ENVIRONMENTAL IMPACTS OF CLAY BRICKS IN SOUTH AFRICA

Management Summary and consolidation report of the LCA study
“Life Cycle Assessment of clay brick walling in South Africa”

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Management Summary

Over the last years, a detailed analysis of the environmental impacts of clay brick production and utilisation in South Africa was commissioned by the Clay Brick Association (CBA) of South Africa and Swisscontact, co-funded by the National Research Foundation and conducted by the University of Pretoria (UP). The study was performed using specific production data from 86 out of the 102 clay brick production sites in South Africa which are members of the CBA. The analysis was conducted in accordance with the ISO 14040 and 14044 standards with an external review in order to aim at the highest quality standards. In accordance with the ISO 14040 and 14044 standards, the results were summarised in an extensive report produced by UP and tailored for environmental experts which describes the detailed methodology, data basis and all the assumptions used in the study.

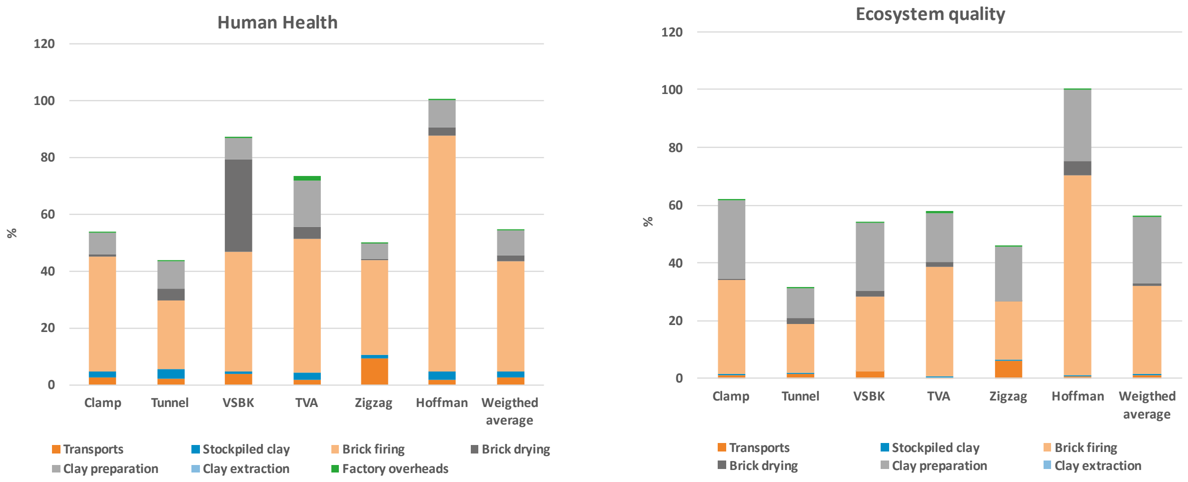
In order to facilitate the dissemination of the findings of the reports amongst the members of the CBA and stakeholders perhaps without expertise in environmental assessment, Swisscontact contracted Quantis to extract, in collaboration with UP, the most relevant results from the main report and consolidate these in this separate document. Hence, the aim of this short report is to summarize the main framework, results and findings of the study “Life cycle Assessment of clay brick walling in South Africa” (Vosloo *et al.* 2016a) and simplify its presentation.

The methodology chosen for the study is Life Cycle Assessment (LCA), an internationally and scientifically recognised approach which quantifies the environmental impacts of products, systems or services by analysing the emissions produced and the resources consumed during their production, use and the end-of-life phase. Using this approach, the potential damages to human health, to ecosystem quality, to climate change and the consumption of non-renewable resources were assessed for the life cycle of clay bricks in South Africa. Moreover, the study differentiates between six brick manufacturing techniques, which are defined by how the bricks are fired in different types of kilns. The kilns considered in the report are:

- Clamp kiln
- Tunnel kiln
- Transverse Arch kiln (TVA)
- Hoffman kiln
- Vertical shaft brick kiln (VSBK)
- Zigzag kiln

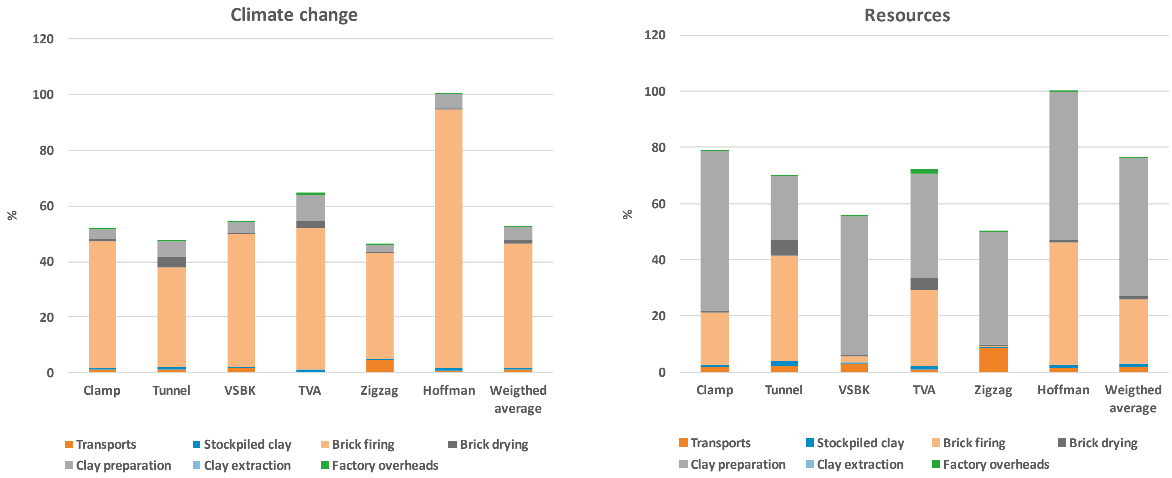
To be able to compute the environmental assessment, specific data for each technology were collected with respect to the production year 2012 - 2013 in terms of quantities of consumed materials and chemicals as well as of the required energy. The analysis addressed firstly the production of the clay bricks and subsequently their entire life cycle, including their use in an average South African building.

Figure I and Figure II show, respectively, the results for the damages to human health, to ecosystem quality, the contribution to climate change and the consumption of non-renewable resources for the six investigated technologies (and the industry average weighted through the various production volumes) with respect to the production of 1 kg of fired brick. The results highlight the main brick production steps and take into account the impacts deriving from all main processes involved, including, for example, the production of the raw materials needed, of the energy vectors used and the emissions deriving from the combustion of fuels used in the different production steps or in the vehicles used for the transport services.



(a) (b)

Figure I: Human Health and Ecosystem Quality



(a) (b)

Figure II: Climate change and Resources.

Overall, the results vary considerably between the environmental indicators and it is not possible to identify a single technology which always performs best and which can therefore be considered superior to the other ones in all aspects. At the same time, production based on the Hoffman kiln always performs worse than the other technologies. Overall~~,~~ and independently of the firing technology used, what the results also show is that, with few exceptions~~,~~ and for all environmental indicators, the main contributions to environmental impacts occur during clay preparation and during the firing steps, whereas the other manufacturing processes play an almost negligible part. With respect to clay preparation, the high impacts in ecosystem quality and resources are mostly caused by the production of the coal which is mixed to the clay. During firing, the main impacts come from the emissions of the coal added to the clay mixture as internal fuel or, in case of the Resource indicator, from the additional fossil fuels (and particularly coal) used for combustion. Hence, a key measure for reducing the environmental impacts of clay brick production is to reduce as far as possible the amount of coal and fossil fuels used, both, as internal fuel mixed during clay preparation and external fuels added for combustion in the firing step.

Further, the analysis also shows that the electricity used in the production process leads to appreciable impacts in all technologies and particularly for the Tunnel and TVA, where contributions of around 15% to 30% of the overall impacts of these technologies can be observed, mainly due to the clay preparation step. As can be seen in the appendix, this is due to the higher electricity consumptions of these two production routes.

Overall, considering the weighted average of all environmental impacts for all the considered production sites and technologies, the production of 1 kg of clay brick in South Africa can be associated with the emission of 0.27 kg of CO_2-equivalents (meaning that not only the effect of CO_2, but also the one of other substances like methane, for example, is taken into account). Based on the yearly production of 9’611’178’437 kg fired bricks considered for 2012/2013 in this study, this leads to a total of 2.6 million tons CO_2 equivalents emitted per year.

