MODELING ENVIRONMENTAL IMPACT OF UNFIRED BRICKS IN INDIA

by

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Abstract

Brick manufacturing requires a considerable amount of energy and land, but these numbers have been difficult to quantify in rural parts of the developing world. The environmental impact of unfired bricks in India is investigated through modeling the effects of materials composition and processing on energy consumption, carbon dioxide equivalent emissions, and land surface area use. The analysis uses a cradle-to-gate life cycle assessment to quantitatively estimate these impacts. The depth of soil extraction has a significantly affects the land use required for bricks; changing this depth in practice or through regulation has the potential to reduce environmental impact without affecting brick performance. The impact of unfired bricks depends greatly on composition, in particular the amount and type of stabilizer and the incorporation of fly ash. While stabilizers increase the environmental burden, the performance gain is potentially worth these effects when compared to energy intensive fired bricks. Future work could expand the model to quantify the relevant cost and performance tradeoffs with environmental impact.

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Introduction

Although bricks have been commonly used in building structures for millennia and have been studied quite a bit in recent decades (Kathuria & Balasubramanian, 2012), research into the environmental impact of brick manufacturing in the developing world is sparse. This report aims to quantify the environmental impact of unfired bricks through modeling unfired brick manufacturing processes in India, enabling both an estimate of the impact and creating a tool to evaluate the effects of materials composition and processing on the environmental impact.

The ‘cradle-to-gate’ approach used here considers all upstream inputs and processes of the creation of the final product, an unfired brick. The model takes existing data, descriptive information about the manufacturing process, and some carefully considered assumptions to produce an estimate of the environmental impact of an unfired brick in terms of energy consumption, carbon dioxide emissions, and land surface area requirements.

While unfired bricks were the primary brick form used for centuries before firing was invented, fired bricks have more recently been favored by those who could afford them due to the improved strength and durability (Illston & Domone, 2001). However, unfired bricks are still widely used in the developing world and are becoming more prevalent as innovations in both recipe and processing have improved strength and durability while maintaining the low cost, a simple manufacturing process, and low environmental impact (Kathuria & Balasubramanian, 2012).

India’s large and growing brick industry, its rapidly expanding economy, and the variety of development levels across the country make it a good case study for this research. As of 2012, “no study exists in India or elsewhere that has tried to estimate the impact of soil loss and productivity due to brick-making” (Kathuria & Balasubramanian, 2012). Nearly all research in the environmental impact of bricks has focused on the firing process, primarily because firing is responsible for nearly all polluting emissions of fired bricks and greater than 90% of the energy consumption (Energy for Building, 1991).

Additionally, quantitative environmental impact research has been done in the context of more developed countries, where fired bricks are common and unfired bricks often non-existent. Research into the brick industry in developing countries includes unfired bricks, but typically focuses on cost and labor instead of environmental impact (Hodge, 2007).

This report will address the gap in understanding of environmental impact between fired and unfired bricks through modeling the land surface area required, the energy consumed, and the greenhouse gas emissions per brick in India. The introduction will explore the brick industry in India, including components of typical bricks and the brick manufacturing process. The methodology section explains the cradle-to-gate life cycle assessment approach used in this analysis. The next section explores parameters of interests, the relationships between the environmental impact and known data about brick manufacturing, and the various assumptions built into the model. The results and discussion provide estimates of the land surface area required, the energy consumed, and greenhouse gases emitted per brick and, more importantly, analyze the sensitivity of these results to material composition and processing. Finally, suggestions for expansion of this research continue closing the gap in understanding and enable more thorough understanding of the brick industry in the developing world are suggested.

What is a brick?

The definition of a 'brick' is often ambiguous, as some people use it nearly synonymously with 'block' and others distinguish based on shape or material composition. In this document, 'brick' refers to a masonry unit made from primarily earthen materials. While masonry units must not be rectangular prisms, they must be regularly shaped so they can be stacked to form a lasting structure.

Both unfired and fired bricks are common in structures throughout the world. Typically, bricks are primarily composed of earthen materials such as clay, sand, and soil. Silty clay loam and silty clay soil most often produce good results and are widely available (Kathuria & Balasubramanian, 2012). For compressed, unfired bricks, the ideal soil composition is 20-35% clay and 30-50% sand, with some silt, stabilizer, and water (Maini, 2010).

Brick Manufacturing Process

People have made bricks for millennia in many different parts of the world, developing different recipes and processes for the bricks they use. Despite some of the differences, every brick begins with the extraction of raw materials, which must be sifted and mixed together, and must be formed into the desired shape. The manufacturing process of bricks can be summarized into a few major steps, illustrated in Figure 1.

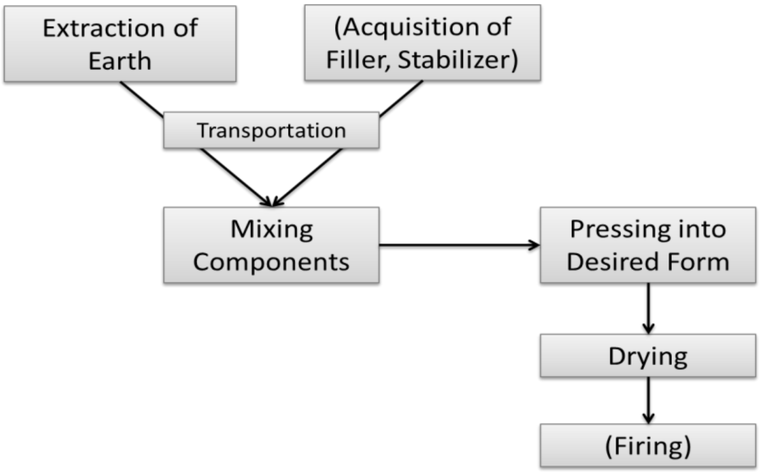

Figure 1 Brick Manufacturing Process Flowchart

Making different types of bricks requires different components and processing steps. In addition to the steps mentioned above, components are often sifted or somehow purified before being mixed. Sometimes, stacking bricks is considered its own step because it may affect the drying time, required labor, and cost. Although the unfired bricks in this analysis are by definition not fired, the firing step is included in the process flow chart because it is the final process for so many bricks and it is therefore important to understand how it fits in.

The simplest bricks are simple mixtures of clayey soil and water, pressed into the desired shape and dried in the sun. Some bricks include fillers such as straw, rocks, or extra sand to reduce the cost, though often also reducing the structural integrity. Others include small amounts of stabilizers such as cement or lime, which strengthen bricks and are discussed in more detail below.

