ENERGY EFFICIENCY OF BUILDING TECHNOLOGIES AND CLIMATE CHANGE: A CASE STUDY OF CARBON SEQUESTRATION IN MIGORI COUNTY.

BY

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THIS THESIS IS SUBMITTED IN PARTIAL FULFILMENT FOR THE REQUIREMENTS OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN ENVIRONMENTAL PLANNING AND MANAGEMENT IN THE DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES, UNIVERSITY OF NAIROBI.

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DECLARATION

This PhD Thesis is my original work and has never been submitted for PhD Degree Award in any other University or Institution.

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LIST OF ACRONYMS

ABMT	Appropriate Building Materials and Technology
APHA	American Public Health Association
EAC	East African Community
EC	European Commission
EE	Embodied Energy
ESA	Ecological Society of America
GHGs	Greenhouse gases
GoK	Government of Kenya
ICRAF	International Centre for Research in Agro-forestry
ISSBs	Interlocking Stabilised Soil Blocks
ITCZ	Inter Tropical Convergence Zone
KIRDI	Kenya Industrial Research and Development Institute
LDCs	Least Developed Countries
LVB	Lake Victoria Basin
LVBC	Lake Victoria Basin Commission
LVEMP	Lake Victoria Environment Management Project
NACOSTI	National Commission for Science, Technology & Innovation
NALEP	National Agriculture and Livestock Extension Programme
NEMA	National Environment Management Authority
REDD+	Reducing emissions from deforestation and forest degradation.
UNCSD	United Nations Conference on Sustainable Development
UNEP	United Nations Environment Programme
UoN	University of Nairobi
WGBC	World Green Building Council
WNA	World Nuclear Association

ABSTRACT

The global population has continued to increase leading to a greater demand for housing and associated building materials and products which affects the environment and climate in various ways. The effects on environment happens at different phases mainly at the extraction and manufacturing phase where energy consumed depends on the building technology adopted. Due to inadequate research, data and literature on the application of the building materials in meeting the housing demand, the energy consumed and equivalent carbon dioxide emitted in entire stages of production by building technology processes are lacking in developing countries with no exception to Kenya. This study estimated how building technologies by using soil, water and forest/tree cover affect carbon sequestration potential of these resources. The study was done in Migori county with the objective of establishing energy expenditure of building technologies and their effects on carbon sequestration processes and hence potential contribution to climate change through atmospheric CO_2 accumulation. The study identified the dominant building materials adopted in the county and their embodied energy levels; assessed the extent of adoption of energy efficient building, resource efficiency of mortarless compared to mortared technologies, established the relationship between building materials use and greenhouse gas emissions; and determined suitability of approval processes to promote selected building technologies by Regulatory Authorities. The main hypothesis of the study was that building technologies have no significant effects on carbon sequestration and hence does not contribute to adverse climate change.

The study applied survey, experimental and correlation design approach and adopted both quantitative and qualitative sampling methods to generate primary data towards addressing the research objectives. The survey method was essential in obtaining building technologies, embodied energy and the resultant carbon dioxide emission equivalent of the selected building materials. The county of study was identified by way of purposive sampling. Multi-stage sampling was employed with county as a unit of study, sub-counties forming the study first stratum and the nature of wards (urban and rural) as the second stratum unit of study from which the wards were sampled. The study identified the major approved walling materials in the study area to be bricks and concrete with specific embodied energy of 3.0 MJ/kg and 0.670 MJ/Kg respectively. The study further revealed that there is low application of energy efficient technologies such as interlocking stabilized soil blocks, prefabricated and precast materials. The experimental design revealed that the building materials extraction, manufacture, transportation, and construction consume significant amount of energy and emit greenhouse gas into the atmosphere and that the level of emission of greenhouse gas is dependent on the building technologies adopted. The mortared technology was associated with large amount of embodied energy and equivalent greenhouse gas emission which impact negatively on human life due to high social cost of pollution.

The study findings were used to show national outlook of embodied energy and equivalent CO_2e projections for the years 1800, 2019 and 2050 of the various walling materials. It is demonstrated that less efficient building technologies continues to dominate the housing sector with bricks leading over the period of analysis at 7,176 GJ in 1800, 306,730 GJ in 2019 and

590,263 GJ in 2050 if the current environment of Migori is to prevail nationally. The CO_2 emission associated with the walling materials shows a direct relationship since bricks attracted higher values of CO_2 emission at 22,404 tons in 1800, 575,317 tons in 2019 and 1,104,363 tons in 2050. Similarly, energy efficient building technologies such as ISSB attracted low greenhouse gas emission. The study concludes that there is a strong relationship between the applied building technology and building materials and climate change demonstrating the need to minimize the embodied energy by using energy efficient building technology and adopting the use of walling materials with minimized embodied energy in order to reduce the greenhouse gas emission. The study revealed that there was minimal knowledge on the application of energy efficient technologies and that the approval process does not promote the use of energy efficient building materials and technologies due to lack of policy to spearhead the initiative.

This study is significant in the policy formulation related to the energy efficiency building codes, green building regulations, implementing sustainable environmental strategies and action plans. It is also essential in providing professional knowledge on the causal relationship between building technologies, building material, climate change, environmental sustainability and environmental degradation in the built environment in regard to carbon sequestration relating to soil, water and tree/forest cover

1 INTRODUCTION

1.1 Background

The world today is experiencing major global challenges including climate change which negatively impacts on human survival. Various ecosystems such as soil, water and forest/grass cover mitigate against adverse climate change effects by maintaining optimal carbon sequestration levels. Carbon sequestration implies long term storage of carbon in soils, water and forest cover with soils containing about 75% of carbon that exists on land (ESA, 2000). As demonstrated by the Parties to the Paris Agreement, conservation and enhancement of greenhouse gas sinks and reservoir is significant towards environmental sustainability (UN, 2015). Implementation of the agreement would yield environmentally-friendly buildings that offer occupants protection from adverse conditions through utilization of passive elements. Embracing energy and resource efficiency in buildings has significant contributions towards visual and thermal comfort thereby resulting in reduced carbon emission and adverse climate change effects.

Energy efficiency in buildings encompasses two main components notably; embodied energy and operational energy with buildings noted to be responsible for 1/6th, ¼ and 2/5th of fresh water, forest products and construction materials flows respectively-all which constitutes the embodied energy (Deshmukh and More, 2014). The concentration of building materials, distance covered and the level of disturbance to the environment accelerates greenhouse gas (GHG) emissions thus lowering of carbon sequestration services from the environment. According to the government of Kenya (2015), the commonest environmental materials and products include burnt bricks, cement, quarry stones, lime, concrete blocks, timber, iron sheets, grass, mud and wattle, among others. According to Scheuer et al (2003), manufacturing of building materials including transportation and construction phases amount to 2.2% of the energy consumed in the building material life cycle. The carbon sequestration processes in both terrestrial (biological) and geological provinces denote to a large extent the various land management practices that can be investigated using Geographical Information System (GIS).

A major parameter of analysis in the carbon sequestration vis-à-vis climate change debate is the building material embodied energy (EE). Oka and Sawachi (2013) noted the improved accuracy of computing operational energy use and prediction of carbon dioxide emissions but also highlighted the pending challenge of measuring embodied energy and carbon emissions.

The reason for this ongoing challenge is that the building materials are very different and the processing vary with technologies available. The building sector in Africa is responsible for 54 % of total national electricity consumption (UN Habitat, 2015) while transportation of materials to project sites consume large amounts of energy (Alshboul et al 2008) and this should be factored in determining the embodied energy of such materials. Further, comparison of various modes of transportation propagates for ocean shipping-diesel as the most efficient (0.16MJ/tone-km), followed by rail-diesel (0.25MJ/tone-km) and 15ton truck-diesel of 14ton materials load (1.5MJ/tonne-km) while 35ton truck of 32ton load (0.94MJ/tone-km).

Adverse climate change effects may escalate, if unsustainable building technologies continue to be employed in shelter delivery for the ever increasing population necessitated by high growth rate within the Lake Victoria Basin where the present research was concentrated. The study therefore focused on the building materials, embodied energy and climate change relationship in Migori County of Kenya.

1.2 Statement of the Problem

Population has continued to increase globally with developing Countries leading the pack, Kenya included. This has necessitated higher demand for housing in Kenya, thereby exacerbating pressure on the environment due to demand for building materials and technologies. It is significant to note that quality housing deficit in cumulative terms in Kenya is estimated at over 2 million units with about 244,000 housing units required annually to meet the demands of various income groups (World Bank, 2017). The Government further projects that 200,000 housing units require facilitation to meet the annual short falls of about 132,000 units experienced per year to cater for new urban household formations (GOK, 2017).

Meeting the country’s adequate housing needs implies that environmental resources such as soil, water and forest are extracted in large volumes. These resources are required to meeting the carbon sequestration services as well. Such extraction therefore creates an imbalance in meeting the carbon sequestration services. It is imperative to note that building materials extraction, manufacture, transportation, and construction consume significant amount of energy and emit greenhouse gas into the atmosphere. The challenge is how to optimally use the building material sources in a sustainable manner (SDG 12 on sustainable consumption patterns). By and large, the building materials are associated with embodied energy which has a function of carbon, hence the contribution to climate change (SDG 13), and if well done, lead to sustainability in almost all sectors. Given population increase and the challenges associated with the building sector, the embodied energy of materials and carbon emissions, reduction of carbon sequestration capacity of soil, water and forest cover, it is important that evidence-based policy decision should be made to mitigate climate change.

Hashemi (2015) points out that "almost all available studies on embodied energy have been carried out in developed countries". The present study offers one of the case studies in an African country. This revelation is worrying particularly as 2/3rd of buildings that will be in use by 2050 are not yet constructed in developing countries compared to the developed countries where such buildings already exist. Whereas developing countries have a chance to change the course towards a sustainable built environment by 2050, the developed countries on the other hand may just require policies geared towards retrofitting as opposed to new construction processes in order to mitigate climate change. Past studies demonstrates that the type of technologies used in processing building materials and their application in the housing industry relates to the embodied energy (Weeber et al., 2001; Dixit, 2013).

The study assessed the building materials use, energy consumed and greenhouse gas emission equivalent to enable the formulation of climate change mitigation strategies. In essence, this study provided actual data on measurement of embodied energy as an index of determining the carbon sequestration levels as guided by Intergovernmental Panels Fourth Assessment Report (IPCC, 2007) on buildings and greenhouse gas projections.

The research questions that were addressed are:

1. Which building materials and equivalent embodied energy levels are associated with housing development in Migori County?
2. Are residents of Migori County adopting energy efficient building technologies?
3. Is there significant difference in resource efficiency between mortarless and mortared building technologies as applied in Migori County?
4. How do the building technologies affect GHG within the study area?

5. How suitable are the County building approval processes to promoting selected building technologies in Migori County?

1.3 Objectives of the Study

The overall objective of the study was to determine the impact of building materials and technologies in climate change mitigation and adaptation processes in Kenya.

The specific objectives of this study conducted in the County of Migori were to;

1. Identify the dominant building materials applied in housing development and establish their embodied energy levels.
2. Establish the extent of adoption of energy efficient building technologies.
3. Determine resource efficiency and climate change mitigation levels associated with utilization of mortarless and mortared building technologies.
4. Establish the relationship between energy efficiency levels of building materials and Greenhouse Gas Emission (GHG).
5. Assess the effectiveness of County building approval processes to promote selected building technologies.

These objectives were achieved through testing procedure.

1.4 Study Hypotheses

The research hypotheses formulated for this study as tested and validated by sampled data collected from the field was that;

1. H_O: Appropriate building materials, technologies and designs are predominantly applied in meeting the building demand levels of Migori County.
2. H_O: There are higher proportions of respondents applying energy efficient building technologies.
3. H_O: There is no difference in resource efficiency and mitigation levels between mortarless and mortared building technologies.
4. H_O: Building technologies used in Migori County have no effect on climate change.

5. H_O: County building approval processes are effective in promoting selected environmentally-friendly building technologies.

Significance test of the above hypotheses was at: $\alpha=0.05$

1.5 Justification of the Study

Building sector exhibits the greatest challenge in reduction of GHG emissions given that the sector produces a third of CO_2 emissions (UNEP, 2012). Further, building technologies have been mapped as some of the major factors in the climate change debate as they contribute directly to energy requirement, water balance and atmospheric composition. The United Nations World Commission on Environment and Development (UNWCED, 1987) provides for undertaking building development processes in a manner that least disturbs the earth surface thereby leading to sustainable development. This position is further reiterated by the provisions of Sustainable Development Goals (United Nations, 2015). Built environment sector should further be steered towards achieving zero net energy buildings by 2050 as any new buildings constructed using inefficient energy processes portends lower carbon sequestration levels of soil, water and forest systems (WGBC, 2017). The present study is useful since Kenya may not have building codes that are relevant to adoption of energy efficient building technologies and worse still, there may be no guidelines to assist the construction industry on how to contribute to reduction of carbon discharge in the atmosphere, a proposition that negates achievement of the Paris Agreement (COP21) of 2015 commitments regarding the relationship between buildings and climate change.

The study contribute to; improvement of knowledge on the causal relationship between building technologies, building materials, climate change and carbon sequestration relating to water, soil, and forest cover; empower small entrepreneurs in building and construction through job creation; realization of affordable and safe housing with ripple effects in health, economic livelihoods among others; and establish effective institutions in sustainable housing development at both national and county levels. Energy and resource efficiency application is currently dominating major global debates with United Nations Resolution A/RES/70/1 of 25 September 2015 establishing a universal vision for mitigating global emissions by ensuring increased access to clean modern energy and promotion of energy efficiency as enshrined in Sustainable Development Goal (SDG) 7 and SDG 11 which aims to transform cities and human settlements in a safe, resilient, inclusive, and sustainable (UN, 2016) manner. As stated above, it is fundamental to recognize provisions of COP21 and its 1.5-degree centigrade goal to mitigate climate change through emission reductions, a process is greatly aided by gathering of data and increasing access to information towards decision making for buildings and construction sector stakeholders. This was preceded by the Cancun agreement (2010) as detailed by decision 1/CP.16 emphasizing on deep cuts in global emissions that contain temperatures to 2^{o}C above pre-industrial levels.

1.6 Significant of the Study

The study is significant in the policy formulation related to the energy efficiency building codes, green building regulations, implementing sustainable environmental strategies and action plans. It is also essential in providing professional knowledge on the causal relationship between building technologies, building material, climate change, environmental sustainability and environmental degradation in the built environment in regard to carbon sequestration relating to soil, water and tree/forest cover.

1.7 Operational Definitions

Affordable housing: In the Kenyan context, affordable housing relates to the access of housing by citizens that in itself is adequate and afforded at a maximum cost of about 30% in relation to monthly household income in terms of owner occupier or rental scheme (Modified from GoK, 2016).

Appropriate Building Materials and Technologies (ABMT): The ABMT are forms of building materials and technologies which are applied in meeting the housing needs of the society in sustainable manner. Such materials are locally sourced within specific areas or form part of emerging building materials and technologies (Modified from GoK, 2016).

Building Materials: These are the walling products obtained from direct acquisition on the natural resources of soil, water, geological strata and forest / tree cover. The building code order of 1968 for instance, is material based and solely recognizes conventional building

	materials such as bricks, stones and mortar in its application (Modified from GoK, 2016).
Building Technology:	It implies the technical processes and methodologies adopted in the application of building materials from extraction, production and construction in relation to material processing, design structures and building systems (Modified from GoK, 2009).
Built Environment:	Built environment encompasses human-made space within the housing and urban development sector where people interact by way of living, working and developing on a day-to-day basis with resultant activities necessitating sourcing of building materials from the environment (Modified from Kaklauskas, A. and Gudauskas, R., 2016).
Carbon Sequestration	The biological, chemical or physical removal of atmospheric carbon and storing the removed carbon in the reservoir notably water, soils and vegetation among others (modified from ESA, 2000).
Climate Change	The term relates to the production of greenhouse gases resulting from anthropogenic activities within the built environment of Migori County. As demonstrated in the IPCC Report (2007), building processes are among the human activities with greater impacts on climate change with greater contribution to alteration of the global atmospheric composition over time (UNFCCC, 2005).
Development control:	The process of regulating any physical development within a given land use by ensuring such developments of operations conform to spatial development plans, policies guidelines, regulations and standards as may be issued by the planning authority with an aim of ensuring orderly land use development, environmental conservation, as well as ensuring public health and safety (Modified from PLUPA, 2019).

Embodied Energy	The total energy exploited directly or indirectly in the extraction, processing, transportation, assembly, construction, refurbishment and demolition of a building. This may for instance involve a brick, stone, wood, etc. of a wall (modified from Huberman & Pearlmutter, 2008).
Head of Household	This is the person in charge of the household and makes the decision on behalf of the household from time to time. In African society, it is mostly the father or mother in the absence of the father or the eldest child in the absence of the parents. Most of the household members depends on the household head for daily provision (Modified from GoK, 2013).
Household	This a person or people living in the same dwelling units or house who are answerable to one household head and cooking together (Modified from GoK, 2013).
Interlocking Stabilized Soil Blocks (ISSB):	This is a form of soil based-mortarless construction technology that relies on soil stabilisation at manufacturing / production and dry stacking at the construction stages (Modified from Hydraform Ltd, 2005).
Operational Energy	Post-construction energy needed for maintaining the internal environment of a building during its life-time (modified from Dimondi & Tompa, 2008).
Technological Adaptation	The incorporation of various technologies that contribute to the reduction of vulnerability of natural or anthropogenic conditions hence increasing their resilience to climate change impacts (modified from UNFCCC, 2010).
Weathering:	In the context of this study and with regard to the manufacturing of burnt bricks, weathering is used to imply the process of breaking to smaller portions the large boulders of soil extracted for the moulding process of green bricks (Modified from Hughes, R. E and Bargh, B. L; 1982).

2 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 Introduction

Demand for building materials and products have accelerated in commensurate terms to the increasing population trends globally. The present study examined the past research that relates to energy efficiency of building technologies and resultant effects on climate change, identify existing research gaps and provide objective critique regarding current limitations of methodology in the sector. Major focus was on population with regards to settlement needs and the demand for housing, building materials and sustainability including climate change mitigation, energy efficiency of building technologies, the ecosystem and carbon sequestration processes.

2.2 Built Environment and Climate Change

Climate change is no longer an emerging issue as perceived at the onset of the 21st Century, but has metamorphosed to a real challenge that the global community is grappling with in an effort to achieve the sustainable development agenda (Brundtland Report, 1987). An observation by WGBC (2017) hails the coming into effect of COP 21 in 2015 a great moment in the history of climate change debate. Further there was perfect timing in the release of the IPCC (2018) Report on the desired changes towards maintaining the global average temperatures at below 2^0C, with specific targets of 1.5^0C (Clegg and Sandeman; 2019). In the absence of pragmatic actions by actors from key economic and development sectors, the greenhouse gas emission situation and by extension, the adverse climate change effects are set to worsen in no more than 12 years (IPCC, 2018).

Further, the adverse climate change effects may escalate, if unsustainable building technologies continue to be employed in shelter delivery for the ever increasing population. It is already observed that climate change may not be a new phenomenon given that such changes resulted in the atmospheric CO_2 as early as 1896 which significantly led to fluctuations of temperatures globally (Kininmonth, 2003). In particular, it has become synonymous with global warming which results mainly from the GHG increase leading to trapping of energy (Akadiri, 2011; Loaiciga, 2009). This phenomenon exacerbates global warming situations whose effects are felt in terms of the frequency and severity of harmful effects (Glasby, 2002).

The IPCC report (2007) further depicts the challenges posed by adverse climate change effects that borders on various unpredictable scenarios of weather patterns associated with the atmospheric, water and land resources. About 280ppmv of CO_2 already existed by 1768 and the levels accelerated to 364 ppmv by the year 2009 (Loaiciga, 2009). Further, the world recognized the effect of climate change and through this, 180 Countries adopted Kyoto protocol in 1997 which was operationalized in 2005 thereby obligating 37 industrialized nations to minimize GHG emissions to low concentrations of 5.2 % considering base year of 1990 within the first period of commitment (2008-2012).

At the time of signing COP21 (Paris Agreement) outcome of 2015 on climate change, 195 countries unanimously acknowledged that climate change is real and that there was a strong need to take actions that are aimed at reducing the emissions of greenhouse gases whose lock-in effects compromises the performance of the atmosphere towards adverse climate change mitigation. Among those actions are: decarbonisation of the economy by reducing the use of fossil fuel and promoting clean energy; promotion of low carbon economy; promotion of carbon sink program such as afforestation program; promotion of sustainable urban development; and promotion of sustainable architecture among others.

The status of GHG emissions by selected countries and other categories are; USA (6.8 Gt), India (1.7 Gt), Buildings (9 Gt), with additional GHG from buildings by 2030 having been estimated at 7 Gt (IFC, 2017). The global call for action to tackle “climate emergency” is therefore a call for action from all sectors including a wide range of built environment players from governments, regulators, investors, asset managers, property occupiers among others to deliver the much needed environmental, social and governance factors in the mitigation and adaptation to the adverse climate change effects (Knight Frank, 2021).

The discussions advanced as reviewed from various literature sources by this study is inadequate on the extent to which the use of building technologies can contribute to reduced carbon emissions that cause global warming and consequently climate change. The study therefore set to establish energy efficiency and greenhouse gas emission levels of the various dominant building materials as well as the relationships attributed to climate change effects using GHG emission as a proxy.

2.3 Population and Housing Demand

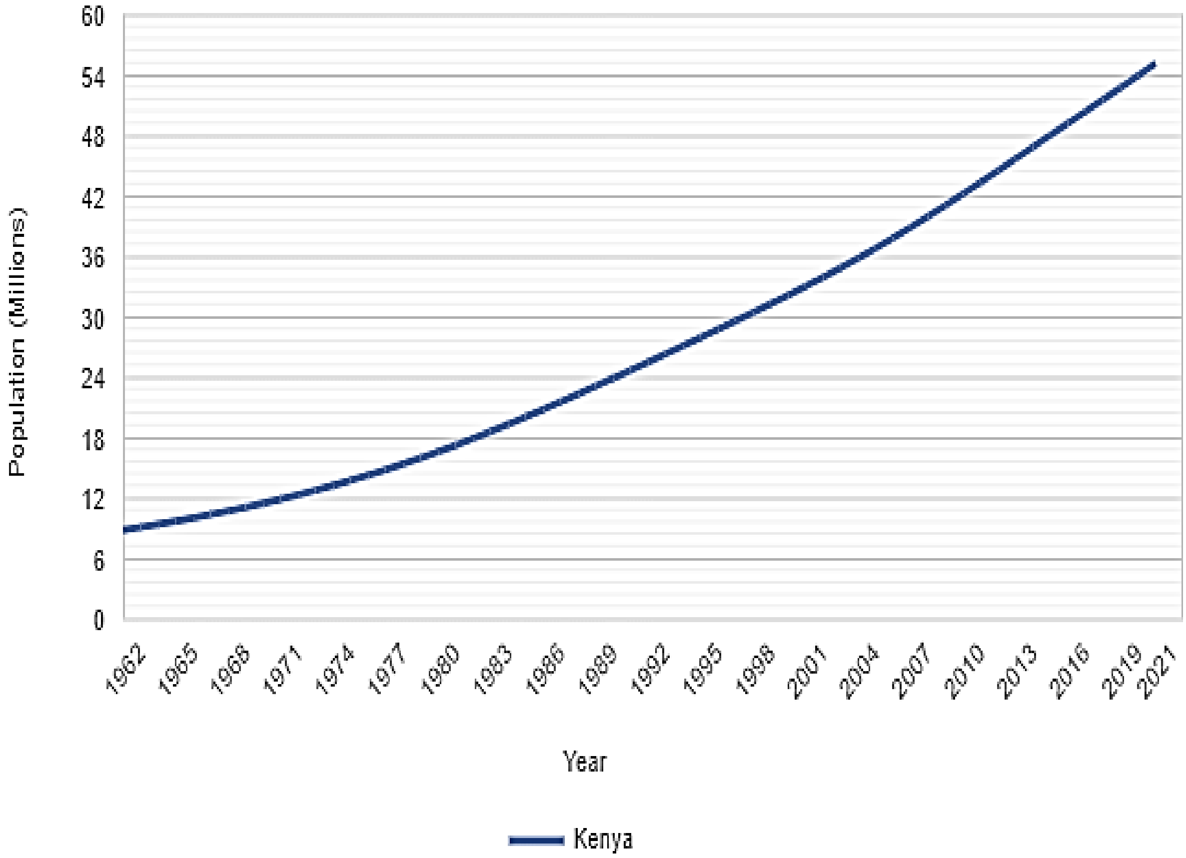
The rapid population growth in the region, if not properly planned, will continue to intensify the competition for building materials exploited from the surrounding environment. Environmental degradation involves unsustainable use of soil, water and forest cover and other resources, thereby affecting carbon sequestration capacity of these natural systems and hence accelerating climate change with negative impacts. The population analysis from 1950 to the year 2030 projections shows that, by the year 2030 the LDCs where Kenya belong will have a population of about 6.89 billion with urban population projected to reach 3.93 billion while rural population is projected to reach 2.96 billion (UN, 2003). Further UN-Habitat (2010) provides that Population of Africa is projected to grow by 706 million between 2010 and 2050 thereby leading to substantial growth in the building sector. A recent publication by Knight Frank (2021) details that the Africa's built environment landscape is significantly changing with priority on adaptation to the local needs within the real estate sphere with focus on sustainability necessitated by rapid urbanization and increasing population. The accompanying population growth rate for the African continent stand at 3.5% p.a with the Africa's cities expected to cumulatively host about 1.3 billion additional people, a figure that will significantly increase the demand for buildings by 2050 with recognition that 80% of such buildings are yet to be built (Knight Frank, 2021).

The world development preoccupation prior to the launch of SDGs focused on implementation of Millennium Development Goals (MDGs), particularly MDG 7 target number eleven that focused on livelihood improvement of 100 million people at minimum within the informal areas by 2020 (UN-HABITAT, 2003), a call that has been emboldened by the adoption of recent global commitments that touches on human settlement (Housing and Urban Development) notably: the Sustainable Development Goals, more so SDG 11 on Sustainable Cities and Communities (UN, 2015), the Paris Agreement (COP21) on Climate Change, the New Urban Agenda, among others.

The observation on the relationship between the population, housing and climate change is backed by a study by Ogola (2018) which notes that increasing human population and the threats posed by climate change continues to put pressure on the already limited environmental resources that support life on earth, as evidenced in the case of land resources such as forests, cropland and water. The world population at 2015 stood at 7.3 billion and is projected to be 9.7

billion by 2050 and 11.2 billion by 2100. Population of developing countries which Kenya is part of is expected to rise from 5.9 billion in 2013 to 8.2 billion in 2050 and 9.6 billion in 2100.

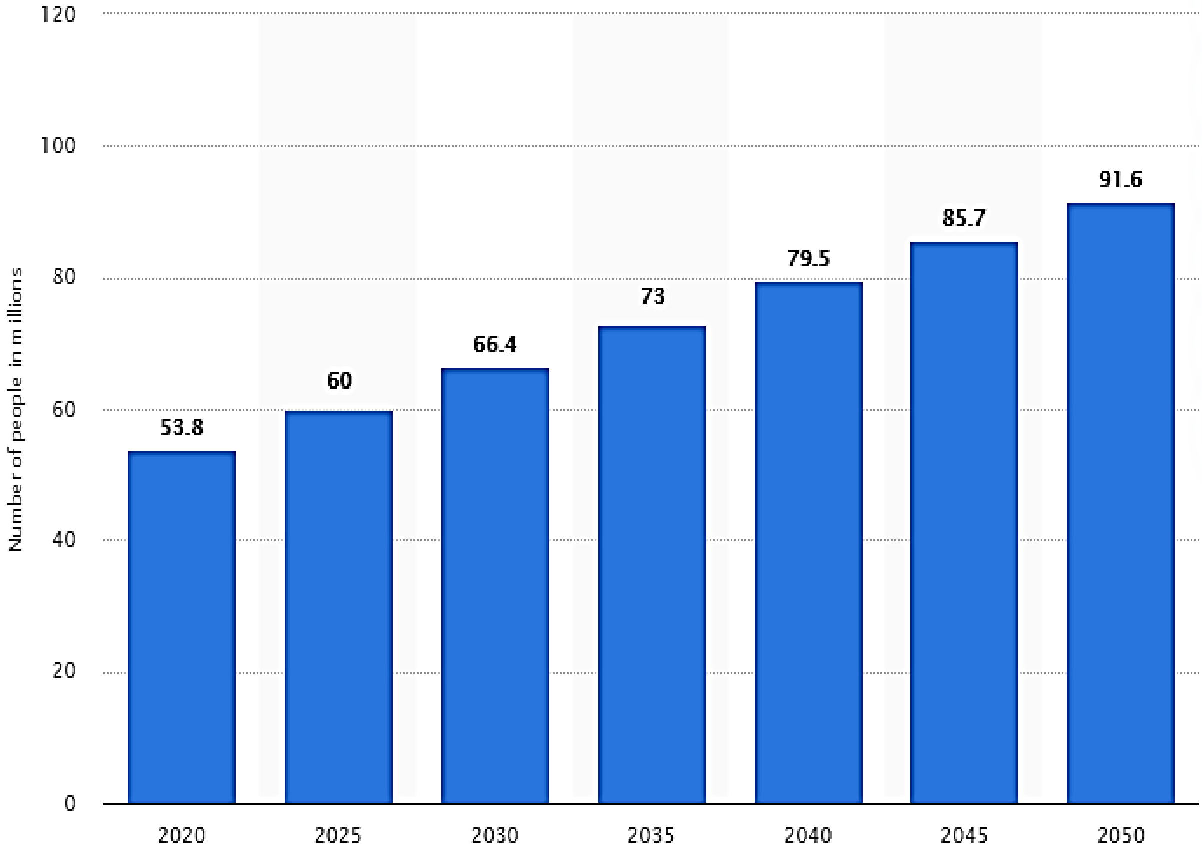
Figure 2.1a: Population Trends of Kenya Since Independence.



Source: UNWE, 2021

Population data obtained from the KNBS and World gridded data were used to show population changes and showed that the population has been increasing from 1979 to 2009. This exponential growth that is being experienced has commensurate effects on the natural resources and systems whose levels of endowment have been unsteady in the last decades. For instance, forest cover in Migori County as at 1979 stood at 1,560 ha, but this slightly increased to 2,593 ha in 1989 and 3,828.8 ha in 1999. The area forest cover however experienced a decline in 2009 and 2013 to 3,519 ha and 2,475.1 ha respectively (Ogola, 2018). The situation presented in the study by Ogola (2018) demonstrates the precarious situation the land mass of several developing Countries are facing in an effort to provide the housing and other building needs as population, settlements and urbanization needs increases, a situation that escalates the environment resources – building materials demand balance. Figure 2.1a and 2.1b shows population trends of Kenya since independence and the 2020-2050 projections respectively.

Figure 2.1b: Population Projection for Kenya (2020-2050).



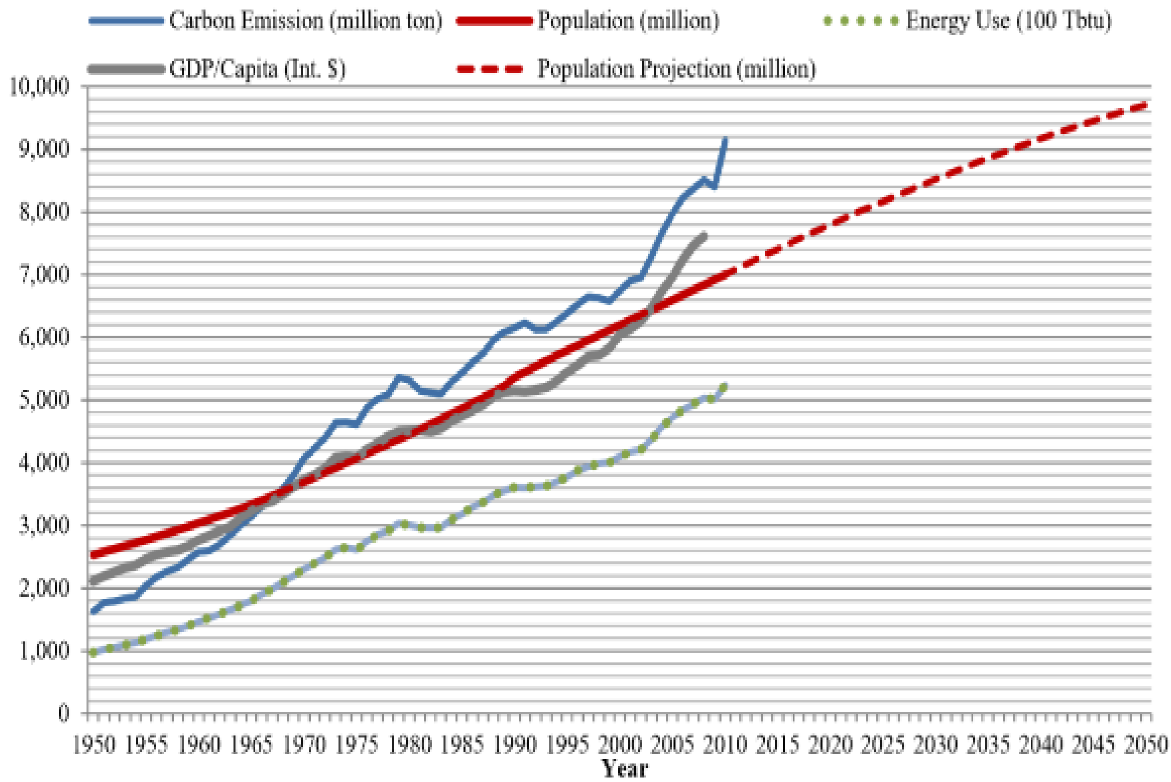
Source: Statista, 2021

The CoK (2010) recognizes housing as a basic human rights and essential component of the right to an adequate standard of living which is critical in fostering social cohesion and development of a nation. Housing is a critical driver of economic development as a result of its forward and backward linkages with other economic development processes and outcomes of the building material production and usage to accomplish housing needs. GoK (2018) committed to deliver an ambitious socioeconomic programs towards livelihood improvement of the citizen. These programs are; affordable housing, universal health coverage, enhancing manufacturing; and food security & nutrition. As part of the development of affordable housing, the government of Kenya has prioritized the provision of 500,000 affordable homes over five-year period with 80% being in the general affordable housing category and 20% focusing on social housing (GoK, 2018). The population continues to demand for adequate housing which are characterized by; legal security of tenure, availability of housing infrastructure and services, materials, affordability, habitability, accessibility, location, and cultural adequacy.

Whereas the Sessional paper no.5 of 1966/67 envisaged direct Government provision of adequate housing at the lowest possible cost, the affordable housing under the big 4 Agenda is premised on a public private partnership delivery model among other strategies. Such delivery models are to be achieved at national and county government as well as the private sector levels with the Government main role being an enabler to the development processes (GoK, 2018). The implementation of this government priority agenda on affordable housing programme (AHP) invokes the relevant provisions of the Public Private Partnership Act (2013) as well the affordable housing development framework which provides for signing of memorandum of understanding (MoUs) with interested county governments to participate in the AHP programme. The implementing Agency (State Department for Housing and Urban Development) has successfully negotiated with the National Treasury for the approval of specially permitted procurement procedure (SPPP) to support fast-tracking of the procurement process. UN-Habitat puts the global estimate of slum populations at 881m (2014) and just under a third of all urban dwellers in the developing world (UN-Habitat, 2014). Sub-Saharan Africa – the region with the highest proportion of the urban population living in slums – over 50% compared to figures ranging between 20% and 31% for other regions of the World. The successful delivery of this Agenda would largely contribute to improvement of slum conditions across the country notably: durable housing structure; access to clean water; improved sanitation; sufficient living space and secure tenure UN-Habitat (2003). The absence of effective housing delivery strategies, Kenyan urban space would continue to be characterized by slum formation to meet the immediate shelter needs of the population (Syagga and Aligula, 2007).

Matrix development consultants in a research report noted that 55% of the residents in Nairobi live in slum areas, which represent only 6% of the total residential area available in the city (Syagga and Aligula, 2007). According to Dixit (2013), population increase is associated with increased level of Gross Domestic Product (GDP), energy use and carbon emission as depicted in Figure 2.2. The current study sets to establish the nature of the relation between: building materials and technologies, and the greenhouse gas emission.

Figure 2.2: Relationship among Population, GDP, Energy Use and Resulting Carbon Emission



Source: Dixit, 2013

The effect of population with regard to greenhouse gas emissions is reflected by the Kaya identity that decomposes the emissions (Dixit, 2013) as provided in equation 2.1:-

Equation 2.1: Kaya Identity on GHG Emissions

GHG = Population * GDP per Person * Emissions per GDP

GHG = POP * (GDP/POP) * (GHG/GDP),

Where:

GHG denotes Greenhouse gas emission

GDP denotes Economic output

POP denotes Population Size

It is further demonstrated that population and affluence are key determinants of the exponentially growing resource use (Holdrein & Eherlich, 1974; Bruce, 2012; Dixit, 2013). As such, attaining a higher standard of living due to increased income levels leads to consumption of more goods and services, thus exerting pressure on the natural capital (Dixit, 2013) with overall negative effect on carbon sequestration levels of key natural resources of soil, tree cover / forest and water. The resultant equation hence takes the form below;

Environmental Disturbance = Population * Per Capita Consumption * Environmental Burden per Unit of Consumption

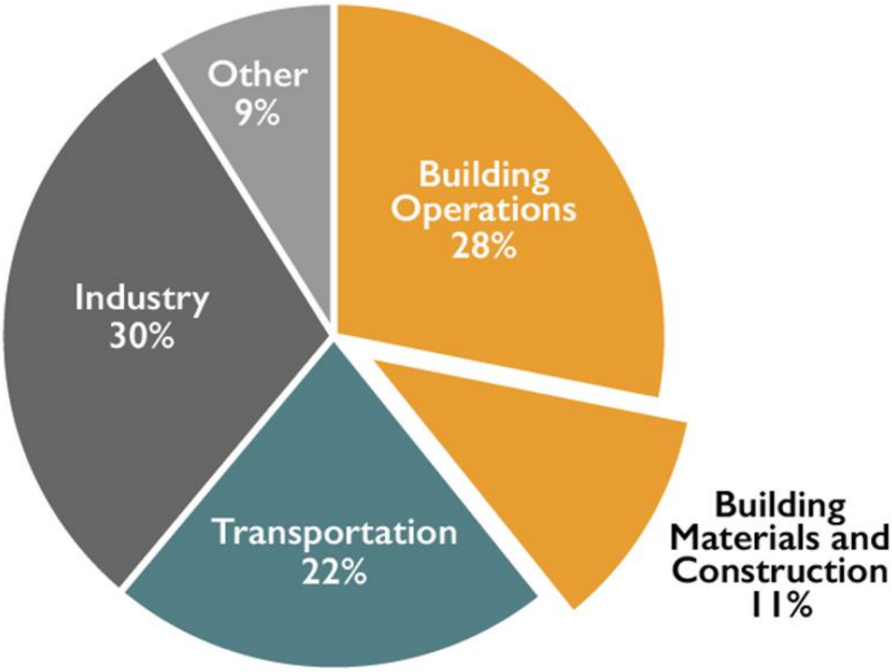
2.4 Building Materials and Technologies

2.4.1 Effects of Building Materials on the Environment

The built environment is a major contributor to the economic prosperity of other sectors as it forms the basis for implementation and improvement of both civil engineering and related human settlement projects (Omayi, 1993). According to UNEP, the building and construction sector is associated with about 5-15% of the GDP of a Country which makes it one of the critical sectors in any given economy. The GABC (2016) demonstrated that the existing global building stock stood at 223 billion M^2 with a projection of 5.5 billion M^2 annually thereby leading a global building scenario of about 415 billion M^2. There are changes in built environment that targets housing and urban development processes including increased advancement in construction and application of engineering equipment that contributes to the selection of appropriate materials for use (Duggal, 1998, Sangori, 2013).

In the research findings of Anon (2000), the number of buildings in Turkey averaged 7,838, 675 with 75% (5,872,803) being residential housing while 51% of buildings employed wall and frame bearing consruction techniques. According to the the Statistical Institute of Turkey (2000), the specific materials used in the building sector in Turkey and the proportion of applications are: bricks (60%), hollow contrete blocks (18%), stone (10%), Sun-dried brick (8%), wood (3%) and other (1%). In Kenya, most of the building materials applied in housing delivery are largely conventional in nature with the majority being concrete, stone, processed timber, plastics, bricks, and galvanized corrugated iron sheets (Sangori, 2013). GoK (2013), provides that the proportion of application of these walling materials in Kenya nationally were mud / wood (34.8%), stone (22.4%) and brick / block (17.1%). Such materials are associated with high levels of embodied energy and CO_2 emission equivalent with potential negative impacts to the environment. Figure 2.3 shows the global CO_2 emission by sector

Figure 2.3: Global CO_2 emission by sector



Source: UNEP, 2017

Classification of the use of walling materials by urban and rural areas, GoK (2013) indicated that 48.9% of the walling in the rural areas applied mud/wood followed by bricks/block at 14.9% compared to urban areas where walling for dwelling units comprised of stone at 44.9%, followed by bricks/blocks at 20.6%. The Kenya Population and Household Survey report of 2019 detailed a total of 12,043,016 households at the national level with major dominant building materials being mud being 27.5%, followed by stone at 16.5%, concrete at 16.3% and bricks at 10.2%. The rural urban divide has dominant walling material for main dwelling units as mud and Concrete at 41.2% and 31.6% respectively. Table 2.1 depicts proportion of walling materials applied in housing delivery as detailed in the Kenya Population and Household Survey (KNBS, 2019). In terms of waste generation and management, Dixit (2013) noted that about 48% of building wastes owe their origin to demolition related processes while components of waste that are associated with refurbishment as well as design and masonry works of new buildings is reflected at 44% and 8% respectively (Dixit, 2013; USEPA, 2009a).