Similarly, the results show that on average the production of 1kg clay brick in South Africa requires 3.46MJ of fossil energy which amounts to a total of about 33.5 billion MJs of non-renewable energy consumed by the sector.

Thereafter the environmental impacts of the entire life cycle of clay bricks in South Africa were evaluated. These include, next to the production of the bricks, their building-in in an average South African building, the electricity required for heating and cooling and the disposal phase at the end of life. With respect to the environmental impacts of brick production, the average impacts from all technologies discussed above were taken for this part of the analysis. A life expectancy of 50 years was assumed for the building and three different wall types were considered:

- 220mm brick wall
- 280mm cavity brick wall
- 280mm insulated cavity brick wall

The average electricity consumptions for heating and cooling of the building were derived from the study by Vosloo *et al.*, (2016b) which takes into account the change in electricity consumption thanks to the different insulation characteristics of the three wall types considered.

Amongst the various scenarios discussed in Vosloo *et al.*, (2016b), one corresponding to a geographical area leading to the smallest consumptions in electricity for heating and cooling in the use-phase was chosen. This was done knowing that for all other climatic regions the impact of the use-phase would just be larger but not alter the conclusions of the analysis.

The results are presented in Figure III for Climate change only since exactly the same trends can be observed for the other indicators.

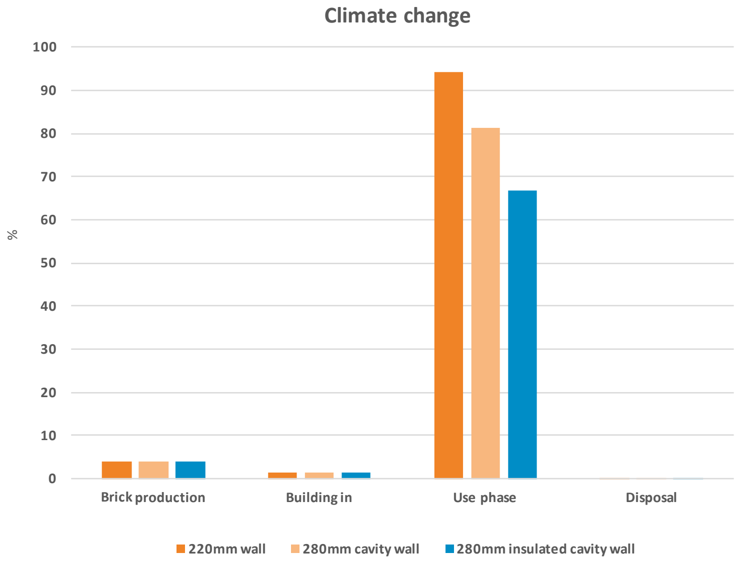


Figure III: Climate change impacts for the life cycle of 3 wall types.

Even for the geographical region where the use-phase has the smallest requirements, the results are completely dominated by the impacts deriving from the production of the electricity used for the heating and cooling of the building. All other life cycle steps including the production of the bricks show minor, almost negligible impacts. The main reasons for this trend are twofold. Firstly, being largely based on coal burning technology, South African electricity is characterised by high impacts. Secondly, thanks to their long life expectancy, the impacts coming from clay bricks production is conceptually spread over 50 years whereas the ones from the electricity production for the use-phase accumulate over 50 years. Further, since the difference in the impacts coming from brick production and building-in for the three different wall types is minimal compared to the savings which can be achieved in the use-phase, thanks to a better insulating wall, it can be concluded that in environmental terms, building structures which lead to electricity savings in the use-phase represents the more favourable solution. The advantages become even more relevant for those regions which are characterised by larger electricity consumptions for heating and cooling.

Overall, the analysis of the life cycle environmental impacts of clay brick walling in South Africa shows a very clear result. When looking at the entire life cycle, the use-phase of the bricks – meaning the impacts deriving from the electricity production required for the heating and cooling of the buildings in which the bricks are built in – strongly dominate~~s~~ the results. Hence, when looking at ways with which the clay brick sector can reduce its environmental impacts in the future, two suggestions can be made with this result in mind.

The first one is to sensitise as a sector, the need for the design of energy efficient buildings and the importance of the building materials. The contribution from the production of the bricks and the construction phase is so small compared to the use-phase, independently of the type of wall built, that building with better insulated walls always leads to considerably lower overall impacts, thanks to the savings in heating and cooling which can be achieved. But of course, another way of reducing the impacts from the use-phase is by changing the environmental impacts of the electricity itself. Considering that the South African electricity mix is largely based on coal technology, fostering the use of renewable electricity sources could lead to considerable advantages. Since these aspects were out of the scope of the LCA of clay brick walling in South Africa performed by UP, a detailed environmental assessment of the advantages and challenges linked, for example, to the systematic installation of photovoltaic panels and solar thermal panels in new buildings, may shed relevant insight on the topic.

Nevertheless, even if environmental impacts from the other life cycle stages are not dominant in the overall results, the clay brick sector should still aim at optimising its production processes since it not only helps to reduce energy costs therefore improving the financial sustainability of the industry, but also environmentally because if every sector reduces its environmental contributions from the production phase, large improvements can be achieved nationally. To achieve meaningful reductions of the environmental impacts along the entire production process, optimisations of both the total energy used as well as the mix between internal and external firing fuel need to be achieved. Otherwise, improvements in the efficiency of the firing step can be offset if these require a higher amount of coal as an internal fuel. As a further measure, the installation at the production plants of renewable electricity sources such as photovoltaic panels to reduce the need of the mostly coal based grid electricity, could also be beneficial in this context for those production routes like Tunnel and TVA which show slightly higher impacts coming from electricity consumption and should be the subject of further investigations.

In the interpretation of the results and conclusions, it is important to keep in mind that the analysis is based on average data from the clay brick production sector. The performance of each brick production plant may look different than that derived in the study. The average values presented concerning the inputs required by the various firing technologies are an important benchmark which can help plant managers in identifying potential optimisation areas. Moreover, the findings and results of the LCA study describe the environmental performance of the clay brick sector in the year 2013. Future studies can refer to these results as a baseline against which improvements or changes can be measured. The Clay Brick Association of South Africa in particular can verify, with periodically run updates of the LCA study, how improvements addressing the identified environmental hot spots are affecting the results of the sector.

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1. Introduction

Over the last years, a detailed analysis of the environmental impacts of clay brick production and utilisation in South Africa was commissioned by the Clay Brick Association (CBA) of South Africa and Swisscontact, co-funded by the National Research Foundation and conducted by the University of Pretoria. The study was performed using specific production data from 86 out of the 102 clay brick production sites in South Africa which are members of the CBA. The analysis was conducted in accordance with the ISO 14040 and 14044 standards with an external review in order to aim at the highest quality standards. In accordance with the ISO 14040 and 14044 standards, the results were summarised in an extensive report produced by UP and tailored for environmental experts which describes the detailed methodology, data basis and all the assumptions used in the study.

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2. Environmental assessment of clay brick production and utilisation in South Africa

Concerns about a number of different environmental issues have reached worldwide attention and have triggered demands for coordinated and urgent action at the global level. While global warming is recognised as a clear threat to society as we know it and international treaties and action plans have been and are being defined to reduce its potential impacts, the more efficient use of resources, the use of renewable resources, as well as the prevention of pollutant emissions in order to avoid human health and ecosystem damages, are more widely accepted as key and unavoidable steps for the transition towards a sustainable development system.

In order to define concrete action towards a sustainable society, the first step is to quantify its environmental impacts in all relevant sectors to understand which factors are particularly damaging and in need of change. Being the largest CO_2 emitter in Africa and the 12th largest in the world (**Figure 1**), this approach also holds true for South Africa.