Stabilizers

Stabilizer is a general term used to refer to compounds which are added to enhance the strength and durability of the brick. They typically react chemically with rest of the brick material either in the presence of heat or water, forming a strong matrix around soil particles, locking them in place and making the brick more stable (Harper, 2011). Portland cement and lime are the two most common stabilizers in unfired bricks, but people have experimented with using fly ash, rice husk ash, and other common materials to improve the quality of their bricks (Maini, 2010).

Portland cement is particularly good for stabilizing bricks made from sandy soils. The calcium silicates react with water to form a matrix with the silica in the grains of sand (Harper, 2011). At least 5% cement should be used to form a cohesive matrix; smaller amounts will reduce cohesion because smaller pieces of matrix separate the clay without joining together to form a full matrix (Maini, 2010).

Lime (CaO) is particularly good for clayey soils as it has a pozzolanic reaction with clay. When exposed to water or a humid environment, the calcium ions in the lime react with the clay to reduce its plasticity (Maini, 2010).

Fly Ash

Fly ash is a byproduct of many industrial processes, which is often both expensive and environmentally harmful to dispose of, but has been incorporated into a variety of masonry units in the construction industry. Although fly ash is not a traditional component of bricks, it is increasingly used into bricks to reduce the cost of raw materials and to deal with the industrial waste.

Fly ash is used both as a stabilizer and as a main component in bricks. Class C, coal-derived, fly ash contains around 20% lime and can be used as a stabilizer on its own, but other types of fly ash are successful stabilizers when mixed with cement (Maini, 2010). Others have used fly ash as a substitute for some percentage of the soil in an effort to reduce the cost of the bricks and to deal with the industrial waste. Making fly ash bricks with over 50% fly ash and using fly ash in conjunction with other raw materials are areas of current research (Chindaprasirt & Pimraksa, 2008).

Because fly ash is a byproduct and typically considered waste, the energy used and carbon dioxide emitted in its production are generally attributed to the intended product, such as paper or coal-derived energy, and not to the fly ash. For this reason, using fly ash is considered environmentally beneficial, even though the industrial process which produce fly ash are energy intensive and polluting.

Environmental Impact Assessment of Bricks

Unfired bricks have been generally assumed to be more environmentally beneficial than fired bricks because they do not include the energy intensive, often polluting step of firing, and have therefore been left out of most environmental impact assessments. Because the firing of bricks is responsible for most of their energy consumption and pollutants, much research has been done on fired bricks and specifically on kiln technologies. One study estimated the embodied energy of a "common [fired] brick" to be 218.2 Btu/in^3 while the embodied energy of an Adobe compressed earth brick made with mechanized production is just 4.46 Btu/in^3 (McHenry, 1984); the difference can be almost entirely attributed to firing. Although those numbers are from a United States context and this analysis focuses on India, a difference of similar order of magnitude between the fired and unfired bricks is expected. Although there are many compressed earth structures which have lasted for centuries, fired bricks can generally bear greater loads and are more suited to the multi-story construction seen in the United States (Nelson, 2002).

Due to the increased prevalence of unfired bricks in areas where fuel is expensive or kiln technology is not accessible, many people are now using and researching different types of unfired bricks, from sunbaked mud bricks to mechanically compressed, chemically stabilized earthen blocks

(Energy for Building, 1991). A rising world population means a growing construction industry, especially in developing countries where unfired bricks are popular for their high durability to cost ratio.

In addition, unfired bricks are seen by some as an environmentally beneficial alternative to fired bricks or concrete blocks. Several organizations in India are researching and promoting the use of unfired, stabilized, and interlocking bricks as a way to improve environmental impact and reduce costs while maintaining performance (Indian Brick Sector, 2012). The tradeoff between environmental impact and performance is particularly interesting, because these are often inversely related but sometimes unrelated or even positively correlated (Reddy & Jagadish, 2003).

The Indian Brick Sector

Approximately 170 billion bricks per year were produced in India from 1997 to 2002 (Indian Brick Sector, 2012). The United Nations Development Programme estimates that the brick sector accounts for 4.5% of India's total annual carbon dioxide emission and consuming about 350 million tons of good quality soil each year (Energy Efficient Improvements in Brick Industry, 2009). While most of these bricks are fired in some way, some significant percentage of them is unfired, especially in rural areas (this number is difficult to quantify given the individual and localized manufacturing nature of the brick industry).

Bricks are a popular construction material in nearly every region of India. The provinces of Uttar Pradesh and Bihar in the northern and northeastern India have very large brick industries, as does a section of Rajasthan in northwestern India (Indian Brick Sector, 2012). Some analysis of the brick industry has focused on the regions around fast-growing cities, such as Chennai, or in the southern state of Tamil Nadu (Kathuria & Balasubramanian, 2012). Much of the unfired brick production is rural and local and therefore more spread throughout the country and more distributed among smaller production centers than the fired brick industry.

Literature data about the embodied energy of bricks and some environmental impact of brick manufacturing in India exists (Reddy & Jagadish, 2003), but it is highly variable across different technology. By modeling brick manufacturing in India, this analysis allows for investigation of how those environmental impacts change with composition and with processing.

Methodology

Life Cycle Assessment is a tool for evaluating environmental impact of an object from its beginnings as raw materials through its use and eventual disposal. Taking a 'cradle-to-grave' approach gives a thorough understanding of the environmental impact at all stages of a product's existence.

In this analysis, only the initial phase of a brick's life time, from the excavation of materials through production, is considered. The use phase, when a brick is part of a building or structure is omitted from the analysis due to the high variability of applications in which bricks are used. While it is not included in this analysis, the thermal properties of the bricks may have a significant impact on the energy used within the building, even though the brick does not appear to be drawing more energy or emitting pollutants at the time.

The disposal phase of a brick's life is also not considered in this analysis. Because the lifetime of a brick is typically greater than 100 years and is often longer than the lifetime of the overall structure (Illston & Domone, 2001), routine maintenance is not typically required. There is a lack of data on the environmental impact of disposal of bricks, particularly disposal scenarios in developing nations. Unfired bricks are sometimes ground up and used again in other bricks of lower quality, though it is unclear how widespread this practice is (Desam, 2013).

