596
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000007	0.000004	0.000001	0.000015
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.172311	0.013890	0.004158	0.206035
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	230449.914982	1388.354885	191.908036	241706.102656
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	57502.080587	471.264169	76.429025	60712.606985
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	126.435312	0.549567	0.197641	128.614537
Land occupation	m2org.arable	0.210350	2.412351	0.085632	5.956718	0.098412	8.763463
Aquatic acidification	kg SO2 eq	0.439226	0.092741	43.722913	0.167126	0.029440	44.451446
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001489	0.005955	0.000381	0.030036
Global warming	kg CO2 eq	77.393856	23.343001	3774.171212	26.855000	3.709173	3905.472242
Non-renewable energy	MJ primary	990.556297	303.533200	52852.291980	575.609995	78.519539	54800.511011
Mineral extraction	MJ surplus	0.062865	0.278908	0.499741	0.467800	0.027544	1.336858

Table 7.47: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 4.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 4							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.318105	0.317287	0.032979	1.449391
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	1.236124	0.357919	0.027565	4.770690
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	1.850093	0.022252	0.013129	1.947711
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	10188.351738	603.019419	26.950373	11324.431725
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000003	0.000004	0.000001	0.000010
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.065610	0.013890	0.004158	0.099334
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	87747.301529	1388.354885	191.908036	99003.489202
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	21894.789608	471.264169	76.429025	25105.316006
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	48.142163	0.549567	0.197641	50.321388
Land occupation	m2org.arable	0.210350	2.412351	0.032606	5.956718	0.098412	8.710437
Aquatic acidification	kg SO2 eq	0.439226	0.092741	16.648163	0.167126	0.029440	17.376695
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.000567	0.005955	0.000381	0.029114
Global warming	kg CO2 eq	77.393856	23.343001	1437.072951	26.855000	3.709173	1568.373981
Non-renewable energy	MJ primary	990.556297	303.533200	20124.312049	575.609995	78.519539	22072.531081
Mineral extraction	MJ surplus	0.062865	0.278908	0.190284	0.467800	0.027544	1.027400

Table 7.48: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 5.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 5							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.589862	0.317287	0.032979	1.721148
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	2.292146	0.357919	0.027565	5.826712
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	3.430629	0.022252	0.013129	3.528247
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	18892.273009	603.019419	26.950373	20028.352996
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000005	0.000004	0.000001	0.000013
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.121661	0.013890	0.004158	0.155385
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	162709.927857	1388.354885	191.908036	173966.115531
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	40599.534978	471.264169	76.429025	43810.061376
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	89.270072	0.549567	0.197641	91.449297
Land occupation	m2org.arable	0.210350	2.412351	0.060461	5.956718	0.098412	8.738292
Aquatic acidification	kg SO2 eq	0.439226	0.092741	30.870708	0.167126	0.029440	31.599241
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001051	0.005955	0.000381	0.029598
Global warming	kg CO2 eq	77.393856	23.343001	2664.766119	26.855000	3.709173	2796.067149
Non-renewable energy	MJ primary	990.556297	303.533200	37316.536288	575.609995	78.519539	39264.755320
Mineral extraction	MJ surplus	0.062865	0.278908	0.352844	0.467800	0.027544	1.189960

Table 7.49: Impact category results for a 280 mm double brick insulated cavity wall with both sides plastered and painted for climatic zone 6.

1m² 280mm Double Brick Insulated Cavity Wall - Exterior Plaster and Paint - Zone 6							
Impact category	Unit	Phase 1 (production)	Phase 2 (building in, operation, maintenance)			Phase 3 (demolition, recycling and reuse)	Total
			Building in	Operation	Maintenance		
Carcinogens	kg C2H3Cl eq	0.607123	0.173897	0.847891	0.317287	0.032979	1.979177
Non-carcinogens	kg C2H3Cl eq	2.871225	0.277857	3.294818	0.357919	0.027565	6.829385
Respiratory inorganics	kg PM2.5 eq	0.048412	0.013825	4.931319	0.022252	0.013129	5.028937
Ionizing radiation	Bq C-14 eq	136.993450	369.116745	27156.482177	603.019419	26.950373	28292.562164
Ozone layer depletion	kg CFC-11 eq	0.000001	0.000002	0.000007	0.000004	0.000001	0.000015
Respiratory organics	kg C2H4 eq	0.007712	0.007964	0.174880	0.013890	0.004158	0.208604
Aquatic ecotoxicity	kg TEG water	8781.917303	894.007449	233885.528422	1388.354885	191.908036	245141.716096
Terrestrial ecotoxicity	kg TEG soil	2387.524537	275.308667	58359.338100	471.264169	76.429025	61569.864497
Terrestrial acid/nutri	kg SO2 eq	1.063905	0.368112	128.320246	0.549567	0.197641	130.499471
Land occupation	m2org.arable	0.210350	2.412351	0.086909	5.956718	0.098412	8.764740
Aquatic acidification	kg SO2 eq	0.439226	0.092741	44.374747	0.167126	0.029440	45.103280
Aquatic eutrophication	kg PO4 P-lim	0.019418	0.002792	0.001511	0.005955	0.000381	0.030058
Global warming	kg CO2 eq	77.393856	23.343001	3830.437639	26.855000	3.709173	3961.738669
Non-renewable energy	MJ primary	990.556297	303.533200	53640.229110	575.609995	78.519539	55588.448141
Mineral extraction	MJ surplus	0.062865	0.278908	0.507192	0.467800	0.027544	1.344308