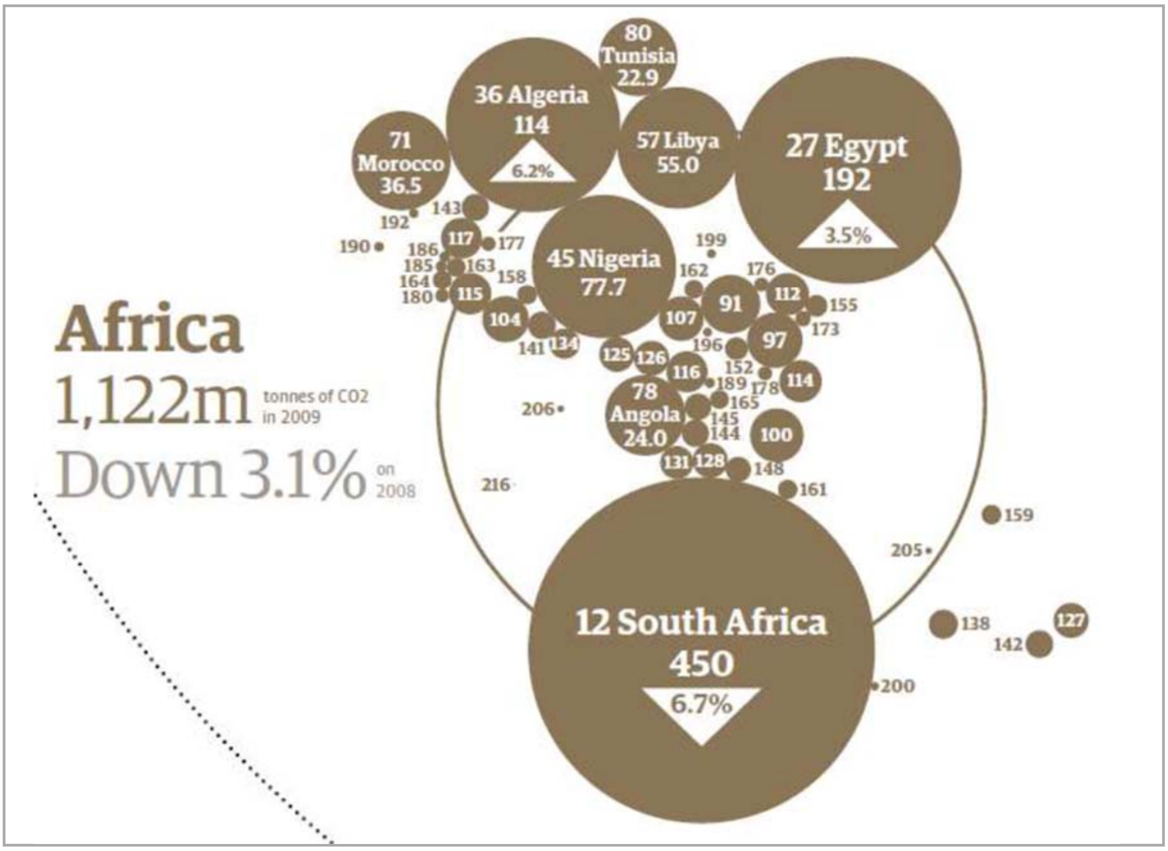


Figure 1: Summary of CO_2 emissions in Africa (McCormick & Scruton, 2012).

It is within this context, and considering that it is well known that the building sector is a major source of greenhouse gas emissions – with about 40% of the emissions caused by the production of major building products carried by bricks (Milford, 2009) – that the CBA decided to assess the environmental impacts of its sector. A key aspect in this choice was that, while more and more environmental claims on building products are made, few of these are based on internationally and scientifically recognised methodologies. Hence, the methodology used for the assessment had to allow the CBA to make environmental claims which were backed by strong scientific evidence. Moreover, because global warming is a daunting challenge and other environmental aspects like damages to human health or damages to the ecosystem too can cause serious impacts on our society, the University of Pretoria, as commissioned by the CBA decided to not only make a detailed assessment of the CO_2 emissions related to the clay brick~~s~~ sector, but to adapt an holistic approach which would look at all major environmental aspects.

The methodology chosen for the study is Life Cycle Assessment (LCA), an internationally and scientifically recognised approach which quantifies the environmental impacts of products, systems or services by analysing the emissions produced and the resources consumed during their production, use and the end-of-life phase. Once the emissions produced and the resources consumed over the life cycle of a product are known, it is then possible to use so called impact assessment methods to quantify the damages produced with respect to specific environmental aspects (**Figure 2**).

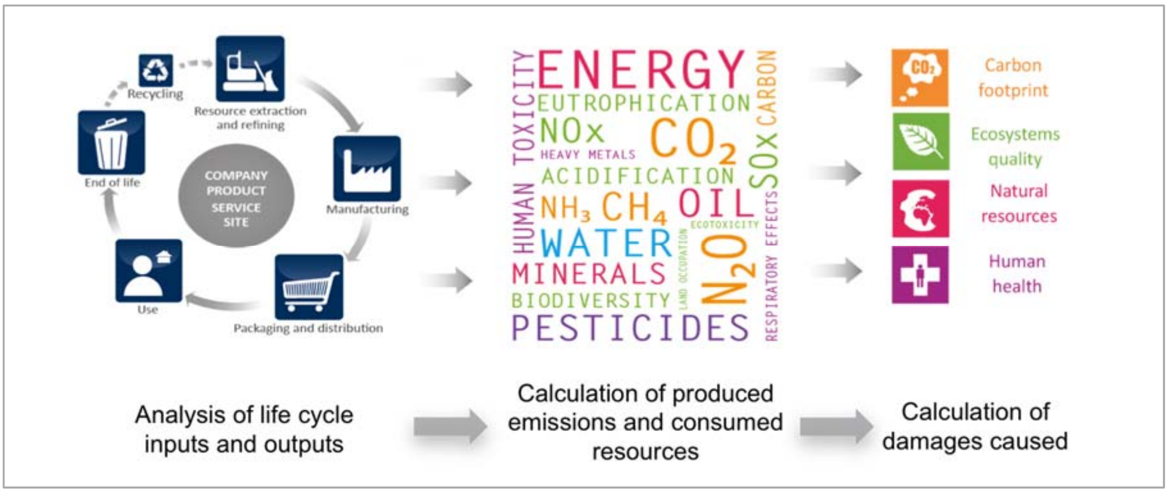


Figure 2: LCA concept.

The impact assessment method considered in the study is Impact 2002+ (Humbert, De Schryver, Bengoa, Margni, & Jolliet, 2014). However, while in the full LCA report “Life cycle assessment of clay brick walling in South Africa” (Vosloo *et al.* 2016a) the results were presented looking at the midpoint categories shown in Figure 3 (and, therefore looking at quite a large variety of different indicators) in this consolidation report the analysis will focus on the Damage Categories of the Impact 2002+ methodology, i.e. Human Health, Ecosystem quality, Climate change and Resources, which are obtained by bringing together all Midpoint Indicators focusing on one of these specific environmental aspects (see right part of Figure 3), thereby simplifying the interpretation of the results.

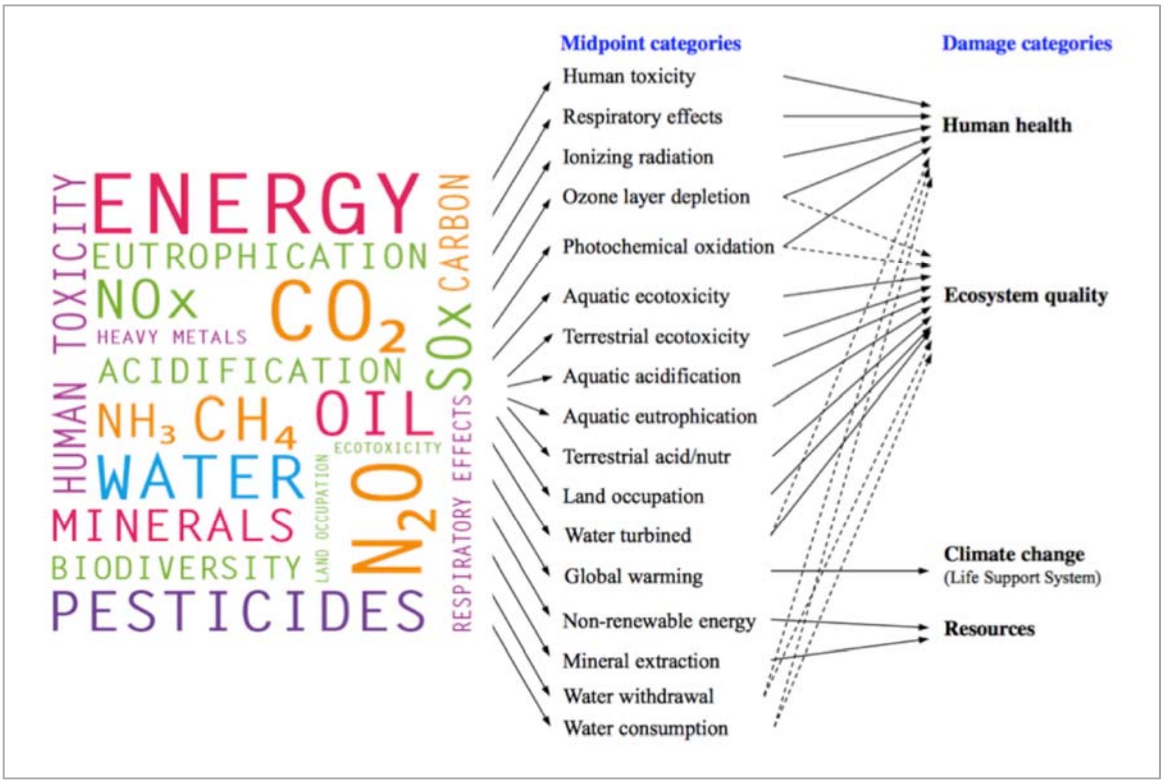


Figure 3: Different levels of the Impact 2002+ methodology.