Several tools and databases of information exist to assist with life cycle assessment modeling. SimaPro 7.0 is a life cycle assessment tool which draws on many databases to determine different environmental impacts. Several different impact assessment methods have been developed and are implemented within SimaPro, including the method from the Intergovernmental Panel on Climate Change's global warming potential assessment from 2007 (IPCC 2007 GWP 100a) which is used in this analysis.

Modeling Environmental Impact of Unfired Bricks

Environmental Performance Indicators of Interest

This model examines environmental impact of unfired bricks in terms of energy consumption, carbon dioxide emissions, and land use. These indicators were chosen because of their relevance to both the brick industry and the current global discussions of environmental impact.

Energy consumption is a measure of the resource inputs to a process. Major process steps such as extraction, mixing, and forming bricks typically require an energy input. This model uses the energy from fuel combined with some information about the efficiency of the machines to determine the energy consumed to produce a brick. While human-powered machines certainly require and consume the energy provided by people, this analysis considered the energy consumption of manual processes to be zero. Going further upstream to determine the environmental impact of the food and water consumed by humans was out of the scope of this analysis. More importantly, isolating the fraction of that energy which the human used to manually power a machine to make bricks would result in a negligible amount of energy.

Carbon dioxide is the primary emission of interest for global climate change. Other greenhouse gases, such as methane, also contribute to climate change and air pollution; SimaPro and eco-invent allow a calculation of the equivalent global warming potential in terms of amount of carbon dioxide. Reporting carbon dioxide equivalent emissions enables comparisons with fired bricks and other construction materials as carbon dioxide emissions are the most widely reported measure of climate change contribution. Other emissions into the air, which are also quite important in terms of pollution and air quality, have been included when using reported carbon dioxide equivalent data but not when calculating carbon dioxide emissions by building up stoichiometric relationships.

Land use refers to the area of land dedicated to this industry and therefore unavailable to others. This model assumes that all of the land use comes from the extraction of the raw materials from some area of land and omits the negligible fraction of area where the bricks are actually processed and produced. All bricks made from earthen materials require significant volumes of material and therefore significant land area. In particular, land use is a particular concern where the depth of extraction is not deep and therefore larger surface areas must be used to extract adequate amounts of soil. The depth of extraction is often limited both by regulations and by technological capabilities.

Assumptions

Due to the large variation in climate across India, soil composition and energy production demands differ throughout the country. Data used in the model come from a variety of sources, sometimes averaged across the country or across the developing world. In particular, carbon dioxide emissions from burning coal in small-scale industrial contexts and diesel fuel in tractors and small trucks came from averaged data in the eco-invent 2.2 database in SimaPro 7.3. Where possible, data is drawn from northern India and primarily from the country itself, but approximations were made by generalizing regional or global data when necessary.

Because most of the unfired brick industry is local and rural, the model assumes that the unfired brick making industry does not get any power from the electric grid. Although India has been working to electrify much of the country, many rural areas still lack access. More importantly, even in electrified areas, brown-outs and black-outs are common, making the grid an unreliable source of energy for businesses which rely on the power. Therefore, the power in this analysis is assumed to be coming from diesel generators or coal and not from the grid. Similarly, despite the growing popularity of solar power, biogas, wind power, and hydropower, these power sources are not often mentioned in literature about the Indian brick industry, so they have been omitted. While these may currently been acceptable assumptions, technological and infrastructure advances in the coming decade may make that untrue in the future.

Transportation has been omitted from the analysis for a variety of reasons. Primarily, data about distances is unavailable and certainly varies by region and within regions. However, various sources have indicated that this omission may be acceptable given that much brick production is local and occurs at or near the site of excavation (Desam, 2013).

The yield for each process step was taken to be 95%. Yields are typically quite high because unused material or broken unfired bricks can be easily incorporated into the raw materials of new bricks of lower grade (Desam, 2013). While the yields at each individual production center are certainly varied, 95% allows for some loss and some errors while reflecting the nature of the brick making process.

Brick dimensions vary by region and by country, depending on the construction needs and the available forming equipment. For the purposes of consistent analysis, bricks were assigned to be 228.6mm long, 101.6mm wide, and 63.5mm thick (Desam, 2013). Unless explicitly analyzing the effects of the brick shape, the total volume of material in the brick is taken to be the product of the three dimensions.

Results are reported per brick, per thousand bricks, or per billion bricks. Using the larger units yields results on a scale which are more easily comprehensible and better suited for comparison to the brick industry as a whole. Additionally, the environmental impact of producing and acquiring the capital required to manufacture bricks would have a significant impact on just one brick, but is negligible when distributed over the thousands of bricks produced using each tool.

Relationships

The model is meant to estimate effects of composition and processing parameters on the environmental impact. The composition and processing also have significant impacts on both the cost and the performance of the bricks, which is beyond the scope of this analysis but an important potential avenue for future work and expansion of the model.

Determining relationships between the environmental impact and information was the foundation for building a model which could take readily available data and, using the assumptions above, estimate an environmental impact for the brick. The functional unit is the basic unit of analysis; here is it the unit for which the environmental impact is calculated, which in this case is a number of bricks. For the most part, the analysis is per brick, but a unit of one thousand or one billion bricks or an annual quantity of bricks produced may be equally useful units of analysis.

The land surface area required per brick is a significant environmental factor for all bricks. Knowing the volume of a brick and the change in that volume due to compression, the volume of earth required for each brick can be simply calculated, as shown in Equation 1.

$$Land\ Use = FunctionalUnit * \left(\frac{\frac{BrickVol * fractionExtractEarth}{(1 - VolChange_{Press}) * Yield_{Press}}}{Yield_{Extract} * \left(Depth_{Extract} - Depth_{UnuseTop}\right)} \right) \tag{1}$$

To determine the land surface area use per brick, relevant inputs included the volume of earth per brick, the volume change due to compression, the process step yields, and the depths of extraction and unusable topsoil. The unusable topsoil refers to the thin layer of topsoil closest to the surface which is typically removed because it is often full of organic matter, roots, and rocks, which should not be incorporated into bricks. The volume change in the brick during pressing of 30% (Nelson, 2002) is used for this analysis because it is on the high end of values found in literature, which would then make the analysis more conservative and yield a higher required land use.

For the pressing and mixing, there are multiple types of equipment which range from manually-powered and self-made to large-scale and fuel-intensive. In the model, the mixing and pressing processes are modeled both as manual and mechanized, with an option to designate whether they are manual operated, which would set the fuel and energy inputs to zero. In all of these cases, there are many different machines which have their own specifications, fuel requirements, energy efficiencies, and effects on the quality of bricks produced. The information from some of the more common pieces of equipment has been averaged to make the results of the model apply most broadly, even as it adds uncertainty to the result. However, if all of the necessary information were available for one specific machine, one could use those inputs instead of the averages and compute a more accurate result for that specific context.