7.8 RECOMMENDATIONS

7.8.1 Cradle to gate phase

The research shows that the production of clay bricks in South Africa is heavily energy intensive. Most of the emissions generated from the cradle to gate stages are attributed to burning fuel during the firing process on the production site where coal is combusted in order to vitrify the clay bricks. The greatest environmental impact is the use of non-renewable energy sources; in this case from the high use of fossil fuels for firing bricks or electricity which is sourced from the South African electricity grid, which in turn is generated almost entirely by coal powered power stations.

The research shows that the Tunnel and Zigzag kilns have the lowest environmental impact overall. These kiln types are considered continuously fired kilns. It is therefore advisable for manufacturers that currently utilise kilns that require start up fuel for each batch of bricks to investigate and consider investment in continually fired kiln technologies such as tunnel kilns.

The clamp kiln, which is the most utilised in South Africa, has an average environmental impact. It is recommended that clamp kiln operators investigate higher quality fuels in order to reduce the overall quantity of fuel used during the manufacturing process.

In all kiln types, the quality and quantity of internal fuel, and burning fuel should be optimised to reduce the environmental impacts inherently associated with the combustion of carbon rich fuels.

7.8.2 Gate to end of operational life phase

The research shows that although the simplest clay brick wall construction type (double face brick wall) poses the least environmental impact during the building in phase, consideration should be given to the context of the wall. Tables 7.14 to 7.49 present the various wall constructions along with their associated operational energy requirements for six climatic zones in South Africa. It is recommended that careful consideration be given to the context of clay brick walls based on this research when identifying the least environmentally impactful clay brick walling type for predominantly clay brick walled buildings in South Africa.

The research is provided as a decision making tool, it is proposed that the reader identifies his climatic zone, which if cannot be decided upon, he then assesses the wall construction type which poses the least environmental impacts and then uses Phase 1 results to assess the environmental impacts associated with the availability of kilns in the area of the development. This way we are proposing the use of decision making on the environmental impacts of clay brick walling in South Africa based on the research presented in this report.

7.8.3 Demolition, waste and recycle phase

Hewitt (2001:27) discusses the benefits of waste recycling in his investigation into recycling construction and demolition waste in South Africa. From the research it was found that the largest waste group was concrete and block/brick waste; however, this type of waste is not directly all landfilled, but often serves as backfill material or in other infrastructure applications (*ibid.*). He (*ibid.*) suggests that there are economic benefits with the reuse of construction and demolition waste at landfill disposal sites since they often require the structural properties of concrete and brick waste for the construction of landfill sites. By reusing the materials in the landfill infrastructure system, there will be a reduction in the need for this material to be purchased, produced and carted in.

Hewitt's (2001:27-28) research also confirms that there is a growing need for second hand building material to be informally collected from demolition sites and transported to informal settlements where community members use this material to construct their dwellings.

The recycling potential can be defined as the potential for environmental benefits acquired through recycling of materials or components (*ibid.* 2001:29). Recycling is a means of reducing society's impact on the environment, and when managed the right way, either through reuse or reprocessing with minimal energy use, this can reduce the total energy consumed in a building's life cycle. For each clay brick which is recycled in South Africa, the emission of 853g of carbon dioxide is avoided.

South Africa is home to some of the most pristine environments in the world, and would benefit from an integrated plan for waste minimization and recycling of construction and demolition waste. The effect of employing such a plan may not be felt immediately, but will definitely bear fruit over the long term.