Hence, the Indicator "Human Health" indicates the potential damage caused by emissions which can have a negative impact on our health through, for example, their toxic or carcinogenic effect, while "Ecosystem quality" describes the impact of a system on the ecosystem by evaluating the potential number of species lost due to the emissions or the induced transformations. Examples of mechanisms which can lead to damages to the ecosystem are the emission of pesticides or land use changes like deforestation. The effect of emitted substances which contribute to global warming is covered by the indicator "Climate change". Finally, "Resources" addresses the consumption of non-renewable resources like fossil fuels or metals.

At the core of the study "Life Cycle Assessment of clay brick walling in South Africa" lies a detailed data collection. Particularly, to assess the environmental impacts from the production of clay bricks, operational data from 86 manufacturing sites were collected, detailing the types and amounts of materials (for example clay, coal, etc.), of energy vectors (like natural gas, electricity, etc.), the typical transport distances needed to transport all the materials to the production sites as well as the transport services needed within the production sites for the manufacturing of the bricks and the typical production processes in use. The data collected cover about 95% of the bricks produced in South Africa and detail what amount of the resources flow into each of the typical production steps of clay bricks manufacturing:

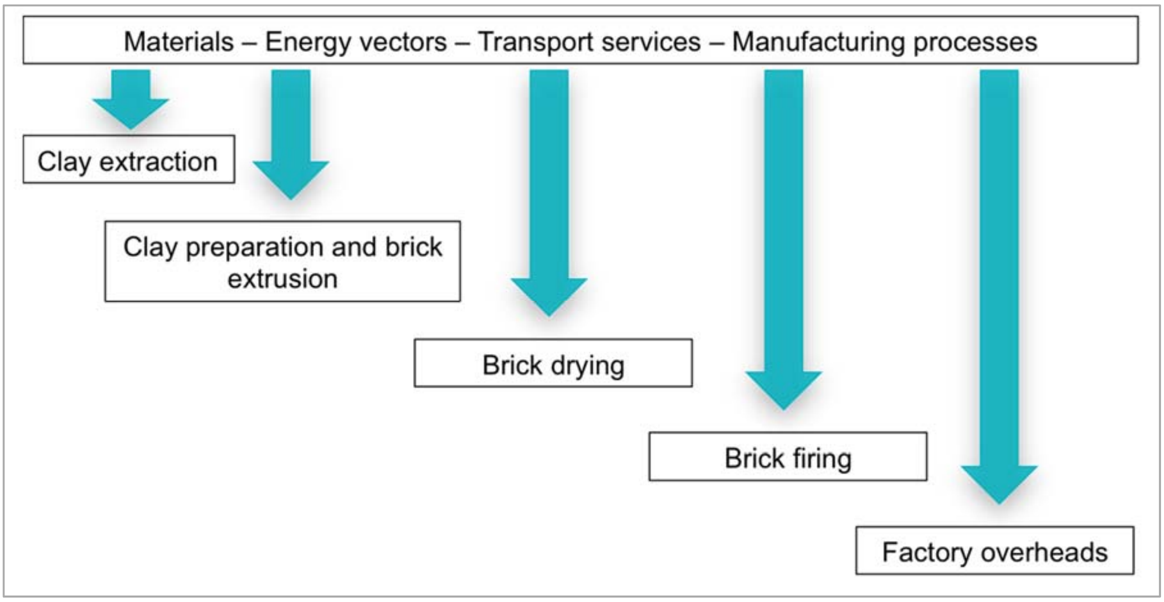


Figure 4: Main steps in clay brick production.

Moreover, the study differentiates between six brick manufacturing techniques, which are defined by how the bricks are fired in different types of kilns. The kilns considered in the report are:

- Clamp kiln
- Tunnel kiln
- Transverse Arch kiln (TVA)
- Hoffman kiln
- Vertical shaft brick kiln (VSBK)
- Zigzag kiln

A brief description of each technology can be found in Chapter 3.

By distinguishing between the various brick production technologies and the various production steps, the study allows the analysis of the strengths and challenges of each production path and to identify areas of optimisation.

With respect to the rest of the life cycle of clay bricks, the study analyses the impacts coming from the brick production phase, the building's construction phase, the building's operational phase (and particularly in terms of the energy consumed for heating and cooling with different types of walls), up to the disposal and recycling phase at the end of life of the buildings (**Figure 5**).

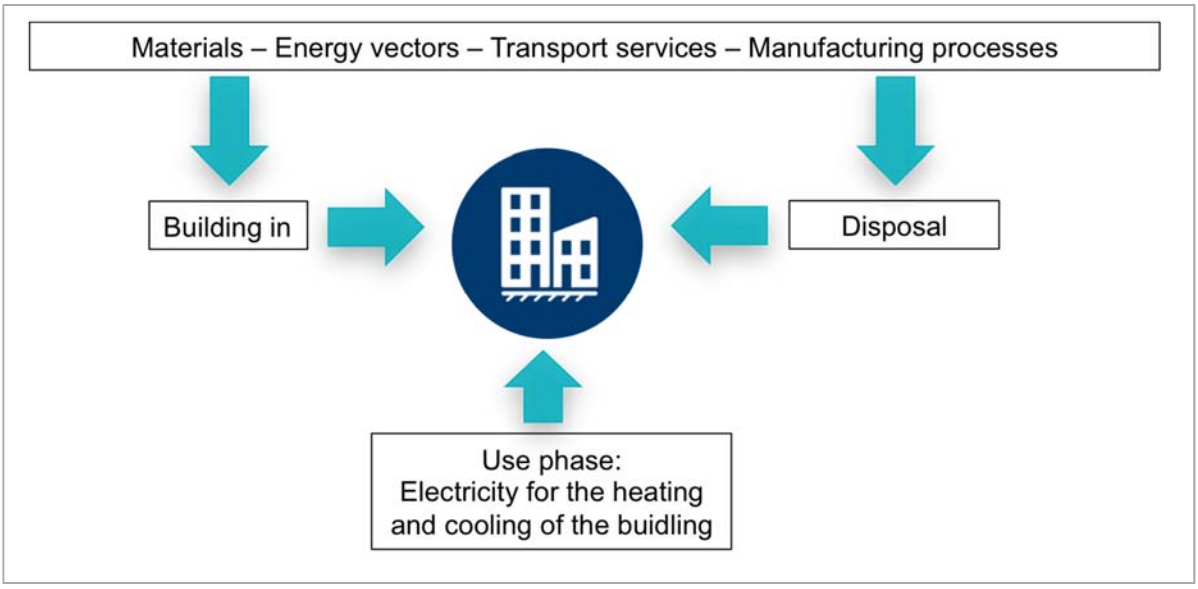


Figure 5: Life cycle stages considered in the study in addition to the production of the clay bricks.

For the assessment of the electricity used for heating and cooling in the building during the operational phase, specific simulations were performed as summarised in the report “A thermal performance comparison between six wall construction methods frequently used in South Africa” (Vosloo, Harris, Holm, van Rooyen, & Rice, 2016b). The building-in and disposal phase were modelled through data sourced from literature.

Next to the data collected from the clay brick producers or sourced from literature, data on the environmental impacts of standard processes like the production of coal or the combustion of natural gas, were taken from the environmental database *ecoinvent.*

3. Brick manufacturing technologies considered in the study

To collect the relevant data for the LCA of clay bricks in South Africa, the University of Pretoria contacted 102 operational production plants. This represents the large majority of manufacturers in South Africa. The breakdown of the contacted producers with respect to the manufacturing technology used is shown in **Table 1**.

Clamp kilns	68%
Tunnel kilns	20%
TVA kilns	6%
Hoffman	2%
VSBK	2%
Zigzag	2%

Table 1: Breakdown of the contacted producers with respect to the implemented manufacturing technology (Vosloo *et al*., 2016a).

