Energy Efficiency of Building Technologies and Climate Change using Geographical Information System (GIS): A Case study of use of soil, water and forest/grass in Migori County, Kenya.

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Abstract. Demand for building materials and products has increased considerably with the rapid growth of population thereby affecting the carbon sequestration ability of the natural environment. Traditionally, data on building materials use, energy expenditure in their sourcing and processing, and carbon dioxide equivalent generated are lacking in developing countries. The focus of this report, being part of an ongoing study is that direct impact on environment occurs at various stages in the building material usage especially at the extraction and production stages for which energy is expended. Environmental products such as soil, water and timber which are the main carbon sequesters are exploited during the manufacture/ or processing of dominant building technologies in Migori thus affecting carbon sequestration potential of the natural ecosystems. The awareness levels amongst the population on energy and resource efficiency in building construction is grossly limited. The Geographical Information System (GIS) on spatial analysis of proximity and neighbourhood tools demonstrated the emerging patterns in terms of soil, water and forest/grass disturbances resulting from the activities of building construction. The ultimate goal is to facilitate formulation of energy efficiency building codes, green building guidelines, improvement of climate change strategy and Action Plan towards Nationally Determined Contribution (NDC) enhancement as well as improve knowledge in the relationship between climate change, building and ecosystem linkages between soil, water and forest cover.

Key Words: Energy Efficiency, Building Technologies, Climate Change, Carbon Sequestration.

1. Introduction
The present research demonstrates the effects of various processes in the preparation of building materials on carbon sequestration ability of the surrounding environment. In particular, it focuses on the extraction, transportation, manufacturing / processing, and resultant energy used in the preparation of the materials in readiness for the construction activities. The building and construction sector is one of the sectors that post high growth rates of 13.1 % compared to overall growth of 5.8 % in 2013 (Economic Survey for Kenya, 2015). This implies that with the current population growth and demand for housing, there will be need for building materials. Most of the materials and technologies in the housing construction industry utilizes various environmental products such as quarry stones, burnt/fired bricks, timber, cement, lime, stabilized soil blocks, iron sheets, mud and wattle, concrete blocks, as well as rammed earth among others (GoK, 2015). The total energy consumed by a building over its service life is known as life cycle energy. The total life cycle energy is composed of two primary components, namely, embodied and operating energy (Treloar, 1998; Hegner, 2007). The embodied energy is the total energy consumed in extraction, transportation and manufacture of building materials, that with increased demand for housing, continues growing in unsustainable manner. Energy is the single largest
source of GHGs that causes global warming and climate change. Besides energy consumption, the environmental impacts of extraction and manufacturing of building materials and related technologies include land cover changes, land degradation; atmospheric pollution, and biodiversity shrinkage, hazardous effects of abandoned quarries and impacts on water resources affect disproportionately countries with rapidly growing population. Currently, building materials use remains largely unregulated. Construction of buildings affect the environment through the life cycle of materials and as such is a key player in sustainable development with the potential to significantly impact on society and the environment (UN-Habitat, 2009).

The recognition of effect of climate change led over 180 countries to adopt Kyoto protocol in 1997, which came into force in 2005 thereby committing 37 industrialized countries to reduce their greenhouse emissions by 5.2 % below to 1990 levels during the first commitment period (2008-2012). According to Intergovernmental Panel on Climate Change (IPCC, 2007) global warming is unequivocal and evidence from weather observations show increasing trend of the global average air and ocean temperatures, widespread melting of snow and average sea level rising. Loaiciga (2009) provides the basis for global warming as the increase in atmospheric CO2 concentration of about 280 parts per million by volume (ppmv) in 1765 to approximately 364 ppmv in 2009. The study examines five sets of variables notably; dominant materials used in housing construction, the technology applied in the construction process, the accompanied energy requirement for the materials and technologies, the existing institutional set up as well as selection criterion of materials and technologies. The overall goal is to determine the sustainability of the building materials requirement, the energy use, its efficiency and contribution to or reduction of GHGs.

2. Methodology
2.1 Methods and tools for data collection
This study employed three different methods including survey, experimental, and spatial analysis techniques in order to acquire the necessary information. Using the survey approach, the source areas identified and information collected from sites of extraction and production of various building materials used for housing development within the study area. The information included type of material excavated (stone, sand, soil, etc.), timber harvested, and any other materials relevant for housing construction. The study surveyed and compiled institutions involved in building technology research, development/manufacturing and promotion. Of specific interest were institutions whose mandate includes enforcement of building standards and certification.