In the case of mixing, the two most common mixing methods include rotating blades, such as in an industrial scale planetary mixer, and driving a tractor for several hours over the ingredients to mix them. While these initially seem like quite different processes, the rotation can be can be modeled using the same relationship. In Equations 2 and 3, the mixer is powered by a diesel electric generator; if the stationary mixer were to be powered by coal or the electric grid or the tractor by petrol, one could easily substitute those energy densities or emissions factors.

$$Energy_{Mix} = FunctionalUnit\,\frac{\left(\frac{Hours}{m^3brick} * \frac{Rev}{hour} * \frac{distance}{Rev}\right)}{\left(\frac{km}{l}\right)_{diesel}}\left(\frac{MJ}{kg}\right)_{diesel}\left(\frac{BrickVol}{Yield_{Mix}}\right) * efficiency \qquad (2)$$

$$CO_{2.Mix} = FunctionalUnit\,\frac{\left(\frac{Hours}{m^3brick} * \frac{Rev}{hour} * \frac{distance}{Rev}\right)}{\left(\frac{km}{l}\right)_{diesel}}\rho_{diesel}\left(\frac{kg_{CO_2}}{kg_{diesel}}\right)\left(\frac{BrickVol}{Yield_{Mix}}\right) \qquad (3)$$

The energy density of diesel fuel is taken to be 42.9 MJ/kg of fuel (Staffell, 2011) and the carbon dioxide emissions factor is 0.0871 kg CO_2 eq per kg of diesel fuel (SimaPro 7.3, Eco-Invent2.2, IPCC 2007 GWP 100a, diesel burned in electric generator).

Similarly, both manual and mechanized presses are common in the unfired brick industry. The energy required to press the bricks into the desired shape can be calculated if one knows the amount of energy required per stroke of the press. Many companies report the available force with which their presses compress the bricks, from which the work done can be estimated knowing the distance the press travels downward to compress the bricks, shown in Equations 4 and 5.

$$Energy_{Press} = FunctionalUnit * \left(\frac{\left(\frac{Energy}{Stroke}\right)}{\left(\frac{Bricks}{Stroke}\right)}\right)\left(\frac{1}{Yield_{Press}}\right) * efficiency \tag{4}$$

$$Co_{2.Press} = FunctionalUnit * \frac{Energy_{Press}}{\left(\frac{MJ}{kg}\right)_{coal}} * \left(\frac{kg_{CO_2}}{kg_{coal}}\right) \tag{5}$$

The energy density of coal fuel is taken to be 25.75 MJ/kg of fuel (Staffell, 2011) and the carbon dioxide emissions factor is 0.0904 kg CO_2 eq. per kg of diesel fuel (SimaPro 7.3, Eco-Invent2.2, IPCC 2007 GWP 100a, hard coal briquette). The fuel for mechanized presses was taken to coal because that seems to be the most common fuel. If diesel were used, one could easily replace the energy density and emissions factors of coal with those of diesel. Should use the values for diesel in the equation above above, the carbon dioxide emissions from pressing are reduced by approximately 40%, but this is not an entirely accurate measure given that burning diesel in a tractor engine and in an electric generator do not have the same energy efficiency or emissions factors.

Despite the challenges and approximations, these relationships take into account the fundamental variables in the brick manufacturing process an provide results of similar order of magnitude to those reported in literature.

Results

Contributions from Process Steps

The breakdown of environmental impact by process step for one plausible brick manufacturing scenario is shown in Figure 2. In this case, the brick composition is 25% clay, 60% sand, 5% cement stabilizer, and 10% water (Maini, 2010). Any sifting or sorting of soil is done manually, but components are mixed together under a diesel tractor and the press is a simple coal-powered press which exerts a force of 100kN (Auroville Earth Equipment, 2013) as it travels downward 10cm to compress the brick by 30% (Nelson, 2002). This analysis also takes the top 25cm of earth closest to the surface as unusable and the greatest depth of extraction to be 3m (Desam, 2013). Unless otherwise indicated, these production specifications and assumptions hold true for the rest of the analyses.

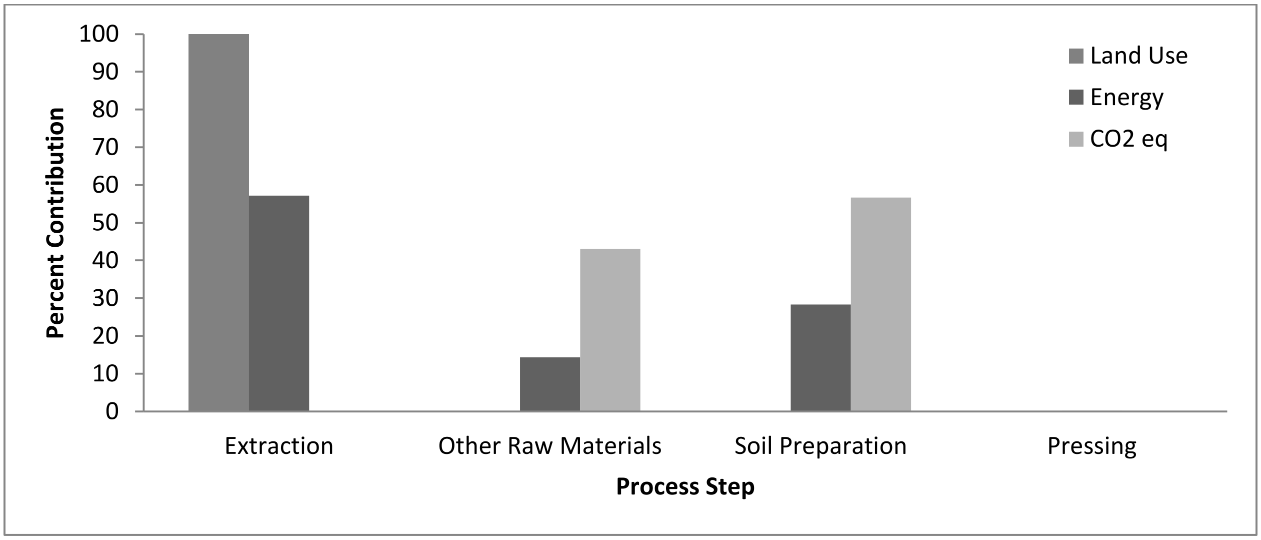

Figure 2 Contributions of each process step to the environmental impact.