Further, a study by Kenya Building Research Centre (2019), which focused on mapping and documentation of traditional building materials in relation to local climate and socio-cultural attachments established the dominant building materials applied in building construction within the coastal region of Kenya. It focused on the location of building materials sources, processing, various plants and supply centres of traditional building materials in the six counties of Mombasa, Kilifi, Lamu, Kwale, Tana River, and Taita Taveta.

The main building materials used by local residents in coastal area of Kenya are; stones, sand, murram, ballast, hardcore, coral, mangrove, timber, and makuti among others. In Lamu East for instance, the materials used include; ballast, clay soil, coral blocks, coral hardcore, hardcore, lime, mangrove poles, metal steel, murram, ocean rocks, sand, thatch and timber. It is further noted that the common building materials available for building construction in Mombasa area are; balcony balustrades, balusters, blocks, bricks, building, stones, cabro, cement, cement sinks, chip blocks, concrete, coral reef stones, culverts, glass limestone, makuti, poles, road caps, sand/coral reefs, stones for cement manufacture, timber / wood, ventilation blocks (KBRC, 2019). On the aspects of appropriate building materials, Syagga (1993) notes that such materials are based on local sources while being sensitive to the prevailing climatic, economic and socio-cultural conditions. Such materials include but not limited to SSBs, natural stone with limited application of heavy machinery (labour intensive), makuti, pozzolanas, adobe blocks and rammed earth.

The scenarios presented by various literature sources on the building stock and building materials in use does not sufficiently relate with the prevailing situation across Kenya. This therefore necessitated the present study in order to establish the relationship in meeting the building demand due to increasing population and the state of the carbon sequestration levels of key natural resources in the production / processing of local building materials of soil, water and forest / tree cover.

Table 2.1: Distribution of Dominant Walling Materials in Kenya and Migori County

	Kenya			County	Sub Counties							
	Kenya	Rural	Urban	Migori	Awendo	Kuria East	Kuria West	Nyatike	Rongo	Suna East	Suna West	Uriri
Conventional Households	12,043,016	7,379,282	4,663,734	238,133	27,014	17,267	39,723	39,358	29,007	27,214	28,839	29,711
Walling Materials by Main Dwelling Units (%)												
Cane / Palm / Trunks	0.8	1.3	0.2	0.1	0.0	0.3	0.2	0.3	0.0	0.0	0.2	0.0
Grass / Reeds	1.9	2.9	0.4	0.2	0.1	0.7	0.3	0.1	0.0	0.1	0.1	0.1
Mud / Cow Dung	27.5	41.2	5.6	56.8	57.3	82.0	62.7	49.9	52.6	49.4	43.3	66.6
Stone with Mud	3.5	4.2	2.4	3.9	3.3	2.6	2.9	2.6	3.4	4.4	5.6	6.9
Covered Adobe	2.7	3.0	2.2	4.5	3.2	1.7	3.1	6.2	4.9	4.2	8.7	2.9
Uncovered Adobe	1.0	1.4	0.3	0.8	0.4	0.2	0.3	1.3	0.5	0.8	1.7	0.7
Plywood Cardboard	0.4	0.4	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Off Cuts / Raised Woods / Wood Planks	1.4	1.8	0.7	0.1	0.1	0.0	0.0	0.4	0.0	0.0	0.1	0.0
Iron Sheets	9.9	6.1	16.0	2.7	2.8	1.1	1.6	8.2	2.3	1.1	1.2	1.3
Concrete / Concrete Blocks / Precast Wall	6.3	6.6	31.6	8.9	11.5	3.7	5.1	7.8	11.7	13.8	11.1	6.5
Stone with Lime / Cement	16.5	8.4	29.3	4.8	5.3	1.9	2.6	5.3	4.6	6.0	7.3	5.0
Bricks	10.2	11.2	8.5	16.8.	15.6	5.7	21.1	16.8	19.9	19.9	19.5	9.9
Canvas Tents	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nylon / Cartons	0.2	0.3	0.1	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0
Timber	7.7	11.2	2.3	0.3	0.3	0.1	0.0	0.1	0.0	0.0	0.1	0.0
Prefabricated Pannels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Not Stated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Source: Extracted from KPHC, 2019

2.4.2 Building Technologies

The literature reviewed in the context of this study is in relation to mortared and mortarless building technologies. Whereas mortared technologies focus on the application of mortar and brick construction process, the mortarless on the other hand relies on less or non-mortar application to bind the material joints.

2.4.1.1 The Use of Mortarless Building Technologies in Housing Delivery

The mortarless construction form a larger component of the green building technologies. Such technologies have low embodied energy, cost-effective, labour-intensive, faster in construction delivery, culturally acceptable and suitable for both rural and urban setups (Hydraform building system, 2009; Sangori, 2012). In Kenya, the application of such technologies were first supported by the adaptive by-laws on building technologies as adopted in 1995 (Code 95). The review process as demonstrated by Kimani and Musungu (2010) commenced in earnest in 1992 with the participation of major players in Kenya's built environment landscape who were drawn from government, industry, civil society and the academia. The aim of the revised building code - adaptive by-law as formulated in 1995 was to enable the implementation of housing standards and guidelines with significant contribution towards; lowering the building cost, encouraging innovative design, promoting local materials and focusing on performance. This process was aimed at addressing the challenges paused by the strict measures contained in the Building of 1968 whose emphasis was more on mortar and Brick construction rather than housing adequacy and affordability as desired by majority of Kenyans who live below the poverty line. The mortarless construction technologies are key in realization of adequate and quality housing. For instance, poor quality housing can affect the health of the family (Martin, 1967).

Morris and Winter (1978), further demonstrated that the number of households and available dwelling units are social facts, while the rule or standard that more than one family per dwelling unit is not acceptable is a cultural fact. The issue of space norm is of great relevance in household and dwellings as it prescribes the amount of space a family should have and are dependent upon family size and composition. Achieving adequate housing through adoption of energy efficient building technologies as propagated in this study is significant towards realization of key activities that are performed within the dwelling units by various households. These includes; sleeping and dressing, personal cleanliness and sanitation, food preparation and preservation, serving food and dining, family recreation and self-improvement, extra-familial association, housekeeping activities, care of infants or the sick, circulation between various areas of the dwelling, operation of utilities (APHA, 1950).

The current global strategy is to encourage all actors in the field of environmental conservation and protection to promote application of green initiatives, more so within the built environment. UN-HABITAT (2011) demonstrated the application of best practices having pioneered an Ultra-Modern building complex in Gigiri, Nairobi that remarkably integrated the green building concept. The new building concept is noted to be useful as it contributes to the generation of about 550 KW of power out of which 65% of the total power generated is used in meeting the operational energy demand of the building. This leaves about 35% of power which is supplied to the national grid system, a scenario that leads to the generation of extra income towards the maintenance of the facility. The practices include; installing of Solar panels and Wind energy generating devices for lighting and heating system, use of special low energy bulbs for lighting, adopting of housing designs utilizing natural lighting and ventilation, biogas for cooking and heating system, and water conserving sensitive taps.

The construction industry has witnessed the emergence of several mortarless technologies with Hydraform ISSB Technology which works with soil based products being a leading industry player globally. Hydraform Machine is one of the available Compressed Earth Block Machines which produces Interlocking Stabilized Soil Blocks (ISBB). Hydraform Machine is a brand by Hydraform International Ltd from South Africa which has supplied Machines and trained several experts in different regions of the world (Hydraform Ltd, 2005).

For instance, over 10,000 homes and buildings have been built using the Hydraform building system in Gujarat and Orissa in India along with HUDCO (Hydraform Ltd, 2009). The same has been used in the reconstruction in Northern Uganda and South Sudan among other localities. Plates 2.1 and 2.2 depicts fields ISSB production in Kenya. The production tools and equipment for ISSB is detailed in Appendix 1K. In Kenya, the Government has been promoting adoption of Hydraform Interlocking Stabilized Soil Blocks through the Appropriate Building Materials and Technology (ABMT) programme.

Plate 2.1 ISSB Material Preparation and Production

Source: Sangori, 2012

Plate 2.2 ISSB Construction Process and Completed Building with ISS Blocks.

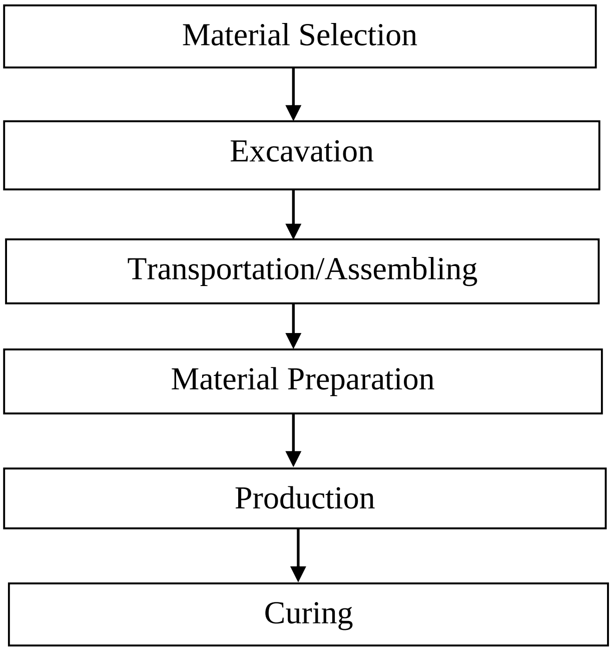
Source: Sangori, 2012

The ABMT programme was boosted with the acquisition Hydraform Machines that support training of communities on production and construction of houses and buildings using ISSB technology across the 47 counties in Kenya (GoK, 2014, Internal report on ABMT). It is imperative to note that the ABMT function is anchored in the Sessional Paper No.3 of 2004 on National Housing Policy (Revised 2016). It involves the establishment of ABMT Centers at the sub-county level as part of flagship projects of the Kenya Vision 2030 which called for establishment of ABMT Centres in each constituency as it were before devolution.

The Ministry has established over 82 ABMT Centres in various constituencies and 1No. Regional ABMT center at Mavoko within the Nairobi Metropolitan Area. The centres are used to disseminate and train on various existing and new technologies that enhance affordability of housing. The Ministry has approximately 208 Block making Machines (201 hydraulic block making machines, 2 hydraulic pan mixers, 2 Vibraforms and 3 manual hand press machines).

By December 2014, over 9302 community members had been trained on Interlocking Stabilised Soil Blocks (ISSB) and over 3000 residential house have been put up since 2012 (GoK, 2014). It is however noted that over 35% of the block making machines were faulty and this greatly impacted on the level of trainings conducted among communities and hence the overall number of projects done. Lack of qualified mechanics and non-availability of spare parts have been a challenge in the maintenance of the Hydraform ISSB Machines since there were no local dealers for the Hydraform Equipment and as such both the machines and accessories were directly imported from South Africa, except in rare circumstance where the local Jua Kali were able to fabricate some spares parts which are not complex in design and form.

Figure 2.3: ISSB Production Processes



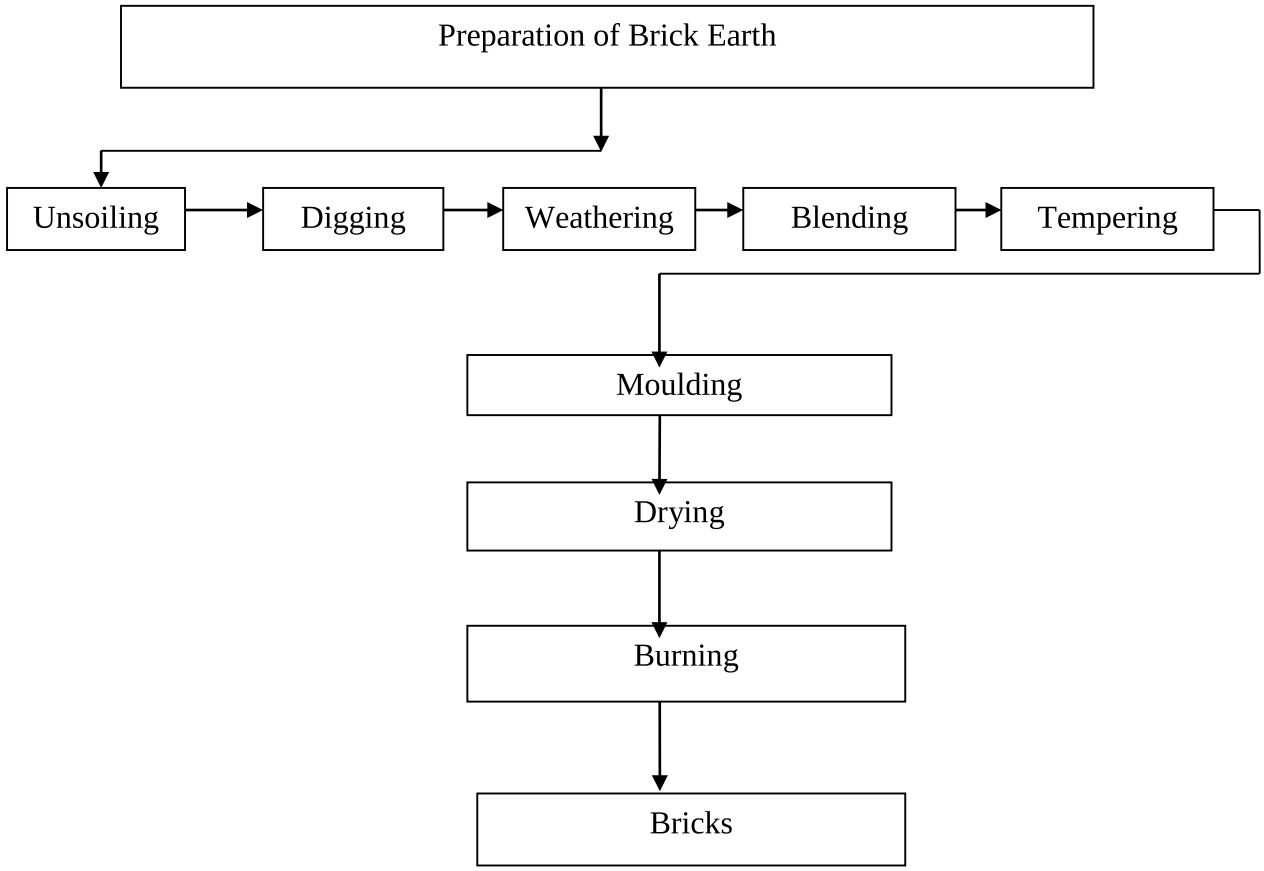
Source: Modified from Hydraform Ltd, 2009

The private sector presence has also been felt with active engagement of Makiga engineering group whose manual/hand press machines are widely used for ISSB production in Kenya and beyond. It is pioneered by Makiga Engineering Company and was a product of earlier research conducted by the University of Nairobi (HABRI) between 1984 and 1994 with the support of the Government. The Makiga Machine is widely used in Kenya and across Africa with major projects in DRC and Botswana. Figure 2.3 outline the steps followed in the ISSB Production.

2.4.2.2 The Use of Mortared Building Technologies in Housing Delivery

Mortared building technologies are represented by mortar and brick construction methods. It involves application of diverse construction materials notably; Quarry stones, burnt bricks, and concrete blocks among others.

Figure 2.4 Operations involved in manufacturing of clay bricks



Source: Adopted from Duggal, 1998

This study focused on 2 mortared technologies as applied by the respondents namely; burnt bricks and quarry stone. The brick production process is demonstrated in Figure 2.4 which outline the stages of operations involved in the manufacturing of clay bricks.

The burnt brick making processes that involves unsoiling, digging, weathering, blending, tempering, moulding, drying, burning and cooling are as defined in Table 2.1

Table 2.1: Description of operation process in the manufacture of clay bricks

SN	Term	Operation definition
1	Unsoiling	The process of cleaning the clay soil by removal of top soil containing impurities. It may involve removal of top layer of soil of about 200mm of the surface depth
2	Digging	The process of removing the clay material from the surface of earth for the manufacture of required clay bricks.
3	Weathering	The process of dissolving the aggregates on the earth surface by water.
4	Blending	Mixing of clay and water to produce the right mixture for quality clay bricks.
5	Tempering	The process of improving characteristics of clay bricks through heating and cooling.
6	Moulding	The act of shaping resultant mixture of wet clay material in moulds and resultant brick shape.
7	Drying	The process of removing water from the moulded clay bricks to pave way for burning process.
8	Burning	The process of exposing dried bricks to certain degree temperatures of about 1100^{o}C in order to gain hardness and strength.
9	Cooling	The final stage in the brick manufacture which follows the burning stage from where the bricks gain the final strength through contraction.

Source: Modified from Duggal, 1998

Brick making involves a series of processes as summarized in Table 2.1 The first process starts with unsoiling which involve the removal of top layer of about 20cm of the selected earth, and it mainly composed of a mixture of stones, gravel, pebbles, roots among other biological physical matter from plant vegetation. The digging operation involve excavation of large quantities of soil which is then gathered and watered for further processing. According to Duggal (1998), the unwanted materials such as gravels, roots and stones are selectively removed and the good soil heaped on up to layers ranging from 60m to120cm. In most cases the heaps are left in the open environment for natural weathering for approximately one months. The weathering process is necessary since it dissolves the aggregates on the earth surface by moistening resulting into homogeneous mass of soil since the existing impurities due to difference sources of soil are oxidised while soluble salts are washed away by rain to reduce the scrumming during the brick burning thereby increasing the quality of soil products.

Blending is another main process where clay and water are mixed with sandy and calcareous soil in optimal quantities to improve the composition of clay to produce the right consistency for quality moulding. The resultant clay for moulding need to be stiff and plastic and this is done through a process known as tempering where human labour is employed to knead the soil by feet. The next process is called moulding and involves providing the right shape for the brick. This can either be done manually or through machine (Duggal, 1998). The moulded brick is then taken through drying process where the moisture content of approximately 7% to 30% of the moulded bricks are eliminated. This process is necessary for controlling the shrinkage that may cause cracks and also save on fuel consumption in addition to time taken to complete the brick burning. The final stage of brick making is burning and this done using a special constructed kiln which can either be dominant kilns' methods, continuous kilns (Bull's trench and Hoffman's kilns) or discontinuous/ intermittent kilns. The damage posed to the environment by brick use could be enormous if sustainable methods are not applied at various stages of brick manufactures, especially during the extraction of earth and burning/firing. The burrows left behind were sighted as having the effect of accelerating malaria infestation if turned to pool of stagnant water suitable for mosquito breeding grounds. On the other hand, wood fuel required during the burning/firing process contribute to loss of vegetation (forest cover shrinkage) as well as increased greenhouse gas emission.

The process of brick manufacture as has been highlighted in heading of Figure 4.1 with various processes that could be disastrous to the environment discussed. Significant damage of burnt bricks was assessed with regard to vegetation loss, landscape degradation and greenhouse gas emission (CO_2) within the study area. The study was designed in away so as measure the damage the various processes involved in the brick manufacture may pose to the environment. For instance, various burrows left behind in areas where earth for the brick making have been excavated were assessed and evaluated for potential damage posed to the surrounding environment. The study further evaluated the damage attributable to the kilns used for burning/firing bricks including the amount of wood fuel consumed by a standard brick kiln and GHG emissions attributed to each standard brick kiln within the proposed study area. As provided by Duggal (1998), the kiln can either be under the ground (Bull's trench kiln) or above the ground (Hoffman's kiln). In continuous kiln the burning process is continuous while in an intermittent kiln the burning process is discontinuous. The intermittent kiln is constructed in such a way that once the kiln is loaded, it is then fired, cooled and offloaded. The kiln is then reloaded making the side walls to cool making it necessary to reheat the kiln during the next firing leading to wastage of fuel (Daggul, 1998). On the other hand, the continuous kiln (Hoffman's and Bull's trench), bricks are arranged in difference compartments/chambers each having different treatments simultaneously. The process is such that in one chambers bricks are fired, in the next chambers they are loaded and in the last are cooled.

Burnt bricks require kilns to be fired for several hours ranging from 48-96 hours and above during the brick burning process resulting in to huge habitat destruction due to increased demand for firewood (Sangori, 2012). During the firing process, the bricks are subjected to certain degree of temperatures of about 1100^{o}C. The mining and burning/firing stages in the brick making process result in biodiversity (vegetation) loss as well as air pollution (carbon dioxide emission) whose extent depends on factors that include kiln design and energy sources. A study conducted in Jintur area of India estimates that 1.89±0.87 acres of arable agricultural land was extracted for manufacture of clay brick per kiln, resulting in land degradation and decrease in herb density and nutrient disorders in flora within the immediate vicinity (Pawar et al, 2008). An internal report by GoK (2017) documents modern fired brick kilns in the outskirts of New Delhi, India which are mainly fired by coal products including some recycling processes which make the manufacturing process sustainable.

The present study therefore focused on establishing the processes involved in burnt bricks manufacture / or production from the Kenyan context with Migori County as a representative study area, and the relationship of such processes with climate change taking resultant GHG emissions burnt bricks production and application processes as a proxy measure to adverse climate change effects.

2.5 Building Materials and Sustainable Development

Building materials and related products as already demonstrated in previous sections, are significant in meeting the housing demand and other construction needs of mankind. Housing as a structure and associated services forms a fundamental human right as articulated in various policy pronouncements including the United Nations (1948), Habitat II (1996), the Council of Europe (2002), the Constitution of Kenya 2010, Kenya Vision 2030, Agenda 2030 on Sustainable Development Goals and the New Urban Agenda (2016) among other instruments.

A focus on sustainable development should ensure that utilization of land, water and forest resources are done in a manner that their exploitation not only satisfies the present residents housing needs but also economized for access by the future inhabitants of the geographical location (Young, 1997; UN, 1992). Additionally, a major outcome of the UNCSD at the Rio + 20 summit in 2012 was the pronouncement on transition to a green economy as a means towards sustainable development.

Sustainable buildings and construction initiatives (SBCI) provides a common platform for built environment actors to undertake resource extraction in a collective manner (UNEP, 2007). Further, Agenda 21 requires governments to establish and strengthen the native building materials industry in line with locally available resources. The industry strives to formulate standards, policies and regulatory processes which encourage the increased adoption of energy efficient building technologies. Kenya being a signatory to these multi-lateral obligations needs to establish various approaches to meeting the housing needs in a sustainable manner.

One of the materials singled out towards achieving sustainability within the built environment by UN-Habitat (2009) is the adoption of stabilized soil blocks (ISSB). According to Sangori (2012) the ISSB technology has been adopted and being promoted by the government towards improvement of housing conditions in various localities across the Country. The ISSB production however depends on; availability of suitable soils (field soil test to be conducted by trained personnel to determine suitability and adequate supervision by well trained personnel on ISSB material selection, preparation, block production, curing, construction and finishes. Soil stabilization in most instances involve the use of laterite soils which in some cases are described as red soils and murram. Ideal soil in the production of ISSB/Hydraform blocks is the sandy-loam soil which requires only soil-cement mixture for block production. In the event of any deviation, a blending agent is added particularly sand / or soft quarry dust (Hydraform Ltd, 2005). In such circumstances, working ratios are computed in the field based on the soil suitability test findings. The number of blocks expected per bag of cement (32.5N) could vary depending on the nature of structure and strength required. For instance, 7Mpa could be achieved by producing 34-38 blocks per bag of cement while 4Mpa block strength could be attained by producing between 57-61 blocks (Sangori, 2012). The choice of desired block strength is determined by the structural requirement with load bearing areas recommended to have blocks of higher strength compared to non-load bearing areas. The strength attained by blocks greatly depend on the quality of the materials, hence right soil, mix and proper curing must be stressed at all times. Curing involve covering blocks with black polythene sheets and watering them for a minimum period of 7 days and upto 14 days.

The advantages of ISSB application is that the blocks are 90% soil and 10% cement; minimal transport cost due to onsite production / manufacture; interlocking property necessitate dry stacking at walling stage hence eliminates use of cement mortar; the uniformity in shape supports less mortar usage in plastering with cement mortar only required for foundation; plaster work only applicable in the first course of block laying and casting of lintel (precast or cast in-situ); elimination of burning / firing due to curing with water thus environmentally friendly; and elimination of facing or dressing as applies to quarry stones leading to time saving and cost minimization (Hydraform, 2005; Hydraform, 2009).

In order to accelerate adoption of ABMTs in Kenya, GoK (2017) report demonstrates the need for: documentation, development and dissemination of location specific ABMTs; accelerating incubation of machines on ABMTs; development of a clear soil classification criteria and database of soil types in all Counties; development of cost-analysis on ABMT; promotion of community participation in ABMT process; creation of an inventory of accredited ABMT professionals, technicians and artisans; as well as enhancement of collaborative research, capacity building on application of ABMT and technology incubation processes; and facilitation of the implementation of an enterprise development model on ABMTs in Kenya (GoK, Internal Report, 2016).

2.6 Criteria for Categorization of Sustainable Building Materials and Technologies

Appropriate Building Materials and Technologies (ABMT) are widely described as processes, materials, elements and tools that are compatible with the local socio-cultural, economic as well as physical and ecological environment of an area (Sangori, 2012). Further, such materials and technologies should be affordable, innovative, safe, environmentally friendly and with significant socio-economic multipliers (GoK, 2015). Appropriateness is however relative and varies with geographical location, prevailing weather, individual needs, income groups and project scope.

Construction activities have a major impact on the environment since it’s the main consumer of various naturally occurring and manufactured resources (Akadiri, 2011). There is therefore a great need to limit adverse effects in addition to adoption of appropriate building material selection processes in decision-making. Different type of tool have been used in deciding on the best material and technologies adopted some of which are; the Multi-Criteria Analysis (a decision-making tool), BRE Environmental Assessment Method (BREEAM), Building for Environmental and Economic Sustainability (BEES), Building Environment Assessment Tool (BEAT 2001) , ATHENA^{TM} Impact Estimator for Buildings, Environmental Preference Method (EPM), Building Environmental Performance Assessment Criteria (BEPAC) and Leadership in Energy and Environmental Design (LEED.

Data from secondary sources obtained from Multi-Criteria Analysis (MCA) and Environmental Performance Method (EPM) processes were used to enrich the primary data obtained from Key informants. The MCA technique enables the use a wide range of data types making it flexible in research. It embraces the use of qualitative and quantitative data which can either be continuous or discrete. The MCA approach has an inbuilt methodology evaluate multiple criteria and objective in building material evaluation which suits the study objective. The use of MCA does not depend on the number and nature of criteria (Van Pelt, 1994). On the other hand, EPM enables the ranking of building materials according to their environmental preference (Akadiri, 2011)

2.7 Embodied Energy of Building Materials

Embodied energy denotes computation method of finding the sum total of energy in the products entire life-cycle. The process of estimating embodied energy involved accounting for energy expenditure at every phase of producing burnt bricks, interlocking stabilized soil blocks and quarry stones. In the building sector, embodied energy is classified into three components: initial embodied energy: energy consumed from the extraction of the raw materials, processing/manufacture of the raw materials and transportation to the building site; recurrent embodied energy: energy required for maintenance, repair or refurbish the building during the service life; and demolition embodied energy which is the energy consumed to demolish/destroy the building to end its life cycle. A detailed inventory of carbon and Energy (ICE) is provided in Appendix 3A. Table 2. 2 details embodied energy of common building materials.

Table 2.2: Embodied Energy in MJ/KG of Building Materials

Authors/Building Materials		Cement	Bricks	Concrete	Timber	Aggregates	Polysterene
1.	Ramesh at el, 2003	6.7	-	-	-	-	-
2.	Reddy, 2004	4.2	1.4	-	-	-	-
3.	Keman, 1996	-	2.5	0.8	9.9	0.3	105.0
4.	Eaton et al, 1998	-	5.8	0.8	13.0	-	-
5.	Hammond & Jones, 2011	5.2	3.0	2.9	7.1	0.1	100.1
6.	Crawford, 2004	14.5	-	-	-	-	-
7.	Chen et al, 2003	7.8	-	-	-	-	-
8.	Blanchard & Reppe, 1998	-	4.5	1.6	5.8	0.9	100.3
9.	Pullen, 2007	6.6	-	-	-	-	-
10.	Almeida et al, 2005	-	-	1.1	0.7	-	100.4
11.	Hammond & Jones, 2008	4.6	-	1.0	8.5	-	-
12.	Yohanis & Norton, 2006	5.9	-	-	-	-	-
13.	Alcon, 2003	6.2	2.7	0.9	2.8	0.4	58.4
14.	Honey & Buchanan, 1992	8.9	-	3.1	1.7	0.3	100.0
15.	Huberman & Pearl, 2008	-	-	1.2	-	-	116.0
16.	Adalberth, 1997a	-	-	2.0	5.2	-	106.7
17.	Scheuer et al, 2003	3.7	2.7	-	10.8	0.2	94.4

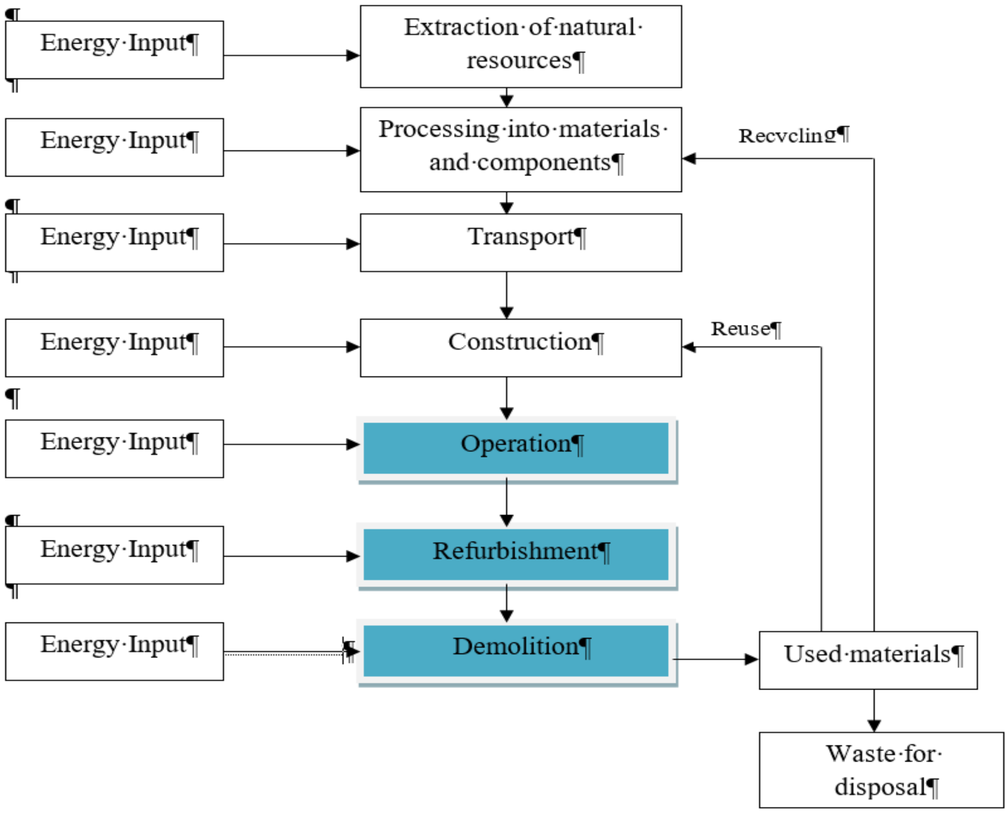
Source: Modified from Dixit, 2013

According to Akadiri (2011), the embodied energy of building materials can be assessed in different ways notably; Input – Output Analysis, Process Analysis, Energy Analysis, Statistical Analysis and Hybrid Energy Analysis. The Input-output analysis involves capturing of all the energy inputs across the whole national economy while process analysis relates to the systematic examination of the direct and indirect energy inputs to a process. On the other hand, energy analysis is a method applied in the estimation of environmental impact of different activities. The statistical analysis is recognized as a method that relies on the published statistics to determine energy use by particular industries. Further, the hybrid energy analysis method incorporates key features of the three analysis methods notable input-output and process analysis.

In the energy measurement, the key parameters for consideration include Gross Energy Requirement (GER) and Process Energy Requirement (PER). The GER methodology mainly focuses on the true embodied energy of the material in use while the PER methodology on the other hand targets direct energy consumption during the manufacturing process. The later measurement method is simpler to work with thus embodied energy that exist in most of the available literature are based on PER which accounts for about 50% to 80% of the Gross Energy Requirement (GER).

It is further noted that it may be impractical to arrive at a single figure in the embodied energy measurement since the resultant EE of each set of materials is influenced by several factors. The EE is dependent on the efficiency of building material manufacturing process, the amount and type of fuel used, distance covered during transportation from the plant to the site amount other factors. UN-Habitat (2010) found it more urgent to improve the environmental performance and energy efficiency in buildings in order to reduce CO2 emissions and help strengthen the ability of Cities to adapt to climate change while improving the quality of the built environment in Africa.

Figure 2.5: Energy Input for Buildings

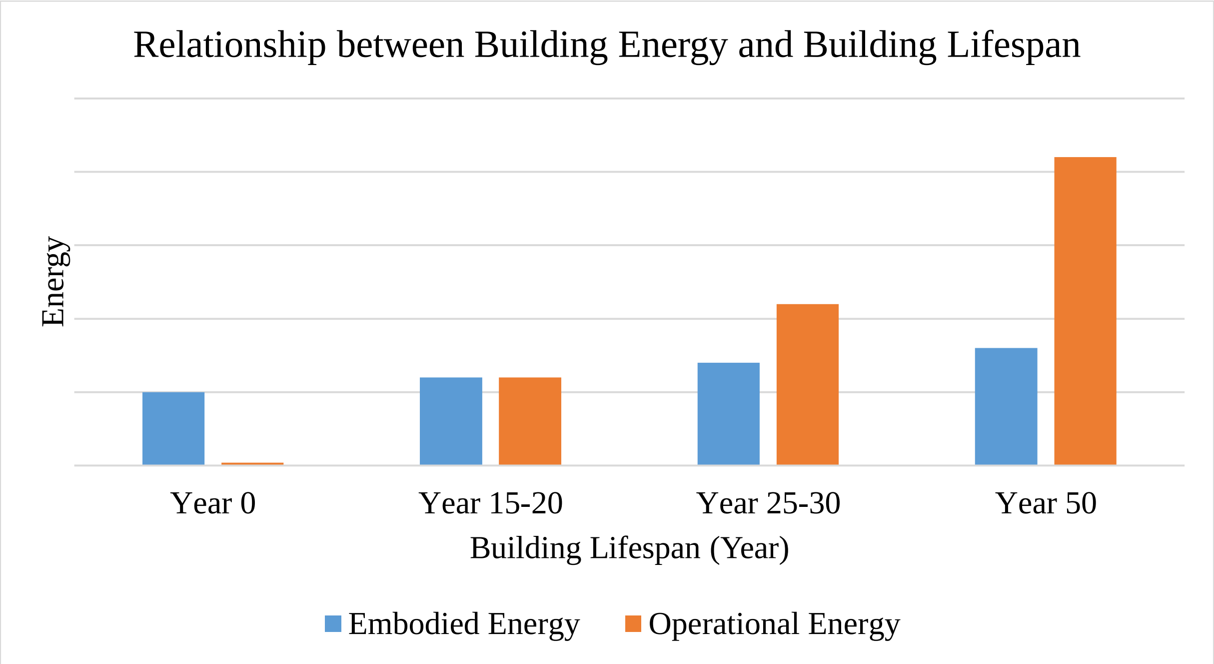


Source: Modified from Akadiri, 2011

The current study is limited to initial embodied energy which has been analysed in the context of energy consumed in the extraction, manufacture and transportation phase processes as depicted in Figure 2.5 with the construction phase being limited to the analysis of resource efficiency. The parameters of resource efficiency in this analysis targeted; total materials used, timelines for construction, labour / manpower and associated costs.

The guidelines for reducing embodied energy as detailed by Geoff and Reardon (2013) provides for: designs for long life and adaptable buildings low maintenance materials; ensuring that materials used can be separated with ease; avoidance of bigger buildings than necessary; recycling of materials; preference for location specific materials; prioritizing low embodied energy materials; reduction of wastages; and general application of passive building designs as well as efficient building envelop design and fittings. According to UN-Habitat (2010) the need for commitment towards the promotion of green building practices, from planning, design, construction and operations of the built environment, as well as to the use of appropriate building materials, technologies, services and processes that minimize CO2 emissions in the continent is a great opportunity to be embraced by both governments and citizens. It is observed that as operational energy is reduced in the post construction stages, the impacts of embodied energy is enhanced, moreso, from year zero to year 50 as depicted in Figure 2.6

Figure 2.6: Relationship between Embodied and Operational Energy



Source: Modified from Koezjakov et al, 2018

2.8 Energy Efficiency and Building Technologies

Building materials energy level analysis is critical in the overall climate change debate discourse as energy input in various products manufacturing and processing yields equivalent greenhouse gas emissions. The analysis of building technology efficiency levels involves comparison of the input – output processes in the material utilization which considered energy efficiency of building materials at the initial stages based on the limitation of this study. World over, the rapid growth of the use of energy in the building industry coupled with and the continuous use of finite fossil fuel has reached unacceptable levels. Lombard et al (2007) noted major concerns that continue to be raised in the application of building materials as being; supply complications, the rate of depletion of energy resources, as well as higher negative environmental impacts associated with the building technology use processes. The environmental impacts of greater concern involve the ozone depletion, equivalent GHG_e, global warming, and climate change (Lombard et al., 2007). The activities related to the production, transportation and construction of the building materials constitutes 2.2% of the primary energy consumed in the material life cycle (Scheuer et al, 2003).

Further, the global building scenario is viewed in different context between the developed and developing countries. Majority of buildings which will be in use in developed countries by the year 2050 are reported to have already been constructed, hence the need of the emerging policies to influence building owners to adopt their buildings with minimal design in a way that would minimized the greenhouse gas emission. The energy requirement of buildings is categorized into embodied and operational energy. It is imperative to note that: energy is consumed in the production of building material; during construction; and operating the completed building especially for lighting, ventilation, heating and house appliances. Stephanie et al (2000) noted that manufacturing processes accounts for about 80% of industrial energy consumption with an equivalent energy related carbon emissions.

Building's embodied energy entails the cumulative energy consumed in the product's entire lifecycle, from the direct consumption during construction and assembly process to the indirect energy required during the manufacture of materials and components for specific buildings (Huberman and Pearlmutter, 2008). It therefore enumerates the energy used during extraction, transportation, processing/manufacture of a building product whose units of measurement are MJ/Kg, tCO_2/Kg. For instance, Buildings for Environmental and Economic Sustainability (BEES) database which is monitored by the National Institute for Standards and Technology's (NIST's), estimates the embodied energy for a common fired clay brick at 9.3 MJ. In the works of Dimoudi and Tompa (2008), building's operational energy entails the cumulative energy used in operating the environment inside the building upon completion of the construction phase. Moreover, the Life Cycle Analysis of building provides that operational energy constitutes 85-95% of the total energy consumption (Thormark, 2006) and associated Carbon

Dioxide Emissions of a building which is generated during the use especially heating, cooling, hot water heating and ventilation among other areas of application.

Various authors including Lenzen and Treloar (2002) established that products with lower embodied energies are more economical, easier to build with, and results into less environmental degradation. In related development and as a solution, UN-HABITAT (2015), propagates for development of green buildings that contributes to the reduction of both embodied and operational energy requirements. According to Moss (2006), the use of energy efficient technologies and materials when designing a building has been promoted by the proponents of built environment sustainability as an effective way of minimizing energy requirements thus prolonging the lifespan of buildings as well as providing environmental sustainability. It is however noted that conversion of energy measurement units (MJ) to Carbon emission equivalent (tCO_2) is not expressly automatic given that various forms of energy emits varying amounts of carbon dioxide. This study nevertheless was conducted to establish the contributions of building materials application in housing development on carbon sequestration levels of soil, water and forest cover within the study area.

2.9 Resource Efficiency of Building Technologies and Climate Change

This section focused on the comparison of building materials and technologies in terms of associated cost at construction level and social cost of greenhouse gas emissions as proxy to the estimation of climate change effects.

Buildings being the core of human settlement formations significantly contributes to the climate change effects. IFC (2017) noted that designing new buildings for greater efficiency is significant in reducing GHG emissions in a cost effective manner. The relationship between population growth, housing and energy are well illustrated in many governmental and non-governmental pronouncements. UN-HABITAT (2011) for instance, recognizes the global role played by built environment in the generation of GHG as one of the largest with residential and work places constituting a third of the energy consumption. With the current precarious status, failure to take action could either double or worsen the level of GHG as we edge towards 2030, being the global year designated for the realization of SDGs. The built environment nearly consumes 40% of energy, a situation which aggravates the climate change effects due to release of higher levels of GHG, particularly, CO_2 (UNEP, 2009).