Eighty-six of the contacted production plants replied and participated in the data collection which corresponds to a geographical coverage of about 83% of all manufacturers in South Africa. Most of these were large production facilities. At each plant, data concerning the production over one year –(between 2012 and 2013) were collected, meaning that data concerning the overall production of 9’611’178’437 kg fired bricks (equivalent to 3’494’973’977 standard bricks) was included in the study. It is estimated that this covers about 95% of the South African national production. Data from the informal sector were not considered, but this is estimated to represent only 3% of the market.

Firing technologies can differ substantially in terms of infrastructure and fuel used, as well as in the combustion procedure. Since this has an impact on the environmental impacts of the various manufacturing paths, a short description of each technology is given in the next paragraph to facilitate the interpretation of the final results.

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 6**. 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 in some cases, but typically around 1000 – 1100 degrees.

Figure 6: Example of a clamp kiln in preparation (Rice, 2012).

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 between 48 to 72 hours and the firing curve is pre-set (which implies that tunnel kilns are continuously fired with brick packs being indexed through the various temperature zones). Maximum firing temperatures typically vary from 1050 C to 1180 C dependent upon the ceramic characteristics of the raw material. **Figure 7** shows a typical tunnel kiln.

Figure 7: Dry bricks entering a gas fired tunnel kiln (Rice, 2012).

3.3 Transverse Arch kiln

The transverse arch (TVA) kilns are fired continuously. Green bricks are placed in cleared chambers in front of the fire. Fired bricks are removed from behind the fire. When a chamber has been completely packed, the entrance is sealed by either bricking it up or with insulated doors after which fuel (coal, oil or gas) is used as a fuel source and fired by means of burners through firing holes in the chamber arch. The fire is then moved through the brick stacks by means of combustion fans drawing a draft through the controlled opening and closing of dampers in front of and behind the kiln arches to be fired. This process occurs every two to four hours depending on the rate of fire travel. The complete firing and vitrification process takes up to two weeks. Heat from the firing zone is drawn forward to dry and pre-heat the newly inserted green bricks while fired bricks are cooled down by air passing through the openings in the arch ends (CBA, 2005). This heated air from behind the fire is utilised in the driers for the drying of the wet bricks. Figure 8 shows the entrance to a TVA kiln. Typically a TVA kiln comprises 30 to 50 adjoining arches in 2 parallel rows.

Figure 8: Transverse arch kiln (EcometrixAfrica, 2014).

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 (Volsteed, du Toit, Mienie, Dickinson, & Coetzee, 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 9** 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*.).

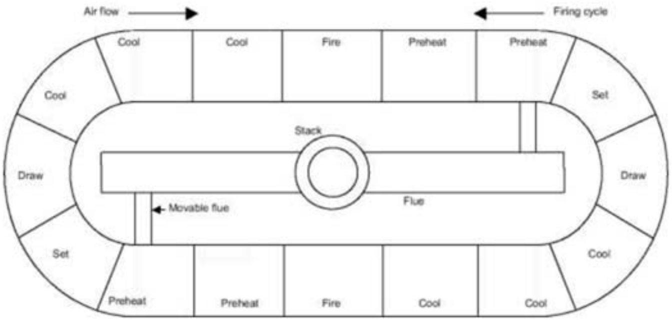


Figure 9: Hoffman kiln basic construction and firing process (Laefer, Boggs, & Cooper, 2004)

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 10** shows the VSBK construction. The firing of a VSBK is done by 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) which allows for faster production of fired bricks. The VSBK technology does not, due to its efficiency in firing, have excess heat in the cooling bricks to be utilised in the drying of bricks. If dryers are utilised then an additional heat source would be required for drying.

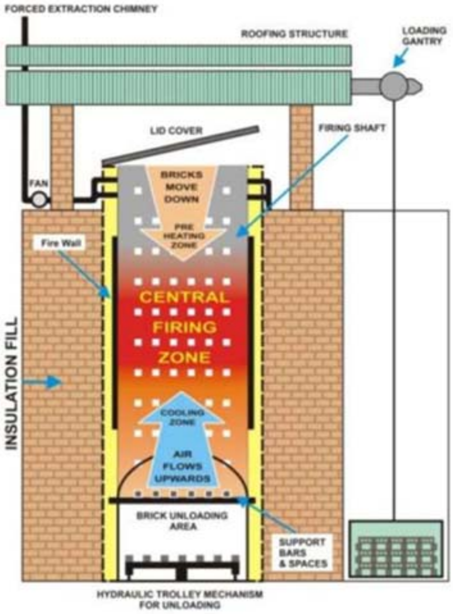


Figure 10: Diagrammatic operation of a VSBK (De Giovanetti & Volsteed, 2012)

3.6 Zigzag kiln

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 11**. 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 11: Zigzag general firing process (HablaZigzagKilns, 2013)

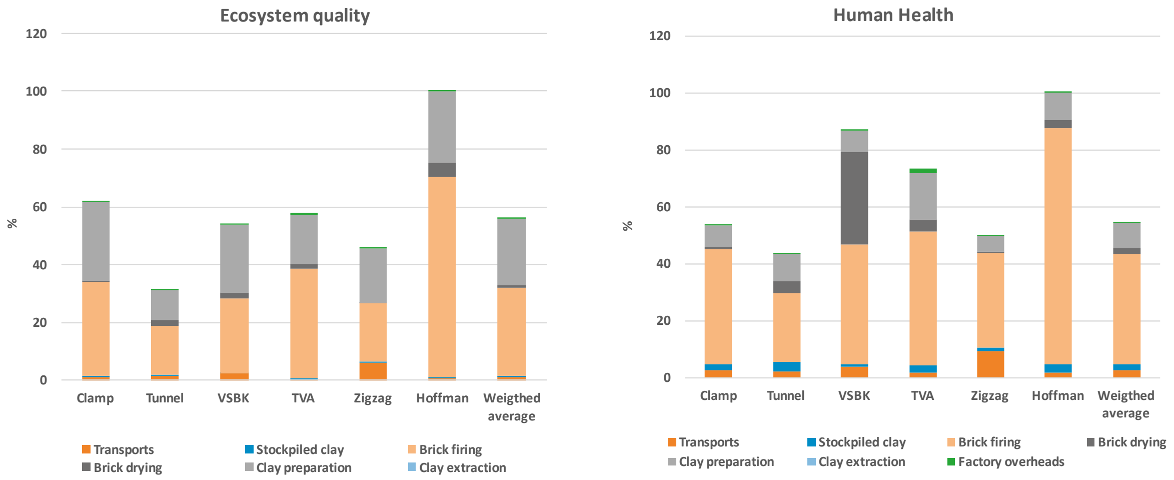
4. Results

This chapter analyses the environmental impacts of the life cycle of clay brick walling in South Africa with respect to the four indicators: Human Health, Ecosystem quality, Climate change and Resources. As described in chapter 2, the indicator “Human Health” describes the potential damages to the human body which can be caused by substances emitted by the analysed processes. Examples can be toxic or carcinogenic substances. The “Ecosystem quality” indicator describes damages caused to the ecosystem in terms of the number of species which might be affected due to emissions or induced land transformations. “Climate change” takes into account the effect of all the emissions which contribute to global warming while “Resources” estimates the consumption of non-renewable resources.

First, only the environmental impacts of clay bricks production will be addressed in order to understand where the main sources of impacts occur and, ultimately, to identify optimisation options. Then, the entire life cycle for three different wall types and climatic zones will be discussed. For some of the technologies (particularly TVA, Hoffman, VSBK and Zigzag) the results are based on a limited number of factories and can be influenced by individual factory characteristics. These results should therefore not be considered as a benchmark of the technologies.