In most parts of developing countries soil continues to be the main materials used for the construction of traditional low-cost houses in rural areas. The experimental phase of the project involved selection of two building materials, notably; burnt bricks and Interlocking Stabilized Soil Blocks (ISSB). The later (ISSB) is being championed by the Government of Kenya towards easing construction costs for the affordable housing scheme. These two products were used in the estimation of carbon emissions accruing during their application in the building processes. Burnt bricks manufacture involves moulding from clay, drying, stacking in a kiln and burned to harden thus becomes more durable. Finally, wood is piled into kiln, set ablaze, and once the wood is burning, the openings are sealed off with bricks and the wood will burn until it is exhausted. ISSB, on the other hand, is unfired bricks.

2.2 Data analysis
Embodied energy is an accounting method of the sum of all the energy required to produce any goods or services and represents the entire product life cycle (HUB, 2009). The energy for the life cycle includes energy used in extraction, transportation, manufacturing, assembling/disassembling, installation, construction/deconstruction and/or decomposition of building materials. Different methodologies use different scales of data to calculate energy embodied in products and services and consensus on the appropriateness of data scales and methodologies is pending thus providing a wide
margin of embodied energy values for any given material\(^1\). In the absence of a comprehensive global database, embodied energy calculations may omit important data, for example, the rural road/highway construction and maintenance needed to move a product, human marketing, advertising, catering services, non-human services, amongst many examples. Such omissions can be a source of significant methodological error in embodied energy estimations. Without an estimation and declaration of the embodied energy error, it is difficult to calibrate the sustainability index, and so the value of any given material, process or service to environmental and human economic processes.

The consumption of energy that is solely responsible for GHGs has been associated with the rapid growth of population and socio-economic development in many countries. For this reason, there is correlation between Greenhouse gas emission and population size and Gross Domestic Product (GDP) per person as illustrated in formula below:

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\text{GHG = } P_0 \times \frac{\text{GDP}}{\text{Person}} \times \frac{\text{Emissions}}{\text{GDP}} = P_0 \times \left(\frac{\text{GDP}}{P_0}\right) \times \left(\frac{\text{GHG}}{\text{GDP}}\right) \ldots (1)
\]

Where:
- GHG = Greenhouse gas emission;
- GDP = Economic output; and
- \(P_0\) = Population Size

### 2.3 Estimation of embodied energy

Although most of the focus for improving energy efficiency in buildings has been on their operational emissions, estimated that about 30% of all energy consumed throughout the lifetime of a building can be in its embodied energy (this percentage varies based on factors such as age of building, climate, and materials). In the past, this percentage was much lower, but as much focus is placed on reducing operational emissions (such as efficiency improvements in heating and cooling systems), the embodied energy contribution has come much more into play. Examples of embodied energy include the energy used to extract raw resources, process materials, assemble product components, transport between each step, construction, maintenance and repair, deconstruction and disposal. As such, it is important to employ a whole-life carbon accounting framework in analyzing the carbon emissions in buildings [14].

The Sustainability Assessment Tool (SBTool\(^2\)), UK Code for Sustainable Homes\(^4\) and USA Leadership in Energy and Environmental Design (LEED\(^3\)) are methods in which the embodied energy of a product or material rated, along with other factors, to assess a building's environmental impact. SBTool is a generic framework and a toolkit for rating the sustainable performance of buildings and projects by local organizations.

Embodied energy is a concept for which scientists have not yet agreed absolute universal values because there are many variables to take into account, but the products are comparable to each other to see which has more and which has less embodied energy. Comparative lists (for an example, see the University of Bath Embodied Energy & Carbon Material Inventory \([8]\)) contain average absolute values, and explain the factors which have been taken into account when compiling the lists.

Typical embodied energy units used are MJ/kg (megajoules of energy needed to make a kilogram of product), tCO\(_2\) (tonnes of carbon dioxide created by the energy needed to make a kilogram of product). Converting MJ to tCO\(_2\) is not straightforward because different types of energy (oil, wind, solar, nuclear and so on) emit different amounts of carbon dioxide, so the actual amount of carbon dioxide emitted

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\(^1\) Dixit, M.K. Embodied Energy Calculation: Method and Guidelines for a Building and its Constituent Materials. A Dissertation by Submitted to the Office of Graduate and Professional Studies in partial fulfilment of the requirements for the degree of Doctor of Philosophy, Texas A&M University.