The increase in anthropogenic GHG levels in recent past has been alarming with the period from 2000 to 2010 recording higher amount of about 10GtCO_{2eq} with contributions from buildings and the entire construction sector portion being 3% (IPCC, 2014). With the same kind of estimations, emission from buildings was projected to rise to 11.1 billion tonnes by 2020. In the Fourth Assessment Report done by UN-HABITAT (2011), IPCC approximated that between 1970 and 2004, GHG emissions due to anthropogenic activities increased by 70% (IPCC, 2007) with the manufacture of building materials contributing about 4 billion tonnes of CO_2 emissions annually. Further, in a comparative study on burnt bricks and Stabilized Soil Blocks in Malawi, it was established that stabilized soil blocks eliminates use of firewood thereby contributing to the protection of natural forests and avoidance of carbon dioxide emissions which in turn protects the Ozone layer (Malunga, 2013). Given the development disparity between the developed and developing countries, the compromise on soil, water and forest carbon sequestration services may be at different levels.

Alcorn and Wood (1998) demonstrated that embodied energy coefficient for building materials involves the analysis of several parameters with the commonest being: county of origin of the data; country of production of material / or inputs; size of the organization where data is produced from; political and market forces impacting on the organization where data is produced from; factors that influence the timeframe of data collection; the size of organization that generates the data sets; level of completeness of the data; nature of records and their completeness; age of the data; relevance of the time period of the data; consistency of time periods for different data component; level of detail of the data; representativeness of factory producing the data.

It is imperative to note that sustainability of a building / or housing as a form of shelter is greatly influenced by the environmental as well as socio-economic and cultural dimensions of the selected building materials and technologies. Use of locally available building materials with low embodied energy provides substantial benefits in decreasing the carbon footprint of buildings, especially in rapidly urbanizing regions where most of the building stock is yet to be built. Use of local materials can also contribute to the resiliency of settlements, as these materials tend to be well suited to the local climate, and can be conveniently altered and replaced using locally available resources. A research output by Sangori et al (2017) on performance of environmentally friendly building materials and technologies, it is instructive to note that of all the ABMTs under promotion in Kenya that ranges to about 18 in number (inclusive of both materials and technologies) less than 20% of Kenya-Specific data could be obtained, hence, it is hard to support any given level of performance of such materials. This particularly research noted the need to volunteer information on Environmental Product Declaration (EPD) in order to bridge the existing data gap that is being experienced in the adoption of various materials and technologies within the Kenya's built environment (Sangori et al., 2017).

However, a conscious choice of sustainable building materials in various global contexts can be made if adequate information on the carbon footprint and environmental impacts for different materials is available for said location. Creating of material Life-Cycle Inventory (LCI) databases of various construction materials is thus an effective way to define the sustainability of different materials. A comparative cost analysis by Guillaud et al (1985) notes that need to take into account several factors in the building economics processes. For instance, taking 1 m^2 of wall, it is observed that relying on the cost of blocks alone is not adequate as both feasibility of the stabilized soil blocks and socio-economic comparative advantages are factors of: cost of raw materials involving extraction, processing and transportation; labour factor for material processing and building / walling; kind of organization involved in the material application processes (CBOs, hired labour and contracting services); building system adopted for the structures and level of finishing (GATE/GTZ, 1985).

Further emphasis is put on the following key aspects; sourcing building materials which are appropriate in nature based on local availability; designing of buildings which are climatically adaptable, sustainable neighbourhood planning that takes into account the sustainable urban planning practices, adoption of renewable energy technologies, as well as development and application of green building rating systems (UN-Habitat, 2010). For instance, Bamboo is considered an environmentally friendly building material as its adoption and use in structural components, finishes, and construction methods is key in reducing greenhouse gas from the built environment

To understand the full impact of the building and construction sector in the climate change debate, there is need to examine the energy consumption in the manufacturing and production of the building materials used within the built environment. The study therefore became significant in providing insights to policy directions and strategies that various Governments' and other actors can embrace in sustaining the optimal carbon sequestration levels in the selected natural ecosystems and to reduce adverse effects of climate change that are associated with the built environment activities thus contributing to environmental sustainability.

2.10 The Adoption of Green Building Rating Tools

The green building rating tools depicts voluntary mechanisms used in the rating and certification of the environmental performance of buildings. According to UN-Habitat (2010), such tools incentivises building owners to go above what is required by government instituted regulatory requirement which in most instances define the baseline level of performance of buildings to be within the legal requirements. The WGBC (2016) notes that less than 1% of buildings exhibits potential of net zero carbon, a situation which is far from the 100% desirable levels of net zero carbon status by 2050. The market trajectory is set for a revolutionary path given the paradigm shift being experienced in the building sector where voluntary actions towards net zero certifications having been enhanced with the current global certification reaching a record 1 billion square metres of green building space (WGBC, 2016).

There are different kinds of tools which are essential in providing criteria for the selection of suitable materials and technologies to enhance environmental sustainability in terms of resource efficiency, social and cultural performance. These tools and techniques were evaluated by the experts in the building industry and they included the following: Life Cycle Assessment (LCA); Multi-Criteria Analysis (MCA); Environmental Product declaration (EPD); Environmental Preference Method (EPM); Building for Environmental Economic Sustainability (BEES); Leadership in Energy & Environmental Design (LEED); Environmental Assessment Method (BREEAM); British Research Establishment (BRE) ATHENA™ Impact Estimator for Buildings; Green Star Rating System; Building Environment Assessment Tool (BEAT 2001); EDGE Green Building Certification System GreenMark Rating System; and Climate Action for Urban Sustainability (CURB) Tool.

The certification tools have been used in varying degree. For instance, the Australian-based Green Star has necessitated certification of approximately 30% of Office Space within Australia's CBD with such buildings providing 62% fewer GHG emission than the average buildings (GBCSA, 2014). The leading certification tool (LEED) recorded a remarkable improvement since inception in 2000 with over 46,600 and 121,900 projects and residential housing units certified respectively by 2015 (USGBC, 2015). It is further observed that about 1,250 commercial buildings were certified and joined the league of green buildings in Germany (BNP, 2016).

The African Continent recorded over 700 certified green buildings with dominant rating tools being Green Star, LEED and EDGE rating systems. The certification trends for the continent is set to be on an upward trajectory due to regulatory reforms (Knight Frank, 2021). For instance, Rwanda is strictly adhering to the implementation of Rwanda Green Building Minimum Compliance Standards for all new commercial developments in the Country while the launch of Eco-Communities & Cities National Framework in Ghana has led to the growth of green buildings in the Country, and the adoption of National Sustainable Development Strategy of Morocco has seen increased growth and uptake of green buildings since the strategy was adopted as a national priority by the Government of Morocco (Knight Frank, 2021). Table 2.3 shows leading countries in green building certification in Africa.

Table 2.3: Leading Countries in Green Building Certification in Africa

S/No	Country	No. of Certified Green Buildings By 2021
1.	South Africa	641
2.	Egypt	22
3.	Kenya	21
4.	Senegal	21
5.	Nigeria	20
6.	Ghana	10
7.	Morocco	9
8.	Namibia	6

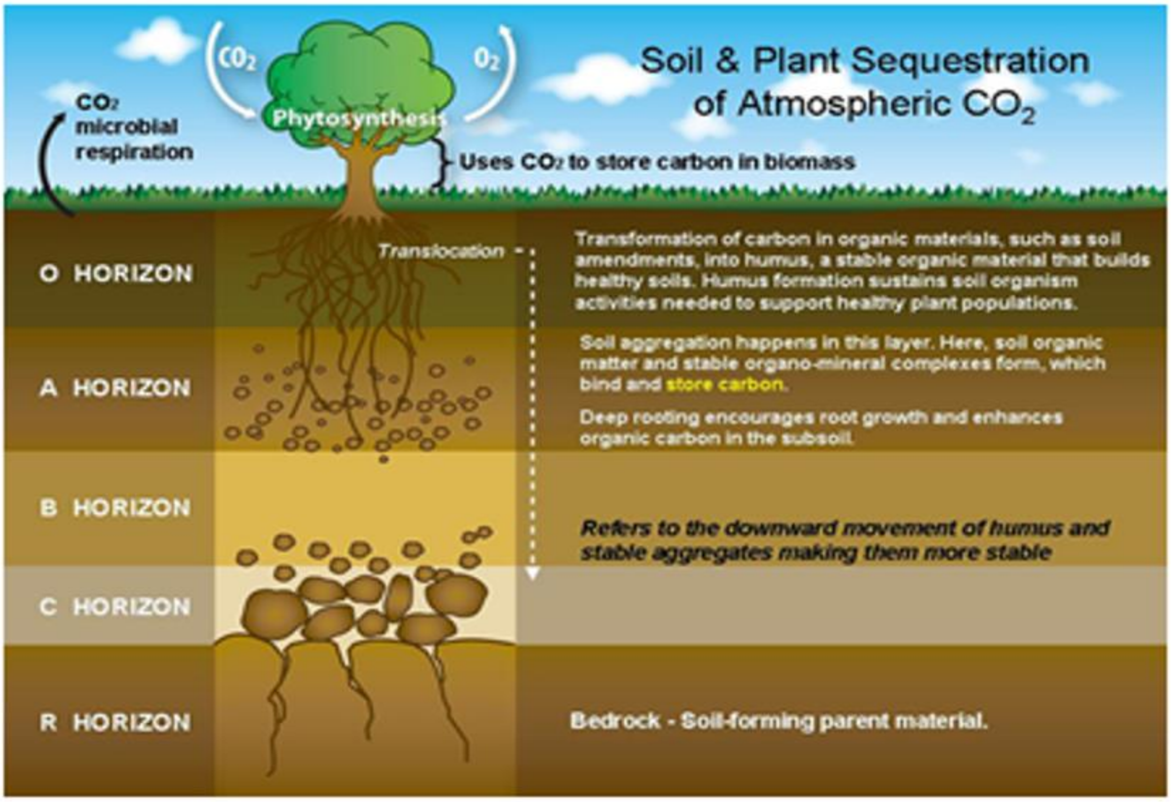
Source: Knight Frank, 2021

The growth and uptake of green buildings is further enhanced by availability of various financial products and instruments that are provided by investors and financial institutions global, regional, national and local levels. According to Stockholm Sustainable Finance Centre (2019) green bonds worth over 2 billion USD were in circulation in the Africa Continent. Key projects targeted by such financing facilities included Acorn Holdings Green Bond that targeted delivery of student accommodation / hostels in Kenya and the green mortgage credit line by Housing Finance to the tune of over 20 million USD for Kenyan Investors (Knight Frank, 2021).

2.11 Carbon Sequestration and Greenhouse Gas Emission (GHG)

Carbon sequestration is the long term storage of carbon in various medium including oceans, vegetation, soils, and geological strata (ESA, 2000). The sequestration processes are aided by some media within various ecosystems. Reid et al. (2005) defines an ecosystem as a dynamic complex of plant, animal and micro-organism communities, and the non-living environment, interacting as a functional unit. Such ecosystems include; soil, water and forest/tree cover which serve as the ultimate carbon sequestration medium thus significantly contributing to climate regulation in the study area. Occurrence of some natural processes such as photosynthesis leads to assimilation of carbon with some proportions being returned through respiration. Figure 2.7 depicts the natural processes of Carbon Sequestration.

Figure 2.7: Soil and Plant Sequestration of Atmospheric CO_2

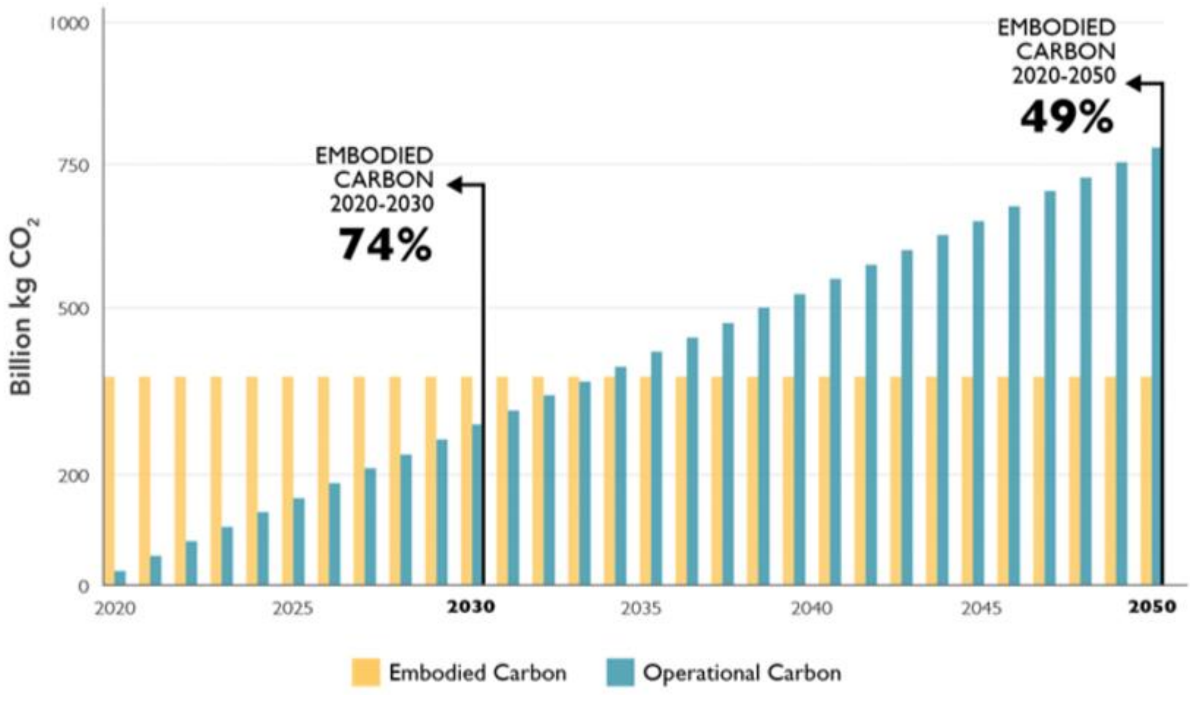


Source: ENVIS Centre, 2011

The ENVIS Centre (2011) demonstrates that disturbance of natural resources and processes relating to soil and tree / or forest cover consequently affects the respiration and the terrestrial carbon sequestration. Through photosynthesis, CO2 is assimilated from the atmosphere with other fractions of CO2 getting cycled through vegetation roots as well as CO2 storage in the soil.

The IPCC (2007) Report detailed that during the 21st C, the resilience of many ecosystems in supporting human settlement is expected to be exceeded by an unprecedented combination of change in climate, associated disturbances and other global change drivers notably; land-use change, pollution and over-exploitation of resources if greenhouse gas emissions are aggravated. Just as being set out for demonstration by this study, it is globally observed that the building and construction sector is responsible for high levels of pollution due to energy consumed in the extraction, transportation, and processing of the raw building materials (Holton et al, 2008).

Figure 2.8: Carbon Emissions of Global New Construction from 2020-2050



Source: UNEP, 2017

The quantification and comparison of the effects of carbon sequestration and storage in buildings taking cognizance of life cycle approaches involves the evaluation of flows and processes which takes place at different timescales and across ecological, technological and economic spheres. Such contributions are pegged on the level of interests in materials, buildings and building stock or sequestration mechanisms involving photosynthesis and carbonation, or the accounting methodology used in quantification of the global warming. Figure 2.8 demonstrates the global embodied carbon in buildings

A major anthropogenic action with far reaching consequences on forest cover is deforestation which has been found to account for 20% of global annual greenhouse gas emissions (IPCC, 2007). This has been necessitated by demand for energy being a key contributor of deforestation and consequently land degradation in Kenya, where final delivered biomass energy constitutes 78% of energy consumed (GoK, 2002). The research was conducted to establish the impact of dominant building materials extraction and manufacturing processes on carbon sequestration of key ecosystems within the study area notably soil, water and forest cover.

2.12 Building Sector Guiding Policies and Regulatory Frameworks

2.12.1 Introduction

The policies and regulatory frameworks are quite significance in the determination of the various types of building materials and technologies that are used in the construction and building sector. Such policies, laws and regulations dictate the environment in which different categories of material and related technologies are applicable, particularly, in the urban and rural areas. Some of the policies and regulatory frameworks that governs the built environment sector in Kenya include; National Urban Development Policy (2016); National Climate Change Act (2016); National Environment Management Authority (1999); National Climate Change Response strategy (2010); National Housing Policy 2004 (Revised 2016); National Adaptation Plan for Kenya (2018); National Construction Authority Act (2011), National Slum Upgrading and Prevention Policy (2016); National Building Maintenance Policy (2015; Urban Areas and Cities Act (2011); National Building Regulations (2009); County Government Act (2012);

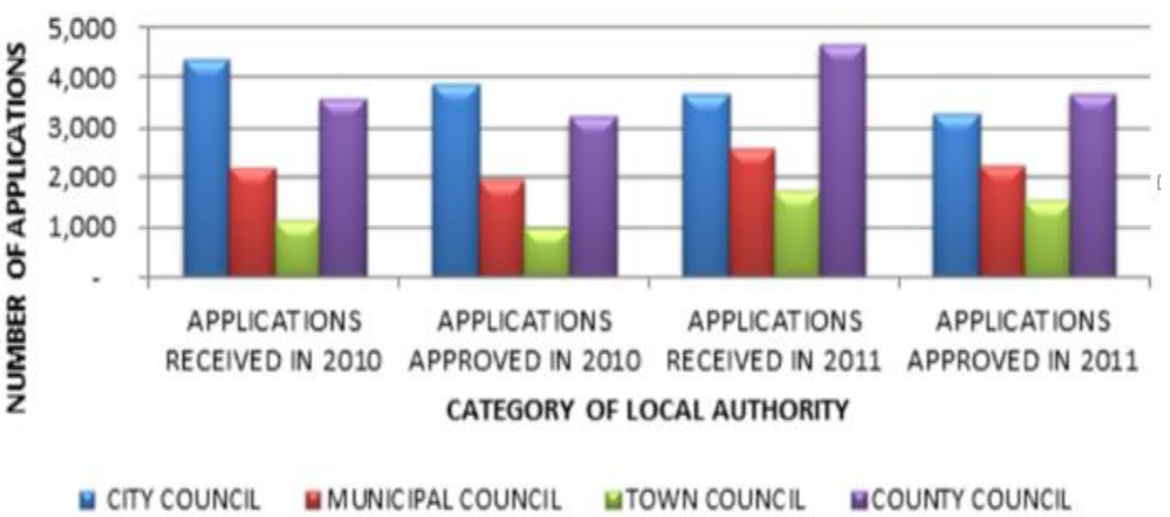
Prior to the promulgation of the Constitution of Kenya (CoK, 2010) which ushered in a paradigm shift in governance structure in Kenya by creating 48 Governments (One National Government and 47 County Governments), the implementation of these policies were largely supported by the then defunct local authorities which operated under the repealed local Government Act. Cap 265. Such local authorities included city, municipal, town, and county councils. Whereas the city, municipal and town councils operated within the urban jurisdiction, the county council's activities covered rural areas and the small urban settlements within their areas of jurisdiction. In the current dispensation under the Constitution of Kenya (2010), the Urban Areas and Cities Acts, 2011 (Amendment, 2019) provides for delineation, classification and establishment of urban institutions under four categories, namely: cities, municipalities, towns and market centres with minimum population of 250,000, 50,000, 10,000 and 2,000 respectively (UACA, 2019). These functions have therefore been taken over and performed by the County Government.

Kenya Vision 2030 aims to make Kenya a middle income Country by 2030 and provides for sustainable Urbanization pathways in the Country. On the other hand, the Big Four Agenda pillar on Sustainable Urban Development and Affordable Housing is a transformative agenda which focuses on meeting the housing demand of the populace including provision of urban infrastructure and services for urban residents in a sustainable manner. In the plan period (2018-2022), the Government prioritized research and development on ABMT which entails collaborative research, documentation and technology transfer on building and construction materials, including training of 20,000 new trainees on ABMT; dissemination of ABMTs; and development of 20 Appropriate Building Materials and Technology (ABMT) Centres. Research in Appropriate Building Technologies as propagated by the government of Kenya aims at conducting research and disseminating findings on appropriate technologies; Key research areas identified in vision 2030 (MTP II) included; brick / soil based materials, natural stones, cement-based materials, wood-based materials, indigenous roofing materials, soil-based products of interlocking nature, and prefabricated buildings among others.

Sessional Paper No.3 of 2016 on National Housing Policy for Kenya provides for facilitation of affordable housing which is adequate and costs not more than 30% of the household income per month to rent or acquire. Such housing situation also covers basic infrastructure including access roads, water supply, sanitation, ICT connectivity, electricity and waste management facilities. The efforts to meeting the affordable housing needs in a sustainable environment is expected to integrate green architecture with minimal use of non-renewable and / or polluting materials and resources in construction and use of the facility (GoK, 2016).

PLUPA (2019) provides for development control and building approval processes in urban, peri-urban and rural areas where such development processes and activities are required to be subjected to the approval processes and issuance of development permission. According to PLUPA (2019), the planning authority is vested in the Cabinet Secretary for Lands and County Executive Committee Member for Lands in case of National and County Government respectively. The development control objectives as envisaged by PLUPA (2019), UACA, 2011 (Amendment Act, 2019) and County Government Act (2012) is to; create orderly physical and land use development, promotion and conservation of the environment, ensuring public safety and health, and realization of orderly and planned building development, planning, design, construction, operations and maintenance. Within seven days upon receipt of development application, the CECM is expected to circulate the same to relevant Departments for views including; land survey, roads and transport, agriculture and livestock, Health, public works and utilities, environment and natural resources, urban development, national security in respect of land adjoining or within reasonable vicinity of safeguarding areas, and any other relevant authority (PLUPA, 2019). The window period for review and receiving comments from lead agencies is 14 days, and where no written response for development permission is received within sixty days, such permission shall be assumed to have been given as per the law. GoK (2013) indicated that more housing development plans were received and approved for the period of 2010 and 2011 in the Cities followed by County councils as depicted in the Figure 2.9

Figure 2.9 Building Plan Approvals in Kenya

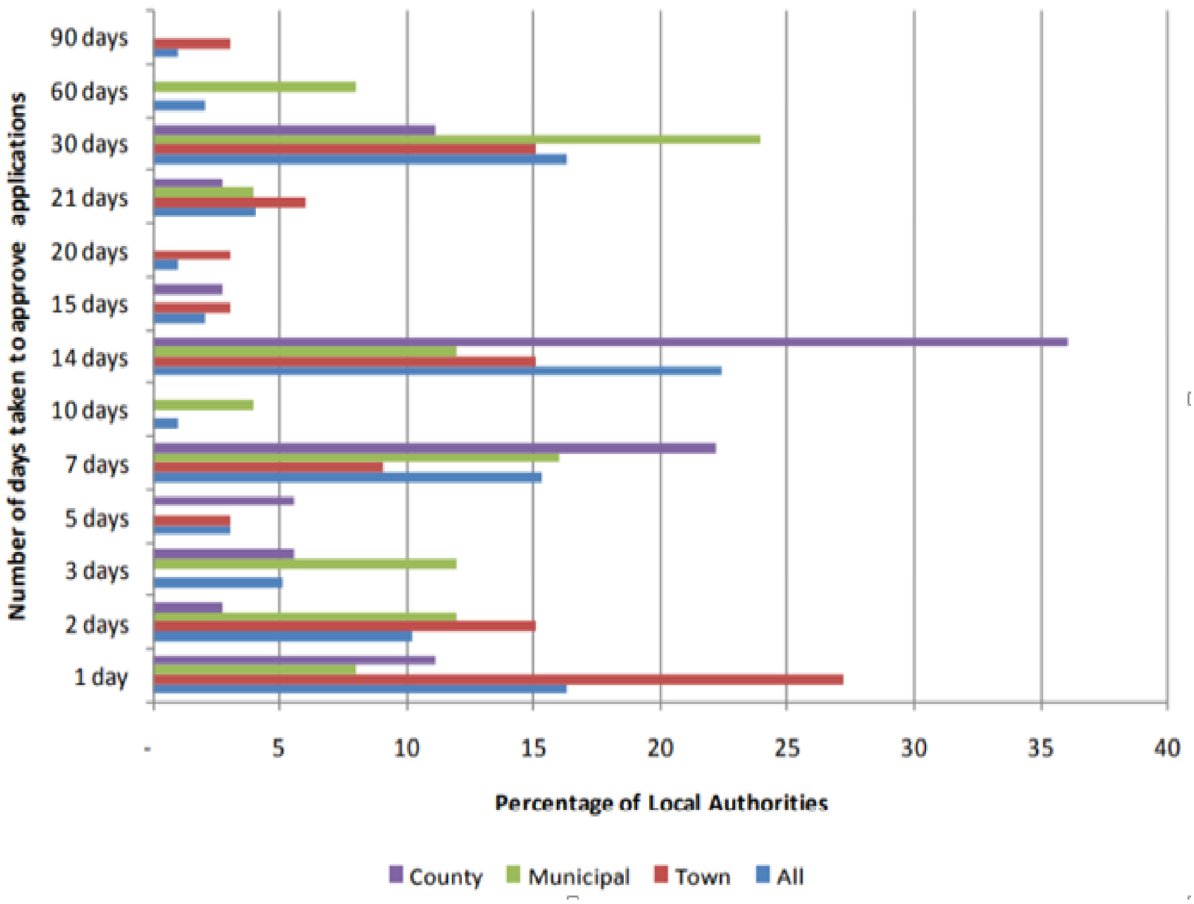


Source: GoK (2013)

The time taken for building approvals as detailed in the Kenya National Housing Survey (2012/2013) ranged from 1 to 90 days to approve building plans by various urban institutions. For instance, town councils took less number of days between 1 and 2 days to approve building plans. The scenario of plan approvals is demonstrated in Figure2.10.

The Kenya National Housing Survey (2013) further provided some reasons as to why approving authorities would decline some building plans submitted for development permission as: insufficient services such as sewerage and water utilities, plot ratio, existing zoning regulations, use of unregistered professionals, conflict with current user, conflict with the existing local physical development, failure to clear annual land rates, conflict over ownership especially where dispute exists among others.

Figure 2.10: Time Taken to Approve Building Plans



Source: GoK, 2013

2.13 International Obligation and Commitments on Promotion of Green Buildings

Kenya is party to several international obligation and commitments whose implementations are key towards the realization of sustainable building practices including mainstreaming green building practices in the built environment development processes. Such obligation includes: Agenda 2030 on Sustainable Development Goals (SDGs); Agenda 2050 (WBCSD); the African Agenda 2063 and New Urban Agenda (NUA, 2016); Paris Agreement (COP21).

Agenda 2030 on SDGs provides for the integration of 2 aspects of SDG 11 (indicator 11.1.1) to make it universal as it helps to capture housing conditions in both developed and developing countries thus addressing the fundamental principle of LEAVE NO ONE BEHIND (UN-Habitat, 2016). The aspects of this indicator are: slum formation and informality in developing countries, and the aspects of inadequate housing which is associated with developed countries. On the other hand, SDG 11 (indicator 11.c.1) focuses on utilization and manufacture of local sustainable building materials in LDCs. The entire lifecycle of such materials including production; extraction of the raw materials, manufacturing into ready building products, trading, application of building products and recycling / end-of-life usually takes place within the same region, that is location specific in nature (SDG Indicator 11.c.1). Housing development has a close linkage to local economy as residential construction contributes between 7% and 10% of the total labour force in developing economies, hence the relative use of local building materials and resources in the construction industry greatly impacts positively on the local economies of LDCs. Further, the development of local sustainable building materials and technologies have potential ripple effects on associated retail and consulting industries. Table 2.4 shows the linkages between built environment and SDGs.

Table 2.4: Built Environment Linkages with SDGs

SDGs	Particulars	Linkages with the Built Environment
1.	Ending poverty including all forms of poverty situations everywhere.	Promotion of local building materials creates economic empowerment and livelihood improvement
2.	Ending hunger, achieving food security and improving nutrition as well as promotion of sustainable agriculture.	Adoption of sustainable building materials leads to harmonious existence of the natural ecosystems thereby enhancing agricultural productivity.

SDGs	Particulars	Linkages with the Built Environment
3.	Ensuring healthy lives and promoting well-being for the age cohorts.	Provision of adequate and quality housing, and sustainable urbanization is key towards maintaining good health of the population
4.	Ensure inclusive and equitable quality education and promote lifelong learning opportunities	Realization of affordable housing within 30 per cent of the household incomes enables the households to meet other needs like education.
5.	Achieve gender equality and empower all women and girls	Improvement of settlements and living conditions especially in slums and informal settlements provides opportunity for prosperity of all gender and other vulnerable groups in society.
6.	Ensure availability and sustainable management of water and sanitation for all	Sustainable housing design and integration of energy and resource efficiency technologies like water saving equipment / infrastructure contributes to sustainability in the water sector.
7.	Ensure access to affordable, reliable, sustainable and modern energy for all	Integration of green building practices including use of renewable energy technologies is significant towards sustainability in the energy sector
8.	Promote, inclusive and sustainable economic growth, full and productive employment and decent work for all	Promotion of local building materials and technologies increases employment opportunities and enhances inclusivity among residents.
9.	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation	Adoption of emerging building technologies enhances innovation in the building industry making the industry more resilience.
10.	Reduce inequality within and among countries	Promotion of sustainable urbanization is key to reducing inequality among the 47 Counties in Kenya.
11.	Make cities and human settlements inclusive, safe, resilient and sustainable	Facilitating preparation of climate resilience spatial plans and mainstreaming use of appropriate building materials and technologies enhanced inclusivity, safety, resilience and sustainability in Cities and Human Settlements.
12.	Ensure sustainable consumption and production patterns	Use of local building materials in a sustainable manner contributes to realization of healthy environment.
13.	Take urgent action to combat climate change and its impacts	Addressing the issues of cities and climate change, given that cities have causal effect but

SDGs	Particulars	Linkages with the Built Environment
		at the same time bore the brunt of adverse effects of climate change
14.	Conserve and sustainably use the oceans, seas and marine resources for sustainable development	Sustainable use of building materials from the coastal region is key towards achieving sustainability within the oceans, seas and marine resources.
15.	Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt biodiversity loss	Application of local building materials and enforcement of development control is key in the protection and restoration of terrestrial ecosystems including forests.
16.	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels	Economic empowerment and livelihood improvement for urban dwellers and other households across the country is key towards realization of peaceful and inclusive societies.
17.	Strengthen the means of implementation and revitalize the global partnership for sustainable development	Successful facilitation of affordable housing delivery and sustainable urbanization relies on the level of participation of potential partners and other relevant stakeholders.

Source: Modified from UN-Habitat, 2016

Agenda 2063 on the Africa We Want, Particularly, towards a Prosperous Africa, based on Inclusive Growth and Sustainable Development. The African Agenda is a strategic framework for the socio-economic transformation of the continent over the next 50 years with a guiding vision of “an integrated, prosperous and peaceful Africa, driven by its own citizens and representing a dynamic force in international arena”. The aspirations of Agenda (2063) provides for an African Continent that prioritizes its people within the development context including the youths. This is critical in the realization of sustainability within the built environment given that most locally-based building materials and technologies which are associated with sustainability principles find much favour with the youthful population that is abundant within the continent. For the first time in history, the Paris Agreement (COP21) of 2015 recognized the crucial role buildings play in climate change mitigation and adaptation processes including sustainable neighbourhood planning. Further, Agenda 2050 by the World Business Council for Sustainable Development envisions a world of 9 Billion people living well in smarter buildings with net-zero energy usage.

2.14 Climate Change Adaptation Mechanisms in the Built Environment

Climate change has indeed reached unprecedented levels as observed by various scientists and renowned scholars. For instance, Odingo (2009) observed that climate change would make it impossible for the World to realize the Millennium Development Goals (MDGs) thereby leading to increased poverty with food security situation worsening. According UNEP (2011), adaptation to climate change involve social and institutional learning in addition to outcomes or options to respond to climate projections with effective adaptation equipping people and institutions with various contingencies. In Kenya, existence of climate variability is associated with economic costs as depicted by sporadic floods and droughts with massive macro-economic costs which impedes economic growth as happened with droughts of 1998-2000, 2004/2005 and in 2009 as well as major floods of 1997/98 and 2006 (SEI, 2009). Moreover, the impacts of climate change witnessed between 1998 and 2000 events had an estimated economic cost of $2.8 billion ranging from: the loss of crops and livestock, forest fires, damage to fisheries, reduced hydro-power, reduced industrial outputs, unreliable and reduced water supply and overall environmental degradation.

The cost associated with the effects of climate change is felt in the built environment with equal measure and innovative adaptive ways are sought for the adverse contributions from the built environment sector towards climate change to be minimized. The NCA (2020) draft building code provides for the adoption of locally available construction materials that exhibits low embodied energy; sustainably exploited and re-cycling potentials as a way of enhancing adaptation in the sector.

2.15 Summary of Literature on Major findings

Chapter 2 of the study discussed the current issues of research and their state with regard to building technologies, embodied energy requirement, state of atmospheric greenhouse gas (carbon dioxide) and resultant climate change relationship among related areas.

The review of the literature in this study revealed that there was inadequate research in the subject matter especially in the developing countries context where Kenya and the African continent belong at present. Although climate change may not be a new phenomenon given that changes in atmospheric CO_2 manifested as early as 1896 (Kininmonth, 2003), the challenge has been the less traction given to the built environment’s contribution to the processes leading to climate change, a situation which the current study seeks to address.

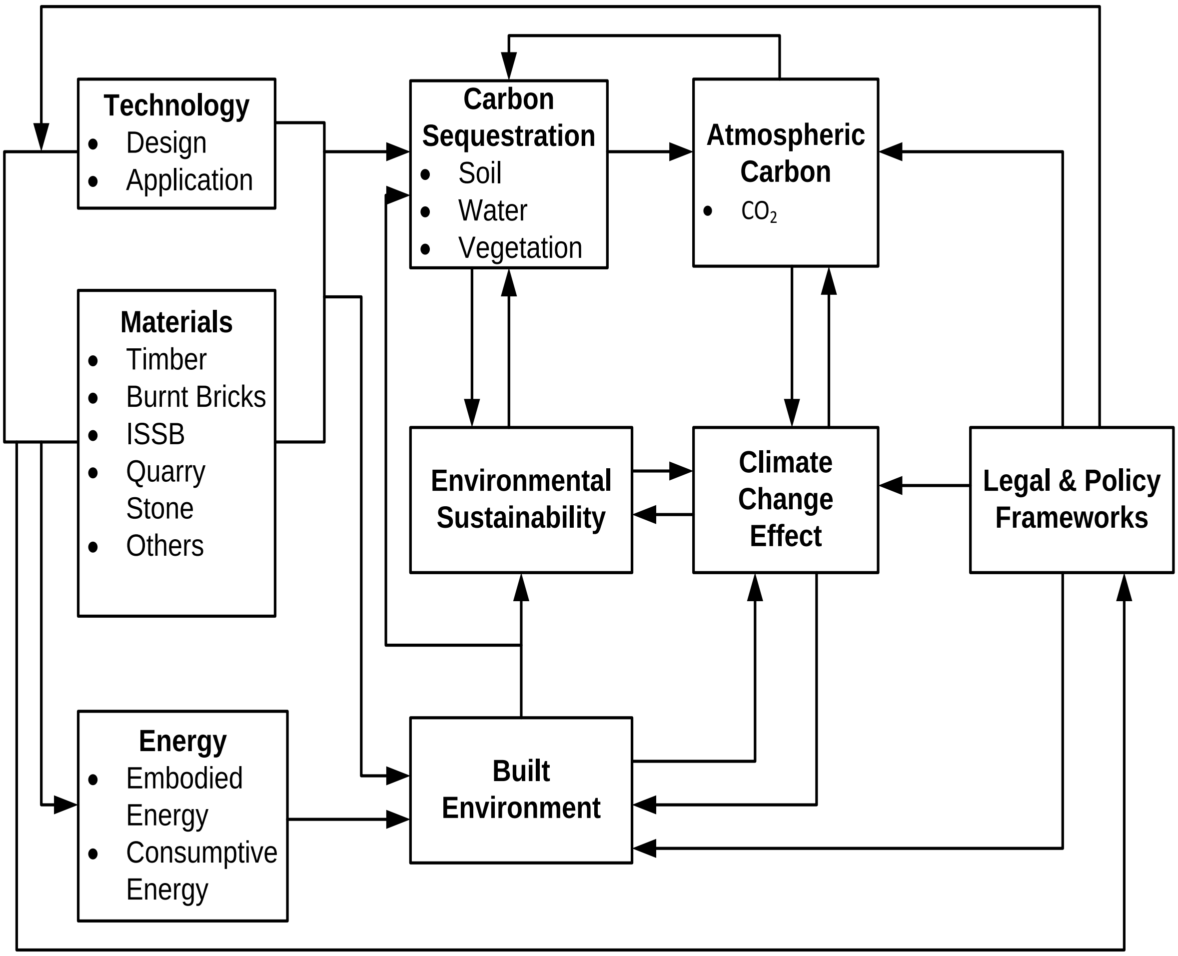
A look at the national development focus and strategies for Kenya note the development of several policy instruments which commenced with the Kenya Vision 2030, the Kenya Constitution (2010) and MTP II & III which provides frameworks for development in a sustainable pathway. The literature further notes that key climate action documents that serve both short and long term climate actions for Kenya including NCCAP (2018-2022) and the enhanced NDC for year 2020 are largely inadequate on the aspects data for the built environment. The is significant in providing data to aid reporting on the progress towards the implementation of Paris Agreement (2015) and the development of long term low GHG development strategy (GIZ, 2021) for the built environment sector.

A Study by Alshboulet al (2008) focused on cost in building industry in Jordan while tracking production processes of quarry stone from extraction, transportation, sawing and finishing. The results were on embodied energy of dimensioned stone, which in essence is low as main preparatory process involve quarrying and cutting / or dressing, a situation that may not reflect full contributions of building materials to adverse climate change effects. Huberman and Pearlmuter (2008) in their research conducted in Negev desert area, being one of the regions of Southern Israel, identified building materials which optimizes building’s energy requirements over the entire life cycle by comparing actual material composition and possible alternatives with result indicating that embodied energy of the building accounts for about 60% of the overall life cycle energy consumption. This particular study however did not provide impacts of building materials on carbon sequestration levels of soil, water and forest cover which is a key pillar of this study.

In his study, Malunga (2013) undertook a comparative study on Stabilized Soil Blocks (SSB) and burnt bricks involving survey of seven nursing homes in Malawi. The major findings of this study is that SSBs contributes to forest protection as application of firewood is avoided but the contributions to climate change by way of interlocking techniques was however not provided. In related studies, Sangori (2012) focused on the environmental impacts of Hydraform Interlocking Stabilized Soil Blocks (ISSB) as a sustainable building material which was however limited to one particular product while Hashemi et al (2015) noted the limited number of embodied energy studies on walling materials in Africa as the study pointed out that “almost all available studies on Life Cycle Assessment and embodied energy are from developed Countries leaving no case studies in African Countries.

2.16 The Conceptual Framework

Figure 2.11 Conceptual Framework



Source: Author (2020)

The conceptual framework presents a relationship that exists in the building technologies and associated energy levels on the one hand and the environmental sustainability including effects on carbon sequestration and climate change on the other hand. It underpins the philosophy of a holistic integration of environmental planning within the framework of built environment and associated activities. The major theory advanced in this study, is that adoption of energy efficient building technologies leads to increased carbon sequestration which in turn yields low atmospheric carbon with the overall contributions towards climate change mitigation / or minimized global warming effects. The resultant interventions are achieved through the right policies / sustainable building policies and regulations.

The carbon sequestration is in relation to the ability of the natural ecosystems towards carbon storage including maintenance of global minimum tree cover at 10%, less disruption of the soil / or reduced burrows during building materials extraction and minimal water use through consumption and reduced wastages during building materials manufacture and construction stages while building energy scenarios in this study focused on the estimation of embodied energy of building materials in relation to the extraction, manufacturing and transportation aspects. Housing / buildings being at the core of this analysis, is influenced by the available materials and technologies. Such materials and technologies impacts on the carbon sequestration levels of the natural ecosystems either positively or negatively. The negative impacts associated with use of the building technologies has the potential of lowering the natural ability of the various ecosystems to store carbon which ultimately affects the climate change aspects in a negative way. On the other hand, application of energy efficient building technologies has the advantage of positively impacting on the carbon sequestration levels of the ecosystem thereby positively impacting on the climate change.

Further, the embodied energy of both the building materials and technologies adopted in the production and/or extraction of local building materials were assessed vis-à-vis the energy requirement and associated carbon sequestration levels in soil, water and forest cover. The study however excluded the contributions associated with geological strata. In this study the dependant variable was climate change which is measured in terms of greenhouse gas emission levels but is represented by carbon dioxide emission equivalent while building technology comprising of applicable technologies and materials for housing development depicted the independent variable and is measured in terms of energy consumed during the full building material life cycle. The application of the building technologies can either have a negative effects of carbon sequestration levels of ecosystem relating to soil, water and forest/tree cover, the consequence of which results into higher GHG emissions. This may lead to increased level of CO_2 that affects the atmospheric ozone layer thereby exacerbating the negative effects of climate change further leading to environmental degradation which manifest in various forms including erratic flooding, extreme drought and famine, unpredictable cyclones and rise in sea levels among other extreme phenomena. The conceptual framework also foresees same effects due to direct impact of the built environment as a results of unsustainable extraction of the building materials. The environmental degradation negatively affects human habitation leading to high social cost of pollution which impact negatively on the GDP.