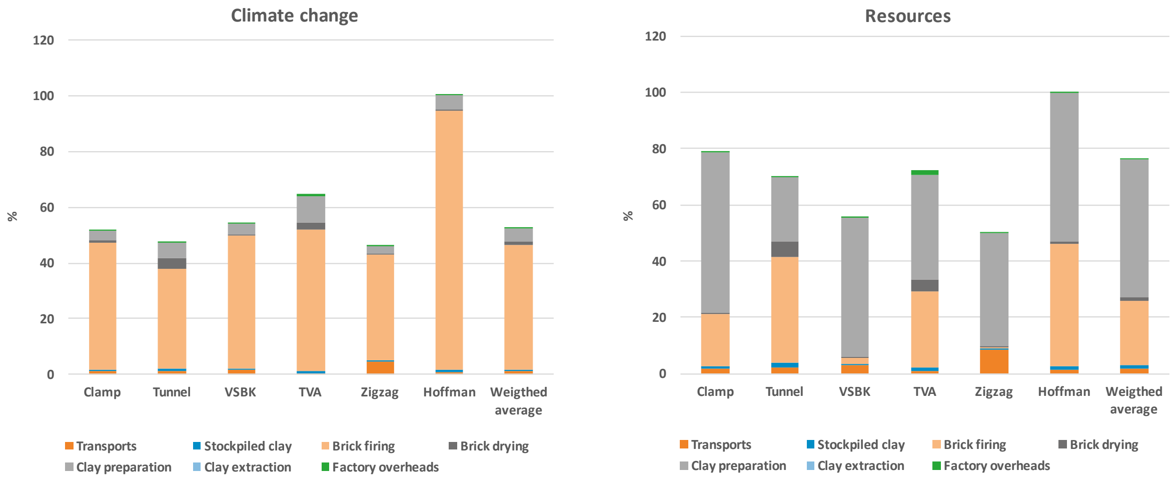
4.1 Environmental impacts of clay brick production

Figure 12 and **Figure 13** show, respectively, the Human Health, Ecosystem quality, Climate change and Resources results for the six investigated technologies (and the industry average weighted through the production volumes of the technologies) with respect to the production of 1 kg of fired brick. The results highlight the main brick production steps and take into account the impacts deriving from all main processes involved including, for example, the production of the raw materials needed, of the energy vectors used and the emissions deriving from the combustion of fuels used in the different production steps or in the vehicles used for the transport services.



(a) (b)

Figure 12: Human Health and Ecosystem Quality



(a) (b)

Figure 13: Climate change and Resources.

Overall, the results vary considerably between indicators and it is not possible to identify a single technology which performs best in all damage categories and which can therefore be considered superior to the other ones in all aspects. At the same time, production based on the Hoffman kiln performs worse than the other technologies for all indicators. Overall and independently of the firing technology used, what the results also show is that, with few exceptions and for all indicators, the main contributions to environmental impacts occur during the clay preparation and during the firing steps, whereas the other manufacturing processes play an almost negligible part. With respect to clay preparation, the high impacts in Ecosystem quality and Resources are mostly caused by the production of the coal which is mixed with the clay. During firing, the main impacts come from the emissions of the coal added to the clay mixture as internal fuel or, in case of the Resource indicator, from the additional fossil fuels (and particularly coal) used for combustion.

With respect to Human health, the impacts in the clay preparation phase come from the coal and originate from the emissions caused at the coal mine during extraction, whereas during firing, particularly damaging emissions are sulphur dioxide, Dioxin 2,3,7,8, Tetrachlorodibenzo-p, nitrogen oxides, particulates and ammonia..

When looking at Ecosystem quality, the largest contributions in clay preparation derive from aluminium emissions occurring in the coal mine. Similarly, aluminium emissions are also a key contributor during firing due the use of coal as internal fuel.

In Climate change, the main contributing process is firing and the dominating cause is the fossil CO_2 emissions coming from the combustion of the coal; both~~,~~ coal added to the kiln as well as coal mixed to the clay during preparation.

With respect to the indicator Resources, the main impacts are caused by the addition of coal to the clay mixture as this depletes the reserves of coal. Similarly, the use of non-renewable fossil fuels in the firing steps (mostly coal or gas) leads to other relevant contributions.

Some of these trends can be understood looking at the input of coal, both, as internal and firing fuel for all technologies as shown in Table 2 (the complete list of relevant inputs is shown in the annex).

	CLAMP	TUNNEL	TVA	HOFFMAN	VSBK	ZIGZAG	
Coal mixed as internal fuel during preparation	95.81	26.42	42.39	83.58	80.01	66.36	Grams coal per kg fired brick
Coal added as external fuel during firing	32.91	13.03	41.09	76.35	2.50	0.00	Grams coal per kg fired brick
TOTAL	128.73	39.44	83.48	159.93	82.51	66.36	Grams coal per kg fired brick

Table 2: Coal input in the clay preparation and firing step.

The fact that bricks produced with the Hoffmann kiln always perform worse than the other routes is related to the fact that this technology requires the highest amount of coal, both in terms of internal fuel during clay preparation, as well as external fuel during the firing step. The Tunnel kiln option performs well in the indicators Human health, Ecosystem quality and Climate change thanks to the smaller amounts of coal used as internal and external fuel. It does not perform as well with respect to Resources due to other fossil fuels (oil and gas) used in addition to coal.

The Zigzag option performs fairly well thanks to absence of additional fossil fuels in the firing step. The other technologies perform better or worse, depending on the specific amounts of internal and external fuel used. The VSBK route, for example, has very small impacts in the Resource indicator when it comes to the firing step – thanks to the fairly low amount of coal used as additional fuel, but performs worse in other steps and indicators due to rather high amount of coal mixed as internal fuel. So, in general, focusing only on the reduction of fossil fuels in the firing step might not lead to a reduction of the overall impacts if a higher amount of coal is then required as internal fuel. To achieve an overall reduction of the environmental impacts of brick production, both~~,~~ the amount of coal used as internal fuel as well as the amount of fossil fuels used during the firing step have to be reduced. The overall contribution of coal impacts are summarised in **Figure 14**. This graph shows for each technology the relative coal contribution in each indicator, both in terms of coal input and its combustion emissions, as opposed to all other causes (for example other materials or energy inputs – in blue). As discussed above, for most technologies coal impacts are the dominant contributors in all indicators. One of the main exceptions is the Tunnel route which is the one with the smallest coal input.

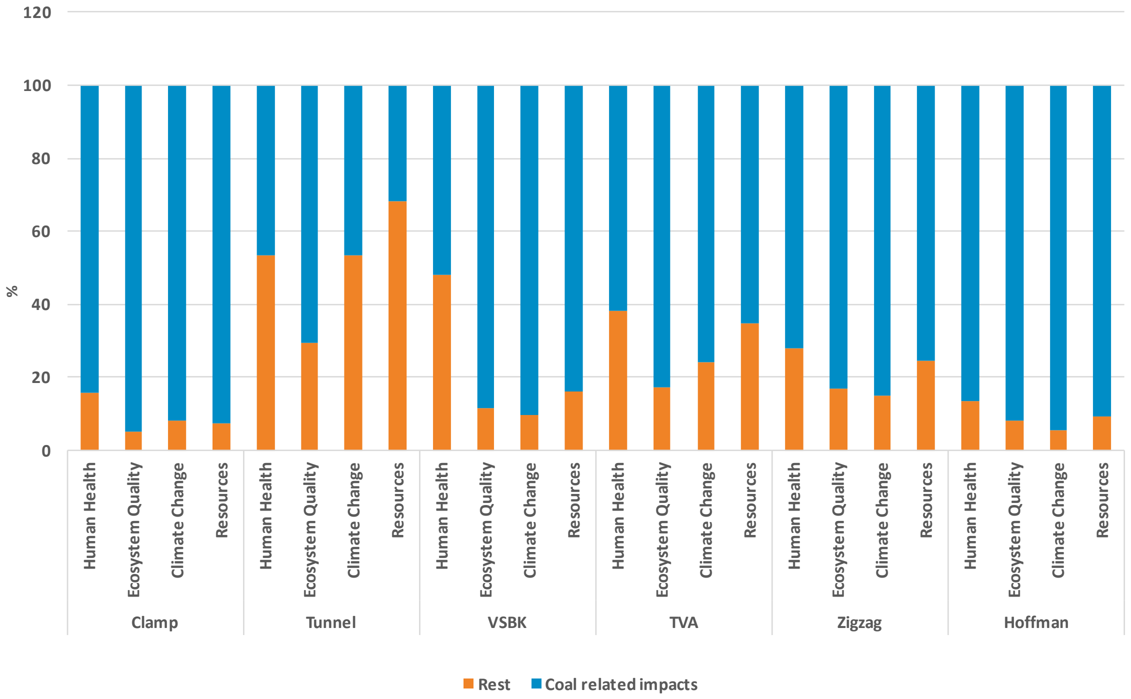


Figure 14: Relative coal contribution for each technology and indicator.

Finally, the contribution to the overall impacts from the use of electricity during the production process was also analysed. The results are shown in **Figure 15**, which highlights - for each technology – the fraction of environmental impacts caused in each indicator by the electricity used in production (in red) as opposed to all the other causes (for example material or other energy inputs – in blue).