South Africa has its own unique set of environmental, social and economic characteristics; some broad suggestions for waste reduction for South Africa adapted from an effective waste management plan proposed for the Himalayas by Gambin *et al*. (2003) are:

7.8.3.1 AN INTEGRATED APPROACH TO WASTE MINIMIZATION (Gambin *et al*. 2003)

Their study covers the various aspects of waste minimization such as a legal framework, waste action plans, waste reduction grants and setting waste reduction targets. A hierarchical approach is necessary and this starts with avoiding unnecessary resource use, recovering resources which would normally be sent to landfill sites (this includes reuse, reprocessing, recycling and energy recovery from energy intensive manufactured goods). The most effective way of achieving waste minimization is involving every person on a project team coupled by providing the facilities for recovery. It is imperative for waste minimisation to start at the design phase of a project to the completion stage. Waste minimization is an overall approach, and cannot be accounted for at the end of a project.

7.8.3.2 A LEGISLATIVE FRAMEWORK FOR AN INTEGRATED APPROACH TO WASTE MINIMIZATION (Gambin *et al.* 2003)

Lessons from Sydney and NSW in developing a legislative framework for an integrated approach to waste minimization are mostly relevant to the South African context, the main suggestion being to act now rather than later. In developing South Africa, construction activities and urbanization are bound to increase in tandem with population and economic growth, with concomitant increase in the generation of waste material. Less than a decade ago, the state of New South Wales in Australia and the City of Sydney did not have an integrated waste minimization approach, and waste minimization and resource recovery did not seem an issue of much concern until it became evident that the prevailing situation was not environmentally sustainable.

7.8.3.3 A CULTURE OF WASTE MINIMIZATION AND RECYCLING (Gambin *et al*. 2003)

This trait is not an easy one to develop but it is so essential for sustainable development in South Africa. Community-based waste education programs and a waste grant scheme that provides financial support for community members to reuse and recycle waste are critical to changing the mind-set of the people at the grass root level. The prejudices of recycled materials being inferior to virgin materials will need time and effort to eradicate as is evident in the survey findings in Sydney. A noteworthy point is that there is a significant difference between the type and quantity of waste produced in South Africa and in Australia. This is assumed due to the different developmental categorization of these two countries.

7.8.3.4 A PRICING POLICY TO PROMOTE WASTE REUSE, REPROCESSING, RECYCLING AND ENERGY RECOVERY

Gambin *et al.* (2003) found that a pricing policy to promote waste re-use and recycling will harness the market forces to bring about the required changes for waste reduction. If people in South Africa could be made aware of the economic benefits from re-use, reprocessing or recycling of waste they will be less likely to dispose of their waste, especially disposing their waste in an illegal manner. A carrot and stick approach would be appropriate, where re-used, reprocessed and recycled materials should be made cheaper than virgin materials as an attraction while the cost for landfill disposal or punitive action taken for illegal disposal of waste should act as a promoting factor for waste reduction. The pricing policy will have to make adjustments for the socio-economic profile of South African citizens, e.g. by imposing a heavy penalty for illegal dumping in parallel with South African style community-based education programs.

7.8.3.5 SET TECHNICAL STANDARDS AND APPROPRIATE QUALITY CONTROL CHECKS

Gambin *et al*. (2003) suggest that ensuring conformance of the recycled products to proper technical standards and the implementation of appropriate quality control tests are the vital factors necessary to promote the growth of the recycling industry. In South Africa, however, it may be more difficult to ensure that suppliers of recycled construction material do not undercut each other by compromising on the quality standards, which would be detrimental to the recycling industry once confidence of the clients in the recycled products is undermined.

7.8.3.6 REDUCING WASTE DURING THE DESIGN PHASE OF A BUILDING

It is recommended that the design professionals be made aware of the opportunities to reduce waste during the later construction phase through an understanding of the characteristics and sizes of proposed materials as well as of the construction process when they are designing the building.

7.8.3.7 REDUCING WASTE DURING THE CONSTRUCTION PHASE OF A BUILDING

Hewitt (2001:45) proposes the following items to be included in building contract waste management plans:

- Reduce waste generated during the design and procurement phase of a building project.
- Provide accurate data regarding forecasts of volumes, costs and types of waste generated on building projects.
- Incorporate the mandatory use of specialist recycling organizations.
- Improve the handling of waste in order to increase the percentage of waste being suitable for recycling or reuse.
- Measure and benchmark waste statistics for projects.

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