\(^2\) Larsson, N. 2015. SBTool for 2015 International Initiative for a Sustainable Built Environment. May 2015

\(^3\) LEED. Homepage of LEED. 2013, http://www.usgbc.org/leed.
when a product is made will be dependent on the type of energy used in the manufacturing process. For example, the Australian Government [9] gives a global average of 0.098 tCO2 = 1 GJ. This is the same as 1 MJ = 0.098 kgCO2 = 98 gCO2 or 1 kgCO2 = 10.204 MJ.

3. Results

The dominant building materials in Migori County was determined at household level. The research established several materials in use including natural stone, burnt bricks, concrete blocks, iron sheets, timber, mud and interlocking stabilized soil blocks (ISSB) among others. Figure 1 presents the dominant building materials used in housing delivery and building construction in Migori. One of the key enablers towards realization of the 500,000 affordable housing programme of the Big Four Agenda is the adoption of emerging / appropriate building materials and technologies. Currently, the Government policy on housing identifies ISSB as instrumental in unlocking the adequate and affordable housing potential of rural areas. This study set to compare the environmental performance of burnt bricks and ISSB as applied within Migori County with an aim to establishing the contributions of the two types of building materials to carbon sequestration conditions within the study area.

Figure 1. Awareness of dominant building materials in Migori County

3.1. Production of Interlocking Stabilized Soil Blocks (ISSB) in Kuria West.
The project site at Kehancha prison, Kuria West sub-county in Migori County. The project targeted the production of 3000 Interlocking Stabilized Soils Blocks. The technology aimed at offering low-cost housing solutions, involving the production of building blocks that interlock with each other during construction hence eliminating the need for mortar to bind the blocks.
Figure 2: Sketch Map of Kehancha ISSB production site in relation to Material Sourcing Points

The interlocking blocks production process involved use of Hydraform Machine that compresses a mixture of sifted soil (the main raw material), water and cement to produce solid building blocks with interlocking features. The process involved; on-site excavation of soil, sourcing of river sand, quarry dust (on-site), cement for stabilization (hardware), water for production and curing, diesel to run the Hydraform machine and mobilization of local labour. The soil, quarry dust and sand were mixed with cement at a predetermined ratio/proportions based on the clay-sand content of the soil, and compressed to produce interlocking stabilized blocks. Soil/sand/ quarry dust/cement ratio varies according to soil type and can be determined by testing the soil. For the present experiment, the total Interlocking Stabilized Soil blocks produced were 2,908.

From the above analysis, the Kehancha Prison Interlocking Stabilized Soil Block making process used:
- 1 bag of cement was equivalent to 7 wheelbarrows of soil mix
- 1 bag of cement produced 57 ISSB
- 40 litres of diesel was used during the entire ISSB production process.

The study applied Geographic Information System (GIS) to show the relationship of distance of building materials transportation to construction sites as depicted in figure 2 above. The study demonstrated that the longer the distance, the higher the GHG emission associated with the building materials depending on the mode of transportation.
Figure 3: Map showing Migori CBD in relations to other areas where main building materials used in the town are sourced.

The GIS platform was further used to demonstrate that some materials exploited by residents of Migori County were sourced and transported over long distances which further aggravates the GHG emission associated with the building sector.
3.2 Production of Burnt Bricks:
Preparation of brick earth commences with process of removal of soil top of about 20cm that normally contain stones, pebbles, gravel, roots among other physical matter after clearing the trees and vegetation. The excavated soil mass is puddled, watered and left over for weathering and subsequent processing. According to Duggal (1998), stones, gravels, pebbles, roots, and any other unwanted materials removed from the dug earth and the soil is heaped on level ground in layers of 60-120cm. It is then left in heaps and exposed to weather for at least one month in cases where weathering is necessary to develop homogeneity in the mass of soil, particularly if from different sources as well as to eliminate impurities, which are oxidized. Soluble salts further dissolve by rain to prevent scumming during brick burning in the kiln.

Blending process involve mixing of earth with sandy-earth calcareous-earth in suitable proportions to modify the composition of soil and moderate amount of water mixed to obtain the right consistency for moulding. On the other hand, tempering which consist of kneading the earth with feet is done to make the mass stiff and plastic. Duggal (1998) provides explanation for moulding as giving the shape required by the brick from the prepared brick earth through action of hand or machine aided.