To understand the full scope of the relationship between the building technologies and climate change, the legislative framework in practice which guides the building approval processes forms the intervening variable. By adopting energy efficient and other environmentally friendly building regulations and approval processes has the potential of enhancing the carbon sequestration levels of the environment. However, the continued application of regulations and policies that only recognizes application of conventional building materials and technologies will lead to lowering the carbon sequestration levels of ecosystems thus resulting into continued aggravation of negative climate change impacts.

Building's embodied energy entails the sum total of energy consumed in the product's entire lifecycle with Carbon dioxide as the main by-product of energy consumption. In this study Consumptive energy also refers to operational energy which is the energy used in the post construction stage of the building. This include but not limited to energy used for lighting, cooling, heating, consumption by appliances and other domestic energy requirement. This level of energy also depends on the energy efficient building design that integrates passive building designs while incorporating natural lighting, building orientation in terms of east-west or north-south directions. This study was limited to the embodied energy analysis since the experimental design did not cover the post construction building performance in terms of energy requirement. The institutions that are involved in coordinating material use and housing development processes comprised the intervening variable with the effectiveness of such institutional set up being an integral part of this study.

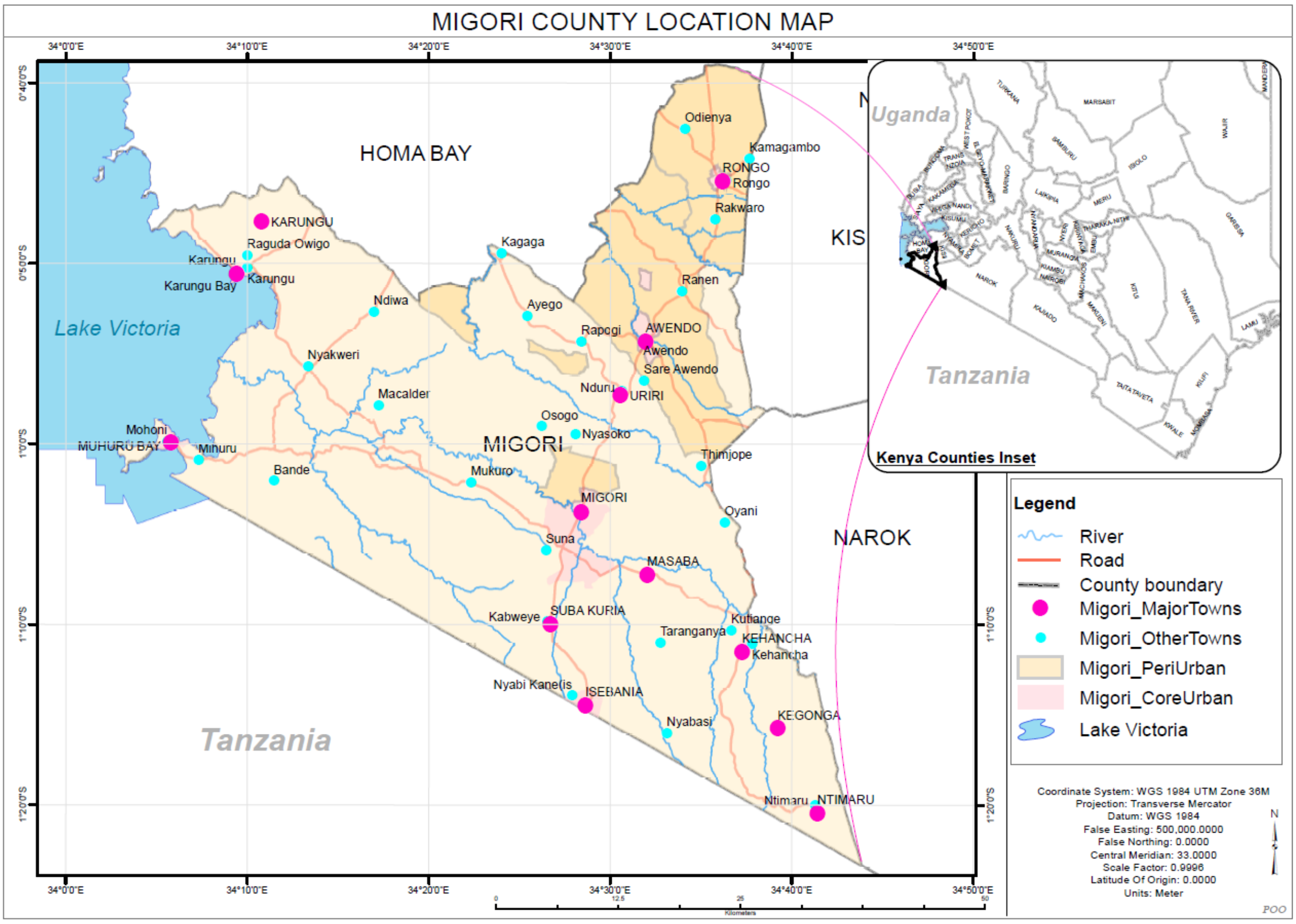
In this study framework, the environmental sustainability is achieved through the optimum application of energy efficient building technologies and building materials coupled with sustainable built environment leading to acceptable carbon sequestration with either minimal or inconsequential adverse climate change effects that does not impact human habitation negatively in terms of social cost of pollution. The balance on carbon sequestration levels exhibited by soil, water and forest / tree cover is used to demonstrate low levels of atmospheric greenhouse gas emissions (CO_2) from built environment activities given that the GHG has been taken as proxy to the climate change measure.

3 STUDY AREA

3.1 Location.

The main study area was Migori which is one of the 47 Counties in Kenya as depicted by the location map in Figure 3.1.

Figure 3.1 Location of Migori County in the Kenyan Map.



Source: Modified from KNBS, 2019

The research also relied on data from other areas which had direct association in housing delivery / construction processes within the study area to complement the data sources as set *a priori*. These sites included; Homa Bay, Kisii, Nyamira, Kericho and Kiambu counties. Table 3.1 provides the area in km^2 of the study area by sub-county and wards being the administrative and political jurisdictions respectively.

Table 3.1Area by Sub-County and Ward

S/No	Sub-County	Ward	Area in Km^2
1.	Rongo		**208.40**
		North Kamagambo	46.40
		Central Kamagambo	29.10
		East Kamagambo	63.90
		South Kamagambo	69.00
2.	Awendo		**261.90**
		North Sakwa	53.90
		South Sakwa	108.80
		West Sakwa	54.30
		Central Sakwa	44.90
3.	Suna East		**207.30**
		God Jope	42.50
		Central Suna	27.70
		Kakrao	94.80
		Kwa	42.30
4.	Suna West		**282.80**
		Wiga	103.60
		Wasweta II	54.80
		Ragana – Oruba	30.30
		Wasimbete	94.10
5.	Uriri		**380.70**
		West Kanyamkago	107.60
		North Kanyamkago	110.30
		Central Kanyamkago	57.40
		South Kanyamkago	69.70
		East Kanyamkago	35.70
6.	Nyatike		**677.70**
		Kachieng	56.00
		Kanyasa	83.20
		North Kadem	204.70
		Kanyarwanda / Macalder	136.40
		Kaler	58.70
		Got Kachola	93.90
		Muhuru	44.80
7.	Kuria West		**317.20**
		Bukira East	34.20
		Bukira Central / Ikerege	31.40
		Isibania	5.30
		Makerero	30.60
		Masaba	88.80
		Tagare	54.10
		Nyamosense / Komosoko	72.50
8.	Kuria East		**240.50**
		Gokeharaka / Getambweka	52.50
		Ntimaru West	33.80
		Ntimaru East	20.30
		Nyabasi East	57.00
		Nyabasi West	76.90

Source: Migori County CIDP (2018-2022)

Migori County border Lake Victoria whose basin is situated between latitudes $1^0$16'N and $1^0$54'S and longitudes $33^0$55'E and $35^0$51'E. It is located between latitude 0^o24 South and 0^o40` South and longitude $34^o$E and $34^o$50`E covering total area of 2,596.5Km^2 including approximately 478Km^2 of water surface CIDP (2013). The Lake Basin total area in the Eastern Africa Region covers about 68,000 Km^2 and spans 400 Km North-South and 240Km East-West.

On the Kenyan territory, only 6% of the lake surface exists while the portion of the Lake in Tanzania and Uganda comprises of 51% and 43% respectively (LVEMP, 2005). The land catchment area is wide at about 193,000Km^2 with the catchment on the Kenya side being 42,460Km^2. Lake Victoria Basin and the catchment on the Kenyan side covers an area of about 38,913 Km^2 out of which 4,113 Km^2 comprises the Lake surface area. Migori comprises of a population of 1,116,436 (KNBS, 2019). The Lake ecosystem is quite significant to this locality as the livelihoods of most inhabitants depend both directly or indirectly on its sustainability. The study is therefore, timely given the importance of the topic in the current climate change debate both at the national, regional and global levels.

The present study area was a suitable choice due to the fact that it exhibits several landforms, agro-ecological and bio-climatic conditions, particularly, the modified equatorial climate as well as arid and semi-arid conditions. Such prevailing conditions are key in providing valuable information for reliability throughout the project area as well as basic data for similar study elsewhere in Kenya, and where applicable, globally. Further considerations of Migori as a suitable research location in this study was due to: the existence of distinct rural and urban population which is appropriate for study comparison in terms of obtaining the predominant building materials; the homogeneity within the sampled wards of urban and rural nature as a representative of developing country (Kenya) which provides a basis for generalization of the study findings; the prevailing conducive soils which are fit for experimental study as well as close proximity of forests ecosystems; familiarity with the study area, language, culture and history of the area making it easier to coordinate and conduct the research with ease; the cost of undertaking research played a significant role given the low cost due to proximity to the home area, availability of experience research assistants and ease of accessibility by supervisors to the research area; and ready support by policy implementers at the county level (Particularly, the Department of Housing in Migori and Kehancha GK Prisons) by collaborating in experimental design and application of ISSBs within the study area.

3.2 Physiographic Conditions

3.2.1 Geology and Soil

The Geological derivation of the study area is mostly from ancient Precambrian Rocks, with small areas of Tertiary volcanic and Sediments in the North West as well as Quaternary Sediments along Lake Victoria. A report of a study commissioned by the Government of Kenya, GoK (1975) demonstrated that over 80% of the total area is composed of soils derived from two main series of ancient rocks, the Kavirondarian and Nyanzian Volcanic North of the Migori River; and Intrusive Rocks that mainly comprised Granites with some dolerite dykes south of River Migori. It is further established that the topography of the study area is characterized by "relatively acid" parent rock and granite covering the Sub-Counties of Nyatike, Migori, Kuria East, parts of Rongo and Kuria West Sub-Counties. The rest of the sub-counties are however covered by the Nyanzian and Bukoban rocks. Table 3.2 depicts the existence of numerous undulating hills that characterizes the landscape of the area of study;

Table 3.2: Existing Hills within the Landscape of Migori

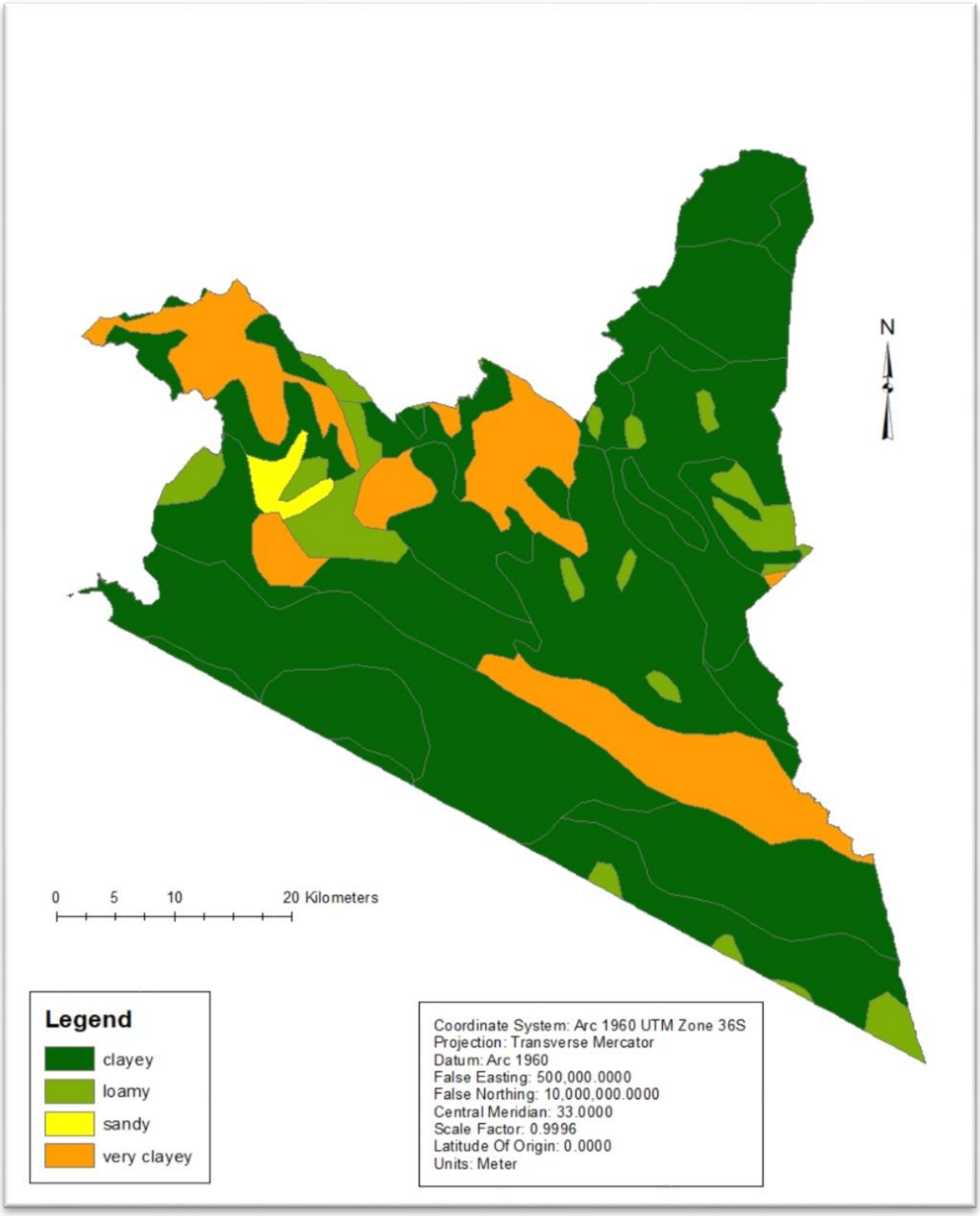
S/No	Hill	Height (M)	Sub-County
1.	Nyakunde	4625	Uriri
2.	Ogengo	4300	
3.	God Sibwoche	1475	
4.	God Kwer	1420	Nyatike
5.	Mukuro	1454	
6.	Nyabisawa	1489	
7.	God Kwach	1340	
8.	Renjoka	1592	Kuria West
9.	Maeta	1733	Kuria East

Source: GoK, 1975

In terms of physiographic conditions, Migori County lacks volcanic rocks a situation which contributes to residents travelling long distances to access preference building materials of volcanic nature. Given that transportation is one of the input factors in the embodied energy materials and with the fact that the study area is deficient of building stones leading to sourcing of such materials from neighbouring locations makes it suitable for study to bring out the effects hauling distance in the embodied energy calculation and estimation of equivalent GHG emissions.

The use of earth in the production of soil base products as building materials is significant for this study. According to Earth Construction (1994), earth has the potential of being stabilized vide diverse range of physico-chemical stabilizers in order to eliminate the reversibility of cohesion and swelling nature due to contraction and expansion upon wetting and drying.

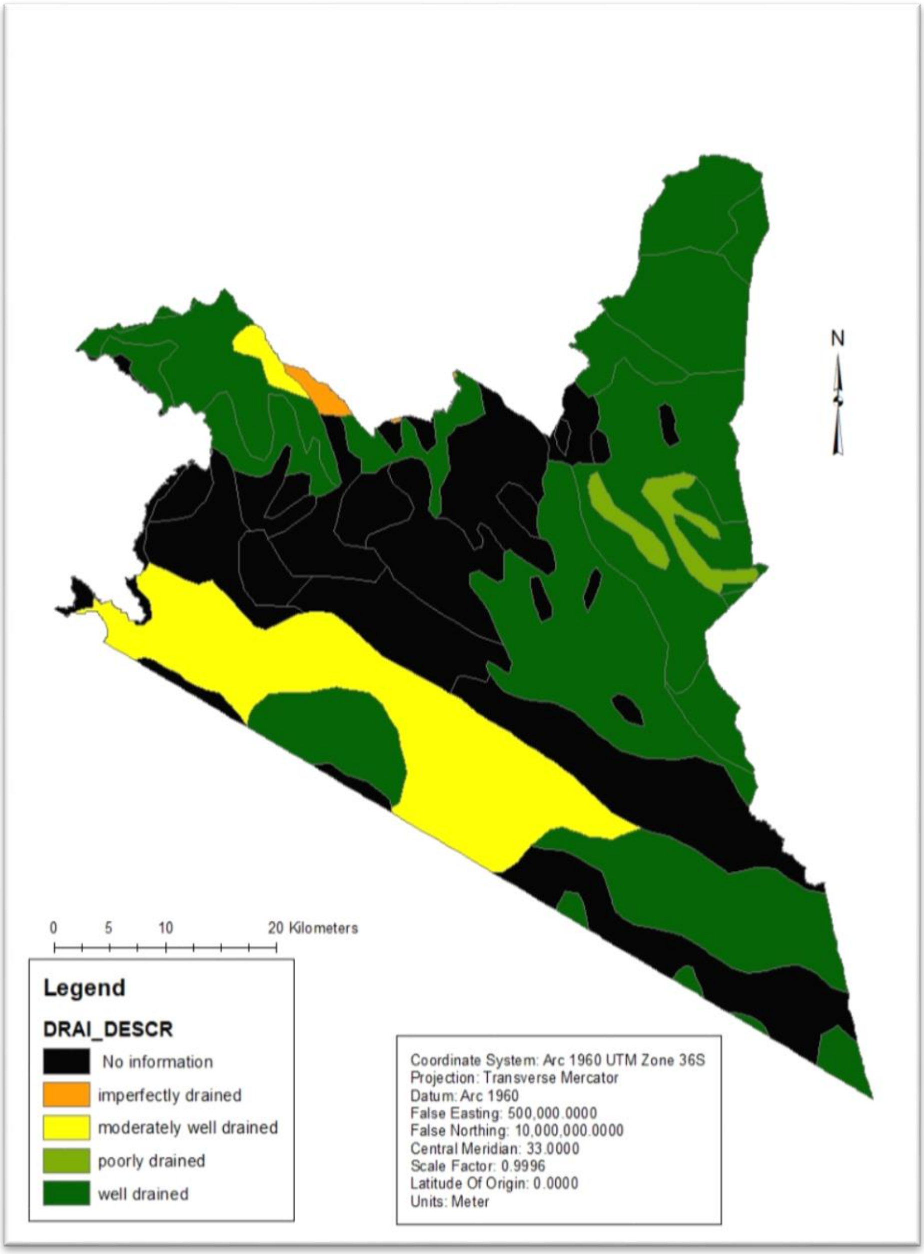
Figure 3.2a: Soil Types of the Study Area



Source: Author, 2020

The use of earth recognizes three traditional stabilizers obtained from naturally occurring substances notably; oil base products, glues and tannins. The use of glues as stabilizers involve application of gum Arabic and animal glue. On the other hand, the oil based products mostly involve sheanut butter and linseed oil while tannins rely on horse urine and decoction of nere tree back (CRATerre, 1990). The application of these stabilizers however largely depend on local skills. In modern times, the industrial stabilizers with wider application include cement, lime and bitumen.

Figure 3.2b: Nature of Soils in Terms of Drainage



Source: Author, 2020

The use of clay provides three main types from where to choose a good quality as a building soil. Such soils should possess right proportions of clay, silts, sand, gravels and pebbles (Practical Action, 2008). These types of clay soils are Kaolinite, Illite and Montmorillonite with Kaolinite being relatively stable with low cohesion, Illite clay type has average stability and cohesion characteristics while Montmorillonite is noted to be highly sensitive to water with high cohesion. Figure 3.2a and 3.2b depicts the type and nature of soils in the study area.

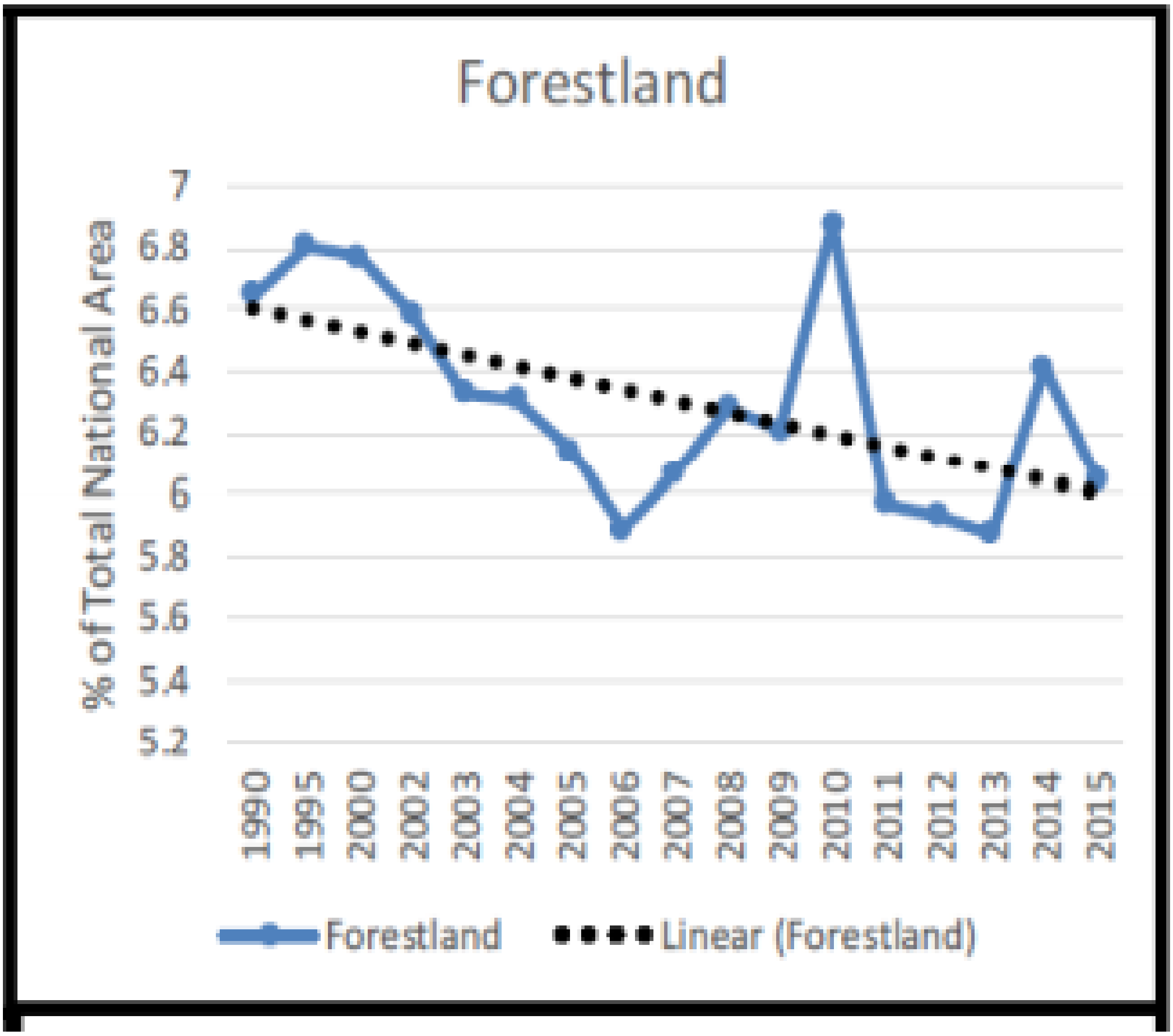
3.2.2 Land Use and Forest Cover

Forest cover is one of the main environmental resource within the Kenyan landscape which plays a crucial role in climate balance. Forest resources are beneficial to the environment and general population since they provide water catchment and conservation functions as well as carbon sinks. According to GoK (2010), Kenya comprises of 58.0 million ha with approximately 2 per cent being characterized by inland water bodies. The expansion of urban areas (cities and towns) as a result of the ever increasing population growth have contributed to enormous destruction and deterioration of the forest cover across Kenya. The deforestation and degradation is mainly necessitated by way of encroachment into forest areas and accelerated exploitation of forest products for construction and energy (GoK, 2010). Figure 3.3 depicts land use trends in forest lands.

GoK (2020) further established that the Country's tree cover was enhanced upwardly to a positive figure of 7.29% in 2017 from the figures of 7.2 % in 2013. On the other hand, the State managed forests increased from 1.2m ha to 2.4m ha with the production of 222,124 bamboo seedlings and 800m tree seedlings facilitated so far. To realize the vision of attaining the 10 per cent tree cover by 2030, the Government has rolled out and sustained the initiative that is geared towards the rehabilitation and protection of the five major water towers namely Aberdares Range, Mt. Kenya, Mau Forest Complex, Mt. Elgon and Cheranganyi Hills as well as the other water towers and catchment areas across the Country.

The major forest conservation and management practices as advocated for by the government and other actors in the conservation efforts include; promotion of forest based nature enterprises, promotion of bamboo establishment, establishment of forest plantation, establishment of commercial woodlots, and utilization, and control of invasive species among others.

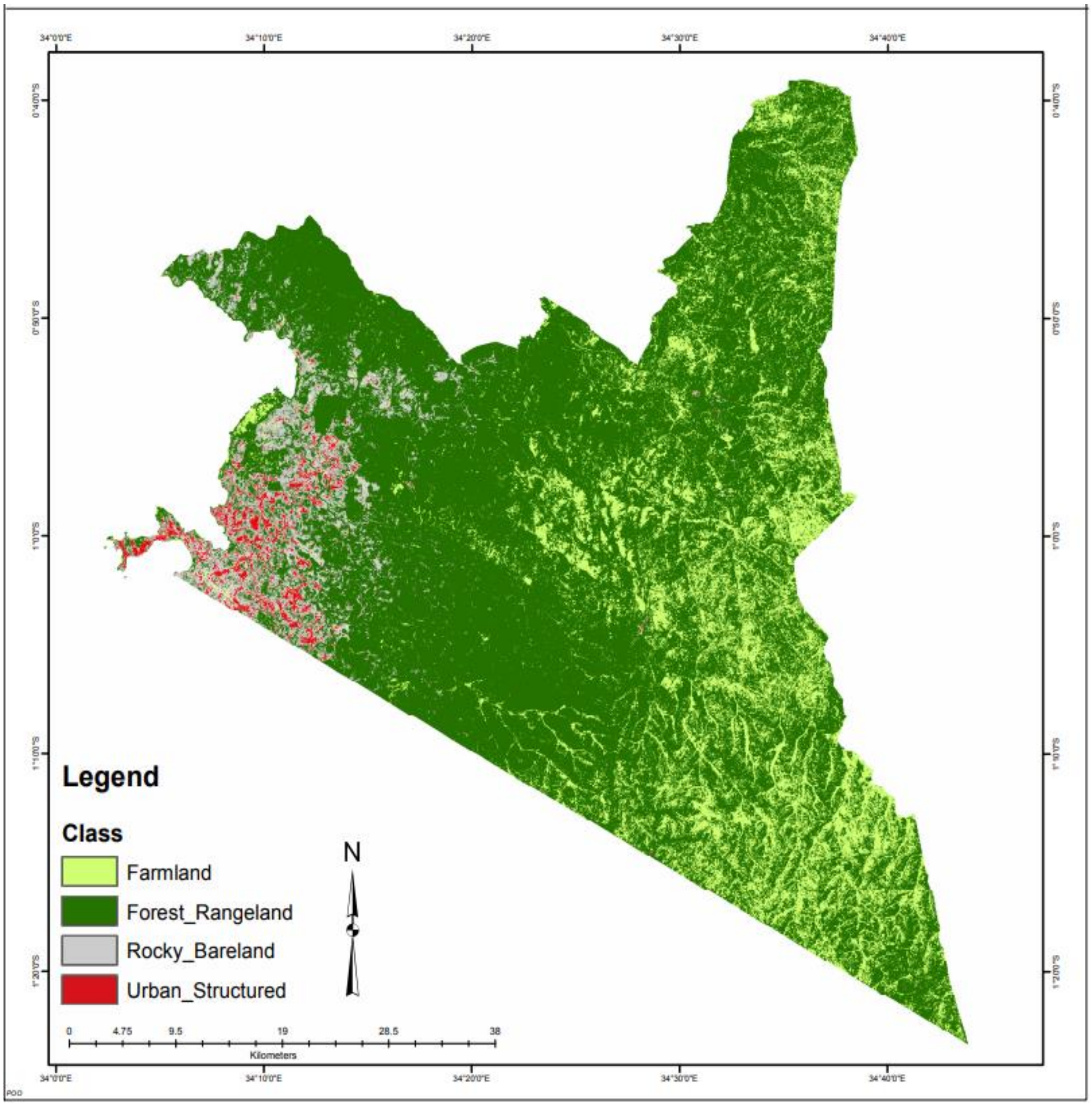
Figure 3.3: Trends in Forest Cover Land Use in Kenya



Source: Government of Kenya (2020), NIR 3

The deployment of GIS technology enabled comparison of forest cover in the study area for periods 1984 and 2020. Figure 3.4a and 3.4b demonstrates the land use land cover changes in relation to forest cover brought about by demand for settlements and urbanization needs among others due to increasing population.

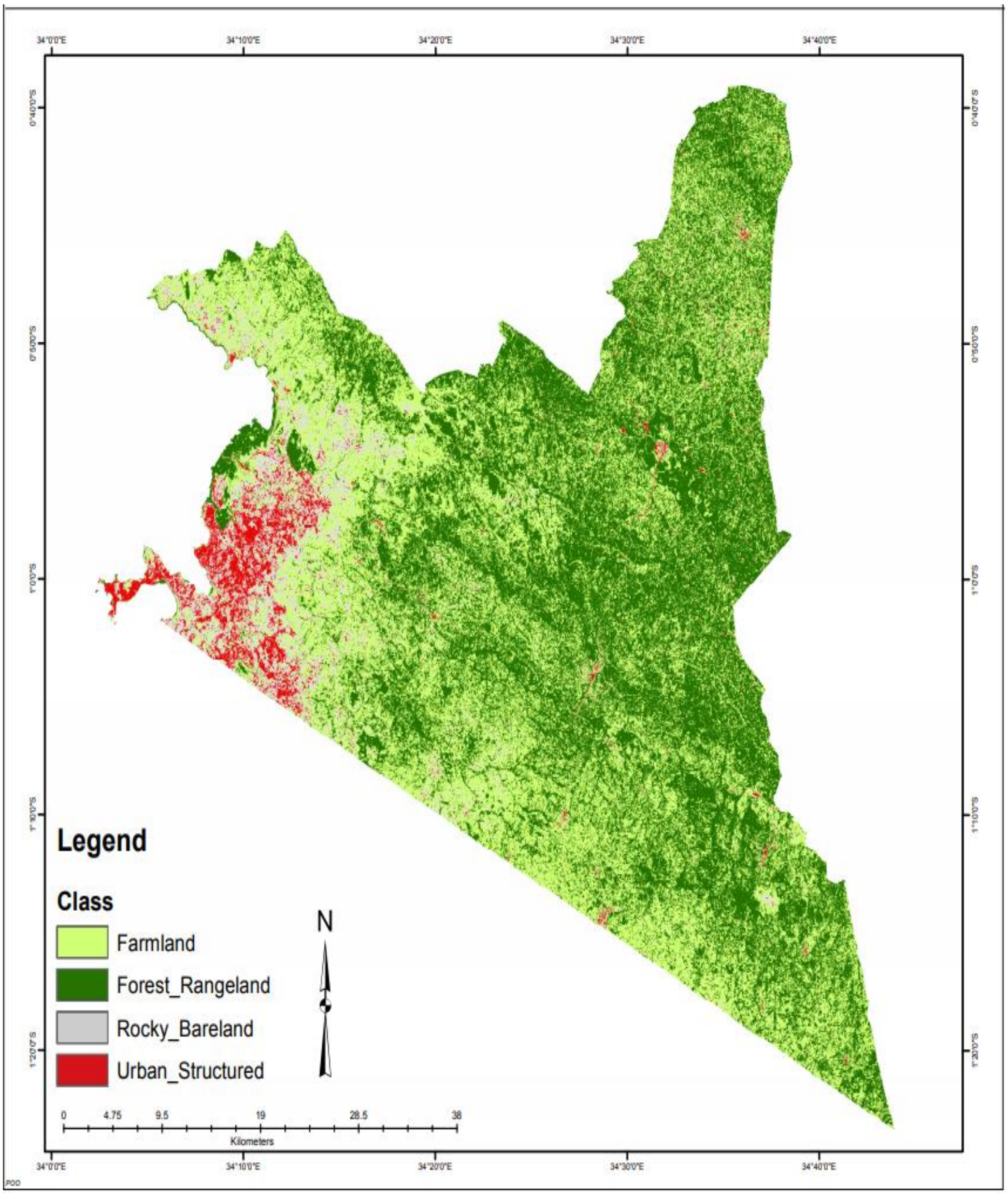
Figure 3.4a: Land Use Land Cover Map for 1984



Source: Author, 2020

There is significant variation in forest cover within the lower and upper catchment areas with the upper catchments exhibiting large and dense trees with definite trunks. The riverine vegetation consists of vegetation along the rivers which include forests and wetland grasses. The urban and rural, various social amenities including learning institutions, health facilities and recreational facilities have used local building materials. Timber from forests, building stones, sand, soil, grass, bamboo among others that plays a vital role in carbon sequestration are increasingly needed as building materials and are extracted from the environment. The study set to establish the effects of building materials exploitation and the consequent impact on carbon sequestration services of soil, water and forest/grass cover.

Figure 3.4b: Land Use Land Cover Map for 2020



Source: Author, 2020

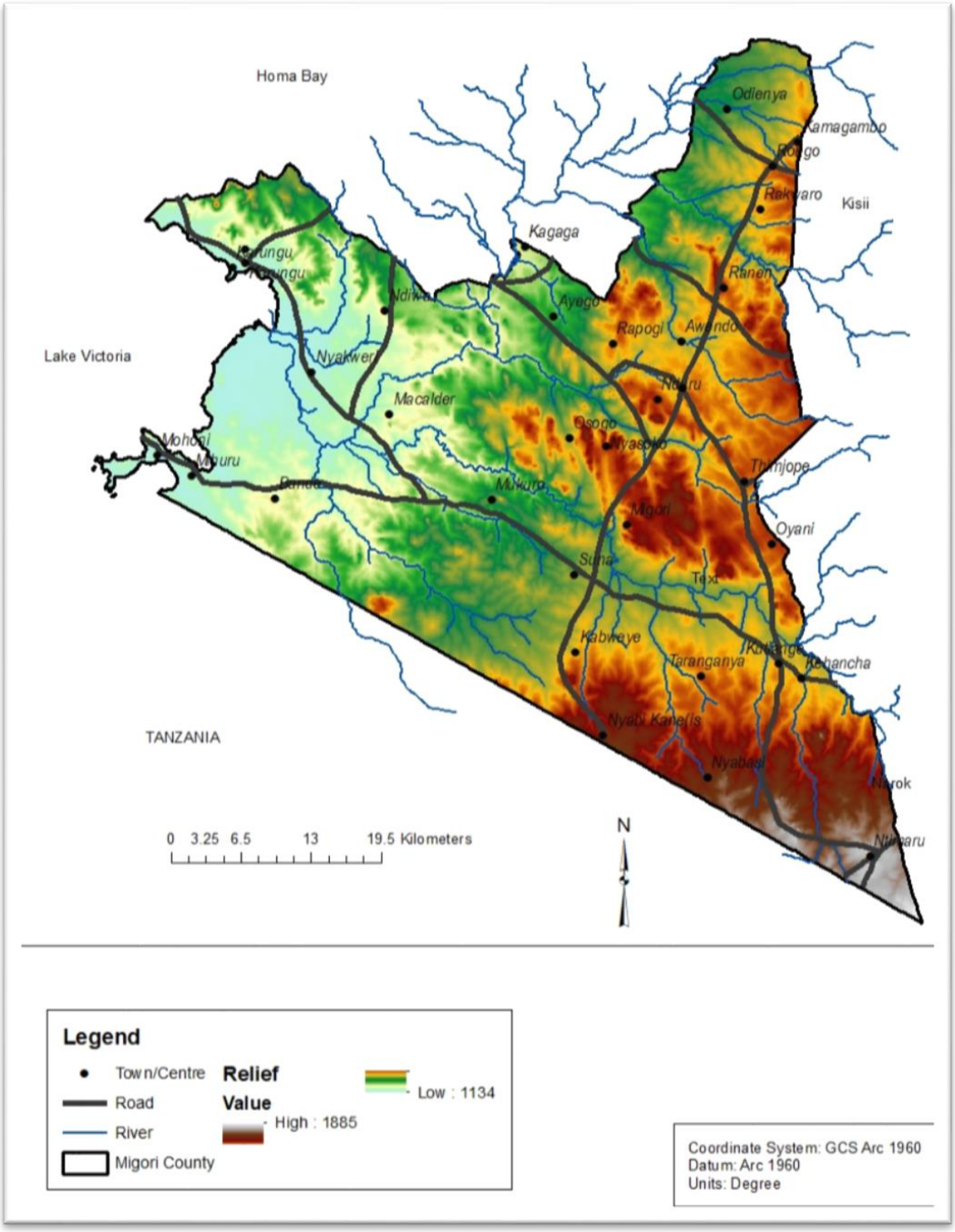
3.2.3 Climate and Hydrology

Migori County, given its proximity to the lake region, experiences an inland equatorial climate which is modified by the effects of altitude, relief and the influence of L. Victoria. The study area receives approximately 700mm – 1800mm on average of rainfall annually. It is characterized by long rains which occur in the months of March and May, with short rains being experienced around September and November. The area is further characterized by dry periods which are experienced in two phases notably; December to February and June to September. The particular areas which are more susceptible to climatic changes due to unreliable and poorly distributed rainfall include; Nyatike, Muhuru and Karungu as well as parts of Kegonga area.

The annual temperature ranges for the study area is 24^0C - 31^0C, with high humidity and a potential evaporation of 1800mm - 2000m per year. The area is traversed by major Rivers; Kuja that originates from Mau Forest Complex, with Migori having its origin from the Kuria Highlands while river Riana owes its origin to the Kisii Highlands. There are also seasonal rivers such as Ongoche, Oyani and Sare which criss-cross the area and joins River Kuja before draining into Lake Victoria.

The influence of altitude and relief within the study area are necessitated by the existence of high elevation due to numerous highlands with the Kenyan catchment exhibiting a general elevation of up to 3000m above sea level especially on the catchment areas within the Mau Escarpment (GoK, 2002). The temperatures and rainfall are generally lower within the basin than typical equatorial conditions necessitating the area to be classified as sub-humid with temperatures ranging between 20^0C to over 35^0C (LVEMP, 2005). The rainfall regime which is mainly controlled by the movement of the ITCZ ranges between 700mm to 1800mm with considerable spatial variations in rainfall within the entire catchment mainly due to the locations of the highlands and nearness to lakeshores. In normal situations, long rains occur between March and May while short rains between September and November, but there is however a significant shift of this pattern in present times due to climate change effects. Figure 3.5 depicts the drainage pattern of the study area.