The analysis is obviously very sensitive to the processing technology choices and also to the assumptions made when building the model. As this entire endeavor focuses on unfired bricks, the drying and curing process does not require any non-human energy inputs or emit any pollutants into the air. The fact that land use is entirely from extraction comes directly from the assumptions in the model and is therefore not a particularly significant result. All of the choices made for the analysis shown in Figure 2 seemed representative of the mechanized portions of the brick industry. Many unfired bricks are made using much more labor and much less fuel, reducing the impacts of the preparation and forming steps and therefore raising the importance of the raw materials acquisition.

The composition also affects the environmental impacts. A similar analysis could be done using lime as the stabilizer instead of cement, which causes the contribution from 'other raw materials' to plummet because lime is initially extracted from the ground before processing and because cement is responsible for so much of the carbon dioxide emissions.

While the model does compute an estimated environmental impact per brick, the contributions from each process and the sensitivity to changing certain parameters is significantly more interesting. The effects of many of these variables on the environmental impact indicators are explored in the remainder of the results.

Statistical Analysis

The uncertainties and coefficients of variance are determined using a data quality index and assuming a normal distribution of error. The data quality index allows quantitative assessment of the qualitative reliability of the data found in literature by assessing the data in terms of geographic relevance, temporal relevance, technological relevance, and the reliability of the sources. Recent data from the brick manufacturing industry in India which could be verified by multiple sources is the most relevant and gets the best data quality score. But much of the information used in this model may be from brick manufacturing in other parts of the world, other manufacturing sectors in India, or an average across a few pieces of information. This quality of data is reflected in the error bars in subsequent figures.

Sensitivity to Brick Shape

As one might expect, introducing hollow sections or thinner regions of the brick reduces the amount of material required for a single brick, reducing the environmental burden of that single brick. However, these effects are not even distributed across environmental indicators or across the process steps. The ‘fraction hollow space’ refers to any empty volume in the space of the rectangular prism formed by multiplying three outer dimensions of the bricks. The effects of varying the amount of empty volume in unfired bricks are displayed in Figure 3. The same brick composition of 25% clay, 60% sand, 5% cement, and 10% water and the same assumptions about mixing, pressing, and extraction are used for the analysis.

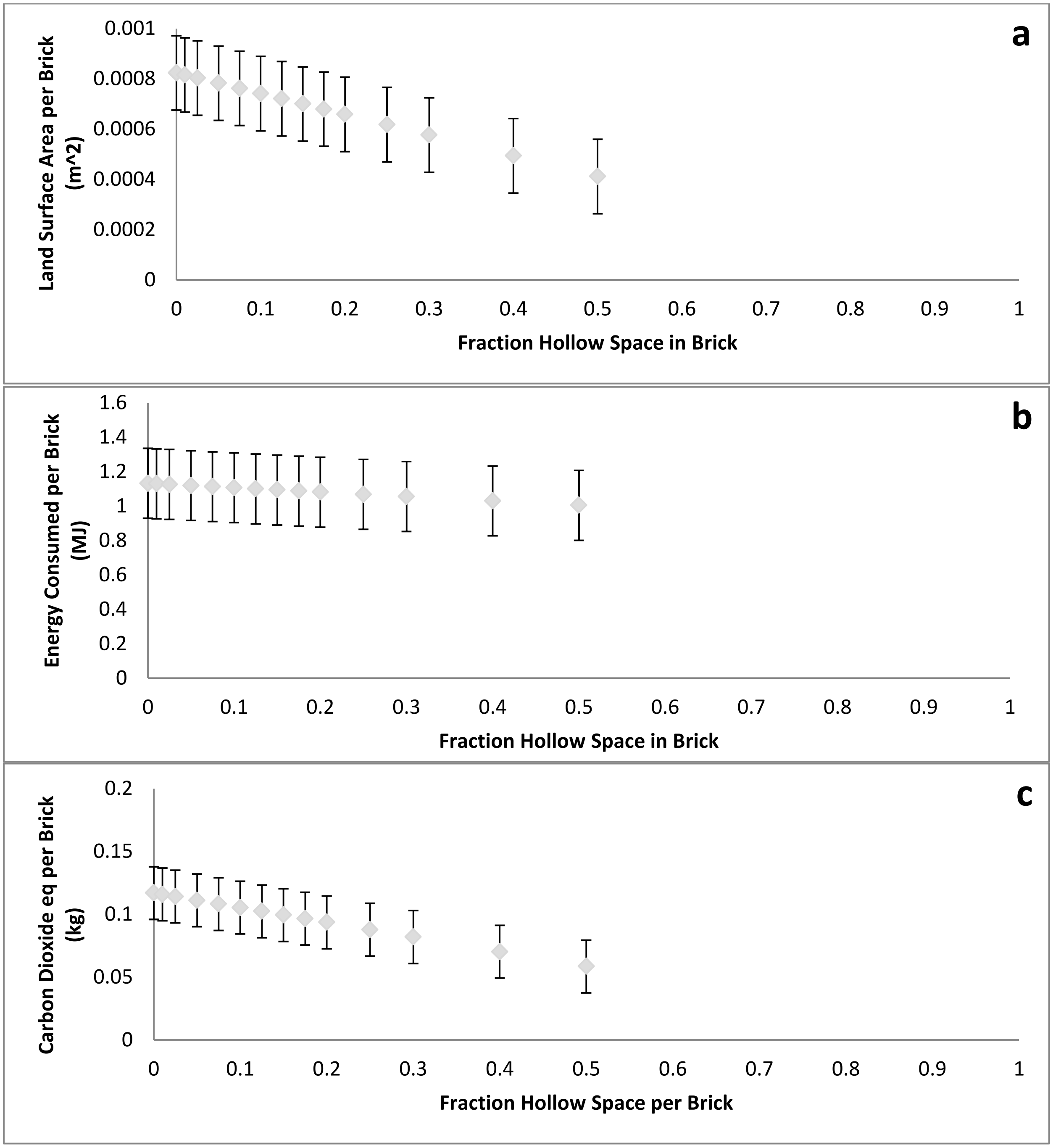

Figure 3 Effects of hollow sections on the a) land use, b) energy consumed, and c) carbon dioxide emitted per brick

The shape of the brick has a reasonably large effect on the environmental impact, but the slopes in Figure 3 illustrate that this is not evenly distributed. Using less material per brick has an obvious correlation with the land use required for each brick. The correlation with energy consumption is less extreme because the pressing requirements for the bricks are the same, regardless of any hollow compartments or changes in shape.