The drying stage in the brick making process involve removal of moisture which is always approximately 7-30% of the green bricks in order to control the shrinkage and save on fuel as well as time during the brick burning. As such, the burning is the last stage in the brick making process which may involve application of two dominant kilns’ methods, that is, the continuous kilns (Bull’s trench and Hoffman’s kilns) as well as use of discontinuous kilns (intermittent kiln).
3.3 Quarry stone excavation and processing:

In the history of masonry, stone for construction was common wherever civilization existed near mountains or rocky outcrops as may be seen in the Egyptian Pyramids that existed along the rock borders of the Nile Valley (Hashmin. and Deboucha, 2011). In the eastern civilization, remains of historical masonry of the Great Wall of China, which is as one of the seven construction wonders in the World. Building stones constitute a permanent walling material that meets government standards for structural use as well as community social status. This makes their use for construction purposes in Kenya to be extensive, particularly where suitable rock deposits occur (Uglow, 1999). According to Everett (1994), quarry stones used in building as blocks, slabs, slags, setts, roofing slates and damp-proof courses. Other uses of stones including aggregate for concrete, terrazzo, mortars, plasters, renderings, tarmacadam and onastic asphalt; granules for surfacing bituminous felts; powders for extending plant; abrasives; and rock wool for insulation.
Discussions

According to IPCC (2007), deforestation is responsible for about 20 per cent of global annual GHGs emissions. Demand for energy is one of the main drivers of deforestation and land degradation in Kenya, where final delivered biomass energy accounts for 78% of energy consumed (GoK, 2002). Accelerated deforestation rate in Kenya is through illegal encroachment and settlements, logging and livestock grazing. The application of natural stone in the construction process is associated with various phases notably, mining and transportation. The mining methods of stone products at times normally constricts the vegetation cover and contributes to air pollution, a situation that is worsened when the products are to be transported over long distances with un-road-worthy vehicles. In the case of burnt bricks, there are huge burrows that are discarded after soil extraction as well as large quantities of wood fuel sourced from the environment for firing the bricks for a period of between 48-96 hours (Sangori, 2012). The use of ISSBs involve excavation of soil for block production but there is no firing involved and the curing process is done by watering the blocks. Kilns for Burnt bricks are fired for a period ranging from 48 to 96 hours or more during the manufacturing process, which contributes to huge habitat destruction through the demand for firewood (Sangori, 2012).

UN-HABITAT (2011) notes the contributions of buildings to GHG emissions worldwide as one of the largest with the consumption of about 1/3rd of energy taking place in residential and work places. The already precarious situation could double and even worsen as time tickles towards the year 2030 by which is the globally designated period for the realization of SDGs. In related development, the building and construction sector in general is associated with nearly 40% of annual energy consumption with an equivalent release of GHGs and resultant adverse climate change effects (UNEP, 2009). Energy input analysis relating to the built-environment products in this study will be covering extraction, transportation, processing. According to the National Institute for Standards and Technology’s (NIST’s) Building for Environmental and Economic Sustainability (BEES) database, the average embodied energy for a common fired clay brick is about 9.3 MJ (8800 Btus). Further, application of energy efficient materials when designing a building envelop has been advocated as an effective way in the reduction of building energy requirements thereby increasing the lifespan of such buildings as well as ensuring the consistency in performance over time leading to a healthy environment (Moss, 2006).

Additionally a 15-ton truck-diesel of 14-ton materials load yields an embodied energy of 1.5MJ/ton-km while a 35-ton truck-diesel of 32-ton load results in 0.94 MJ/ton-km.

Conclusions

The analysis of building technologies application in relation to soil, water and forest / grass conditions within Migori County has proved useful in contributing to our understanding of climate change. Key results of the study show that transportation of building materials, vehicles with smaller capacity / volume are potentially capable of yielding higher carbon footprint than large vehicles with higher volume of material load. This calls for policy direction to ensure transportation relating to built-environment needs are streamlined and in compliance with low emission targets. Burnt bricks are
associated with higher embodied energy and, since it is the product with higher application, a deliberate policy that supports research and development of environmentally friendly methods of brick manufacturing should be initiated jointly by the national government, county government, academia and research institutions in order to ensure synergy and seamless communication amongst stakeholders in the building industry. The study noted the impact of relying on quarry stone given that it has higher magnitude of landscape disturbance hence higher footprint as it involves transportation over long distances. In comparing the performance between the Burnt Brick and Interlocking Stabilized Soil Blocks, the latter is more beneficial to carbon sequestration value of the natural system given that it is devoid of depleting forest cover.

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