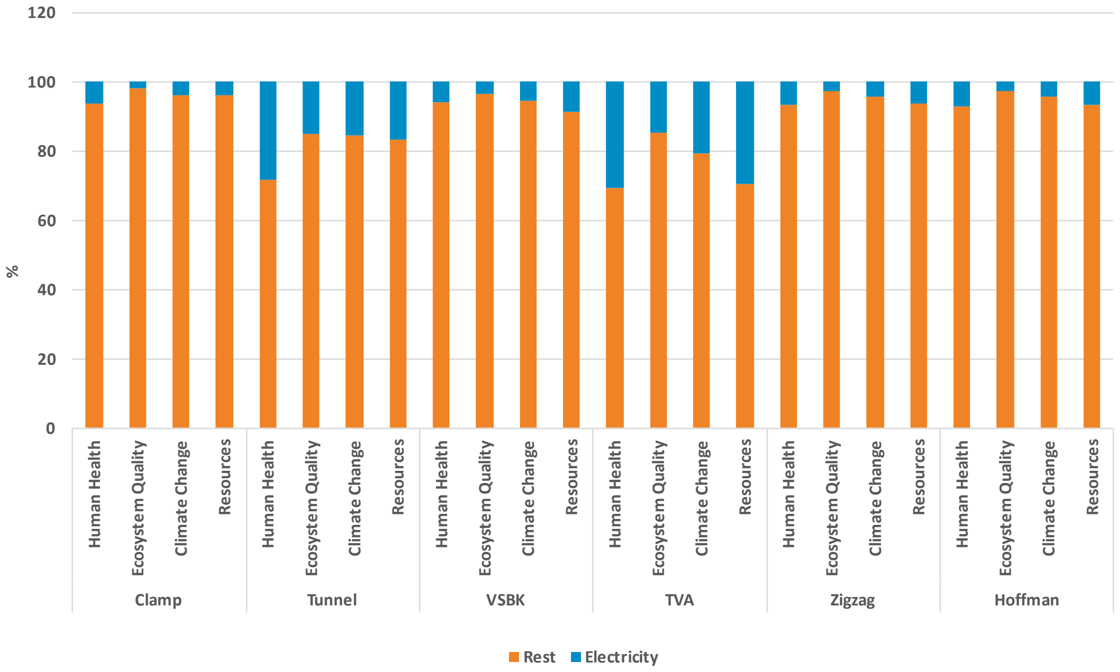


Figure 15: Impacts coming from the production of the electricity required in the manufacturing process (in red) as opposed to the ones coming from all other processes or inputs involved (in blue).

The figure above shows that the electricity used in the production process leads to appreciable impacts in all technologies and particularly for the Tunnel and TVA, where contributions of around 15% to 30% can be observed, mainly due to the clay preparation step. As can be seen in the annexure, this is due to the higher electricity consumptions of these two production routes.

Overall, considering the weighted average of all environmental impacts for all the considered production sites and technologies, the production of 1 kg of clay brick in South Africa can be associated with the emission of 0.27 kg of CO_2-equivalents (meaning that not only the effect of CO_2, but also that of other substances like methane, for example, is considered). Based on the yearly production considered in this study, this leads to a total of 2.6 million tons CO_2 equivalents emitted per year.

Similarly, the results show that, on average, the production of 1kg clay brick in South Africa requires 3.46MJ of fossil energy which amounts to a total of about 33.5 billion MJs of non-renewable energy consumed by the sector.

4.2 Analysis of the entire life cycle

This paragraph analyses the impacts of the entire life cycle of clay brick walling looking at the combined impacts of clay brick production, of their use in a building structure, of the corresponding use phase in terms of electricity needed for heating and cooling of the building and of the final disposal.

The values for the electricity consumption of the use phase of an average building in South Africa are based on the study "A thermal performance comparison between six wall construction methods frequently used in South Africa" (Vosloo *et al.*, 2016b). The life expectancy of the building is assumed to be 50 years. In terms of the technology considered for brick production, an average production technology was modelled taking the operational values of the different production routes and averaging these with data on the productivity of the brick sector. Data on building-in and disposal were taken from literature.

In order to understand how the various life cycle phases and how different wall types – which lead to different electricity consumptions in the use-phase due their specific insulation properties – influence the overall results, three different scenarios were analysed based on the following observations. First of all, out of all the scenarios presented in Vosloo *et al.*(2016b), the ones focusing on the geographical area which is characterised with the lowest electricity consumption for heating and cooling were selected. This was done knowing that in all other scenarios the impact of the use-phase would be larger, but would not change the conclusions of the analysis. The scenarios with the smallest use-phase would therefore allow to understand the minimum impact of the use phase on the total life cycle of clay brick walling in South Africa. Thereafter, three different wall types with increasing insulation characteristics were considered. This was done in order to analyse the interplay between the higher impacts likely to arise with better insulating structures and the environmental savings which can be obtained from the corresponding smaller energy consumptions in the use-phase. The analysed wall types are - going from the least insulating to the one with the highest insulation:

- 220mm brick wall
- 280mm cavity brick wall
- 280mm insulated cavity brick wall

Table 3 summarises the electricity consumption used in the analysis based on the findings of Vosloo *et al*.(2016b). For each walling type, the consumption for an average South African building was considered.

SCENARIOS WITHIN GEOGRAPHICAL REGION WITH LOWEST ELECTRICITY CONSUMPTION IN THE USE PHASE	WALLING	ELECTRICITY CONSUMPTION FOR HEATING AND COOLING IN AN AVERAGE BUILDING
Low insulation	220mm brick wall	38.86 kWh/m^2
Medium insulation	280mm cavity brick wall	35.56 kWh/m^2
High insulation	280mm insulated cavity brick wall	27.54 kWh/m^2

Table 3: Electricity consumption of the use phase for three different insulation levels (Vosloo *et al*., 2016b,.

The results are presented in **Figure 16** for Climate change only since exactly the same trends can be observed for the other indicators.

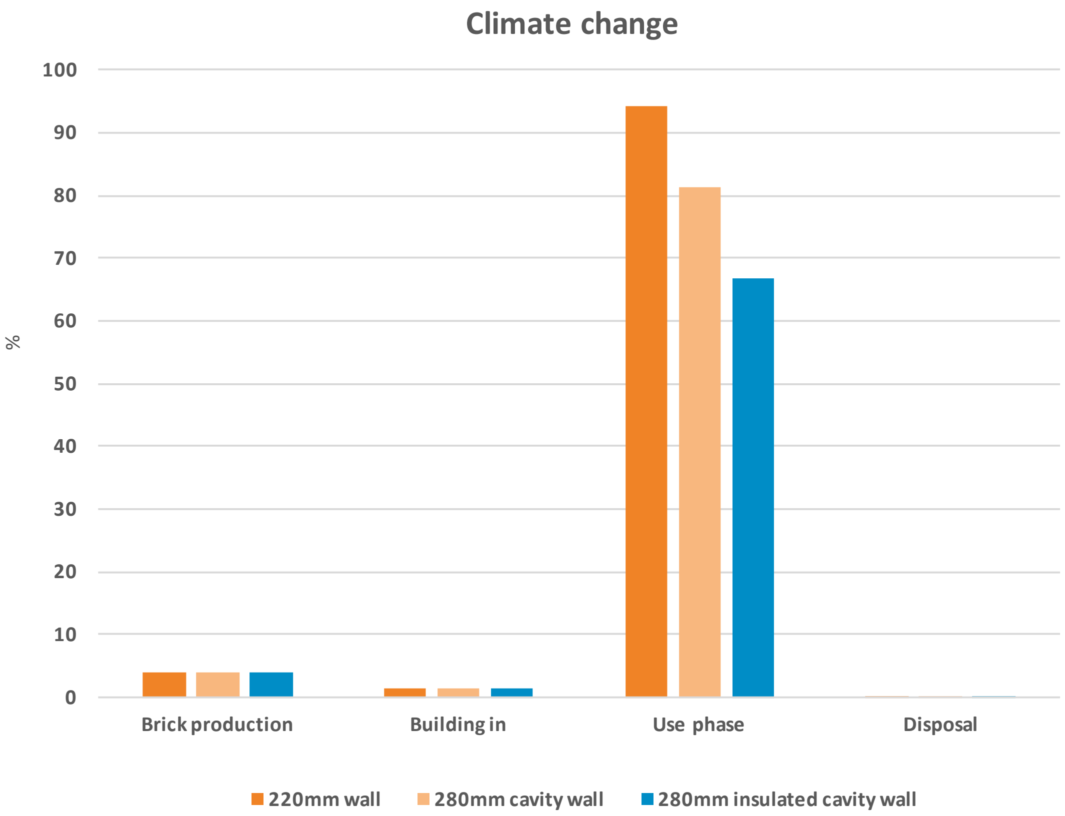


Figure 16: Climate change impacts for the life cycle of 3 wall types in climatic zone 1.