Figure 3.4: Drainage Patterns of the Study Area



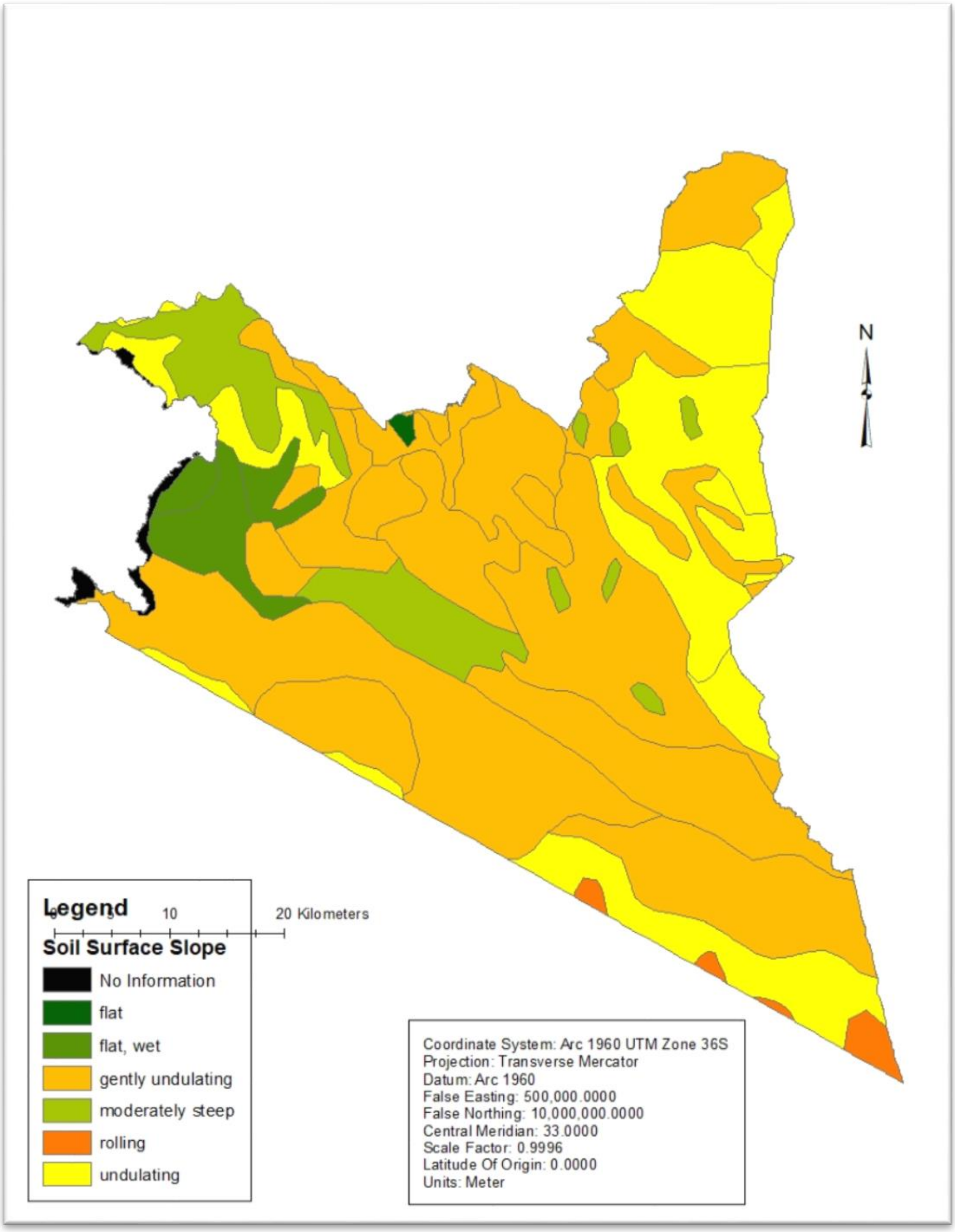
Source: Author, 2021

3.3 Sources of Building materials

The building materials are products of geology and soils, climate and rivers, land use/land cover (forests, grasses, farmlands) and population dynamics in the county. Most parts of Western Kenya comprise of the East African Craton as well as the Precambrian formations of metamorphosed volcanic and sedimentary deposits that belong to the Nyanzian and

Kavirondian systems. Granitic rock formation covers most parts of Kuria East, Kuria West, Nyatike, Rongo and Migori Sub-Counties.

Figure 3.6: Soil Surface Slope.



Source: Author, 2021

Soil types within the lake basin include; Cambisols, Planosols, Vertisols, Regosols, and Ferralsols, with most parts of the study area comprising of black cotton soils while the lake shore lowland areas are dominated by alluvial soils mainly sandy loam type which is well drained. Such rock formation and prevailing soils enables extractions of building materials including ballast, building stones, river and rock sand, soapstone among others to support housing development needs in the region. Figure 3.6 demonstrates the soil surface slope of the study area.

3.4 Socio-economics of Migori County

Socio-economics of the county is the main driver of increased demand for building materials. There are 166,487 households (KNBS, 2013) spread in 8 sub-counties, namely, Rongo (19,499), Awendo (21,819), Suna East (18,664), Suna West (18,221), Uriri (20,867), Nyatike (27,333), Kuria West (27,354), and Kuria East (12,730). The sources of livelihood of the inhabitants are fishing, farming, bee keeping, trading activities, quarrying and mining. Forest and woodland resources have experienced adverse changes due to rapid population increase and commercialization of timber. Development of human settlement through unsustainable acquisition of the building materials as well as application of unsound technologies poses major challenges to other use benefits of the catchment. Demand for and supply of building materials depend on socio-economics of the county.

A combination of geographical factors and population dynamics influences land use and land cover, the latter forming agro-ecological divisions. Migori County is divided along the following agro-ecological zones (County Government of Migori, 2016). The upper midland (UM) and lower midland (LM) resulting into six agro-ecological zones namely: UM1 (Eastern Rongo), LM5 (Uriri, Kehancha, Ntimaru and some parts of Kegonga), UM2-3 (Rongo, Uriri, Mabera, Kegonga), LM1-2 (Suba East), LM3 (Nyatike, Karungu), and LM4 (Western Nyatike, Muhuru). The study examined the extent to which these agro-systems have been affected by increased demand of building materials.

4 METHODOLOGY

4.1 Introduction

Gerring (2007), provides one of the definition of what constitute a case study and which this study finds relevant in application. In the definition, a case study is an empirical, in-depth and multifaceted inquiry that seeks to illuminate the dynamics of a single contemporary social phenomenon (Gerring 2007; Akadiri, 2011). Literature review further details the aspects of combining data collection methods and research strategies in undertaking a case study (Fellow and Liu, 2003). Undertaking case study is significant in understanding the complexity of the subject matter for further application in generalization of the findings. The main reason of choosing a case study approach is due to its richness of data and deeper insight into subject under investigation (Hancock, 1998).

The study commenced with a survey of relevant literature including various peer-reviewed references in order to establish and familiarize with the current state of research and the existing gap in the research interest field through the Literature-Based Discovery (LBD) as provided in Dixit (2013) The LBD method was pioneered by Swanson (1986) with wide application in biomedical science, but has since been demonstrated to be useful in creating new knowledge in other disciplines (Weeber et al., 2001; Dixit., 2013)

Case study was used to show the relationship between energy efficiency of building technologies, carbon sequestration levels and effects on greenhouse gas emission as a proxy to climate change.

4.2 Study Design

The study applied survey, experimental and correlation design approaches. The survey aimed at collecting data at two levels (household survey and housing professional/practitioners). The household survey targeted local residents (home owners / or tenants) while key informants involved housing professionals / practitioners, particularly, the policy formulation and implementation team. The key informants' groups were further sub-divided into specific (public institutions) and general key informants where the former are based at the County Headquarters and the latter had national coverage by way and reached through referencing.

The experimental design targeted collection of primary data from mortared and mortarless building technologies while correlation design focused on the relationship between energy efficiency levels of building materials and greenhouse gas emission (GHG). The study design is focused by objectives with objectives one, two and five largely dealing with survey design approach that focuses on household survey and key informants. The third objective focused on experimental design involving mortarless and mortared building technologies while the fourth objectives depended on correlation design.

The Study covered three sets of data namely; households, key informants and experimental data. It applied a sample survey design of stratified sampling procedure beginning with purposive sampling of county of research (Migori) and stratified sampling of 8 sub-counties, and the selection of two wards from each sub-county purposively. The choice of these wards was necessitated by the desire to establish the extent of application and enforcement of regulations on building plan approvals as per development control (PLUPA, 2019) requirements as well as the extent of adoption of mortared and mortarless building technologies. This was followed by random sampling of households and key informants by way of referencing. The process further involved an experimental sampling for product assessment targeting mortared and mortarless building technologies.

The data collected at the household level in the study was based on the types of building materials, sources of building materials, and distance to building materials sources. It involved administration of questionnaire to the sampled households where feedback on the mode and processes involved in owner occupier housing was documented. It further involved tracing all material sourcing locations within and outside the study area based on the data capture tools as set *a priori* and by way of reference made by the respondents respectively.

The key informant data targeted housing professionals and practitioners within the study area and at the national level. The professionals / or practitioners who participated in the study from Migori were mainly government officials who largely interact with the building approval processes. This study aimed at establishing the number of building plans approved for both urban and rural wards as the units of study. It targeted key government offices at Migori county headquarters notably; Physical Planning, Survey, Housing, Public Works, Kenya National Bureau of Statistics among others. The prioritization of the above offices and associated professionals / or technocrats was necessary for acquisition of the right data intended for this particular study.

The experimental design involved analysis of processes involved in the production/processing of mortared and mortarless building technologies. In particular, it focused on adoption and use of interlocking stabilized soil blocks (ISSBs) and burnt bricks (BBs). These processes were analysed at two different sites in Kehancha (Kuria West) and Kakrao (Suna East) sub-counties. The site at Kehancha mainly deployed the use of Hydraform ISSB machine which applies the hydraulic system that is run by diesel fuel while the Kakrao site deployed the use of Makiga ISSB Machine model which is mechanical in nature and free from use of fuel. The current study is however limited to the comparison of the use of Hydraform ISSB output processes with the burnt bricks.

The experimental data was collected on types of raw materials required, amount of raw materials used and energy consumption levels based on the material manufacture / production processes. The data acquired was analysed to measure or estimate the embodied energy levels, awareness levels, resource efficiency and suitability of approval processes for various building technologies. The hypotheses testing and significance test in all cases were based on $\alpha=0.05$.

4.3 Data Type and Sources

To measure the embodied energy for Burnt Bricks (BB) and Interlocking Stabilized Soil Blocks (ISSBs), the study relied on primary data relating to the amount of soil required to produce a unit product, the amount of disturbance per unit product, energy input per unit product, sources of energy input, distance travelled to obtain the energy source, distance travelled to obtain the product (building material) to building site. Secondary data involved review of existing literature on building materials application, embodied energy levels, carbon sequestration processes and climate change effects. The resultant data was envisaged to demonstrate that a particular construction technology with less global warming effect would be associated with high carbon sequestration ability and vice versa.

4.4 Data Collection

4.4.1 Reconnaissance Study

The process of data collection commenced with a reconnaissance to the study area to identify sample elements for household respondents and map out building materials sources. This was significant in determining the trend necessitated by shift in economic status of the people which result in shift from temporary buildings to permanent houses with implications on soil, water and vegetation (tree cover) capacity to perform carbon sequestration services. Convenience sampling approach, given the existence of discrete situation was used to identify residents who have used various building materials for inclusion in the sample elements list. Both measurement and estimations of energy-related Carbon Emissions for Manufacturing Industries (CEMI) of industrialized building products and Input-Output Analysis of locally produced building materials were applied to provide data relating to building materials energy requirement, carbon sequestration levels and climate change mitigation and adaptation within the study area.

Key Informants targeted in this study involved government officials at national level, county officials and specific NGOs and CBOs groups. Under the general key informant category, 50 participants were purposively targeted with 31 responses recorded. The respondents' categories included Policy Makers, implementing and enforcement agencies, Architects and Engineers, property developers, researchers, capacity building institutions and local community groups among others.

The county government offices targeted heads of key departments that deals with planning, survey, housing, public works and statistical data. The response was considered as fair representation for this study.

4.4.2 Sample Frame

The study involved two sets of population notably building materials sources and household respondents. The household sample frame from where the sample size for the household survey were drawn consists of 166,500 (KNBS, 2009). The survey involving all dominant building materials were purposively done with focus on extraction / or production and distribution points within the study area. The tool for data relating to selection criteria of building technologies that are considered appropriate were administered to 30 key informants who were selected purposively while providing fair representation of key stakeholders and included government officials, NGOs and civil society representatives and faith based organization leaders.

4.4.3 Sample Size

The sample size for the household survey was determined using the Proportionate Sample Size formula. According to Israel and Glenn (1992), calculation of the sample size is necessary for combination levels of precision, confidence and variability. The methodology is also propagated in Fisher's Model for sample calculation which is suitable for this study as the population involved is more than 10,000. The proportionate sampling size procedure described above was therefore adopted as fronted by Chava, F. et. al. (1996) in the equation 4.1 below:-

Equation 4.1: Proportionate Sampling Size Procedure

$$n = \frac{z^2 p.q.N}{e^2(N-1) + z^2 p.q} \qquad \textbf{\textit{4.1}}$$

Where;

N	=	Population Size = 166,500
n	=	Sample Size
p	=	Sample Proportion =0.5
q	=	1-p = (1-0.5) =0.5
e	=	Acceptable error level at 0.05
Z	=	Standard variant value = 1.96

This being an internationally recognized method and a best practice for surveys involving huge population coupled with heterogeneous and diverse sample elements, resulted into a representative sample size.

$= 1.96^2 \text{ X } 0.5 \text{ X } 0.5 \text{ X } 166{,}500 / 0.05^2 (166{,}500-1) + 1.96^2 \text{ X } 0.5 \text{ X } 0.5$

= 159906.6 / 417.2079

= 384

The resultant household sample size of 384 was proportionately distributed to the 8 sub-counties of Migori county during the study while taking into consideration an error margin of 5%.

Table 4.1: The level of sample size representation for each Sub-County.

S/No	Sub-County	No. of Households (Sample Frame)	No. of Household (2019 Census)	Proportionate Sample Size	Sample Size Obtained	Response Rate
1.	Rongo	19,500	29,087	45	37	82.2%
2.	Awendo	21,800	27,033	51	45	88.2%
3.	Suna East	18,700	27,302	43	45	104.7%
4.	Suna West	18,200	29,251	42	42	100.0%
5.	Uriri	20,900	30,039	48	48	100.0%
6.	Nyatike	27,300	40,257	63	51	81.0%
7.	Kuria West	27,400	39,789	63	59	93.7%
8.	Kuria East	12,700	17,363	29	29	100.0%
TOTAL		**166,500**	**240,168**	**384**	**356**	92.7%

Source: Modified from Kenya National Bureau of Statistics (KNBS, 2013)

The sample elements were arrived at as summarized below;

- All households qualified for sampling within the homogeneous population (either rural or urban).
- Representative sample size of 384 was arrived at statistically using the proportional sampling size procedure as expressed in equation 4.2
- Sample size obtained proportionately was distributed among households among the 8 sub-counties using stratified sampling techniques.
- Purposive sampling was applied to identify the ward units (based on either urban or rural ward) as the study factored in the largest urban surface in each sub-county and a purely rural ward without urban influence.
- A particular category of households was randomly sampled with replacement.

KNBS (Census, 2019, Vol.1) further provides population figures by sub-counties for Migori as follows; Awendo (117,290), Kuria East (96,872), Kuria West (208,513), Nyatike (176,162), Rongo (124,587), Suna East (122,674), Suna West (128,890) and Uriri (141,448). These recent statistics however were availed when the sample for the study had been effected and field assignment conducted.

4.4.4 Data Collection Instruments

The data collection for the three level of research focus (household survey, key informants and experimental design) were supported by a number of tools/Instruments.

In the households survey: GPS was used to map the geospatial location of the households and the material sourcing sites; tape measure was applied to take the dimension of the housing structure; digital camera was used to take still photos of the housing structure and material sourcing sites; questionnaire (Appendix 4A) was the main data collection tool used to obtained the field data during the interviews with household heads/ rental occupiers while field note books were used to record all field observation and any other additional information provided by the respondents. In the key informants survey, two sets of questionnaire were used targeting public institution respondents (Appendix 4B) and general key informants' respondents (Appendix 4C) and field note book were used to capture the relevant data from the respondents. The experimental design targeted two soil-based products notably; burnt bricks and ISSB. For burnt bricks, the major tools / or instrument used were GPS, tape measure, weighing machine, spades, rake, jembe/hoe, wheelbarrow, grass, watering can, bucket, moulds, brick kiln, block tester, field data sheet and laptop. For ISSB, the major tools / or instruments used were: GPS, tape measure, weighing machine, Hydraform machine, spades, rake, jembe/hoe, wheelbarrow, polythene paper, watering can, bucket, block cutter, block tester, masonry equipment, field data sheet and laptop.

The measurement of two important parameters of carbon sequestration (energy and carbon dioxide) were supported by a number of the listed data collection instruments. Given that the EE and CO_2 measurements and comparison for experimental design targeted three process phases of material extraction, processing and transportation, some of the key instruments in the EE and CO2 measurements included: weighing machine to determine the mass of raw materials and finished products; GPS which provided co-ordinates at material sourcing locations and construction sites, hence enabling calculation of the hauling distance; brick kiln and hydraform machine on the hand provided the platform to estimate the biomass and fossil fuels used in the production of burnt bricks and ISSBs respectively. Appendices 1. J and 1. K provides detailed descriptions of various tools used in the production and application on ISSB.

4.4.5 Data Collection Procedure

The data collection was conducted by the use of both experimental design and survey design as discussed in the succeeding sections.

4.4.5.1 Experimental Design

The experimental design was significant in addressing the third and fourth objectives of the study. While objective three focused on resource efficiency and climate change mitigation levels associated with utilization of mortarless and mortared building technologies, the fourth objective was set to demonstrate the relationship between energy efficiency levels of building materials and greenhouse gas emission (GHG) as a proxy to climate change effect. The contribution towards resources efficiency and climate change mitigation levels was demonstrated by two soil based products of burnt bricks and ISSB. The choice of soil based products for this purpose was due to the fact that the study area lacked volcanic products hence soil based building materials. The choice of the burnt bricks its wide application by the majority of the residence at 23.6% as depicted in the Kenya National Housing Survey (2013). The choice of ISSB as part of experimental design was informed by deliberate government efforts to promote ISSB as an alternative environmentally sound building material (GoK 2004; GoK 2016).

The experimental design touching on objective four was conducted through the comparison of embodied energy and equivalent GHG in the use of mortarless and mortared building technologies. The mortared building technologies was analysed using burnt bricks and quarry stone walling. The choice of burnt brick was due to its dominance in the study area while quarry stones was the next preferred walling material due to its recognition as a permanent walling materials by existing regulations (Building Code, 1968; GoK, 2009).

The experimental design approach provided platform for the analysis of building materials and estimation of associated embodied energy. The resultant estimated embodied energy was used to derive equivalent greenhouse gas (carbon dioxide) emission. To achieve this, the study used collaborative approach with local residence, process owners, secondary data and independent experimental design. The researcher employed collaborative approach involving local residents who are already in extraction and processing of building materials in order to follow-up the process and acquire factual / accurate information up to the end. In addition, the researcher interviewed process/project owners to provide secondary data estimates of the inputs and their associated energy in all the process involved in the building material production. The researcher further conducted independent experimental design with a view to determine the estimated embodied energy of the selected dominant building materials within the study area. It is imperative to note that the collaborative approach employed as part of this study significantly reduced the cost of carrying out the study.

The experimental design was applied on the three dominant building materials involving burnt bricks, quarry stones and interlocking stabilized soil blocks (ISSB).

a) Experimental design for clay bricks

The experimental design was in two fold involving visiting the sampled sites for material extraction / or processing where interviews were conducted with the local residence and process owners. The information generated included: the raw materials as inputs (soil in tonnes, tree logs used in firing the kiln, amount of water, time taken in the processing chain, number of workforce among others); the types of kiln to be adopted; the distance covered in sourcing the raw material sources; and the distance of transporting processed products to construction sites.

The information on the construction process was established from process owners. This study sampled an existing facility at Kehancha prison in Kuria East which enabled acquisition of secondary data in supplementing the data requirements for this study. The site was suitable as it provided an opportunity for control analysis at the same site where a similar facility of same standard (area of 66.7 M^2) was constructed using ISSB.

The following procedure was used in documenting the burnt bricks manufacturing process:

Step1: Conveniently select local experts in production of Burnt bricks to aide in the practical process; geo-reference study sites using GPS receiver; assemble soil, water and wood; and design standard brick moulds of 9” X 9” X 4 ½” with selected local artisans.

Step2: Design burnt brick kiln with a capacity of 4500 bricks; quantify amount of materials assembled by volume (M^3); and mould 4500 bricks. During the study, the local process owners had brick kilns with capacity of between 10,000 – 12,000 bricks at different sites. The collaborative approach adopted focused on 10,000 brick kiln in the analysis.

Step3: Allow the wet bricks to dry.

Step4: Arrange dried bricks in the brick kiln; supply the brick kiln with wood fuel; fire the bricks in the kiln; monitor the burning time to readiness; and estimate the associated energy (J) and carbon dioxide emission levels.

Step5: Construct a standard house defined by 4500 bricks produced; estimate mortar use and energy equivalent (J) of cement processing; and monitor time of delivery to inform analysis of appropriateness.

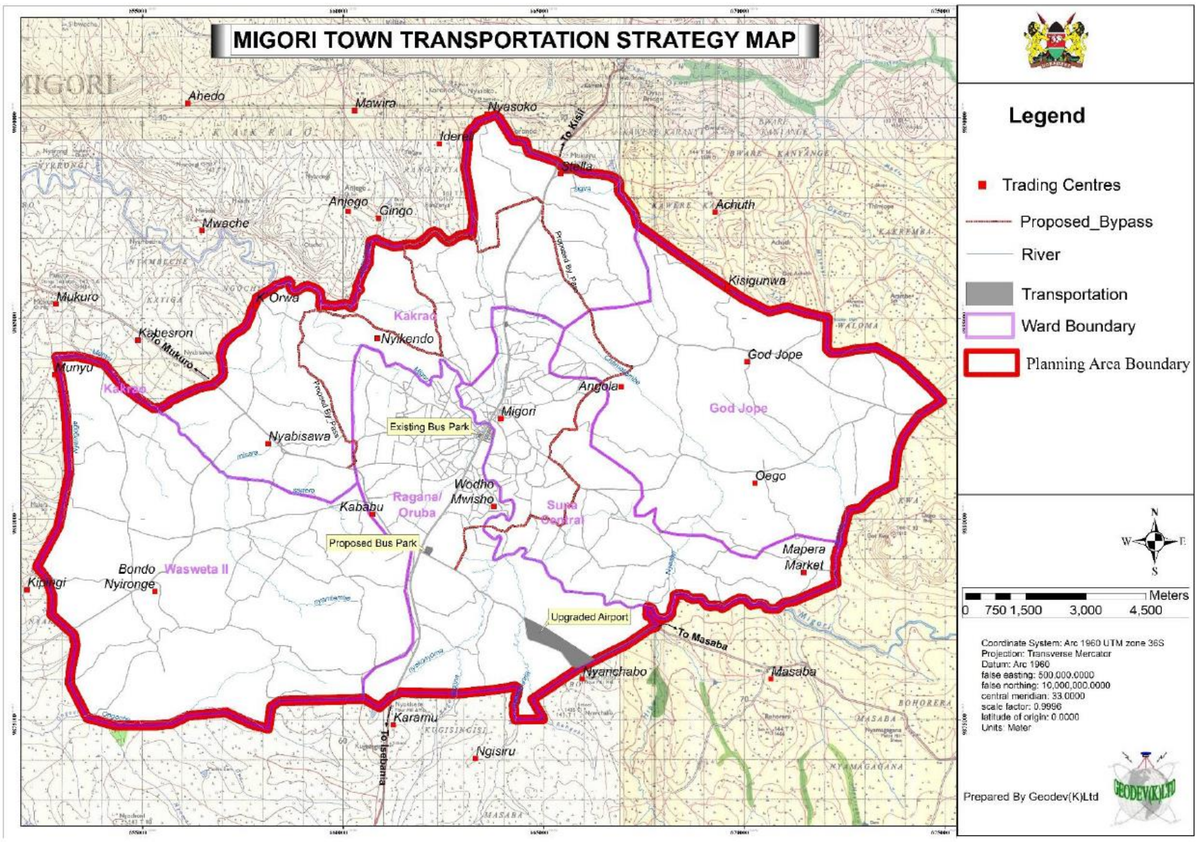
Plate 4.1: Material Preparation and Moulding of Bricks

Source: Researcher, 2020

b) Experimental design for Interlocking stabilized soil blocks (ISSB)

The experimental approach adopted in the case of ISSB involves two sites notably: Kehancha prison in Kuria East and Kakarao in Suna East (Migori Municipality). Figure 4.3 shows the location of Kakrao area within Migori town.

Figure 4.3: Kakrao ISSB Experimental Site



Source: Modified from Geodev, 2019

The complete experimental was done at Kihancha prison which encompasses material selection, site clearance, local labour sourcing, production and construction. ISSB Manufacture involves use of Manual and Hydraulic Block Making Machines as depicted in Plates 4.2.

Plate 4.2: Hydraform ISSB Machine and Makiga ISSB Machine

Source: Field Survey, 2020

The procedure followed are outlined below:

Step1: Conveniently select local experts in production of ISSB products to aide in the practical process of producing standard ISSB of 9” X 9” X 4 ½” in size; geo-reference study sites using GPS receiver; and assemble soil, sand, cement and water for block production.

Step2: Source a Hydraulic Block Making Machine; quantify amount soil, sand, cement, diesel and water by volume (M^3) assembled; and produce and cure 3100 ISSBs.

Step3: Cure ISSB blocks and quantify the water use during curing

Step4: Estimate associated energy (J) and carbon dioxide emission levels equivalent.

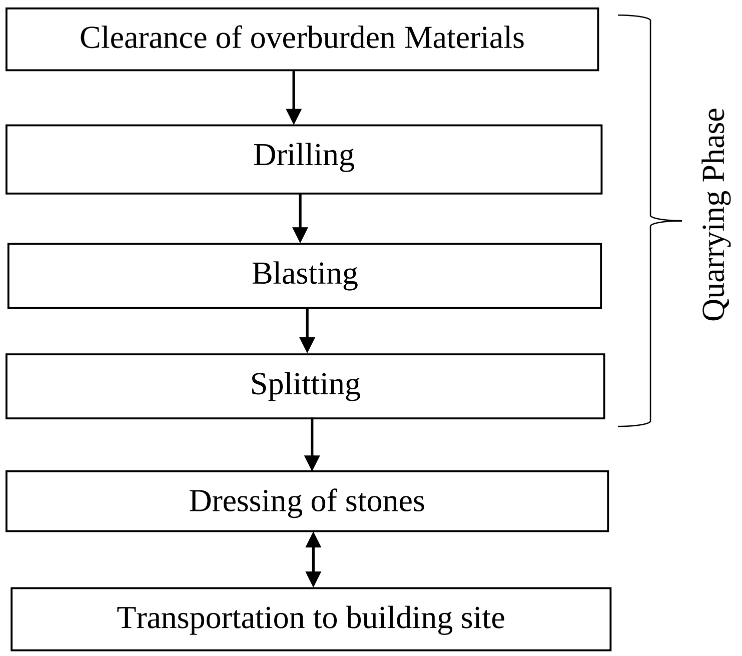
Step5: Construct a standard house defined by 3100 interlocking stabilized soil blocks; estimate mortar use and energy equivalent of cement processing; and monitor time of delivery to inform analysis of appropriateness.

c) Experimental design for quarry stones

The selection of quarry stones for experimental analysis was necessitated by the information provided by the process/project owners during the interview. One of the main quarry site in the neighbourhood which was cited by way of referencing involved Oriwo turf in Rachuonyo North sub-county. It was established, that Oriwo turf is a major supply area of quarry stones to the study area and beyond. A visit to this site revealed the existence of over 50 quarrying points. During the visit to Oriwo turf, the researcher interacted with some project owners at the extraction and construction sites who gave consent for analysis on an experimental basis to be carried out on the process of application/utilization of quarry stones.

The construction site where experimental analysis was carried out for this purpose was in Kanyaluo ward. Although this was outside the sampled wards, it provided complementary information which was useful to the study as similar houses were already built and secondary information provided in the study area. Hence this was to provide primary data for analysis and tracking of embodied energy parameters. Figure 4.4 depicts the process of quarry stones processing.

Figure 4.4: Quarry Stone Exploitation Processes



Source: Modified from Savery, 1997

The salient steps followed in the experimental design were as follows:

Step1-Extraction: At the extraction point, the activities observed involved quarrying which was mostly labour intensive. The extraction process was done through manual digging using hand tools and then dressed by chipping to the appropriate size and shapes.

Step2- Transportation: The quarry stones were manually loaded and off-loaded into 10tonne lorry for transportation to the building sites which was about 20 km away.

Step3: - Dressing of quarry stones: The dressing of quarry stones to refined shapes and appearance then followed. This process was observed to be labour intensive and the chips removed are used for back filling.

4.4.5.2 Survey Design

The survey design was explored in collecting data on use of materials in the study area as well as views of the respondents on the criteria to be adopted in classifying existing and potential materials as appropriate. The survey design employed the use of household questionnaire and key informant interview guide.

Plate 4.3 Key informant interview on quarry stone

Source: Author, 2020

In summary, the survey involved four major steps as outlined below;

- Determining the trend of buildings necessitated by shift in economic status of the people which result in shift from temporary buildings to permanent houses.
- Analysing data from secondary materials including Census reports for the past 30 years to bring out trends in building.
- Collecting current information in the study area to validate the trend in housing development in the study area.
- Estimating embodied energy of building materials and associated carbon sequestration equivalent to soil, water and forest cover.

Key informants interview was used to obtain primary data from professionals in the building and construction industry. This aspect of research targeted both public and private sector players who deal with policies and regulatory frameworks that are aimed at influencing the adoption of energy efficient building materials and sustainability aspects. Besides the study area, the researcher sought information and relevant data from other areas where building materials were sourced by a section of respondents due to non-availability of the preferred materials for building within Migori.

A case in point of such materials are quarry stone and large-sized bricks. The quarry stones are mainly sourced from Oriwo area (West Karachuonyo), Kedowa (Kericho), Ndarugo (Thika), Tabaka (Kisii) as demonstrated in plates 4.3, 4.4, 4.5 and plate 4.6

Plate 4.4: Quarry Site at Kedowa in Kericho

Source: Author, 2020

Plate 4.5: Quarry Site at Ndarugo in Thika

Source: Author, 2020

Plate 4.6: Quarry Site at Tabaka in Kisii

Source: Author, 2020

The large-sized burnt bricks are sourced mainly from Sironga (Nyamira). The information generated during the visit to Oriwo Turf, Kedowa, Ndarugo and Sironga was quite significant and complemented the research findings. Plate 4.7 depicts burnt brick production in Sironga.

Plate 4.7: Burnt Brick Production site at Sironga

Source: Author, 2020

The data generated from Key informants related to current appropriate building materials and technologies, policy and regulatory framework, building materials sustainability selection criteria techniques in Kenya. The key respondents were mainly from the building and construction industries and their stakeholders such as: Ministry in charge housing development and urban regeneration programmes, National Housing Cooperation (NHC) Kenya Building Research Centre (KBRC), Kenya Green Building Society (KGBS), National Construction Authority (NCA), UN-Habitat Low Emission and Climate Resilient Development (LECRD) Project and among other respondents.

In terms of policy and regulation, the sampled respondents were expected to evaluate the level at which the main guiding development processes such policies, regulations and international obligations supports the adoption of emerging buildings technologies. This study singled out the following policy and regulations: National Urban Development Policy (2016); National Climate Change Act (2016); National Environment Management Authority (1999); National Climate Change Response strategy (2010); National Housing Policy 2004 (Revised 2016); National Adaptation Plan for Kenya (2018); National Construction Authority Act (2011), National Adaptation Plan for Kenya; Agenda 2030 on Sustainable Development Goals (SDGs); National Slum Upgrading and Prevention Policy (2016); National Building Maintenance Policy (2015); Paris Agreement (COP21), 2015; Cities and Urban Areas Act (2011); National Building Regulations (2009); County Government Act (2012); Agenda 2050 (WBCSD); the African Agenda 2063 and New Urban Agenda (NUA), 2016.

There are different kinds of tools which are essential in providing criteria for the selection of suitable materials and technologies to enhance environmental sustainability in terms of resource efficiency, social and cultural performance. These tools and techniques were evaluated by the experts in the building industry and they included the following: Life Cycle Assessment (LCA); Multi-Criteria Analysis (MCA); Environmental Product Declaration (EPD); Environmental Preference Method (EPM); Building for Environmental Economic Sustainability (BEES); Leadership in Energy & Environmental Design (LEED); Environmental Assessment Method (BREEAM); British Research Establishment (BRE) ATHENA^{TM} Impact Estimator for Buildings; Green Star Rating System; Building Environment Assessment Tool (BEAT 2001); EDGE Green Building Certification System GreenMark Rating System; and Climate Action for Urban Sustainability (CURB) Tool.

4.5 Sampling Techniques and Procedure

The study adopted both quantitative and qualitative sampling methods. The quantitative techniques used included both multi-stage and simple random sampling while qualitative methods applied included purposive sampling technique. Multi-stage sampling involved the county as a unit of study with cub-counties forming the study first stratum and the nature of wards (urban and rural) as the second stratum unit of study from which the wards were sampled as illustrated in Table 4.2. The study sampled specific urban ward purposively by picking the largest wards that serve the sub-county headquarters resulting into eight sub-county urban wards. On the other hand, the study purposively picked the adjacent rural wards to the sampled urban wards due to their proximity making it easier to administer data collection tools and minimizing cost of research.

Table 4.2: Sampling frame by Sub-county and Nature of Ward

S/No	Sub-County	Nature of Wards	Ward
1.	Rongo	Rural	North Kamagambo
		Urban	Central Kamagambo
		Rural	East Kamagambo
		Rural	South Kamagambo
2.	Awendo	Rural	North East Sakwa
		Rural	South Sakwa
		Rural	West Sakwa
		Urban	Central Sakwa
3.	Suna East	Rural	God Jope
		Urban	Central Suna
		Rural	Kakrao
		Rural	Kwa
4.	Suna West	Rural	Wiga
		Rural	Wasweta II
		Urban	Ragana – Oruba
		Rural	Wasimbete
5.	Uriri	Rural	West Kanyamkago
		Rural	North Kanyamkago
		Urban	Central Kanyamkago
		Rural	South Kanyamkago
		Rural	East Kanyamkago
6.	Nyatike	Rural	Kachieng
		Rural	Kanyasa
		Rural	North Kadem
		Rural	Kanyarwanda / Macalder
		Rural	Kaler
		Rural	Got Kachola
		Urban	Muhuru
7.	Kuria West	Urban	Bukira East
		Rural	Bukira Central / Ikerege
		Urban	Isibania
		Rural	Makerero
		Rural	Masaba
		Rural	Tagare
		Rural	Nyamosense / Komosoko
8.	Kuria East	Rural	Gokeharaka / Getambweka
		Urban	Ntimaru West
		Rural	Ntimaru East
		Rural	Nyabasi East
		Rural	Nyabasi West

Source: Author, 2020

The study area comprises of 8 sub-counties as strata and 40 wards which exhibits varying degree of building materials endowment. Two wards (rural and urban) in each sub-county were selected purposefully from where the sample elements for household survey were drawn. The study sampled two wards per sub-county (urban and rural) as units of data collection.

The survey targeted an urban ward due to the desire to incorporate the largest urban surface in each sub-county as well as a rural ward due to the desire to incorporate a purely rural ward without urban influence in the study. Sampling of urban and rural wards was significance in understanding the homogeneity and heterogeneity conditions in the adoption of building materials and technologies due to differing economic index that exist between urban and rural wards. The study underscored the description of homogeneity to reflect the same characteristics within classification of urban or rural wards. The heterogeneity conditions on the other hand implied different characteristics which are exhibited by urban and rural wards in the adoption of building materials and technologies The purpose for this sampling technique was to demonstrate the extent of application and enforcement of various policies and regulations that govern the built environment sector when it comes to building materials and technology choices as well as approval processes and granting of building permits.

4.6 Criteria for Sampling

The Criteria for sampling involved verifying the total households in Migori county, determining the sample size using proportionate sample size determination method, using error margin at 95% confidence level, distribute sample size proportionately between the sub-counties, further distribution of the sample size equally between the two strata (rural and urban wards), identification of the sample elements (households) purposively and administer the survey tools to capture data on building materials (flooring, walling and roofing) Data Processing and Analysis

4.6.1 Data Processing

Data processing involved validation of returns from the field, verification of information captured, creating of code book, data capture, checking for entry errors, followed by creation of data file.

4.6.2 Data Analysis Techniques

The study focused on the establishment of embodied energy of building materials in Migori county and equivalent greenhouse gas emissions (CO_2e). This was to aide in the projection of the overall interactions and adverse impacts which human activities pauses to the natural ecosystems (Soil, Water and Tree / forest cover) as they utilize the local building materials in meeting the shelter demand.

4.6.2.1 Determining the Dominant Building Materials

The dominant building materials in the study area was identified through the analysis of the sampled household questionnaire. The sample data was subjected to both exploratory and inferential statistical tools. The exploratory tools were used to determine the dominant building materials in Migori county in terms of the modal materials and individual variation from the modal materials. This was more so in relation to numerical and categorical data.

The inferential tools were used to measure differences in the building materials within the rural/urban and between the rural/urban ($\alpha = 0.05$). The inferential tool for within county was the single sample chi-square test while the between rural/urban was measured for statistical independence using the chi-test of independence ($\alpha = 0.05$). The use of the technique above is aimed at bringing out the level of homogeneity and heterogeneity in the application of dominant building materials within the rural and urban settlement.

The Chi-Square Test procedure groups a variable into categories and a determination is made by testing the null hypothesis that the observed frequencies is the same with the expected values. The Chi-Square Test statistics generated through SPPS provided Chi-Square values and significant level and were interpreted to understand the dominants building materials. The low significance value ($p \leq 0.05$) suggests that the walling materials differ across the rural and urban wards and that there exist dominant walling materials in the study region.

The resultant dominants walling materials with higher frequencies were later subjected to further analysis related to embodied energy and carbon dioxide equivalent generated during their extraction, transportation and construction.

The study further adopted Kruskall Wallis Test (K-test) in the analysis of dominant walling materials in Migori County. The (K-test) is non-parametric analysis equivalent to ANOVA test in parametric analysis and it works by ranking the variance of sample data. The test statistics is Chi square value and it is an indication whether the independence either comes from the same population or not. The default null hypothesis is that the multiple sample come from the same population. In this case it was used to indicate whether the building materials were the same or different across the county as a way of obtaining dominant building materials.

The H-test does not assume normally and can also be used where sample size is small as opposed to standard ANOVA. The K-test uses the rank to determine the variability and therefore appropriate to apply in ordinal or nominal data type – the same scale used to collect data on dominant building materials.

The H- Test is depicted by the formula expressed in equation 4.2.

Equation 4.2: **Kruskal-Wallis H Test**

$$H = \frac{12}{n(n+1)} \sum_{i=1}^{R} R_s^2 - 3(n+1) \qquad \textbf{\textit{(4.2)}}$$

Where: H = represents the K-test;

n = being the number of observations in all samples; and

R_i = taken to be the Sum of assigned ranks.

The study also adopted the linear regression analysis to determine the relationship between energy efficiency levels of building materials and climate change. The regression was given in this format giving the relationship between the greenhouse gas emission (dependent variable) and embodied energy (independent variable).

$Y_i = \beta_o + \beta_1 X_i + €_I$ ***(4.3)***

Where:

Y_i = outcome variable which is equivalent to Greenhouse gas emission in terms of CO_2

X_i = corresponding predictor variable which is equivalent to embodied energy

β_o = an intercept of the model if the predictor is at zero value, it is constant for the regression coefficient

β_1 = is the mathematical relationship between the greenhouse gas emission and the outcome of the regression coefficient of embodied energy

$€_I$ = Error term. Since normality is assumed, the error term is equal to zero.

The resultant model regression equation is used to predict the level of GHG as a proxy to climate change outcome with a provision for an error term given in the equation.

The study employed least squares method inbuilt in SPSS to determine the line of best fit for the data used to establish the relationship between the two variables as a further test for linearity. The outputs of linear regression analysis were summary of descriptive statistics, model summary table, ANOVA table, regression coefficient table, histogram graph and PP plot graph. ANOVA table is used for testing whether the model is statistically appropriate for prediction. The model summary shows the strength of association between the independent variable (embodied energy) and dependent variable (greenhouse gas emission). Histogram graph and P-P plot graphs are used to test the normality as one of the assumption to be met for the model to be considered fit for prediction.

4.5.2.2 Estimating the Embodied Energy

In this study, every phase of energy expenditure for extraction, manufacture and transportation was entered as the independent variable in the general linear model to measure the sum total of energy per cubic unit surface (m^3), therefore the embodied energy, is specified by the formula presented in equation 4.4:

$$\textbf{\textit{Embodied Energy}} = Energy\ used\ in\ Extraction + Energy\ used\ in\ Manufacturing + Energy\ used\ in\ Transportation$$

$$i.e;\ EE_p = \sum_{i=1}^{n} E_i = E_1 + E_2 + \cdots + E_n \qquad \textbf{\textit{(4.4)}}$$

Where;

EE_p =represents the total energy input from each process phase.

i = the number of individual operations in each process phase

E_i =is energy used in each operation within the process phase

n =is the total number of operations within the phase

The individual process phases are summed up to provide the Total Embodied Energy for a particular building material as detailed in equation 4.5.

$$Total\ Embodied\ Energy\ Calculation, EE_T = \sum_{p=1}^{N} EE_p = EE_1 + EE_2 + \cdots + EE_N$$

(4.5)

Where;

$$\sum_{p=1}^{N} EE_p = Summation\ of\ Total\ Energy\ input\ from\ all\ process\ phases$$

p = the individual phase involved in material processing/manufacture

EE_p = Energy input for each process phase

N = is the total number of process phases

To estimate the embodied energy for each construction material, the quantity of material was multiplied by weight (Q_i) with the embodied energy coefficient (EE_{cm}) using a formula as described in equation 4.6:

$$EE_m = \sum_{i}^{n} Q_i EE_{cm}$$

(4.6)

Where;

EE_m = Embodied Energy of Building Material *in MJ*

Qi = Weight of the Building Material Kilogram

EE_{cm} = Embodied energy per unit quantity (MJ/Kg) also known as embodied energy coefficient

a) Transportation Embodied Energy

Transportation of the materials from where they are sourced to the site was the major contributor to the embodied energy. The transportation energy, EE_T was obtain by adding all the energy used in transporting the building material used in the transformation process as indicated in equation 4.7.

$$EE_T = \sum_{i}^{n} EE_{ti}$$

(4.7)

Material transportation energy for each material (EE_t) where the mode of transport is a vehicle was calculated by getting the product of distance covered by the material (D_m), number of trips (RT_m), fuel energy coefficient (EC_f) and the lower heating value of the fuel used (LHV_f). Most of the vehicles used for transportation were using diesel fuel and the vehicle efficiency were obtained from the manufacturers database based on the predominant type of vehicles used for the transportation in the study area. The common vehicles used in transportation needs within the study area were 7tons, 10tons, 16tons, 18tons and 32tons Lorries mainly of Isuzu and Tata Models. The embodied energy for a particular building material was therefore obtained using equation 4.8.

$$EEt = D_m RT_m \, EC_f \, LHV_f \qquad \textbf{(4.8)}$$

The transportation energy is a function of the type of the vehicle used in terms of fuel consumption capacity and type of fuel used and the haulage distance. Most of the mode transportation employed in the study region used diesel fuel with negligible proportion using petrol fuel. The study considered fuel heat values which gives a reflection of the amount of heat released during the consumption by fuel type. It is a measure of the energy density and expressed in Joules (J) / Specified quantity, (WNA, 2018). The heat values of various fuels used in the transportation and processing of dominant building materials that were analyzed in this study are diesel (42-46 MJ/Kg), Petrol (44-46 MJ/Kg) and Firewood-dry (16 MJ/KG). A detailed tabulation of heat values of various fuel products is provided in Appendix 3B.