Changing the shape to make bricks interlock, while maintaining full density, can also reduce the environmental impact. The materials, fuel, and processing which go into producing each brick are generally unchanged. However, interlocking bricks require significantly less mortar, if any at all. This model does not capture these benefits of interlocking bricks because its scope is limited to the production of bricks and does not include the use phase or evaluate bricks in the context of larger structures.

Sensitivity to cement content

Because cement is both energy intensive to produce and emits a substantial amount of carbon dioxide during production, both from the chemical reaction and from the burning of fuels, the amount of cement included has the potentially to dramatically affect the environmental impact. The analysis of the effect of the cement percentage assumes the same processing technology and extraction depth assumptions. The composition varies with the amount of stabilizer, maintaining 10% water and reducing the amount of soil so that the total was still 100%. A range of from zero to fifteen percent cement is included to capture the effects of using no stabilizer and an extremely large amount, higher than reported in literature for bricks (Maini, 2010). Results are summarized in Figure 4.

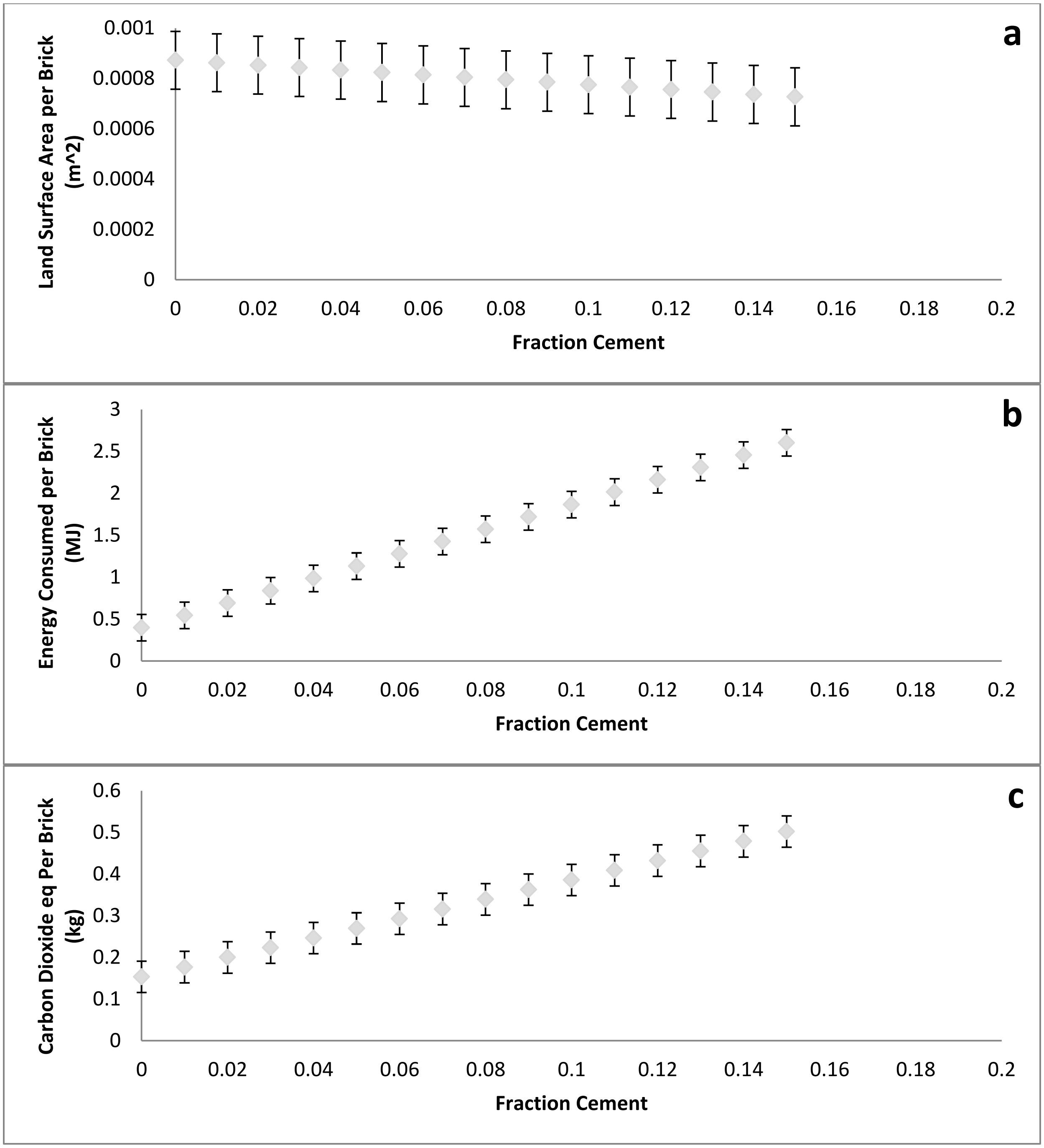

Figure 4 Effects of cement content in brick on the a) land use, b) energy consumed, and c) carbon dioxide equivalent per brick

Increasing the fraction of cement in the formulation has a particularly large impact on the carbon dioxide emissions and also increases the energy requirement while slightly reducing the land use. The reduction in land use is unsurprising as it correspondingly decreases the amount of raw materials which are extracted from the earth. The increase in energy is due to the very energy intensive cement production process, so using 5% cement leads to a 12% increase energy requirement. The carbon dioxide emissions increase is due not only to the emissions from burning fuel to drive production but also from the chemical reaction which occurs when the cement is made. Using just 5% cement in the recipe increases the carbon dioxide emissions by 75% over a recipe with no cement.

Due to the high cost of cement, many brick makers only use just as much as necessary, around 5%, in their formulations (Maini, 2010). The cost-efficient option is in this case also the environmentally friendly one. However, there are other ways to additionally reduce the environmental impact by substituting other oxide-rich compounds, such as rice husk ash or fly ash, for some of the cement.