Even for the geographical region where the use-phase has the smallest requirements, the results are completely dominated by the impacts deriving from the production of the electricity used for the heating and cooling of the building. All other life cycle steps including the production of the bricks show minor almost negligible impacts. The main reasons for this trend are twofold. Firstly, being largely based on coal burning technology, South African electricity is characterised by high impacts. Secondly, thanks to their long life expectancy, the impacts coming from clay bricks production is conceptually spread over 50 years whereas the ones from the electricity production for the use phase accumulate over 50 years. Moreover, since the difference in the impacts coming from brick production and building-in for the three different wall types is minimal compared to the savings which can be achieved in the use-phase, thanks to a better insulating wall, it can be concluded that in environmental terms, building structures which lead to electricity savings in the use-phase represents the more favourable solution. The advantages become even more relevant for those regions which are characterised by larger electricity consumptions for heating and cooling.

5. Discussion

The analysis of the life cycle environmental impacts of clay brick walling in South Africa shows a very clear result. When looking at the entire life cycle, the use-phase of the bricks – meaning the impacts deriving from the electricity production required for the heating and cooling of the buildings built from bricks – strongly dominate the results. Hence, when looking at ways with which the clay brick sector can reduce its environmental impacts in the future, two suggestions can be made with this result in mind. The first one is to sensitise, as a sector, the need for the design of energy efficient buildings and the importance of using the most appropriate building materials. The contribution from the production of the bricks and the construction phase is so small compared to the use-phase, irrespective of the type of wall built, that building with better insulated walls always leads to considerably lower overall impacts, thanks to the savings in heating and cooling which can be achieved. But of course, another way of reducing the impacts from the use-phase is by changing the environmental impacts of the generated electricity itself. Considering that the South African electricity mix is largely based on coal technology, fostering the use of renewable electricity sources could lead to considerable advantages. Since these aspects were not within the scope of the LCA of clay brick walling in South Africa performed by the University of Pretoria, a detailed environmental assessment of the advantages and challenges linked, for example, to the systematic installation of photovoltaic panels and solar thermal panels in new buildings, may shed relevant insight on the topic.

Nevertheless, even if environmental impacts from the other life cycle stages are not dominant in the overall results, the clay brick sector should still aim at optimizing its production processes since, it not only helps to reduce energy costs therefore improving the financial sustainability of the industry, but also environmentally because if every sector reduces its environmental contributions from the production phase, large improvements can be achieved nationally. Overall, considering the weighted average of all environmental impacts for all the considered production sites and technologies, the production of 1 kg of clay brick in South Africa can be associated with the emission of 0.27 kg of CO_2. Based on the yearly production considered in this study, this leads to a total of 2.6 million tons CO_2 emitted per year. Similarly, the results show that on average the production of 1kg clay brick in South Africa requires 3.46MJ of fossil energy which amounts to a total of about 33.5 billion MJs of non-renewable energy consumed by the sector. With respect to the production processes required for clay bricks, the results indicate that, almost independently of the firing technology used, the largest environmental impacts occur in the clay preparation and the firing steps. This is mostly due to the coal mixed with the clay as internal fuel and due to the fossil fuels (and coal particularly) used for combustion in the kilns. To achieve meaningful reductions of the environmental impacts along the entire production process, optimisations of both the total energy used as well as the mix between internal and external firing fuel need to be achieved.

Otherwise, improvements in the efficiency of the firing step can be offset if these require a higher amount of coal as an internal fuel. When comparing the different firing technologies, it is important to notice that there is not a single production route which always performs better than the other ones in all indicators, meaning that it is not possible to identify a technology which, in environmental terms, outperforms all the other ones. At the same time, production based on the Hoffman kiln performs worse than all other technologies in all indicators which can be explained by the fact that, based on the average data collected, it is the production route which requires the largest amount of coal as both internal fuel and combustion fuel in the kiln. The Tunnel and Zigzag technologies tend to perform better than other technologies in various indicators, mainly thanks to the lower amounts of coal used in the production processes. Overall, the Clamp, VSBK and TVA show results which lie in-between the best and worst results, with fluctuations with respect to the different indicators which depend on the specific types and quantities of fuels used. Also, a large reduction in the damages to human health can be achieved in the VSBK average results by avoiding the use of disposed tyres as a combustible in the drying step as is currently done in some of the production plants.

Finally, some production routes (and particularly those based on the Tunnel and TVA kiln) have higher electricity consumptions which can lead to contributions of between 15 to 30% of the environmental impacts of the total manufacturing process. In these cases, the implementation of efficiency measures to reduce the electricity consumption can have a significant influence on the overall results. As a further measure, the installation at the production plans of renewable electricity sources such as photovoltaic panels to reduce the need of the mostly coal based grid electricity, could also be beneficial in this context and should be the subject of further investigations.

In the interpretation of the results and conclusions, it is important to keep in mind that the analysis is based on average data from the clay brick production sector. The performance of each brick production plant may look different than that derived to in the study. The average values of the inputs required by the various firing technologies are an important benchmark which can help plant managers in identifying potential optimisation areas. Moreover, the findings and results of the LCA study describe the environmental performance of the clay brick sector in the year 2013. Future studies can refer to these results as a baseline against which improvements or changes can be measured. The Clay Brick Association of South Africa in particular can verify, with periodically run updates of the LCA study, how improvements addressing the identified environmental hot spots are affecting the results of the sector.

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7. Annexure

	TECHNOLOGY							
	Clamp	**Tunnel**	**TVA**	**Hoffman**	**VSBK**	**Zigzag**	**Weighted average**	
Step/Process								
Fuel transport								
Lorry transport	15.8	14.3	4.49	11.6	34.4	105	15.02	kgkm
Pipeline for gas		10.9	0.182				1.99	kgkm
Mining								
Diesel	2.71E-02	5.61E-02	3.93E-02	4.69E-02	1.45E-02	2.03E-02	3.35E-02	MJ
Clay preparation, wet green brick 1kg								
Light fuel oil	3.60E-10	3.60E-10					3.13E-10	kg
Electricity	8.75E-03	2.76E-02	4.66E-02	1.89E-02	1.33E-02	9.03E-03	1.63E-02	kWh
Hard coal	7.86E-02	2.64E-02	4.24E-02	8.36E-02	8.08E-02	6.64E-02	6.54E-02	kg
Clay input	0.78	0.89	0.90	0.77	0.78	0.82	0.82	kg
Transport of wet brick 1kg								
Diesel	0.0103	0.00223	0.00303	0.00119	0.0114	0.0162	0.00806	MJ
Drying of wet brick 1kg								
Heat, hardwood logs	4.89E-05			9.16E-02			6.20E-04	MJ
Electricity	2.01E-04	6.64E-03	1.47E-02	3.47E-03	2.00E-03	9.03E-04	2.93E-03	kWh
Heat, gas		7.77E-05					1.41E-05	GJ
Heat, coal		5.30E-02					9.60E-03	MJ
Used tyres (burnt for heat))					8.63E-03		1.48E-04	kg
Emissions from coal burning	3.09E-02						2.12E-02	MJ
Wet brick input	1.15	1	1	1	0.99	1	1.10	kg
Transport of dried brick 1kg								
Diesel	1.04E-02	1.15E-03	3.92E-03	1.19E-03	1.11E-02	1.62E-02	8.02E-03	MJ
Firing - 1kg of fired brick								
Electricity	6.82E-05	6.68E-03	1.29E-02	3.71E-04	1.67E-03	9.03E-04	2.64E-03	kWh
Heat, heavy oil	5.63E-07	5.99E-03	1.65E-02				2.81E-03	MJ
Hard coal	3.29E-02	1.30E-02	4.11E-02	7.64E-02	2.50E-03		2.98E-02	kg
Heat, gas		9.66E-04					1.75E-04	GJ
Heat, light fuel oil		4.64E-03					8.40E-04	MJ
Emissions from coal burning	2.25	1.07	2.39	4.57	2.38	1.90	2.07	MJ
Dried brick input	1.06	1	1	1	1	1	1.04	kg
Transport of fired brick to sales 1kg								
Diesel	7.51E-03	6.31E-03	1.31E-02	1.10E-02	5.85E-03	1.62E-02	7.90E-03	MJ

Table 4: Main simulation parameters based on the average values obtained through the data collection of the investigated brick plants.

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