The model of the vehicle used during transportation provided the estimate for the fuel consumption hence embodied energy. Equation 4.8 was further modified by replacing energy Coefficient values with vehicle fuel consumption values which were readily available giving equation 4.9.

EEt = Haulage Distance (D_m) * Round Trips (RT_m)*Vehicle Fuel Consumption (VC_f) * Lower Heat Value of Fuel (LHV_f)

$$EEt = D_m RT_m \, VC_f \, LHV_f \qquad \textbf{(4.9)}$$

Given that haulage distance is measured in KM, Round trips has no dimension, Vehicle consumption is measured in Litres/KM and heating values are measured in MJ/litres, the dimension analysis to prove the method could be adopted as given in equation 4.10:

$$EEt = KM * 1 * \frac{litres}{KM} * \frac{MJ}{litres} = MJ \qquad \textbf{(4.10)}$$

At every step of analysis, the embodied energy coefficient was calculated by dividing the total energy (MJ) used in transportation by the quantity of material (Kg) transported to obtain value of embodied energy per unit weight (MJ/Kg) for comparison purposes. Given that both transport and labour represent a constant figure, computation of selected building materials embodied energy was therefore done using the embodied energy formula provided in 4.10 and measured in MJ/Kg (*Embodied Energy in MJ/KG).* The formula was applied in estimating embodied energy for other dominant building materials within the study area.

b) Calculation of Hauling Distance of the Material (Dm)

The distance between the material source and project sites was calculated by the use of coordinates that were obtained during the study period. The mathematical formula for calculating the distance of two coordinates on a spherical object was adopted by the use of trigonometric function as specified in equation 4.11.

Dm=ACOS [(sin(Lat-place_1*PI()/180)*sin(Lat-place_2*PI()/180)+cos(Lat-place_1PI()/180)* cos(Lat-place_2*PI()/180)*cos(Lon-place_2*PI()/180-Lon-place_1*PI()/180))]*RE ***(4.11)***

Where:

Dm = Distance between two coordinate points

Lat_Place_1 = the first latitude point

Lat_Place_2= the second latitude point

Lon_place_1 = the first longitude point

Log_place_2= the second longitude point

PI()=π and is a function that returns number 3.141592, the value for pi

Sin() = returns the sine of an angle. The number is converted into radians for which you want the sine and is given Degree* PI()/180 since $180^o = \pi$ rad

ACOS() = 1/Cosine() and gives the inverse of cosine. The angle is given in radians in ranging from zero to pi ($0 \leq x \leq \pi$)

RE = the radius of the earth at the equator which is 6378 Km

The data captured both the location where the materials were sourced and the location of the building sites in terms of longitudes and latitudes. The data was extracted and exported to the excel platform where ACOS function was applied to generate the haulage distance which was taken to SPPS for further analysis.

c) Calculation of EE for Bricks

The calculation of embodied energy for bricks involved the analysis of all the inputs employed in the manufacture of the bricks and transportation to the site for construction. The major materials and inputs were soil, water and wood fuel. The energy for processing and transportation were added to prove the total EE. In cases where embodied energy coefficients were provided, they were assumed to be related to embodied energy for processing/manufacturing. The transportation embodied energy was then added only where they were significant especially for distances beyond 2 km from the construction site.

Soil was excavated from the site and EE_{cm} was used to calculate EE by multiplying EE_{cm} by the quantity of soil (Qi) used in the manufacture of bricks. The water used in mixing the soil was transported using a pickup consuming a total of 36 litres of diesel. In this case EEt was obtained by computing the products of LHV_f of diesel (42MJ/litres) by litres of diesel consumed (36 litres). Further embodied energy in water was taken as processing energy and was obtained by getting the product of EE_{cm} (0.20 MJ/Kg) and the litres of water used (3600 litres). Water was also used during the construction of kiln and the procedure for calculating EE was repeated. Eucalyptus logs were used to fire the bricks where 5 mature trees were cut which resulting into 40 logs of 86 kg each.

The logs were cut using a power saw which consumed a diesel fuel of 4 litres. Using the LHV_f, the researcher obtained the processing energy by computing the products of LHV_f by number of litres of diesel consumed. Wood logs were transported 4 km away and in the process more fuel were used and subjected to the analysis. The wood logs were combusted to burn the bricks and in the process heat was produced equivalent to the product of LHV_f of eucalyptus logs (16 MJ/Kg) and the quantity of wood logs (3,440Kg).

Finally, the burnt bricks were transported 4 km away to the construction site consuming 2 litres of fuel which was further subjected to the analysis process. Total embodied energy was further computed by obtaining the sum total of all the energy used in the process in accordance the previous equation discussed. Embodied energy coefficient for the bricks (MJ/kg) was then computed by dividing the resultant energy obtained in the entire process by the quantity of soil (Kg) used in the manufacture of bricks. This demonstrated by equation 4.12.

$$Embodied\ Energy\ Coefficient\ of\ Material = \ EE_{cm} = \frac{EE_m}{Q_i}$$

(4.12)

d) Calculation of EE for ISSB

The calculation of embodied energy for ISSB also involved the analysis of all the inputs employed in the manufacture of the ISSB and transportation to the construction site. The major materials and inputs for this particular study were soil, quarry dust, sand, cement, water, diesel fuel and polyethylene covers/rolls. The energy for processing and transportation were added in the computation to provide the total EE. The same process used in calculating EE for bricks was employed. Soil was excavated from site and quarry dust was also obtained from the site and did not attract energy in transportation, EEt. The experimental design for ISSB was generated at 7% cement. The study equally computed EE for 5% and 10% cement composition as provided below.

In the analysis, the higher contributor of EE in ISSB embodied energy was considered to be cement since it has a relative higher value of embodied energy coefficient of 4.6 MJ/Kg. The analysis was conducted using ratio and proportionality. Lower percentage of cement would lead to breakages and wastages with low cost while higher percentages would lead to less wastages given high quality attained during production. However, this might be associated with higher expenditure level in terms of cost of production and energy used. The mathematical model was employed to manipulate the percentages of the mixture without affecting the volume or weight generated to produce the same number of blocks.

e) Calculation of EE for Wattle

Wattle are young trees of one-inch diameter used in the construction of traditional houses with a combination of mud and sisal strips. The study revealed that the wattles were usually processed through manual cutting and transported to construction site using human carriage, animal transport or motorbike. For the purposes of computation of transportation energy, this study adopted motorbike as the mode of transportation of wattle. The study established that one bunch of twig comprising of about 10 twigs had a total mass of 10Kg. This means that one twig yielded 1 kg of mass.

The steps followed in calculating processing/cutting energy included:

i. Noted that processing/cutting is done manually using a Panga
ii. Taking the hand capacity as 45N and the cutting distance at 2 metres.
iii. Computing the work done, W = Force x Distance =Energy in Joules
iv. To process or cut one twig of approximately one-inch diameter completely takes 8 strokes. The process involved cutting the standing tree/twig and removing the other branches and leaves.
v. The study assumed that the manual process did not emit significant level of CO_2e.

The steps followed in calculating the transportation energy and equivalent CO_2e in wattle application included:

i. Motorbike was adopted as the mode of transport.
ii. The distance travelled was 8 km per round trip
iii. Fuel consumption per round trip was 0.32 litres with fuel consumption of 0.04 litres/Km
iv. Each round trip involved transporting 50 kg of material
v. Heat values for petrol fuel was 44 MJ/litre
vi. Energy consumed during transportation was obtained by getting the product of heat value for petrol fuel and the litres of fuel consumed per Kilogram of material transported.
vii. CO_2 emission equivalent was calculated using combustion equation as 2.39 $KgCO_2$/kg

4.6.2.2 Estimating the Embodied greenhouse gas emission (CO_2)

The embodied greenhouse gas emission of the material within the initial lifecycle boundary was calculated using Equation 4.13.

$$ECO_2 = \sum_{1}^{i} ECO_{2i}$$

(4.13)

Where ECO_{2i} and ECO_2 are the amount of embodied green gas emission of the of the i^{th} type of building material and the total building material respectively. Further, the emissions for each of the material used for the building (ECO_{2i}) was obtained by multiplying the quantity of the material (Q_i) by the CO_2 emission coefficient of the i^{th} type of the material (CO_2EC_m)as expressed by equation 4.14.

$$Embodied\ Greenhouse\ Gas\ Emission = ECO_{2i} = \sum_{1}^{i} Q_i CO_2 EC_m$$

(4.14)

The researcher adopted both estimation and calculation approaches to determine the embodied energy by integrating the field data and available data on CO_2 emissions of the building materials to obtain the estimated greenhouse gas emission.

a) Calculation of Embodied greenhouse gas emission in Burnt Bricks

The greenhouse gas emission in burnt bricks was determined by obtaining the sum total of CO_2 emission used in the entire process as discussed above. The CO_2 generated during extraction, manufacturing process and transportation were added to produce total CO_2 emitted during BB production and construction. The main input/material that generated CO_2 emission were soil, water, wood fuel, diesel fuel, and combustion process. Soil contain CO_2 emission equivalent of 0.02 $KgCO_2e/Kg$ and this value was multiplied by the mass of soil excavated to derive the total CO_2 released from soil. In addition, during the wood fuel logging process and transportation of logs and bricks, the litres of diesel used were obtained and CO_2 equivalent computed.

CO_2 Equivalent by the use of diesel fuel was calculated using mole concept, stoichiometry and combustion equation. One litre of diesel contains 86.2% of carbon and weighs 0.835 kg which results into 0.72kg of carbon.

By the use of mole concept, the moles were obtained using question 4.15;

$$Moles = \frac{Mass\ of\ Carbon}{Molecular\ Mass\ of\ Carbon}$$

(4.15)

$$Moles = \frac{720}{12} = 60\ Moles$$

By the use of stoichiometric ratio, the moles of Carbon are the same as moles of carbon dioxide since the ratio is one to one. Further, the molecular mass of Carbon dioxide is 44 gms (12 + 16*2)

$$Mass\ of\ Carbon\ dioxide = Moles\ of\ CO2 * Molecular\ Mass\ of\ Carbon = 60 * 44.01$$
$$= 2640\ grams = 2.64\ Kg$$

Combusting one litre of diesel will therefore produce 2.64 kg of carbon dioxide using up 1.92kg of oxygen.

By the use of the above approach, the CO_2 equivalent for combusting diesel was obtained as 2.64 KgCO_2/litre. Similar derivation was used to calculate the CO_2 emission from petrol resulting into 2.31 KgCO_2/litre.

During the brick burning, Eucalyptus logs were used. Eucalyptus logs contain between 47% - 50% carbon. This study adopted average values of 48.5% as the composition of carbon in Eucalyptus logs. This implied that 1kg of Eucalyptus wood contain 1000 * 0.485 of carbon which was equivalent to 485 grams of carbon. The mass of carbon was used to obtain the equivalent moles (41.67) which were then used to obtain the mass of CO_2 released by burning the wood.

$$Mass\ of\ Carbon\ dioxide = Moles\ of\ CO2 * Molecular\ Mass\ of\ Carbon$$
$$= 41.67 * 44.01 = 1778.7\ grams = 1.779\ Kg$$

I kg of wood fuel contains 0.48 kg of carbon which produce 1.779 kg of Carbon dioxide when combusted consuming 1.29 kg of oxygen.

Eucalyptus tree takes between 5-15 years to obtain full maturity. Young tree absorbs 5.9Kg of carbon per year, while mature tree absorbs 22 kg of carbon annually. The study assumed that the productive life cycle of the eucalyptus trees was prematurely eliminated resulting into 10 years forgone for active carbon absorption. The carbon forgone for the five trees used to burn bricks was calculated by getting the product of forgone carbon dioxide per year, number of trees and years used to complete the productive age.

This expression is provided in equation 4.16.

$$Forgone\ Carbon\ dioxide\ Sequestration = CO2\ sequestered\ per\ tree\ per\ year * Number\ of\ Trees * Number\ of\ remaining\ productive\ year$$

(4.16)

$$Forgone\ Carbon\ dioxide\ Sequestered = 22 * 5 * 10 = 1100\ Kg$$

The table below provides the inputs/material that produced CO_2 in the process of making the burnt bricks. The Carbon dioxide equivalent for the burnt bricks were obtained by dividing the total CO_2 emitted in the entire process by the weight of bricks burnt as given in equation 4.17.

$$Equivalent\ Carbon\ Emission\ of\ Bricks, EC_m = \frac{Total\ Emmitted\ Carbon\ in\ the\ entire\ process, ECO_{2i}}{Mass\ of\ Bricks\ burnt, Qi}$$

(4.17)

b) Calculation of Embodied greenhouse gas emission in ISSB

The calculation of greenhouse gas emission for ISSB also involved the analysis of all the inputs employed in the manufacture of the ISSB and transportation to the site for construction. The major materials and inputs were soil, quarry dust, sand, cement water, diesel fuel and polyethylene cover/roll. The CO_2e for processing and transportation were added to provide the total greenhouse gas associated with the process. The table below provide the main input/materials and some of the processes that generated CO_2 at various phases. The same process used in calculating ECm for BB was employed. In this particular study, the key raw materials notably; soil and quarry dust were excavated on-site, hence accruing CO_2e traced to the transportation phase was negligible.

4.6.2.3 Determining the extent of Application of Energy Efficient Building Technologies

Energy efficiency building technologies denotes sustainable housing development and determining adoption levels by residents of Migori is quite significant in this study. The preliminary phase involved the use of exploratory data analysis tools to measure the extent of adoption. The result of the exploratory analysis was used to create adoption level which was then used in measuring differences in adoption at different levels notably: between sub-counties, wards (rural/urban) and type of use (residential/non-residential). The analysis was done using single sample t-test within the factors and using One-Way ANOVA or K-test (α = 0.05) between factors as depicted in the equation 4.2

4.6.2.4 Establishing Resource Efficiency Levels

The study compared the resource requirements in producing unit block of ISSB and BB respectively and in constructing a M^2 of a wall using ISSB and BB. The efficiency levels were measured in terms of raw materials (sand, cement, soil, water, fuel), embodied energy, GHGe, labour per man-day and time for construction up to lintel level.

The detailed research analysis on resource efficiency focused on the following aspects while focusing on the selected materials and technologies for experimental design in the study area. The key parameters of the experimental design involved: The level of material saved in terms of percentages; embodied energy consumption; equivalent carbon dioxide emission; cost of materials and technology use; time of construction delivery; and labour requirement.

The research adopted $1M^2$ of walling area as the unit of comparing resources among various dominant materials examined in the study.

Table 4.5 Resource efficiency analysis parameters

Resource Analysis	Method of Analysis	Parameters of measurements	Unit of Measurements
The level of material saved in terms of percentages	Comparing the total materials applied per unit area and related cost	Mass	Kg
		volume	Litres
		Level of material saved	%
Embodied energy consumption	Comparing the embodied energy coefficient and associated cost	Embodied energy	MJ
		Embodied energy coefficient	MJ/kg
		Cost	USD ($ = Kshs. 105)
		Level of embodied energy saved	%
Equivalent Carbon Dioxide Emission	Comparing the CO_2e and associated environmental cost	CO_2 emission	Kg
		CO_2 equivalent	Kg CO_2e/Kg
		Cost to the environment	USD ($ = Kshs. 105)

		Level of CO_2 saved	%
Cost of materials and technology use	Comparing the summation cost associated with building the house including GHG emission levels	Total cost used	USD ($ = Kshs. 105)
Time of construction delivery	Comparing the speed of construction delivery from production to walling	Time	Days
		Time saved	%
Labour requirement	Comparing the labour requirement in terms skilled and non-skilled labour	Skilled	Man-days
		Non-Skilled	Man-days
		Labour saved	%

Source: Author, 2020

4.6.2.4.1 Comparison of Embodied Energy and CO_2e from ISSB Technology with 7% cement ratio as the baseline.

The dominant building materials and associated technologies used in construction by residents of Migori county have different outputs of EE and CO_2e levels. At the construction stage, cement material was taken as the base material of analysing the EE and CO_2e associated with various construction technologies.

According to Hydraform Ltd (2009), the process of ISSB production commences with the selection of suitable soil for block manufacture; getting river sand / or suitable aggregates of quarry dust to site where applicable; sieving of materials using the right mesh (8-10mm size); setting up the production site for maximum capacity; levelling the site for stacking of the blocks and curing; sensitization of the workforce (8-10 labourers) on machine safety, operations, material preparation, rations, mixing, handling of green blocks and curing by watering of blocks.

The study involved working with the labour force / trainees organized by the Department of Housing (Migori) at Kehancha Prison site who were trained on the various aspects of the technology use for a period of 14 days. The detailed description of the process and steps followed in the production of ISSB blocks at the experimental site in Kehancha is depicted in section 5.4.2.2 (Tables 5.21 – 5.29) where it is demonstrated that the use of 7% cement ratio in the material mixture yields approximately 60 blocks (actual 58 ISSB ± 2)

It therefore follows that, to estimate cement savings and equivalent CO_2 reduction in the application of, the approach adopted for the 5% and 10% cement ration involved the following steps;

a) Scenario involving 5% cement ratio

i. Total mass of cement used in the case of 7% cement ratio = 2750kg

ii. Total Material mixture = 38,150kg

iii. Total mixture for 5% cement ration = 7/5*38150 = 53410kg

iv. Deducting 38150kg from 53410kg = 15260kg being excess kgs yield of cement

v. Cement saved = 5/100*15260 = 763kg of cement saved

vi. From the model = reduce kgs by 763kg to estimated CO_2 reduction

vii. Deducting 763kg from 2750kg = 1987kg

viii. Equivalent CO_2 for 1665.29kg of cement mixture = 0.073kg CO_2e/kg.

b) Scenario involving 10%

i. Total mass of cement used in the case of 7% cement ratio = 2750kg

ii. Total Material mixture = 38,150kg

iii. Total mixture for 10% cement ration = 7/10*38150 = 26705kg

iv. Deficit 38150kg - 26705kg = 11445kg being additional kgs of cement required

v. Additional Cement = 10/100*11445 = 1,144.5kg of cement required

vi. From the model = add kgs by 1,144.5kg to estimated CO_2 increase

vii. Increasing 2750kg by 1,144.5kg = 3894.5kg of cement

viii. Equivalent CO_2 for 3248.52kg of cement mixture = 0.114kg CO_2e/kg.

4.6.2.5 Determining Suitability of Building Approval Processes

The building approval processes is key to promoting use of energy efficient building methods among county residents. The study established the suitability of various regulatory tools used by the national and county departments in promoting environmentally-friendly buildings.

4.7 Scope and Limitations of the Study

The study was conducted in Kenya taking Migori county as a case study represent scenarios in developing countries. The research focused on building materials used for walling within the study area. The study involved estimations of embodied energy (EE) of building materials and technologies in relation to climate change by analysing greenhouse gas emission, resource efficiency and carbon sequestration levels (soil, water and forest products). The study used greenhouse gas emission as a proxy measure to climate change effect since observed climate change events can only be detected over longer durations.

Similarly, the carbon sequestration estimation and analysis was limited to material sources of extraction and production. Further, the experimentation phases were restricted to raw materials extraction, production, and construction stages thus not covering the operation, refurbishment and demolition phase. The study therefore excluded the aspects of Life Cycle Analysis (LCA) that covers operation, refurbishment/maintenance and demolition/end of life in buildings in analysing embodied energy of the building materials. The scope as demonstrated in Figure 2.5 covered extraction of natural resources, process into materials and components, transportation and construction with construction phase being limited to walling to lintel level

The study aimed at demonstrating through causal relationship that by increasing greenhouse gas emission, the effects and impacts on climate change are perceived but did not explore the direct impact of building materials and technology use on climate change. The study is further limited to the use of urban and rural wards for purposes of representation taking into consideration of heterogeneity of the study area hence the rural and urban divide is not taken as a basis for testing the hypotheses of the study. These limitations were addressed by combining the experimental design as an additional method for checking on the efficacy of the estimates.

5 BUILDING MATERIALS AND EMBODIED ENERGY

5.1 Introduction

The research findings as discussed in this chapter addressed objectives one and two of the study which involved identification of the dominant building materials applied in housing development and their embodied energy levels as well as the extent of application of energy efficient building technologies.

The research hypotheses addressed under this chapter were;

1. H_O: Appropriate building materials, technologies and designs are predominantly applied in meeting the building demand levels of Migori county.
2. H_O: There are higher proportions of respondents applying energy efficient building technologies.

The results and discussions that relates to the first two objectives of the study are presented and discussed in the succeeding subsections of this chapter.

5.2 Survey Response

The household survey sample for this study was guided by the household in Migori as at 2009 Kenya Population and Household Census which stood at 166,500 households. The 2009 census data was appropriate for this study given that it was the only available data at the time of conceptualization and formulation of the research. Table 5.1 depicts the sample size representation from the study area by sub-county.

Table 5.1: Depicts the Level of Sample Size Representation for Each Sub-County.

S/No	Sub-County	No. of Households (Sample Frame)	Proportionate Sample Size	Sample Size Obtained	Response Rate
1.	Rongo	19,500	45	37	82.2%
2.	Awendo	21,800	51	45	88.2%
3.	Suna East	18,700	43	45	104.7%
4.	Suna West	18,200	42	42	100.0%
5.	Uriri	20,900	48	48	100.0%
6.	Nyatike	27,300	63	51	81.0%
7.	Kuria West	27,400	63	59	93.7%
8.	Kuria East	12,700	29	29	100.0%
TOTAL		**166,500**	**384**	**356**	92.7%

Source: Modified from Kenya National Bureau of Statistics (KNBS, 2013)

By the time of undertaken the 2019 Census, the study was already underway with the data from 2019 census providing a platform for projections.

5.3 Dominant Building Materials and Associated Embodied Energy in Migori County

The study provides the relationship of the ways employed towards production of building materials and the ability of the surrounding environment to provide the GHG emission balance for environmental sustainability. It focused on the initial life cycle of the building materials from extraction, manufacturing, transportation, construction and energy consumed by these activities. According to Economic Survey of Kenya (2015), building and construction industry recorded high growth rates of 13.1% in comparison to 5.8% in 2013 indicating high population growth coupled with demand for housing and other building needs. The common environmental materials and products that are used to provide housing needs for urban and rural areas across Kenya include burnt bricks, cement, quarry stones, lime, concrete blocks, timber, iron sheets, grass, mud and wattle, among others (GoK, 2015).

5.3.1 Dominant Building Materials in the Study Area

The study determined the dominant building materials at the household level with sample elements being drawn from the 8 sub-counties of Migori. However, the sources of these building materials were not limited to the study area as some were traced to other localities through referencing by some of the residents who demonstrated preference for certain materials which were available outside the study area. Such material sourcing areas outside Migori included Oriwo Turf in West Karachuonyo Division of Homa Bay, Kedowa in Kericho, Ndarugo in Juja-Thika, Tabaka in Kisii and Sironga in Nyamiri among others.

Oriwo Turf is a major site for quarry stone that served the residents of Migori and other parts of the Country. The location map of Oriwo Turf is represented in Appendix 2A and it stretches from Oriang to Oriwo Area and traverses Samanga – Kadel – Njeri – Oywer – Adiedo – Sare – Twist Centre – Border –Nyamwala – Dengu – Apamo – Siburi – Kandiege – Samanga areas. The basement rocks and resultant quarry stones mined in the area exhibits diverse colours with Alaru area being characterised by rocks which are white in nature; Siburi area (black); and Oriwo area dominated with stones of diverse colours (yellow, red and brown).

The quarries at Oriwo are mainly due to volcanic eruption and lava flow which borders on three distinct fault lines: Kericho-Nyabondo Plateau – Lake Simbi; Wire-Lake Simbi; and Lake Simbi – Kanyamwa Escarpment. The period of these geographic formations related to Carbonatites with Series of hills running upto Asego hills. Another fault line run from Kochia and terminating at Ngegu area in Homa Bay, a phenomenon which resulted from a volcanic eruption with hot mud which happened at Ngegu leading to deposits of lava flow in the area, thus making the soils in the vicinity to be very fertile with most farmers successfully growing bananas and millet among other crops. The interaction with experts in the field of geomorphology further established the existence of large carbonatites which is manifested by the existence of Homa Hills, Kaksingri and Gwasi hills – all found in the western region. The area is characterized by dimensions and thickness of the rock as well as domination by artisols with quarries existing adjacent to the hills. The resultant phenomenon disruption of the landscape especially settlements. The field interaction and observations noted the existence of a water body due to deposition of granitic bowls – metarmophic rocks of basement, that is, Kanyaluo and Wire belt as well as the Kitere belt in Migori which are associated with gold mining whose deposition must have been transported by a water mass.

The volcanic activities in the region were also attributed to the existence of Lime at Homa Hills, Kanjira, Koru and Kariandusi. The rich history associated with the area has connection to the Stone Age people who lived in Kanjira. Indeed, the Kanjira Man must have lived before the sea, which could have happened in the period of 1.8 – 2 million years ago (Field Information). The eastern side of Kanyamfwa exhibits different geology with Samanga fault line extending from Sondu – to – Lambwe Valley; with Gendia – Wire stretch mainly comprising of granites. The colour composition of the basement rocks include; red, brown, yellow, black, white which exists at different locations. Table 4.3 details the some of the main quarry sites within Oriwo turf and the nature of stone endowment based on the dominant colour.

Table 4.3 Quarry Site and Nature of Stone

S/NO	Quarry Site / Location	Nature / Colour of Stone
1.	Oriwo	Yellow, Red and Brown
2.	Siburi	Black
3.	Alaru	White

Source: Researcher, 2020

It is observed that the existence of hard rocks/ stones is due to complete burning of lava. For instance, the Southern region of Oyani – Kitere – Rongo belt exhibits large boulders of granitic rocks which is heavily weathered. This occurrence is similar to the situation exhibited by the Gendia – Kasipul belt which is also highly weathered leading to formation of sand. The sand formation in these regions are easily swept away to river beds, thus resulting to sand harvesting along river beds and lake shores. It is further established that Granitic rocks lead to existence of ballast in the region. In Migori, for instance, use of Laterites, that is, murram when exposed lead to formation of stones used in foundation, especially the hardcore. The availability of building materials in this particular locality was due to volcanic eruption and lava flow.

To prove existence of a large mass of water body, there are traces of deposition of granitic bowls which are depicted by metarmophic rocks of basement especially at Kanyaluo and Wire Belt. The scenario further exists in the Kitere belt in Migori which is associated with Gold mining as such depositions must have been transported water mass. The lime deposition in Homa lime area and Kanjira in West Karachuonyo is a replica of the scenario in Kariandusi around Lake Elementaita in Nakuru County. It is further established that stone age people lived in Kanjira, that is, the Kanjira Man who is suggested to have lived before the era of the Sea in this area at approximately 1.8 to 2 million years ago (Field Interview, 2019). The study further established that eastern side of Kanyamfwa have different geology while Samanga fault line extends from Sondu to Lambwe Valley and Gendia – Wire axis is composed of granitic rocks.

5.3.1.1 General Walling materials

The research established that the household applied the use of building material at different levels with some of the materials identified as quarry stone, concrete blocks, burnt bricks, mud interlocking stabilized soil blocks (ISSBs) and prefabricated and iron sheets. The trends in material use / application reveals the damage to the environment. For instance, at independence when the population was low with the national average being at below 10 million, the environmental condition then, including forest cover, soils and water resources was a healthy one as there was low level of encroachment to the virgin areas due to demand for building materials. Such a situation has dramatically changed for the worse as the population changes continue escalate with 2020 projections having numbers to the tune of about 53.8 million, 2030 population projections being 66.4 million and the 2050 population projections for the Kenya noted to be 91.6 million.

The approaches adopted in the exploitation of these building materials and subsequent interaction with the environment clearly dictates the level of impact on the natural environment and climate change effects. For instance, most quarry stones used within the study areas were extracted and transported several kilometres away.

Table 5.2a:Walling Materials Used

S/NO.	Walling Materials	Frequency	Percent
1.	Stone	23	6.5
2.	Mud	115	32.3
3.	Bricks	139	39.0
4.	Timber	4	1.1
5.	Interlocking Stabilized Soil Blocks (ISSBs)	8	2.2
6.	Concrete Blocks	63	17.7
7.	Iron Sheets	4	1.1
	Total	**356**	**100.0**

Source: Researcher, 2020

The results on building materials by nature of wards (rural/urban divide) is demonstrated in Table 5.2b

Table 5.2b: Walling materials by Nature of Wards

SN	Building Materials	Nature of Ward				Total	
		Urban		Rural			
		Count	Urban (%)	Count	Rural (%)	Count	% within Nature of Ward
1	Stone	17	9.0%	6	3.6%	23	6.5%
2	Mud	41	21.8%	74	44.0%	115	32.3%
3	Bricks	85	45.2%	54	32.1%	139	39.0%
4	Timber	0	0.0%	4	2.4%	4	1.1%
5	ISSBs	4	2.1%	4	2.4%	8	2.2%
6	Concrete Blocks	40	21.3%	23	13.7%	63	17.7%
7	Iron Sheets	1	.5%	3	1.8%	4	1.1%
	Total	**188**	**100.0%**	**168**	**100.0%**	**356**	**100.0%**

Source: Researcher, 2020

The study also analysed the dominant building materials and resultant data by nature of ward as detailed in Appendices 1G1 and 1G2.

The Photos in plates 5.1 and 5.2 demonstrates the extraction process of quarry stones at Oriwo Turf, Ndarugo and Tabaka sites in Karachuonyo, Juja-Thika and Kisii respectively.

Plate 5.1: Quarry Stone Extraction at Oriwo Turf in Karachuonyo

Source: Author, 2020

Plate 5.2: Extraction of Quarry Stone at Ndarugo in Juja-Thika

Source: Author, 2020

Plate 5.3: Extraction of Building Stones at Tabaka in Kisii

Source: Author, 2020

The manufacture of burnt bricks entail use of soil extracted from location-specific sites. Suitable soils fit for this purpose usually contains higher proportion of clay – soil content. The process further involves the application of water for moulding the bricks and wood fuel for burning / firing the brick kilns. Plates 5.4 and 5.5 demonstrates these processes.

Plate 5.4: Moulding of Bricks during Manufacturing

Source: Author, 2020

Plate 5.5: Firing of Bricks in readiness for Construction

Source: Author, 2020

The study demonstrated that production of Interlocking Stabilized Soil Blocks (ISSB) could employ different machinery notably; the manual block pressing machines and hydraulic machines. In Kenya, the manual / hand pressed machines are engineered by different enterprises with lead firm being Makiga engineering ltd. On the other hand, the successful hydraulic ISSB machine which is widely used is the Hydraform machine which is a product developed by Hydraform company ltd from South Africa. Plates 5.6 and 5.7 depicts the ISSB production machines in use within the study area.

Plate 5.6: ISSB Training and Block production at Kehancha Prison in Migori.

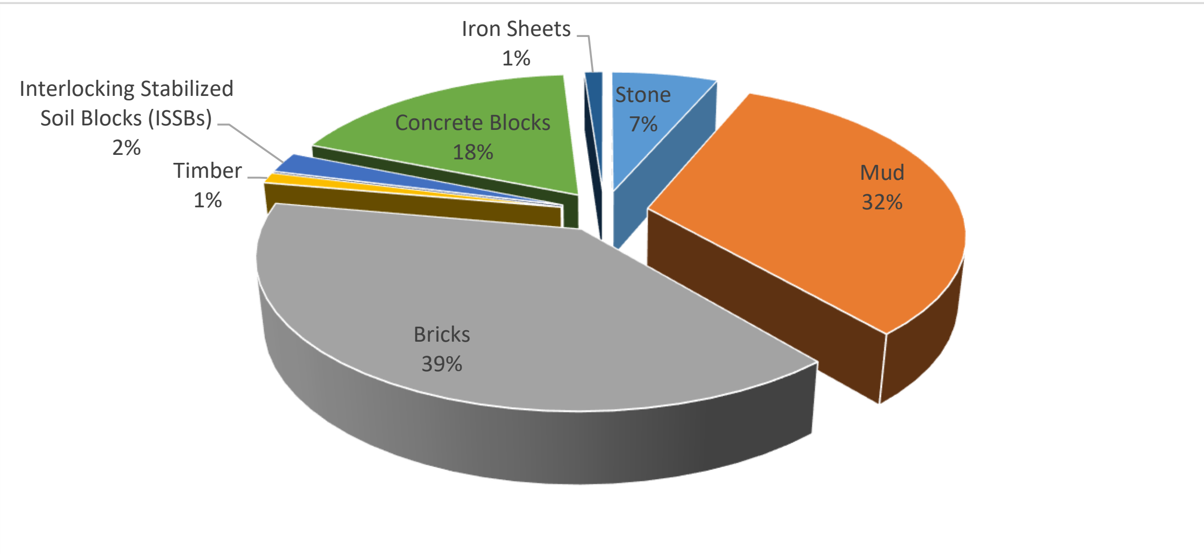
Source: Author, 2020

Plate 5.7: ISSB Production using Makiga Manual Press Machine at Kakrao in Migori.

Source: Author, 2020

The distribution of walling materials as adopted by residents of Migori in meeting their building and construction needs including the provision of housing / shelter is depicted in Fig. 5.1 where brick is still found to be ranking high at 39% followed by mud houses at 32%, concrete blocks at 18% and Stone at 7%. The ISSB, timber and iron sheets all ranked low at 2% and 1 % respectively.

Figure 5.1: Dominant Walling Materials in Migori



Source: Author, 2020

The government has a goal of providing 500,000 units of affordable houses under the Big Four Agenda and intents to adopt the emerging building materials and technologies. The existing government policy identifies ISSB materials as key to achieving this goal especially in rural setups. In order to demonstrate the significance of environmental sustainability in terms of the type of material used, the study experimentally compared the application of burnt bricks and ISSB in order to understand and determine carbon sequestration conditions within the study area.

The study adopted Chi-Square statistics to determine whether there were dominant materials in Migori county. The Chi-Square test procedure groups a variable into categories calculates a Chi-Square statistic. The test works by comparing the observed and expected frequencies in each group/category to check if all the groups have the same proportion values.

Table 5.3a:Chi-Square Analysis of Dominant Walling Materials

S/NO	Dominant Walling Materials	Observed N	Expected N	Residual
1.	Stone	23	50.9	-27.9
2.	Mud	115	50.9	64.1
3.	Bricks	139	50.9	88.1
4.	Timber	4	50.9	-46.9
5.	Interlocking Stabilized Soil Blocks (ISSBs)	8	50.9	-42.9
6.	Concrete Blocks	63	50.9	12.1
7.	Iron Sheets	4	50.9	-46.9
	Total	356		

Source: Author, 2020

The Chi-Square analysis provide the observed and expected values and the residual values which is the difference between the observed and the expected values. The higher the residual value the higher the deviation from the expected which result into higher Chi-Square values. The larger Chi-Square values (χ^2) shows higher differences in observations leading to smaller P-Value. This study demonstrates that the expected value was 50.9 with varied observed values. This implies that the minimum expected cell frequency is 50.9 and any variation above this figure will result into a residual value as depicted in Table 5.3a.

Table 5.3b: Chi-Square Test Statistics

Chi-Square Test Statistics	Values
Chi-square	374.281
df	6
Asymp. Sig.	0.000

Source: Author, 2020

Table 5.3b shows the Chi-Square test statistics with Chi-Square values being 374.281 and degree of freedom being 6 and Asymp. Sig (P-Value) being 0.00. The P-value being the calculated probability of attaining a χ^2greater than or equal to 374.281 if the dominant walling material are uniformly spread the county. The low value (p =0.00) indicate that the walling materials differs across the county and that there are others which are more commonly used within the county. These include; bricks, mud and concrete blocks however, mud is not approved building materials since it is considered to be temporary building materials used to build traditional houses.

In order to test the null hypothesis that environmentally sound building materials, technologies and designs are predominantly applied in meeting the building demand levels of Migori, the study considered only the approved building materials and categorized the building materials into two groups (energy efficient and non-energy efficient materials) and applied a Chi-Squire test. The materials grouped as energy efficient were ISSB, precast concrete and prefabricated timber and iron sheet while the non-energy efficient materials were bricks, concrete blocks and stones.

H0: Environmentally sound building materials, technologies and designs are Predominantly (P) applied in meeting the building demand levels of Migori County.

Null Hypothesis, H_0: P > 50% or P >0.5

Research Hypothesis, H_1: $P \leq 50\%$ or $P \leq 0.5$; α =0.05

Table 5.4a shows the results of Chi-Square test of energy and non-energy efficient building materials applied in Migori county.

Table 5.4a:Category of Energy Efficient Building Materials in Migori

	Observed N	Expected N	Residual	Percent
Energy Efficient Building Material	17	120.5	-103.5	7.1%
Non Energy Efficient Building Material	224	120.5	103.5	92.9%
Total	241			100.0%

Source: Researcher, 2020

The expected value provides the cut of points such that any category above 120.5 expected values is considered to be predominant. In study, the non-energy efficient building materials revealed an observed value of 224 with a positive residual value of 103.5 indicating that it was the predominant groups of materials.

The Non-Energy Efficient Building Materials constituted 92.9% of the walling materials compared to of the 7.1% of energy efficient walling materials. By testing our null hypothesis (Ho: $P > 50\%$ or $P > 0.5$), the proportion of environmentally efficient building material (P) was 7.1% or 0.071 was not greater than 50% i.e. $P \leq 50\%$. Table 5.4b further provides the Chi-Square test statistics of energy efficient building materials in Migori to demonstrate whether the difference was statistically significant.

The larger Chi-square values of 177.8 (critical value is 3.84 at an alpha level of 0.05) demonstrate that there was a larger difference in the two groups of building materials. The p-value was much less than the alpha values ($0.001<0.05$) indicating that there was sufficient statistical evidence demonstrating the two groups of building materials were significantly different. We therefore rejected the null hypothesis and accept the research hypothesis by concluding that environmentally sound building materials, technologies and designs are not predominantly applied in meeting the building demand levels of Migori county.