Sensitivity to fly ash content

Fly ash is not included in traditional bricks, but it has become an important additive to many bricks. The range of fly ash amounts in Figure 5 reflects the fact that fly ash is sometimes used as a stabilizer, typically in conjunction with some cement, to reduce both the cost and the environmental impact of stabilizing and strengthening the bricks and also sometimes serves as a basic ingredient.

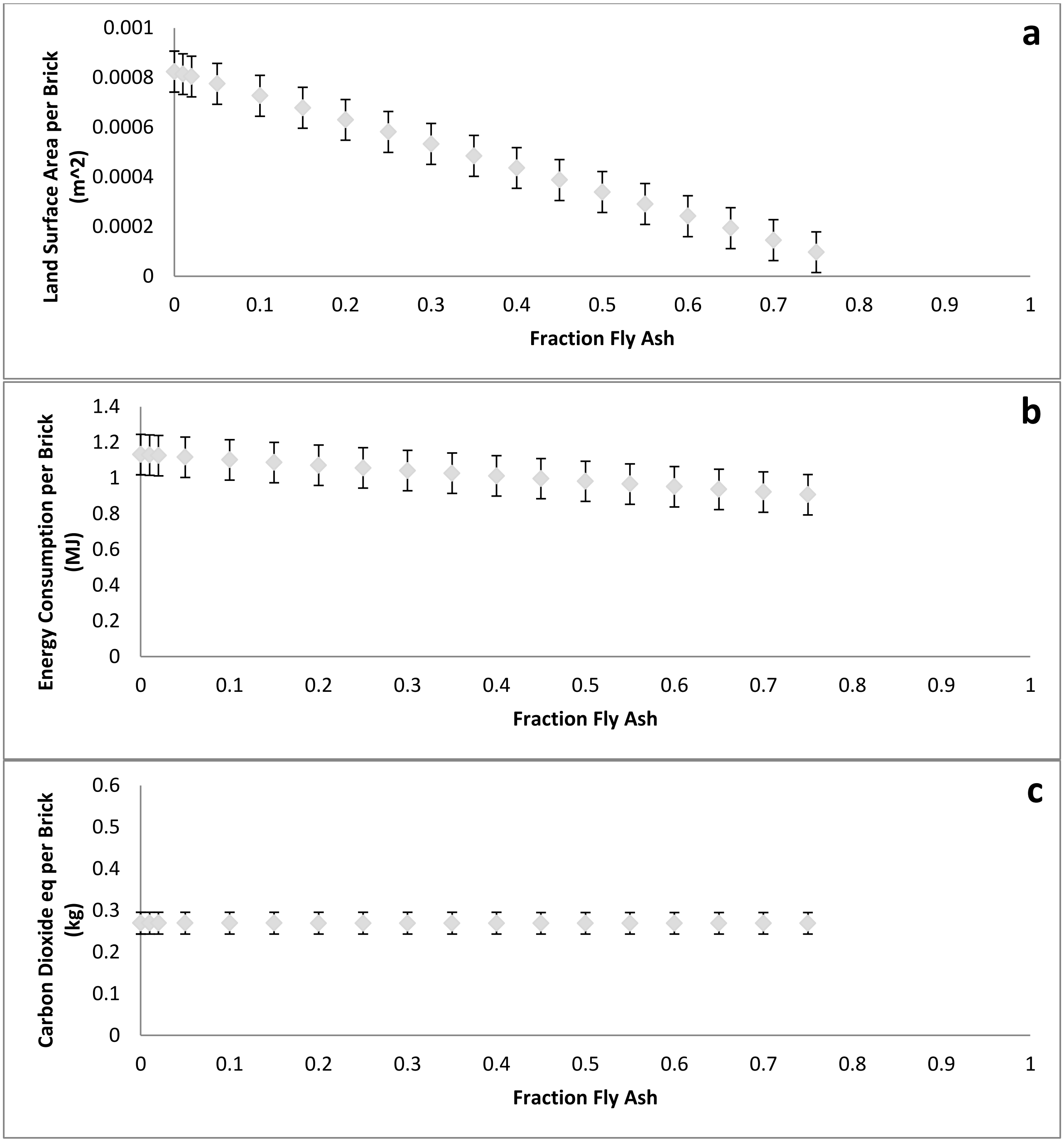

Figure 5 Effects of fly ash content in brick on the a) land use, b) energy consumed, and c) carbon dioxide equivalent per brick

The amount of fly has unsurprisingly has the strongest effects on the land use because at high percentages it substitutes for the soil which would otherwise be extracted from the ground. The reduction in energy is similarly primarily due to the reduction in energy required to extract the soil. Although the carbon dioxide emissions are nearly flat, they do decrease ever so slightly from the reduction in extraction emissions, but the emissions from all other processing and the emissions from cement as the stabilizer remain the same.

As noted previously, transportation of materials is omitted from the analysis, but transportation of the fly ash from the site where it is produced to the site of brick making could potentially be considerable. In some cases, just as others make bricks very near the site of soil extraction, the brick factory may be located very near to the industrial site producing fly ash.

Sensitivity to Extraction Depth

The extraction depth is an incredibly important parameter because it has a very strong impact on the surface area of land used in the brick industry. For unfired bricks, especially those which are made manually and without much additional energy input, the greatest environmental concern is the land use. Two depths are important: the deepest depth from which soil is taken and the depth from the surface at which the soil becomes suitable for bricks. The very top layer of soil is typically full of organic matter, rocks, roots, and other inclusions which produce poor quality bricks, especially when not fired. Figure 6 demonstrates the impact of the altering deepest extraction depth at constant unusable topsoil depths of 0cm, 10cm, 25cm, and 50cm.