Table 5.4b: Chi-square Test Statistics of Walling Materials Used in Migori County

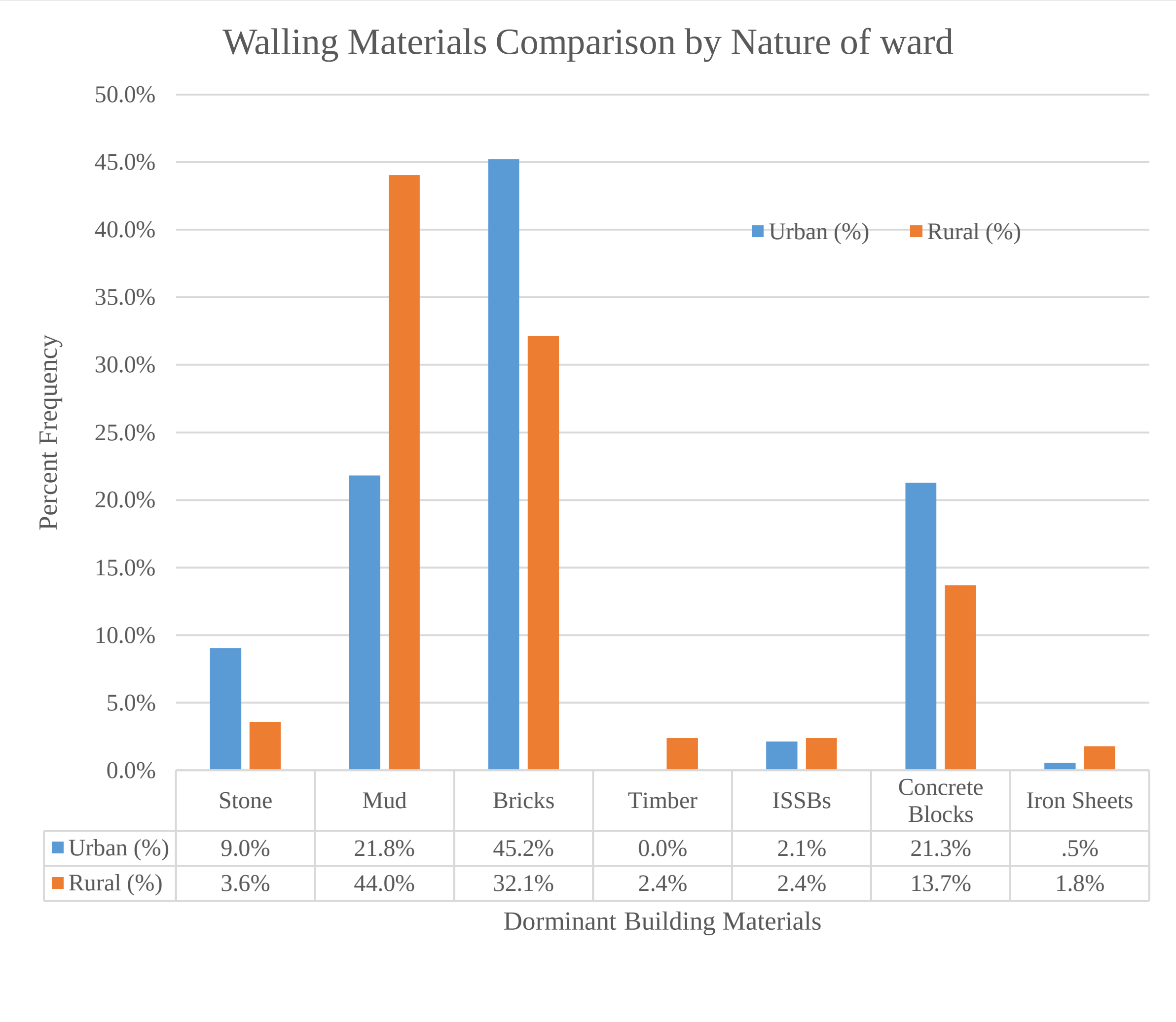
Chi-square Test Statistics	Values
Chi-square	177.797
df	1
Asymp. Sig.	.000

Source: Author, 2020

5.2.1.2 Walling Material by Nature of Ward

The dominant walling materials across the wards included bricks, mud and concrete blocks. This study demonstrated higher application of bricks in urban wards at 45.2% compared to rural ward at 32.1%. The use of mud was higher in the rural ward at 44.0% compared to 21.8% in the urban areas. The comparison for concrete blocks was at 21.3% and 13.7% for urban and rural ward respectively. These analyses are depicted in the figure 5.2.

Figure 5.2: Comparison of Walling Material by Nature of the Ward



	Stone	Mud	Bricks	Timber	ISSBs	Concrete Blocks	Iron Sheets
Urban (%)	9.0%	21.8%	45.2%	0.0%	2.1%	21.3%	.5%
Rural (%)	3.6%	44.0%	32.1%	2.4%	2.4%	13.7%	1.8%

Source: Researcher, 2020

The Kruskal-Wallis Test was used to determine if there was a difference in the adoption of dominant walling materials by nature of the wards (rural and urban).

Table 5.5a:Kruskall - Wallis Test (Ranks) on Walling Materials by Nature of Ward

SN	Rank	N	Mean Rank
1	Urban	188	189.05
2	Rural	168	166.69
	Total	**356**	

Source: Researcher, 2020

The Kruskall – Wallis Test uses mean rank to compare the difference between the groups. The study provided urban ward mean rank at 189.05 compared to rural ward at 166.69.

Table 5.5b: Kruskall – Wallis Test Statistics on Walling Materials by Nature of Ward

Chi-square	4.647
df	1
Asymp. Sig.	0.031

Source: Researcher, 2020

The Tests for several independent samples procedure compares two or more groups of cases on one variable. The p-value estimates the probability of getting χ^2 statistic greater than or equal to 4.674, if there are no differences between the nature of wards.

5.3.1.2 Socio-Economics and adoption Levels of Walling Materials

The study established the relationship of various socio-economic characteristics of the respondents in relation to adoption of building materials and technologies. The data was analysed through cross tabulation of various socio-economic parameter and the use of energy efficient building materials with Chi-Square used as a test statistic to determine the relationships. The age cohorts are significant in reconstructing the records in terms of time series analysis of the state of the environment over the periods. The research therefore benefited from the memories of the various categories of the respondents guided by the age and average time that they had lived within in the study area.

Respondents categories is useful is demonstrating the type of information and knowledge levels to establish whether the level of information is the same to demonstrate wide information levels about a particular material, such information enables the researcher to make quarries received from each category of the respondents. The profession / or occupation is a key parameter for the socio-economic, given that an assumption is made in a manner that the level of profession / or occupation is associated with income levels of the respondents.

In general, the study observed that characterizing households by occupation, age, gender, nature of urban area – all theorizing towards a particular material of adoption, that is the characteristic or individual perception / knowledge / professional influences on the particular choices made in the building materials selection. The results on all the key aspects of socio-economic particulars are presented in table 5.5c which shows the key characteristics in terms of gender, age, level of education, and profession / or occupation. The study further relates the aspects of socio-economic dynamics to the environment conditions which largely depicts the measures of concerns, knowledge and attitude.

Table 5.5c: Cross Tabulation of Socio-economic Characteristics with level of Adoption of Energy Efficient Walling Materials

Group	Characteristics	Walling Materials Used in Migori County						Total		
		Energy Efficient Building Material			Non Energy Efficient Building Material					
		Count	Expected Count	% within Group	Count	Expected Count	% within Group	Count	Expected Count	% within Group
Gender	Male	13	11.3	8.1%	147	148.7	91.9%	160	160.0	100%
	Female	4	5.7	4.9%	77	75.3	95.1%	81	81.0	100%
	Total	17	17.0	7.1%	224	224.0	92.9%	241	241.0	100%
Age	20-35 years	1	2.4	2.9%	33	31.6	97.1%	34	34.0	100%
	36-50 years	8	6.2	9.1%	80	81.8	90.9%	88	88.0	100%
	51-65 years	3	5.9	3.6%	81	78.1	96.4%	84	84.0	100%
	66 years and above	5	2.5	14.3%	30	32.5	85.7%	35	35.0	100%
	Total	17	17.0	7.1%	224	224.0	92.9%	241	241.0	100%
Highest level of education attained	None	1	.7	10.0%	9	9.3	90.0%	10	10.0	100%
	Primary	7	6.7	7.4%	88	88.3	92.6%	95	95.0	100%
	Secondary	4	6.3	4.4%	86	83.7	95.6%	90	90.0	100%
	College	0	2.0	0.0%	28	26.0	100.0%	28	28.0	100%
	University	5	1.3	27.8%	13	16.7	72.2%	18	18.0	100%
	Total	17	17.0	7.1%	224	224.0	92.9%	241	241.0	100%
Professional	Building Practitioners	0	.7	0.0%	10	9.3	100.0%	10	10.0	100%
	Business	8	8.6	6.6%	114	113.4	93.4%	122	122.0	100%
	Farmers	4	3.3	8.5%	43	43.7	91.5%	47	47.0	100%
	Formal Employment	4	3.3	8.5%	43	43.7	91.5%	47	47.0	100%
	Others	1	.8	9.1%	10	10.2	90.9%	11	11.0	100%
	None	0	.3	0.0%	4	3.7	100.0%	4	4.0	100%
	Total	17	17.0	7.1%	224	224.0	92.9%	241	241.0	100%

Source: Author, 2020

Table 5.5c illustrates the relationship between the gender, education level, age and occupation with the adoption level. Across all the socio-economic characteristics, the adoption of energy efficient walling materials was lower compared to non-energy efficient walling materials. The study further conducted a Chi-Square test to determine the relationship of these socio-economic parameters in the adoption level with the results indicating that gender, age and occupation has no influence on the adoption level while education has an influence on adoption levels as indicated by Chi-Square values in Table 5.5d.

In terms of gender, more male headed households at 8.1% were adopting energy efficient walling materials compared to female headed household at 4.9%. In terms of age, the respondents above 65 years were adopting more energy efficient walling materials compared to other age cohorts. The respondents with higher education qualification were established to be adopting more energy efficient walling materials (27.8%) compared to respondents with lower education levels. The impacts of occupation on adoption level of various building materials was not statistically significance in influencing the adoption of walling materials in the area.

Table 5.5d: Chi-Square Tests of Socio-economic Parameters with Level of Adoption of Energy Efficient Walling Materials

Chi-Square Tests			
Groups	Pearson Chi-Square Values	df	Asymp. Sig. (2-sided)
Gender	.833	1	0.3614
Education	14.997	4	0.0047
Age	5.780	3	0.1228
Occupation	1.482	5	0.9151

Source: Author, 2020

5.3.2 Embodied Energy and GHG Emissions

Embodied Energy (EE) in general terms refers to the sum total of energy embedded in products and processes applied in the construction / development of a building (s). The concept and definition however remains at variance depending on the locality and scope of various research works. According to IPCC (2007) one should therefore employ a whole-life carbon accounting framework in analysing the carbon emissions in buildings, a situation which was limited in the present study due to time and resource constraints.

Globally, about 30% of energy accrued to buildings relates to embodied energy, although the highlighted percentage is varied due to the influence of building age, the prevailing climate and nature of building materials among others. In addition, energy is established to be a function of both direct and indirect energy sources. The direct energy reflects energy consumed directly in on-site and off-site operations including construction, prefabrication, assembly, transportation and administration (Fay & Treloar, 1998; Dixit, 2013). For instance, the amount of energy (electricity) used during the extraction of quarry stone (stone cutters and drilling machines) and oil consumed by earthmovers and other heavy machines. It further encompasses maintenance and replacement activities including periodic replacement of components notably; carpet change, repainting of walls, repair of any physical damage and building system maintenance as well as situations involving demolition of buildings.

The indirect energy involves energy used indirectly by a building through non-energy inputs, for instance, the energy spent in manufacturing the building materials, assemblies and equipment installed in the buildings (Boustead & Hancock, 1978; Treloar, 1998 and Dixit, 2010, 2013). Other forms of indirect energy include; a fraction of manufacturing energy of machines, equipment, and apparatus utilized to manufacture materials (Jones, 2008).

5.3.2.1 Embodied Energy and CO_2e of Building Materials from Household Survey

The general household survey yielded 10 walling materials which were applied in housing construction within the study area notably; quarry stones, soil, burnt bricks, concrete blocks, iron sheets, cement, sand, timber, wattle and ISSB. The embodied energy associated with these products are provided in Table 5.6.

Table 5.6: EE and CO_2e of Walling Materials by Households

Walling Materials	No. of H/H	Mean (Tons)	Embodied Energy Coefficient (MJ/KG)	Equivalent CO_2e/Kg	EE per HH (MJ)	EE for sample (MJ)	Kg CO_2e per HH	CO_2e for Sample (Kg)
Stone	27	22.561	1.000	0.056	22,561.11	609,150.00	1,263.42	34,112.40
Soil	46	32.859	0.450	0.023	14,786.36	680,172.75	755.75	34,764.39
Bricks	102	41.213	3.000	0.220	123,638.24	12,611,100.00	9,066.80	924,814.00
Concrete Blocks	11	88.000	0.670	0.073	58,960.00	648,560.00	6,424.00	70,664.00
Iron Sheets	7	9.304	39.000	2.510	362,838.04		23,351.88	163,463.19
cement	67	4.003	5.320	0.830	21,295.88	1,426,824.00	3,322.48	222,606.00
sand	157	33.914	0.100	0.005	3,391.37	532,445.00	169.57	26,622.25
timber	4	1.802	8.500	0.460	15,314.88	61,259.50	828.81	3,315.22
wattle	63	1.890	0.282	0.015	532.09	33,521.66	28.91	1,821.31
ISSB	8	81.360	0.850	0.140	69,156.00	553,248.00	11,390.40	91,123.20
Total					692,473.97	19,696,147.20	56,602.02	1,573,305.96

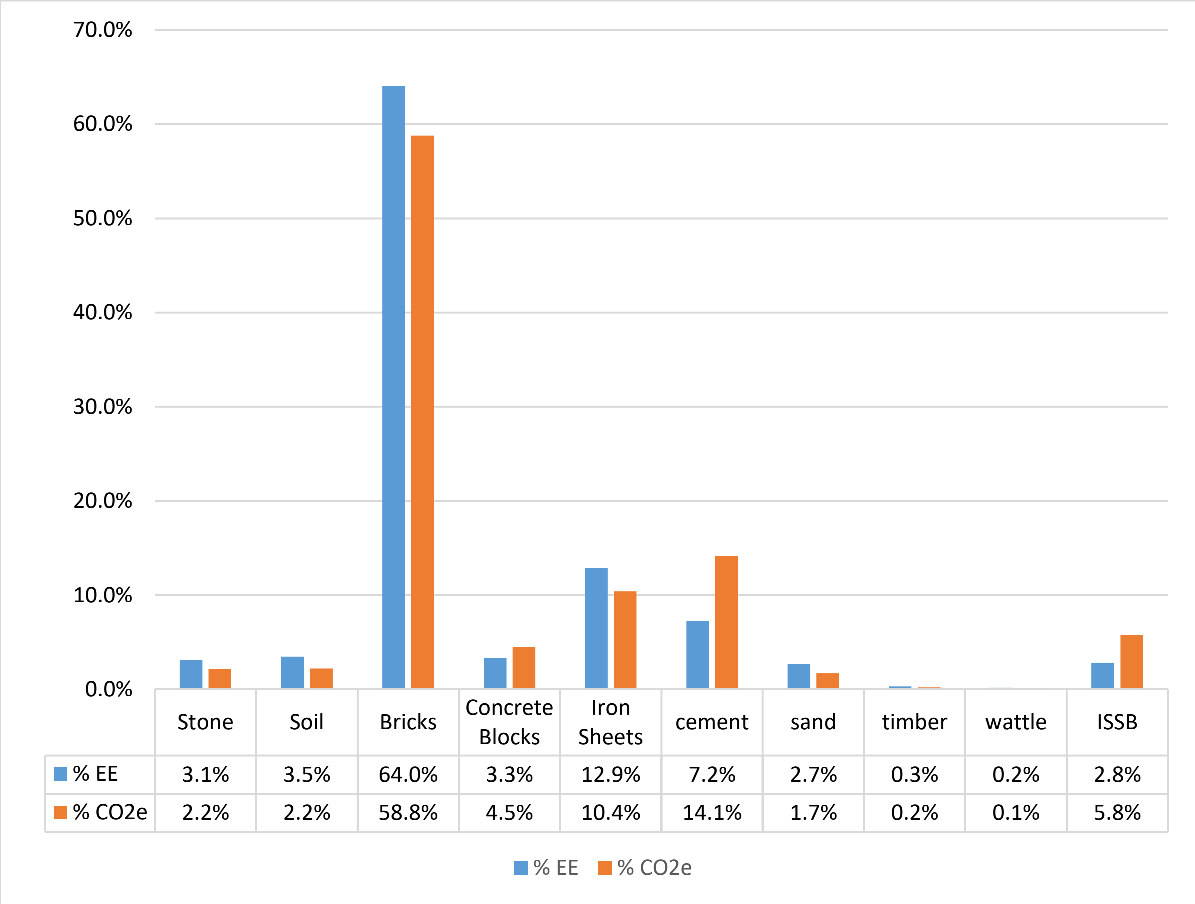
Source: Modified from Dixit, 2013 and Field Research, 2020

The study demonstrated that application of bricks in meeting the shelter needs of local populace is associated with the highest levels of EE and CO_2e at 64.0% and 58.8% respectively. The equivalent CO_2e associated with other building within the research coverage were as follows; cement (14.1%), iron sheet (10.4%), ISSB (5.8%), concrete blocks (4.5%), soil (2.2%), stone (2.2%), sand (1.7%) while wattle and timber had the lowest emission levels at 0.1% and 0.2% respectively.

The study further revealed unique aspects regarding the relationship between EE and CO_2e regarding certain building materials. These particular unique aspects were depicted in cement, concrete blocks and ISSB whose EE levels were 7.2%, 3.3% and 2.8% against the CO_2e levels of 14.1%, 4.5% and 5.8%. A detailed EE and CO_2e of building materials used in the study area is provided in Appendix 1H.

Figure 5.3 shows the percentage of embodied energy and equivalent percentages of carbon emission levels associated with various building materials that are being used in the building sector within the study area.

Figure 5.3: EE and CO_2e of Building Materials in Migori County.



	Stone	Soil	Bricks	Concrete Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
% EE	3.1%	3.5%	64.0%	3.3%	12.9%	7.2%	2.7%	0.3%	0.2%	2.8%
% CO2e	2.2%	2.2%	58.8%	4.5%	10.4%	14.1%	1.7%	0.2%	0.1%	5.8%

Source: Author, 2020

5.3.2.2 Embodied Energy and CO_2e of Building Materials from Experimental Design

The research adopted experimental design which focused on the burnt bricks and ISSB as main materials for experimental analysis. In addition, other key materials used by locals were also analysed including quarry stones, wattle and timber with a view to establishing the embodied energy or resource efficiency levels. The result of the field experimental design is depicted in table 5.7 which provides the calculated values of selected building materials comprising of bricks, wattle, ISSB and tree logs. The application of tree logs was in 2 main areas notable;

i. The local use in the manufacture of bricks through burning / firing; and

ii. The use of logs as poles in the construction of traditional houses where they are combined with twigs.

Table 5.7: Calculated Values of Selected Building Materials EE and CO_2e

Material	Embodied Energy Coefficient (MJ/KG)	Equivalent CO_2e/Kg	Remarks
Bricks	3.02	0.349	EE and CO_2e derived by Calculation
Wattle	0.2816	0.0153	EE and CO_2e derived by Calculation
ISSB	0.887	0.089	EE and CO_2e derived by Calculation
Tree Log	16	1.778	EE from Literature while CO_2e derived by Calculation

Source: Author, 2020

The experimental focus relating to quarry stone was limited to the derivation resource efficiency pertaining to laying of standard wall of a house / building. It therefore excluded the EE and CO_2e calculation during the extraction process. The measure of standard walling area in this study where materials in comparison were applied was in reference to Plinth Area of $66.7M^2$

a) Bricks

Computation of EE and equivalent CO_2e involved tracking the material resource flow from extraction, moulding, harvesting logs for firing and transportation to construction site. Photos in plates 5.8(a, b, c & d) depicted the key steps that aided the calculation of EE and CO_2e for BB.

Plates 5.8a: Field Process towards calculation of EE and CO_2e of Burnt Bricks

Plates 5.8b: Field Process towards calculation of EE and CO_2e of Burnt Bricks

Plates 5.8c: Field Process towards calculation of EE and CO_2e of Burnt Bricks

Plates 5.8d: Field Process towards calculation of EE and CO_2e of Burnt Bricks

Source: Author, 2020

The processes demonstrated by assorted pictorials contained in plates 8 shows stepwise processes involving soil excavation and moulding, drying of green blocks, measuring the area where tree logs are sourced, taking measurement in diameter of each tree/ lot, measuring the mass of each log used in firing the brick kiln, and finally the shape of the fired brick kiln. The above process is summarized as follows;

i. Soil excavation and moulding
ii. Drying and handling of green blocks
iii. Measuring coverage of wood lot area
iv. Taking diameter measurement of harvested log
v. Weighing of each log
vi. Fired brick kiln

The size of the bricks used in this analysis were weighing 5kg. In the overall, bricks are known to be of three types / categories notably; large, medium and large bricks. Photo in plate 9 demonstrates an estate under construction using burnt bricks in Central Kamagambo ward (Rongo sub-county).

Plate 5.9: Town Estate Under Construction with Burnt Bricks in Rongo, Migori County

Source: Author, 2020

The field observation revealed that the logs used in firing the brick kilns were mainly of Eucalyptus of 5 years old. Each wood lot once cut down, produced 8 logs with each log weighing approximately 86kg. A total of 5 mature trees logged for energy need in this scenario gave rise to 40 logs which were used in firing brick kiln with a capacity of approximately10000 bricks. The diameter of maturing Eucalyptus tree which is logged at age 5 years measured approximately 1.5ft.

The study observed that brick production and adoption has applied to meet housing needs and demand in rural and urban landscapes have been on an upward trend. This aspect necessitated the need to establish the efficiency levels of their application which involves both production and construction processes.

Table 5.8 shows all the inputs/materials that were used to calculate the embodied energy for the burnt bricks after taking into consideration the energy used in processing and transportation. The equivalent embodied energy used in making and transporting 4500 BB to the building site was computed to be 67,965.80 MJ while the total mass of the bricks was 22,500 kg. This resulted into specific embodied energy of bricks, EE_{cm} being 3.021 MJ/Kg. The figures obtained is comparable to literature figures given as 3.0 MJ/Kg indicating that there was no significant difference in the prevailing environment of the study area with the one provided through literature.

$$EE_{cm} = \frac{\mathbf{67,965.80\ MJ}}{\mathbf{22,500\ kg}} = \mathbf{3.021 MJ/Kg}$$

The highest contributor to EE of the BB was wood fuel due to higher energy dissipated during combustion process which contributed over 81% of the embodied energy followed by soil at 15%. The rest of the inputs and processes contributed less than 4%.

Table 5.8: Analysis of Embodied Energy for Burnt Brinks

Parameters/ Inputs	Units	Qnty	EE Transport (MJ)	EE for Processing (MJ)	Total EE (MJ)	EE Coefficient (MJ/kg)	Diesel Fuel Consumed (Litres)
Soil	Kg	22500	0.00	10,125.0	10,125.00	0.45	0.00
Water for mixing soil	Litres	3600	1512.00	720.0	2,232.00	0.20	36.00
Wood fuel -cutting (processing)	Kgs	3200	0.00	168.0	168.00	42.00	4.00
Wood fuel/Logs (Transport)	Kgs	3200	168.00	0.0	168.00	42.00	4.00
Combustion process	Kgs	3200	0.00	55,040.0	55,040.00	19.00	0.00
Water for building kiln	Litres	240	100.80	48.0	148.80	0.20	2.40
Transportation of bricks (12Kms)	Pcs of BB	4500	84.00	0.00	84.00		2.00
Total			**1,864.80**	**66,101.00**	**67,965.80**		

Source: Researcher, 2020

The greenhouse gas emission in burnt bricks was determined by obtaining the sum total of CO_2 emission used in the entire process. The CO_2 generated during extraction, manufacturing process and transportation were added to produce total CO_2 emitted during BB production and construction. The main input/material that generated CO_2 emission were soil, water, wood fuel, diesel fuel, and combustion process. Soil contain CO_2 emission equivalent of 0.02 $KgCO_2e/Kg$ and this value was multiplied by the mass of soil excavated to derive the total CO_2 released from soil. In addition, during the wood fuel logging process and transportation of logs and bricks, the litres of diesel used were obtained and CO_2 equivalent computed.

CO_2 Equivalent that was associated by the use of diesel fuel was calculated using mole concept, stoichiometry and combustion equation. In the analysis, the weight of 1 litre of diesel weighs 0.835 kg and consist of 86.2% of carbon resulting into 0.72 kg of carbon. By the use of the above approach, the CO_2 equivalent for combusting diesel was obtained as 2.64 $KgCO_2$/litres as illustrated in Table 5.9. Similar derivation was used to calculate the CO_2 emission from petrol resulting into 2.31 $KgCO_2$/litre as illustrated in the discussions.

Table 5.9: Combustion of Carbon in Diesel Fuel

	Carbon	+	Oxygen	___________	Carbon dioxide
Combustion	C	+	O2	___________	CO_2
Stoichiometric ratios	1	+	1	____________	1
Mass	720gms	+	1920gms	___________	2640 gms
Moles	60	+	60	____________	60
Molecular Mass	12gms	+	16*2=32gms	____________	44.01gms

Source: Author, 2020

During the brick burning, eucalyptus logs were used. Eucalyptus logs contain between 47% - 50% carbon. This study adopted average values of 48.5% as the composition of carbon in Eucalyptus logs. This implied that 1kg of Eucalyptus wood contain 1000 * 0.485 of carbon which was equivalent to 485 grams of carbon. The mass of carbon was used to obtain the equivalent moles (41.67) which were then used to obtain the mass of CO_2 released by burning the wood as illustrated in Table 5.10

$$Mass\ of\ Carbon\ dioxide = Moles\ of\ CO2 * Molecular\ Mass\ of\ Carbon$$
$$= 41.67 * 44.01 = 1778.7\ grams = 1.779\ Kg$$

Table 5.10:Combustion of Carbon in Eucalyptus logs

	Carbon	+	Oxygen	___________	Carbon dioxide
Combustion	C	+	O2	___________	CO_2
Stoichiometric ratios	1	+	1	____________	1
Mass	485gms	+	1293.7gms	___________	1778.7 gms
Moles	41.67	+	41.67	____________	41.67
Molecular Mass	12gms	+	16*2=32gms	____________	44.01gms

Source: Author, 2020

Eucalyptus tree takes between 5-15 years to obtain full maturity. Young tree absorbs 5.9Kg of carbon per year, while mature tree absorbs 22 kg of carbon annually. The study observed that the productive life cycle of Eucalyptus trees used in the burning / firing of bricks by locals were prematurely eliminated resulting into 10 years forgone for active carbon absorption. The carbon forgone for the five mature trees used to burn bricks was calculated by getting the product of forgone carbon dioxide per year, number of trees and years used to complete the productive age.

Hence;

$$Forgone\ Carbon\ dioxide\ Sequestered = 22 * 5 * 10 = 1100\ Kg$$

The Table 5.11 below provides the inputs/material that produced CO_2 in the process of making the burnt bricks. The carbon dioxide equivalent for the burnt bricks were obtained by dividing the total CO_2 emitted in the entire process by the weight of bricks burnt resulting into 0.349 Kg CO_2e/Kg. The figures provided by the literature stood at 0.22 Kg CO_2e/Kg and this indicate that the experimental figures were high. The high figures associated with CO_2e in the experimental phase could be attributed to the higher amount of wood which were used to fire the bricks given that in the experimental study, more bricks were used and energy allocation to the 4500 bricks could not be computed with precision.

$$EC_m = \frac{\mathbf{7,802.91\ KgCO2e}}{\mathbf{22500\mathit{Kg}}} = 0.347\ KgCO2e/Kg$$

Table 5.11:Computation of GHG emission for Burnt Brinks

Parameters	Units	Quantity	CO_2 in Transport	Processing CO_2 (Kg)	Total CO_2	$KgCO_2e/kg$	Fuel consumed (Litres)
Soil	Kg	22500	0.00	450	450	0.02	0
Water	Litres	3600	96.48	0	96.48	0.00	36
Wood fuel - cutting (processing)	Litres	4	0.00	10.72	10.72	2.68	0
Wood fuel/Logs (Transport)	Kgs	3440	10.72	0.00	10.72	0.00	4
Combustion process	Kgs	3440	0	6,123.2	6,123.2	1.78	0
Water -Transport	Litres	240	6.432	0	6.432	0	2.4
Transportation of bricks (12Kms)	pcs of bricks	4500	5.36	0	5.36	0	2
Carbon sequestration for 5 trees (logging)	Trees	5	0	1,100	1100	220	0
Total		**22500**	**118.992**	**7,683.92**	**7,802.912**		

Source: Author, 2020

The major contributor to the GHG emission was the wood fuel with 6,123Kg CO2e contributing 78.4% of the inbuilt energy followed by forgone carbon sequestration from cutting the trees at 14%. The use of trees to fire the bricks increases the embodied energy hence the need to use for efficient modern kiln that would reduce the energy requirement hence reduction in GHG. A particular example of such modern brick kiln has been applied in India as depicted in plate 5.10a and 5.10b which demonstrates large scale brick processing along New Delhi – Agra City highway in India (GoK, 2017) as compared to local brick kilns in the study area.

Plate 5.10a: Modern Brick Kilns in India

Plate 5.10a: Local Brick Kiln

Source: Author, 2020

There exists a huge difference however in comparing the modern fired bricks to the local bricks which are fired with wood-fuel in the current study area as demonstrated above.

b) Wattle

The study has established that rural areas of Migori area still using mud walls. The process of using mud in construction leads to a lot of surface disturbance. Traditionally, the older generations were very conscious of the level of disturbance and mostly the areas for extraction of soil for mud houses were selectively chosen with only areas with ant-hills protrusion were targeted for excavation. It is further noted that the construction with mud involves application of wattle.

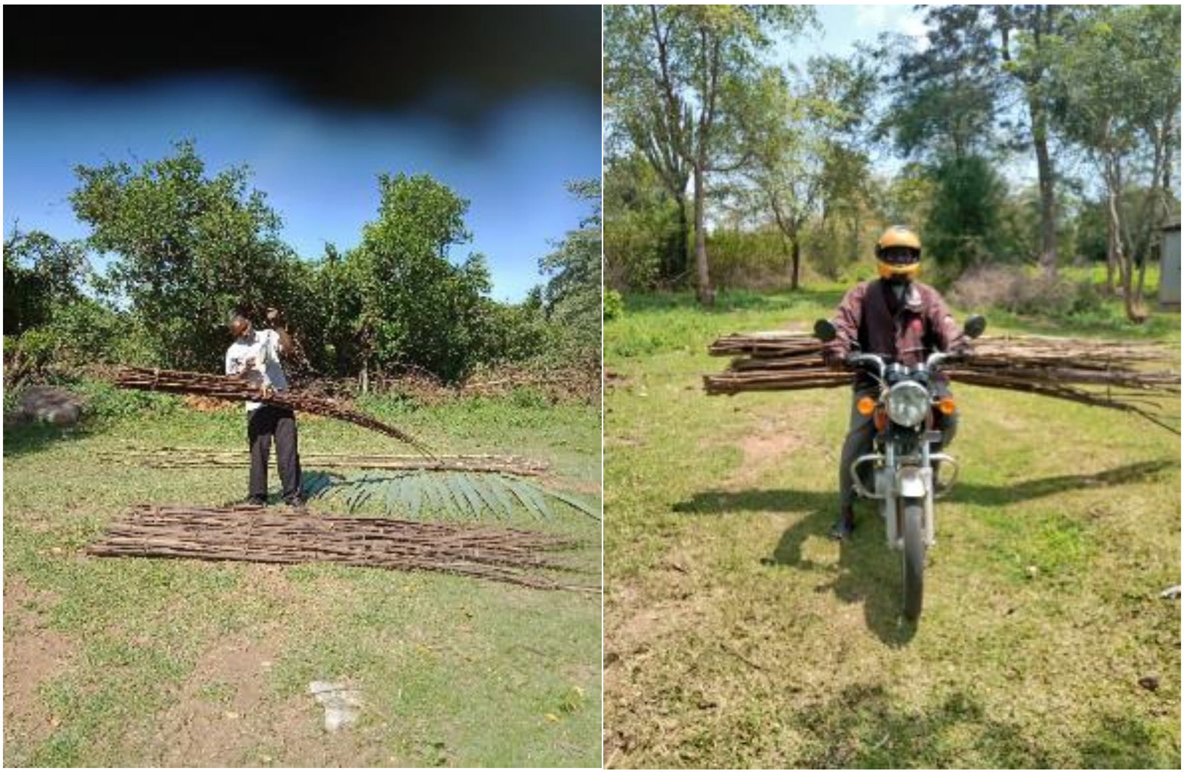
Plate 5.11: Application of Wattle as a walling material

Source: Author, 2020

The wattle material comprises of a bunch of twigs or young trees mainly 1 inch in diameter which are used in constructing traditional houses in combination with loosely moulded soil that is referred to as mud.

Plate 5.12: Taking measurement of a bunch of wattle

Source: Author, 2020



Source: Author, 2020

The study analysis details that one bunch of wattle in dry form weighs approximately 10kg. It is further demonstrated that the set of twigs referred to in this experimental set up in their natural state grow in an area of approximately 2m x 1m. The wattle / twigs, are used in combination with tree logs with the capacity to withstand the load bearing arising from the roof weight in the construction of a traditional house involving application of local building materials notably; poles/logs, wattle/twigs, sisal and mud.

In order to compute the embodied energy and equivalent CO_2 emission, the entire process of cutting and transporting the wattle was evaluated. The transportation mode used was motorbike with fuel consumption of 25km/litre or 0.04 litres/Km of petrol fuel. The energy employed in cutting 1 kg of wattle was computed to be 720 joules while the embodied energy used in transporting 1 kg of wattle was computed to be 0.2816 MJ/Kg giving a total embodied energy from cutting and transportation process to be 0.2823 MJ/Kg.

The equivalent CO_2 emission, was analysed from the fuel used during transportation process covering a distance of 8km per trip with a capacity of 50kg of wattle. The equivalent fuel used in this process was 0.32 litres of petrol resulting into a consumption of 0.006 litres/Kg. Given that emission factor of petrol is 2.39 Kg CO_2e, the equivalent CO_2 emission was computed to be 0.0153 Kg CO_2/Kg

Stepwise Calculation of EE and CO2e for Wattle

The process adopted the formula in equation 4.6 to calculate the transportation embodied energy in the application of wattle.

EEt = Haulage Distance (D_m) * Round Trips (RT_m)*Vehicle Fuel Consumption (VC_f) * Lower Heat Value of Fuel (LHV_f) =8 * 1*0.04*44 =14.08 MJ for 50 kg of wattle

Embodied Transport Energy for 1 Kg of Wattle = 14.08/50 = 0.2816 MJ/Kg|

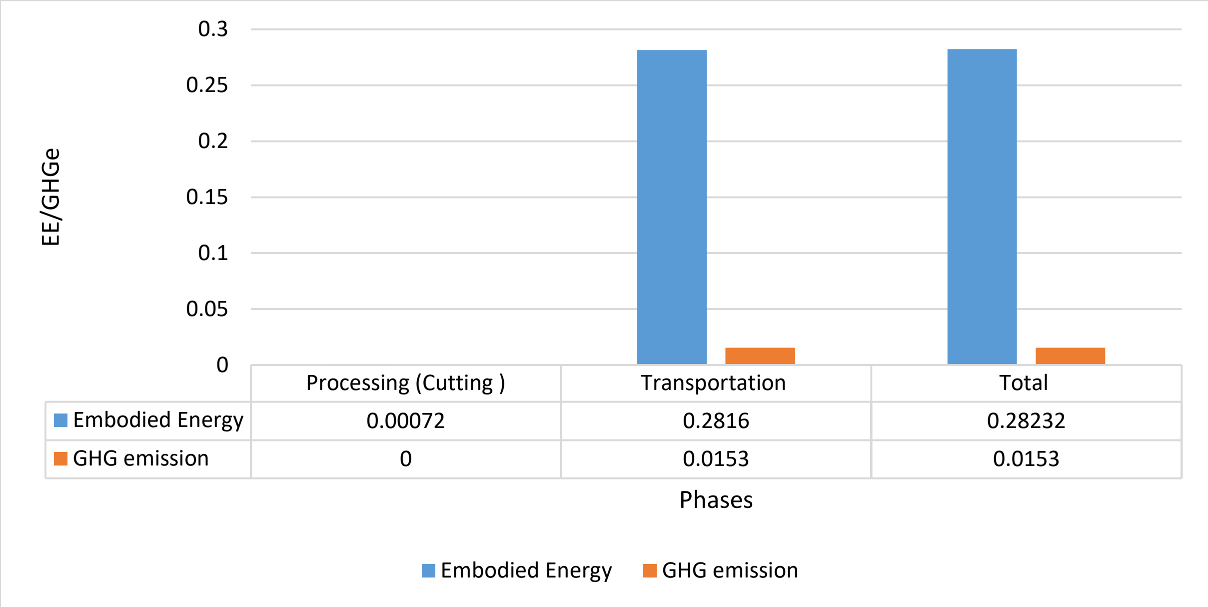
Equivalent CO2e for wattle was calculated by adopting equation 4.15 as follows

$$ECO_{2i} = \sum_{1}^{i} Q_i CO_2 EC_m$$

=0.32 *2.39 =0.7648 Kg for 50Kg of Wattle

Equivalent CO_2 emission for 1 Kg is 0.0153 Kg

Figure 5.4: Embodied Energy and equivalent GHG emission for Wattle



Source: Author, 2020

Embodied energy in process the Wattle was derived as follows:

The force applied in doing work by human hand was adopted as 45N and the distance moved while cutting twigs of 1-inch diameter was observed to be 2 metres. The total number of strokes in cutting each twig from start to completion was observed to be 8 strokes. The total force applied was therefore 45N*8 =360N. Given that distance moved per stroke was 2 Metres. Therefore; Total work done, W = Force * Distance = 360 *2 = 720 joules/Kg. =0.00072 MJ/Kg

Total EE for Wattle = Processing Energy + Transportation Energy =

=0.00072 +0.2816 = 0.2823 MJ/Kg

Total CO_2e for Wattle = Transportation emission

= 0.0153 Kg CO_2e/kg

c) Tree Log/Pole

It is significant to note that globally, the current CO_2e concentrations is approximately 0.04 per cent (412 ppm) by volume which has increased from the pre-industrial levels of 280 ppm. The mature tree / wood lot used in firing bricks are cut at the ages ranging from 5 -7 years (field observation, 2019). On average such trees have full maturity period of 15 years (field interview, 2019). The area covered by 5 mature trees is approximately 13m x 10m (field observation and measurements, 2019).

Plate 5.13: Demonstration of Logging Site for Woodfuel

Source: Author, 2020

d) ISSB

Plate 5.14: Mortarless Construction Using ISSB with Less Sequestered Energy

Source: Author, 2020

The study denotes ISSB as a construction technology which has less global warming effect as it poses minimal negative impact on the ability of the ecosystems of soil, water and forest / tree cover to sequester carbon. The technology is also associated with less sequestered energy. The calculation of EE and CO_2e of ISSB assumed 12kg mass.

The calculation of embodied energy for ISSB also involved the analysis of all the inputs employed in the manufacture of the ISSB and transportation to the construction site. The energy for processing and transportation were added in the computation to provide the total EE. Table 5.12 provide the main input/materials and some of the processes that generated energy. The same process used in calculating EE for bricks was employed. Soil was excavated from site did not attract energy in transportation, EE_T. The total EE was obtained as

MJ while the total quantity of input in the manufacture of ISSB was the summation of soil, quarry dust, sand and cement obtained 38,150Kg

$$EE_{cm} = \frac{\mathbf{33,833.60\ MJ}}{\mathbf{38,150\ kg}} = \mathbf{0.887}\boldsymbol{MJ/Kg}$$

Table 5.12: Computed Embodied Energy in the Manufacture and Use of ISSB (7% Cement)

<table>
<tr><th>Phases</th><th>Parameters</th><th>Units</th><th>Quantity</th><th>EE transport (MJ)</th><th>EE for Processing</th><th>Total EE (MJ)</th><th>Embodied Energy Coefficient (MJ/kg)</th><th>Fuel Consumed (Litres) - Diesel</th></tr>
<tr><td rowspan="6">Production</td><td>Soil</td><td>Kg</td><td>17100.00</td><td>0.00</td><td>7695.00</td><td>7695.00</td><td>0.45</td><td>0.00</td></tr>
<tr><td>Quarry dust</td><td>Kg</td><td>11200.00</td><td>1008.00</td><td>1870.40</td><td>2878.40</td><td>0.167</td><td>24.00</td></tr>
<tr><td>Sand</td><td>Kg</td><td>7100.00</td><td>2100.00</td><td>710.00</td><td>2810.00</td><td>0.10</td><td>50.00</td></tr>
<tr><td>Water</td><td>Litres</td><td>2140.00</td><td>840.00</td><td>428.00</td><td>1268.00</td><td>0.20</td><td>20.00</td></tr>
<tr><td>Cement</td><td>Kg</td><td>2750.00</td><td>252.00</td><td>12650.00</td><td>12902.00</td><td>4.60</td><td>6.00</td></tr>
<tr><td>Diesel Fuel</td><td>Litres</td><td>43.00</td><td>0.00</td><td>1806.00</td><td>1806.00</td><td>42.00</td><td>0.00</td></tr>
<tr><td rowspan="2">Curing Phase</td><td>Polythene roll (2 rolls)</td><td>kg</td><td>46.00</td><td>0.00</td><td>3822.60</td><td>3822.60</td><td>83.10</td><td>0.00</td></tr>
<tr><td>Water</td><td>Litres</td><td>1158.00</td><td>420.00</td><td>231.60</td><td>651.60</td><td>0.20</td><td>10.00</td></tr>
<tr><td></td><td>Total</td><td></td><td>38150.00</td><td>4,620.00</td><td>29,213.60</td><td>33,833.60</td><td></td><td>110.00</td></tr>
</table>

Source: Author, 2020

Most of the inbuilt energy in ISSB was due to cement since it contributed 41.7% of embodied energy followed by extraction of soil at 25%. cement also provides the bonding component required for ISSB to be stabilized for minimal breakages and its ratio is the mixture was essential in the study. The experimental design for ISSB was generated at 7% cement. The study equally computed EE for 5% and 10% cement composition and similar compressive Tables provided in Appendix 1 (1A & 1B).

The study used linear regression model to determine the relationship between cement ratios in ISSB with resultant embodied energy of ISSB. These results are shown in Table 5.13a, 5.13b and 5.13c, which provides outputs on model summary, ANOVA values and regression coefficients respectively.