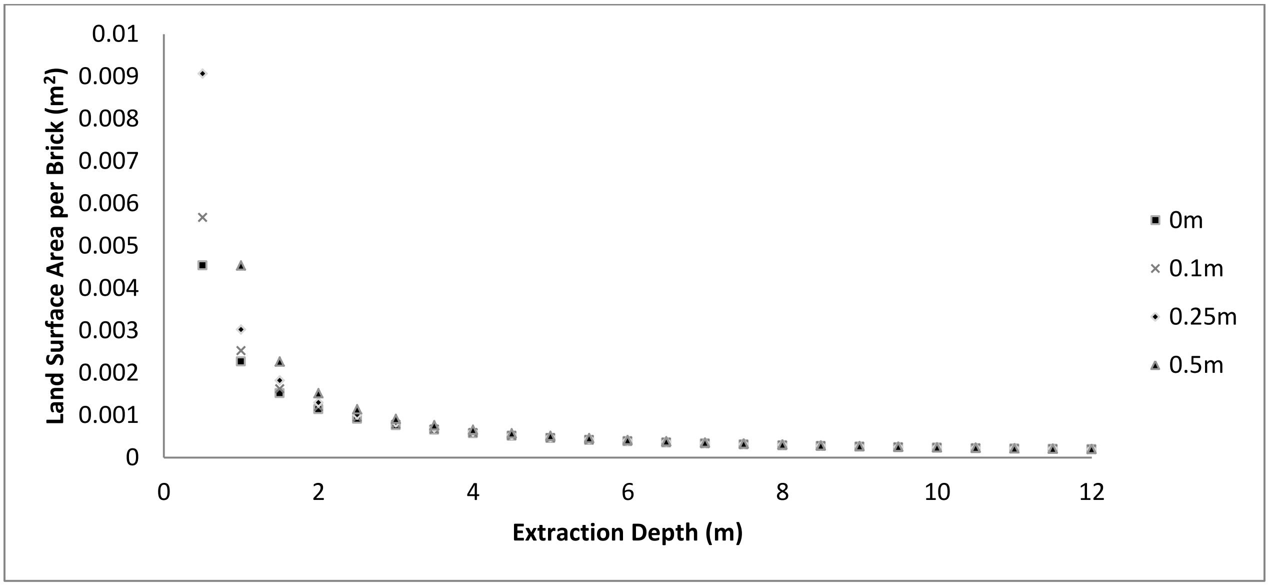

Figure 6 Effects of extraction depth on land use per brick with different depths of unusable surface soil

As one can see in Figure 6, the depth of unused topsoil has a large impact when the maximum extraction depth is less than 3m, but barely raises the land use per brick when much deeper. However, while the incremental impact per brick is small, the brick industry is quite large and the impact is substantial when estimated over the entire industry. At an extraction depth of 3m, the land use per brick is 0.000781m^2 for a unused depth or 10cm and 0.000824m^2 for an unused depth of 25cm. While this difference seems small, it amounts to a difference 43,000m^2 or 4.3 hectares per billion bricks produced. Increasing the maximum extraction depth from 3m to 5m, with the top 25cm of topsoil unused, accounts for 347,000m^2 or 34.7 hectares per billion bricks produced. While, the topsoil removed is often dictated by the quality of bricks and therefore difficult to change, the maximum depth is regulated and has greater potential for reducing environmental impact.

The Indian Ministry of Environment and Forestry regulates the maximum depth for soil extraction, but this is subject to change and does not apply to very small areas of land (Chakravartty, 2012). The depth of extraction is not meant to be greater than 3m, but many extraction sites are more than 10m deep (Desam, 2013). As Kathuria and Balasubramanian point out, “another important dimension to the problem is the depth over which the soil is removed frequently exceeds the agreed depth of soil extraction, which renders land unsuitable for agriculture” (Kathuria & Balasubramanian, 2012). Increasing the maximum extraction depth would reduce the surface area land use per brick, but keeping a shallow depth allows for the possibility that the land area could be used once again for agriculture or as a site for a new building.

Functional Equivalence

It is important to note that the bricks represented by each data point in Figures 3, 4, 5, and 6 are not equivalent and would likely perform quite differently as structural units. While this analysis has used one brick as the functional unit, the environmental impacts of two bricks cannot be directly compared without considering their functional equivalence. Bricks differ in a variety of parameters, including mechanical properties, lifetime, insulating properties, aesthetic appeal, cost, and requirement for mortar or additional materials.

To quantify this, one could establish a functional unit in terms of load-bearing capabilities or lifetime. Every brick has a lifetime and a compressive strength, so reporting land use per year or energy consumption per mega-Pascal would enable better comparisons across bricks.

Quantifying the relationships between composition or shape and strength or durability would enable an analysis of environmental impact for a more appropriate functional unit. Ideally, that analysis could be used to determine which changes could most reduce the environmental impact without detrimentally affecting the performance.

Conclusions

The environmental impact of unfired bricks depends on composition, processing, and policies. The model demonstrates how changing these could significantly affect the environmental impact in either direction. Using unfired bricks already requires significantly less energy and emits far fewer air pollutants and greenhouse gases, but other environmental impact indicators are unchanged regardless of firing.

Altering the brick shape to either require less material or less mortar is one potent way to reduce the land area, the energy, and the carbon dioxide emissions. Depending on the geometry and the fraction of empty volume, it may be possible to make bricks which are nearly as strong and durable as traditional, fully dense bricks.

The effects of changing the composition are also significant, but a bit less clear. Stabilizers clearly contribute a disproportionate amount of the environmental impact of a brick, but they also dramatically increase the strength and durability of unfired bricks, rendering them more comparable in strength to fired bricks and concrete blocks than to non-stabilized unfired bricks. The environmental impact varies significantly across different stabilizers, but the choice of stabilizer is more often dictated by the type of soil, the desired strength outcome, and the cost than by environmental considerations.

While the composition of the main components of the brick from sandy to clayey has little impact on the environmental friendliness of the brick, it may have less direct consequences such as the appropriate type and amount of stabilizer or the amount of water required. However, one can greatly reduce the land required by substituting fly ash for some of the earthen material. Using fly ash additionally helps alleviate the burden of industrial waste disposal.

Governmental policy has the most potential to help with the regulation of the extraction depth for soils. While the government certainly has reasons for keeping the soil extraction zones shallow, potentially to use them again as agricultural land, allowing extraction at a slightly greater depth could significantly reduce the land area burden of a brick. If the shallower earth mines are in fact being reused for another purpose, then perhaps the land area burden of a brick is not so great. But once one reaches a depth at which the site could only be converted into arable land with difficulty, then increasing that depth more could greatly reduce the environmental impact.

Avenues for future work and expansion of this model include considering more functionally equivalent units of analysis, including the use and disposal phases of a brick’s lifetime, and adding a cost dimension. Additionally, revisiting several of the assumptions made in the model and better quantifying them could improve the accuracy of the estimated impact and potentially enable any expansions to be more thorough.

Considering the tradeoffs between environmental impact and performance and cost is the logical and most important next step for this work. This would allow for comparison not only among the various unfired bricks analyzed in the model, but also among different masonry units and building blocks. Stabilized earthen bricks seem to be option which most effectively balances these tradeoffs. The key will be continuing to improve the performance to be comparable to fired bricks while reducing the environmental impact and improving sustainability.

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