Table 5.13a: Model Summary of Cement Rations and Embodied Energy of ISSB

Model Summary					
Model		R	R Square	Adjusted R Square	Std. Error of the Estimate
	1	0.999999978	0.999999955	.999999910	.0000324

Source: Author, 2020

Table 5.13b: ANOVA Values

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.0235067456	1	.0235067456	22331408.193	.00013
	Residual	0.0000000011	1	.0000000011		
	Total	0.0235067467	2			

Source: Author, 2020

Table 5.13c: Regression coefficients

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.585	.000		8430.884	.00008
	Cement	4.308	.001	1.000	4725.612	.00013

Source: Author, 2020

The figure shows linear relationship of the regression model as given below:

$Y = 4.308x + 0.5850$; $R^2 = 0.999999978$

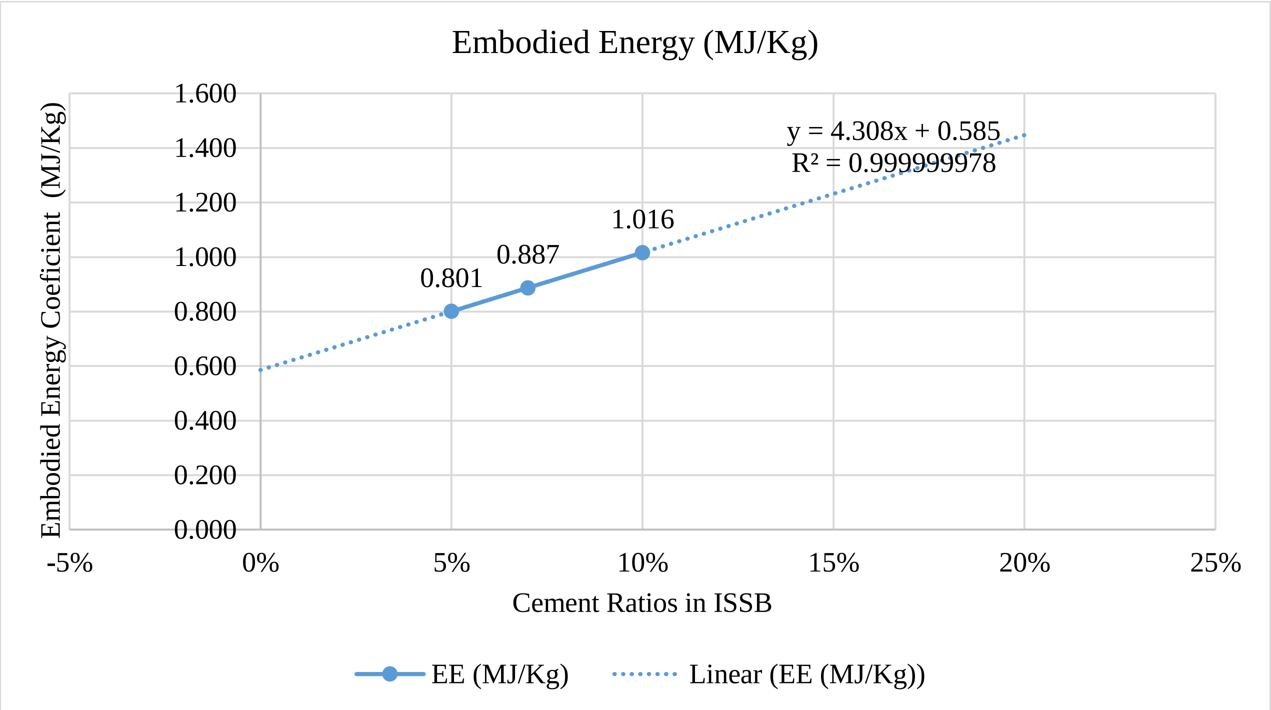
Where;

Y = embodied energy and x = cement ratio

The relationship indicated that at zero cement ratios, the EE for ISSB is 0.585 MJ/Kg being the y intercept of the linear equation. The $R^2 = 0.999999978$ indicates that 99.9999978% of the variance in embodied energy (dependent variable) is explained by the ratios of cement (independent variables). This indicates that other inputs to the manufacture of ISSB are not significant in determining the level of embodied energy since they are localized, labour intensive hence characterized by lower embodied energy which are negligible to influence the model.

Difference ratios of cement and values of EE were plotted using a scatter line graph as showed in Figure 5.6. The figure showed that as the ratios of cement increases, the values of embodied energy increases linearly.

Figure 5.6: Embodied Energy versus Cement ratios on ISSB



Source: Author, 2020

Stepwise Calculation of Number of Blocks at various cement ratios: -

c) Calculations for 10% Cement ratio;

i. 1bag cement (50kg) : 7 parts of soil mixture
ii. 1 bag (50kg) : 455kg of soil mixture
iii. Total raw material mixture = 405 + 50 = 505 kg
iv. % of cement = (50/505) * 100 = 9.9 = 10%
v. Taking each ISSB to be 12kg, then 505kg = 505/12 = 42 blocks
vi. Hence, 10% cement proportion yields 42 Blocks

d) Calculation for 7% Cement ratio;

i. If 10% ratio is equivalent to 505kg
ii. 7% ratio = (10/7) * 505 = 721.43 kg total mixture
iii. Given that each block weighs 12kg, therefore 721.43 = 721.43/12
= 60 blocks

e) Calculation for 5% Cement ratio

i. Comparing with 10% ratio which is equivalent to 505kg
ii. 5% ratio = (10/5) * 505 = 1010 kg of mixture
iii. Taking each block to be 12kg
iv. Therefore, 1010kg mixture of raw materials yield = 1010/12 = 84 blocks

The calculation of greenhouse gas emission for ISSB also involved the analysis of all the inputs employed in the manufacture of the ISSB and transportation to the site for construction. Table 5.14 provide the main input/materials and some of the processes that generate CO_2 at various phases. The total EC_m was obtained as 3,403.86 Kg while the total quantity of input in the manufacture of ISSB was the summation of soil, quarry dust, sand and cement given as 38,150 Kg

$$EE_{cm} = \frac{\mathbf{3,403.86\ KgCO2e}}{\mathbf{38,150\ kg}} = \mathbf{0.089\mathit{KgCO2e/Kg}}$$

The highest GHG emission was obtained from cement which constituted 69.1% of the greenhouse gas emission followed by soil at 10.3% and quarry dust at 6.8%.

Table 5.14: Computed GHG in the Manufacture and Use of ISSB (7%Cement)

Phases	Parameters	Units	Quantity	Processing -CO_2 (Kg)	Transportation -CO_2 (Kg)	Total CO2 (Kg)	$KgCO_2e$/kg	Fuel consumed (Litres)
Production	Soil	Kg	17100.00	393.30	0.00	393.30	0.023	0.00
	Quarry dust	Kg	11200.00	257.60	0.00	257.60	0.023	0.00
	Sand Production	Kg	7100.00	35.50	0.00	35.50	0.005	0.00
	Sand Transportation	Kg	0.00	0.00	134.00	134.00	0.000	50.00
	Water - Transport	Litres	2140.00	0.00	53.60	53.60	0.000	20.00
	Cement	Kg	2750.00	2282.50	16.08	2298.58	0.830	6.00
	Diesel Fuel	Litres	43.00	115.24	0.00	115.24	2.680	0.00
Curing Phase	Polythene roll (2 rolls)	kg	46.00	89.24	0.00	89.24	1.940	0.00
	Water - Transport	Litres	1158.00	0.00	26.80	26.80	0.000	10.00
	Total		**38150**	**3,173.38**	**230.48**	**3,403.86**		**86.00**

Source: Author, 2020

The experimental design for ISSB was generated at 7% cement ratio. The study further computed EC_m for 5% and 10% cement ratios for comparison purposes as depicted in Table 5.15. This analysis demonstrates that cement is the greatest contributor of CO_2 emission levels in application of ISSB technology since cement product relatively possesses higher value of greenhouse gas equivalent which stands 0.83kgCO_2e/kg. Taking the analysis of the three ratios (5%, 7% and 10%), it is demonstrated that the lower percentage of cement ratio yields less CO_2 emission while the higher percentage of cement ratio is associated with higher levels of CO_2 emission. The application of ISSB in construction takes cognizance of the variation examined especially the issue / quantities of cement based on individual ratios ad strengths to be achieved with / or either 5%, 7% and 10% cement proportions. The CO_2e analysis at 5% and 10% cement rations is provided in Appendices 1C and 1D.

Table 5.15:ISSB Yields with Various Degree of Cement proportions.

Parameters	**% of Cement**			**Remarks**
	5%	**7%**	**10%**	
No. of ISSB	84	60	42	As per input by 12kg block
EE (MJ/Kg)	0.801	0.887	1.016	
CO2e (kgCo2e/Kg	0.073	0.089	0.114	

Source: Author, 2020

The study used linear regression model to demonstrate GHG emission equivalent in relation to cement ratios applied in the production of ISSB. These results are shown in Table 5.16a, 5.16b and 5.16c, which provides outputs on model summary, ANOVA values and Regression Coefficients respectively.

Table 5.16a: Model Summary of GHG Emission in relation to Cement ratio

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.99994	0.99988	0.99975	0.0003244

Source: Author, 2020

Table 5.16b: ANOVA Values

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.00085389	1	.00085389	8112.000	.007
	Residual	0.00000011	1	.00000011		
	Total	0.00085400	2			

Source: Author, 2020

Table 5.16c: Regression Coefficients

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.032	.001		45.789	.014
	Cement	.821	.009	1.000	90.067	.007

Source: Author, 2020

The regression model produced a perfect linear regression model given as follows:

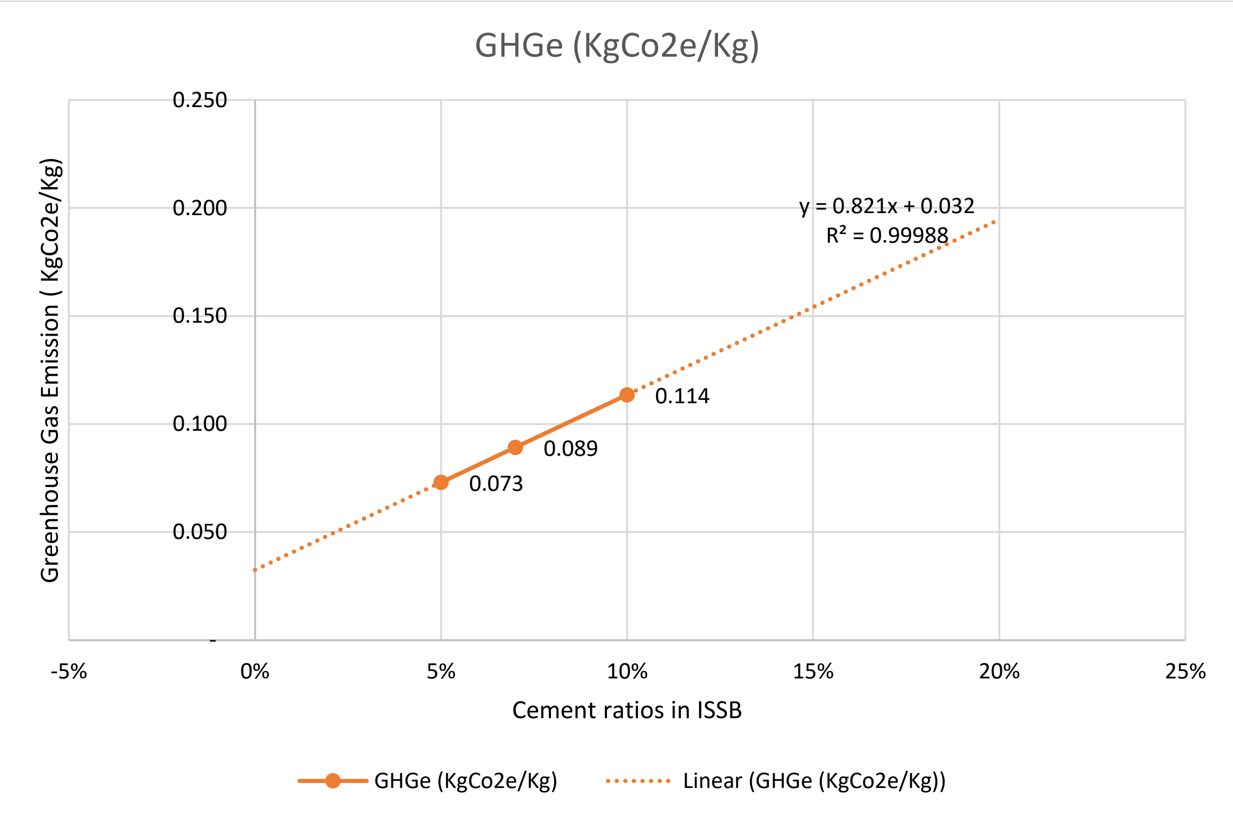
$Y = 0.821X + 0.032$; $R^2 = 0.99988$;

Where Y = GHGe and

X= cement ratio

The model indicates that greenhouse gas emission fully depends on the ratios of cement and that all other inputs produces minimum emission as demonstrated by lower residual values in the ANOVA table. Figure 5.7 indicates how GHGe varies with cement ratios in the cement.

Figure 5.7: GHGe versus Cement ratios on ISSB



Source: Author, 2020

e) Quarry Stone

The quarry stones used in Migori are sourced from other localities leading to long distances travelled to access the desired qualities. The main sites revealed by this study included Oriwo area in Karachuonyo, Ndarugo in Juja-Thika and Tabaka in Kisii. Given the mode of transportation used, the heat values for type of fuel used is likely to escalate the EE and equivalent CO2e associated with transportation phase.

Plate 5.13: Demonstration of Common Lorries Used in Transportation of Quarry Stones

Source: Author, 2020

The summary of dominant building materials, EE and equivalent GHG emission levels from experimental design analysis and literature review are as provided in Table 5.2.

Table 5.2: Dominant Building Materials with EE and CO2e Levels

Dominant Building Material	**Embodied Energy Coefficient (MJ/KG)**	**Equivalent** CO_2**e/Kg**	**Remarks/ Source**
Stone	1	0.056	Literature source
Soil	0.45	0.023	Literature
Bricks	3.02	0.349	Calculated Author, 2020
Concrete Blocks	0.67	0.073	Literature
Iron Sheets	39	2.51	Literature
cement	4.6	0.83	Literature
sand	0.1	0.005	Literature
timber	8.5	0.46	literature
Tree Log	16 (Literature)	1.778 (Calculated)	-
wattle	0.2661	0.01442	Calculated Author, 2020
ISSB	0.887	**0.089**	Calculated Author, 2020

Source: Author, 2020

5.4 Extent of Adoption of Energy Efficient Building Technologies

5.4.1 Types of Energy Efficient Building Technologies

The study underscored that in the early 1980s and mid-1990s, various institutions drawn from both the public and private sector engaged in research on local construction materials that mainly related to the walling and roofing aspects in building construction. The lead architect of the research component at the time was the University of Nairobi through its research institute, The Housing and Building Research Institute (HABRI) in collaboration with a host of other institutions. The initiative was mainly supported by GTZ at the time (currently GIZ) and involved undertaking research on various aspects of low cost housing and community participation in both rural and urban areas. The research targeted Public Universities, local NGOs, key International Agencies with interest in sustainable human settlements and other institutions, both public and private (Sangori, 2013).

The ISSB technology is one among several emerging building technologies that have been integrated and applied by the built environment practitioners at global and local levels. There are several ISSB technology developers and promoters who operate at local, regional and global scales. For instance, Hydraform Building Systems, 2009 demonstrates that Hydraform-Interlocking Stabilized Soil Blocks (ISSBs) technology has been widely used in most parts of the World with various projects spread in India, USA, Turkey, South Africa, Botswana and Uganda among other Countries (Hydraform, 2009). In Kenya, the technology was introduced in the year 2003 with formal launch of Appropriate Building Technology (ABT) Programme undertaken in 2006, an initiative that has since spread to most parts of the Country where over 93 Appropriate Building Materials and Technology (ABMT) Centres have been constructed. The ABMT Programme objectives included; lowering construction cost, improving quality of housing, enhancing speed of construction delivery, achieving environmentally friendly construction, and empowering community members to generate income and contribute to social inclusion among the youths and women who participate in Hydraform-ISSBs related activities (Sangori, 2012).

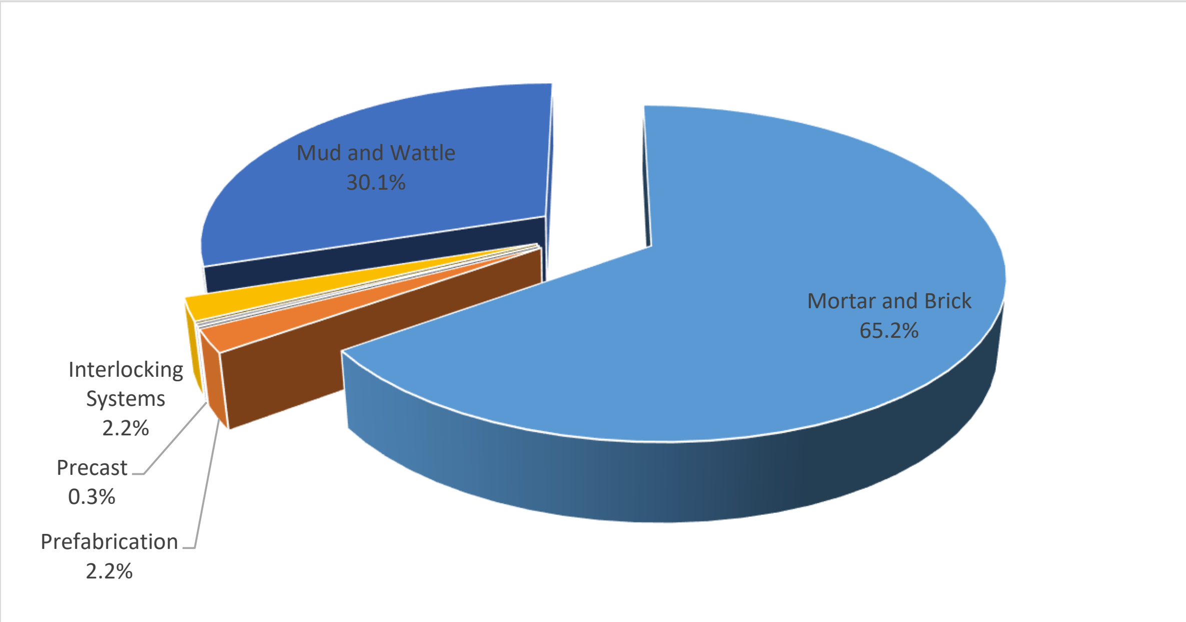
The standards and regulations towards the process of Cement: Soil stabilization and application in building construction in Kenya are guided by the requirements pertaining to Soil: Cement Blocks production (KS02-1070), approved in 1992 as a quality control measure (Gooding, 1995). On the other hand, Internationally, the Hydraform- ISSBs technology complies with the

South African National Building Regulations, satisfying the requirements for structural performance, rainwater penetration, fire protection, thermal performance and durability, and is nationally approved for use under certificate № 96/237 (Hydraform manual, 2005; Sangori, 2012). The current policy framework advanced by the Government of Kenya is similar to the policies which were driving the housing agenda in the 1990s and the year 2000s. The present situation has seen more emphasis on the delivery of 500,000 affordable housing units within a five-year period. This is being supported by the application of appropriate building materials and technologies including ISSBs, Prefabrication materials and technologies, and other emerging affordable building technologies.

Similarly, in the period of 1984 to 1994, a lot of research and emphasis were laid on use of location specific building materials and technologies with net effect of reducing the housing cost and achieving overall housing affordability. To enhance wider adoption of these technologies, the research efforts then saw the approval of adaptive by-laws of 1995 (Code 95) which was meant to facilitate the application of appropriate and affordable local building materials. To sustain the application of ABMTs in the housing sector, the Government mainstreamed the use of the same in the Sessional Paper No.3 of 2004 on National Housing Policy. The Policy framework at the time called for research and dissemination of ABT in housing provision especially towards improving the poor housing conditions in rural areas whose figures stood at 300,000 housing units at the time. The current development framework which is being propagated by the Government of Kenya under the Big 4 Agenda recognizes the contribution of ABMTs and other Emerging building technologies with greater energy and resource efficiency in the delivery of affordable and adequate housing in Kenya.

Study findings demonstrates low application levels of Energy Efficient Building Technologies, particularly the Interlocking Stabilized Soil Blocks (ISSB), Prefabricated and Precast Construction methods. Figure 5.8 showed that the main building technology adopted in the study area was mortar and bricks or concrete constituting 65.2% followed by mud and wattle at 30.1% while the energy efficient building technologies such as ISSB, Prefabrication and Precast constituted 2.2%, 2.2% and 0.3% respectively. The overall percentage of energy efficient building technology stands at 4.7% compared to 65.2%. This analysis does not factor the proportion of mud and wattle which yielded 30.1% as the existing laws and regulations does not permit the use of mud and wattle in provision of housing within urban areas.

Figure 5.8: Types of Construction Technology



Source: Author, 2020

In order to further demonstrate the prevalent building technologies adopted in the study area, Chi-Square analysis was employed as presented in Table 5.3a and 5.3b. The null hypothesis indicated that there were high proportion of respondents applying energy efficient building technologies in the study area as stated below.

H0: There are high proportions of respondents applying energy efficient building Technologies.

Null Hypothesis, H_0: P > 20% or P >0.2

Research Hypothesis, H_1: $P \leq 20\%$ or $P \leq 0.2$; $\alpha = 0.05$

The study finds demonstrated that mortar and bricks technology which is considered to be low Energy Efficient Technology was the predominant building technology with higher observed value of 232 and higher positive residual value of 160.8. This was followed by mud and wattle with a higher positive residual value of 35.8. The technologies considered to be Energy efficient scored lower observed values with negative residual values. The expected number was 71.2 constituting 20% as the critical percentage for the technology to be considered dominant.

Table 5.3a Chi-Square Analysis of Construction Technology

SN	Construction Technology	Observed N	Expected N	Percent Observed	Residual
1	Mortar and Brick	232	71.2	65.2%	160.8
2	Prefabrication	8	71.2	2.2%	-63.2
3	Precast	1	71.2	0.3%	-70.2
4	Interlocking Systems	8	71.2	2.2%	-63.2
5	Mud and Wattle	107	71.2	31.1%	35.8
	Total	**356**			

Source: Author, 2020

The chi-square value of 562.567 indicates that the P-value (0.00) is less than 0.05 and therefore the research rejected the hypothesis that there were high proportion of respondents adopting energy efficient technologies in the study area. The study therefore concludes that the building technologies adopted in the study area are different across the household and that low energy efficient technologies are commonly used.

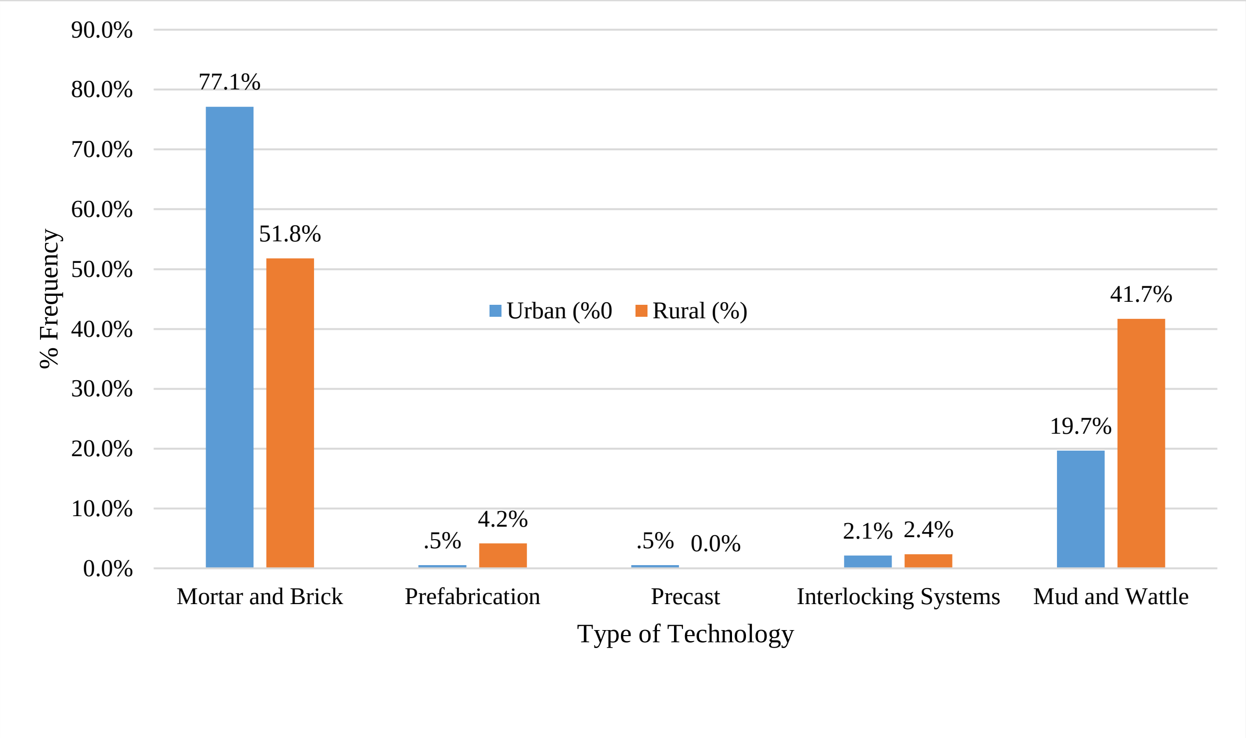
Table 5.3b: Chi-Square Test Statistics

Chi-square	562.567
df	4
Asymp. Sig.	0.000

Source: Author, 2020

The study further analysed the levels of energy efficient technologies in terms of rural and urban regions in order to find out any significant difference on the building technologies adopted. The results presented in Figure 5.9 and Table 5.4 indicate that the dominant technologies in both the rural and urban remains the same. However, mortar and bricks was highest in the urban setup at 77.1% compared to rural at 51.8%. In the same way mud and wattle was predominant in the rural areas at 41.7% compared to urban setup at 19.7%. The study further demonstrated low adoption of energy efficient building technologies in both the rural and urban set since ISSB scored 2.4% in rural areas compared to 2.1% in urban setup. It was further noted that 4.2% of households adopted prefabricated housing in rural areas compared to only 0.5% in the urban setup.

Figure 5.9: Distribution of Walling Technology by Nature of Ward



Source: Author, 2020

Table 5.4: Types of Construction Technology by Nature of Ward

SN	Construction Technology	Nature of Your Ward				Total	
		Urban		Rural			
		Count	Urban (%)	Count	Rural (%)	Count	% within Nature of Ward
1	Mortar and Brick	145	77.1%	87	51.8%	232	65.2%
2	Prefabrication	1	0.5%	7	4.2%	8	2.2%
3	Precast	1	0.5%	0	0.0%	1	0.3%
4	Interlocking Systems	4	2.1%	4	2.4%	8	2.2%
5	Mud and Wattle	37	19.7%	70	41.7%	107	30.1%
	Total	**188**	**100.0%**	**168**	**100.0%**	**356**	**100.0%**

Source: Author, 2020

Inferential analysis was done by the use of Kruskal-Wallis Test to determine if there was a relationship between the type of ward and the adoption of the energy efficient building technologies in the study areas. Taking ward as units of comparison was key in demonstrating the extent of application of various built environment policies and regulations, especially with regard to the building approval processes involving building materials and technologies considered safe for habitation.

Table 5.5a:Kruskal-Wallis Test (Ranks) on Types of Construction Technology by Nature of Ward

SN	Nature of Your Ward	N	Mean Rank
1	Urban	188	157.25
2	Rural	168	202.28
	Total	356	

Source: Author, 2020

Table 5.5a and Table 5.5b provides the mean rank statistics and Kruskall-Wallis test statistics. The mean rank values as per the research findings shows a big value indicating significant difference in the adoption technologies in rural and urban set up. This was further confirmed by a lower p value ($p=0.00\leq0.05$) indicating that we reject the null hypothesis and a firm that the application of energy efficient technologies in Migori county is dependent on the type of wards.

Table 5.5b: Kruskall–Wallis Test Statistics Types of Construction Technology by Nature of Ward

Chi-square	24.402
df	1
Asymp. Sig.	0.000

Source: Author, 2020

The results and analysis as discussed provides a basis for comparison on the views held in the use of building technologies in different areas. UN-Habitat while defining the SDG indicators for SDG11 called for global support in use of local building materials. The SDG indicators especially 11.c.1 calls for embracing local materials towards construction and retrofitting of sustainably resilient and resource-efficient buildings (UN-Habitat, 2018). Locally available building materials refers to materials where the entire lifecycle from extraction, manufacturing, sale, application, recycling / end-of-life is performed within the same locality. It is further noted that the environmental and economic impacts of selected construction materials is significant in the analysis of building's overall sustainability, as application of location specific building materials with low embodied energy is associated with decreasing carbon footprint of buildings. Further observations detail that application of local materials is key towards resiliency of settlements due to their adaptive capacity to the local climate and flexibility in use which allows for ease of alteration and replacement with locally available resources.

The certainty in choice of sustainable building materials cannot however be guaranteed in the absence of data relating to carbon footprint and environmental impacts of each selected material, hence documentation and creation of County specific life-cycle inventory (LCI) databases of dominant building materials is paramount in the definition and mainstreaming of sustainability path within the built environment.

6 RESOURCE EFFICIENCY AND CLIMATE CHANGE

6.1 Introduction

The research findings as discussed in this chapter addressed objective three of the study which focused on resource efficiency in relation to mortarless and mortared building technologies. The study explored the resource efficiency in relation to climate change for both the mortarless building technologies and mortared building technology. The research hypothesis that was tested and validated by this study was as expressed below:

H_O: There is no difference in resource efficiency and mitigation levels between mortarless and mortared building technologies.

The experimental design singled out burnt bricks and quarry stones for mortared building technology and ISSB for mortarless building technology. The study limited itself to the construction phase and production phase for ISSB and BB and construction phase for quarry stone.

6.2 Mortarless Building Technologies

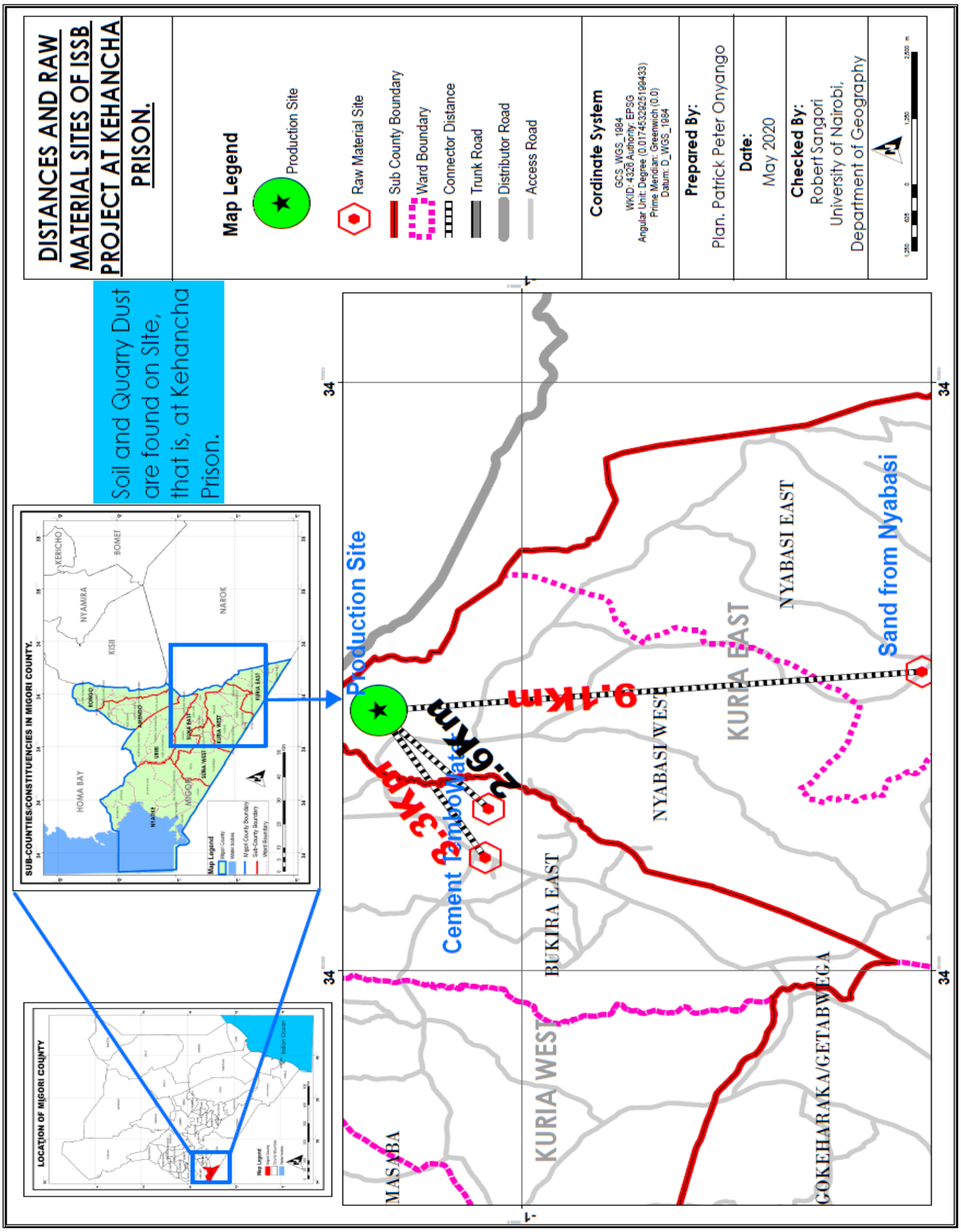
The mortarless construction form a larger component of the green building technologies. Such technologies have low embodied energy, cost-effective, labour-intensive, faster in construction delivery, culturally acceptable and suitable for both rural and urban setups (Hydraform Building System, 2009; Sangori, 2012). In Kenya, the application of such technologies were first supported by the adaptive by-laws on building technologies as adopted in 1995 (Code 95). The aim of the building code formulated in 1995 was for enabling housing standards and guidelines by lowing the building cost, encouraging innovative design, promoting local materials and focusing on performance. This process was aimed at addressing the challenges paused by the strict measures contained in the Building of 1968 whose emphasis was more on mortar and brick construction rather than housing adequacy and affordability. The mortarless construction technologies are key in realization of adequate and quality housing. For instance, poor quality housing can affect the health of the family (Martin, 1967). Further, according to Morris and Winter (1978), the number of households and the number of available dwelling units are social facts, while the rule or standard that more than one family per dwelling unit is not acceptable is a cultural fact. The issue of space norm is of great relevance in household and dwellings as it prescribes the amount of space a family should have and are dependent upon family size and composition. Achieving adequate housing through adoption of energy efficient building technologies as propagated in this study is significant towards realization of key activities that are performed within the dwelling units by various households. These includes; sleeping and dressing, personal cleanliness and sanitation, food preparation and preservation, serving food and dining, family recreation and self-improvement, extra-familial association, housekeeping activities, care of infants or the sick, circulation between various areas of the dwelling, operation of utilities (APHA, 1950).

The current global strategy is to encourage all actors in the field of environmental conservation and protection to promote application of green initiatives, more so within the built environment. UN-HABITAT (2011) demonstrated the application of best practices having pioneered an Ultra-Modern building complex in Gigiri, Nairobi that remarkably integrated the green building concept. The new building concept was useful in generating 550 KW of power out of which 65% is consumed by the building while 35% is fed to the national grid system providing extra income. The practices include; installing of Solar panels and Wind energy generating devices for lighting and heating system, use of special low energy bulbs for lighting, adopting of housing designs utilizing natural lighting and ventilation, biogas for cooking and heating system, and water conserving sensitive taps.

6.2.1 Raw Materials and Production Process

The energy efficient building materials has a major component of renewable energy which is characterized by; re-usable and recycling content; low emission levels; lower toxicity level; sustainable extraction; durability and local production. A case study involving application of Appropriate Building Materials and Technologies (ABMTs) details the aspects of raw materials selection, resource mobilization, on-site interaction, Site Preparation, Block Production and Construction processes. For instance, in 2004, the Ethiopian Government inaugurated construction of Bole/Gerji Pilot Apartments consisting of 700 cost-efficient apartments that integrated best practices involving; training-on-the–job, promotion of micro and small enterprises (SME), diversification and professionalization of the construction sector, mobilization of the savings, and timely provision of basic services. The project involved engagement of 750 workers in the daily production of hollow-concrete blocks with majority (75%) comprising female workers and 86 micro enterprises supplying metal doors and windows. In Kenya, analysis was conducted regarding the adoption of ISSBs with the study area being Migori County as depicted in Figure 6.1.

Figure 6.1: Material Sourcing Points in Kehancha for ISSB Production



Source: Researcher, 2020

The project targeted the production of 3000 ISSB. The aim of the technology is to provide housing at low cost and involved the production of blocks that interlocks with each other so as to eliminate the use of mortar as used in conventional methods. The ISSBs training on block production and construction can be apportioned into two parts with the first part comprising production of blocks slated for seven (7) days, and part two meant for construction using the produced and well cured blocks which can be used for walling after fourteen (14) days, particularly in the case of medium size houses. It is however noted that cement fully cures and gains strength after 28 days. With good rations, workmanship and proper curing, the blocks should be ready for use with a period of 14-21 days. The caution to be taken relates to ensuring that every piece of block is subjected to a minimal curing by watering for a period of 14 days from the day of production. The use of Hydraform technology in ISSB production has the potential of higher daily block output of up to 1500 blocks in the case of single chamber machine and 3000 blocks with the involvement of double chamber machine.

During soil selection, due considerations to be given for sandy-loam soils with sand proportion being higher than clay and silt, while sand should be blended with soil in case of high clay content. The best soil for production of quality Hydraform-ISSBs was classified as Sandy-Loam soil. The soil should contain more sand than clay and silt (fines). If the results of the suitability test found high clay content, then soil should be blended with sand or be produced with higher clay and silt contents, but with a caution to know the level of plasticity index used to gauge the quality of blocks produced (Hydraform, 2009).

Table 6.1: Plasticity Levels Required ISSBs Production.

Range Soil as raw materials for ISSB	Percentage (%) by mass of silt and clay during sieving		Plasticity Index Maximum levels	Calculated block strength after curing
	Minimum	Maximum		
Range A	10	35	15	4 MPa
Range B	10	25	10	7 MPa

Source: Hydraform, 2009

To establish the suitability of soil, both laboratory and field aided tests could be applied. According to Hydraform International (2009) which specialization in the manufacture of ISSB machines, there are a number of simple field soil test methods available which include but not limited to the following;

i. Visual Test,

ii. Wash Test,

iii. Jar Test and

iv. Shrinkage Test

These tests may however, not determine with 100% precision the suitability of soil as they rely on observations without detailed analysis of soil characteristics. Table 6.2 shows the soil classification by aggregates.

Table 6.2: Soil classification by Aggregates

SN	Soil Classification	Particle Size in mm
1	Gravel Soil	>2.0
2	Sand Soil	0.06 – 2.0
3	Silt Soil	0.006 – 0.002
4	Clay Soil	<0.002

Source: HABRI, 2003

The ISSB is produced using Hydraform Machine and it function by compressing the mixture of soil, cement and water through a mold with interlocking features to produce a solid block.

6.2.2 ISSB Experimental Design Scope and Outputs

The project involved reconnaissance to the site where a pre-test was conducted to establish the suitability of local soil and other raw materials towards production of quality Interlocking Stabilized Soil Blocks (ISSB) targeting a total of 3100 blocks. The final number of blocks were guided by the housing typology and design for implementation which was measuring 66.7M^2. Several tests were done and a mixture of normal onsite soil, quarry dust from the drilled borehole and sand was identified as suitable for the resultant mixture. Local Labour was mobilized and trained on procedures of making the ISSB.

The training involved Material selection, preparation, mixing, leveling of block yard, machine operation and maintenance, block production, stacking, curing and storage. During production phase, blocks were covered with black polythene papers to conserve moisture required in the hardening process. The blocks were then watered for a minimum of seven days and left to harden for additional 7 days. Upon completion of the curing process, the blocks were ready for application in the construction process within 21 days of production. The items applied in the ISSB production and construction processes are provided in Appendix 1J. The production process is demonstrated in tables 5.22 – 5.30 which depicts the blocks production process for each day of training at the experimental study site in Kehancha. The model of the machines used from Hydraform are in two forms notably; single and double chamber hydraulic – diesel operated- machines. To optimally operate, a single chamber machine requires a labour / workforce of about 8-10 unskilled personnel while a double chamber machine optimally operates with approximately 16 unskilled personnel. Once the local labour force is mobilized, simple on-site training is organized which involves material preparation, rations, mixture preparation, levelling of block yard, machine servicing and operation, handling of wet blocks, stacking of blocks in the yard and curing of blocks. Tables 6.3a, 6

Table 6.3a: Day 1- ISSB Production Pretest.

Sand		**Quarry Dust**	**Normal Soil**	**Cement**	**Water at Production**
3		3	1	1	42
0		1	4	1	12
TOTAL MIXTURES					
3		4	5	2	54
MIXTURE RATIO – SOIL: CEMENT					
12				**2**	
6				**1**	

BLOCKS PRODUCED = 105 INTERLOCKING BLOCKS

From the pretest, the ratio of stabilized soil mix (Normal soil, quarry dust and lake sand) to cement was 12 wheelbarrows of soil to 2 bags of cement, this was later simplified to ratio 12:1. A total of 105 blocks were produced on this day. This number of blocks equated to the number of bags of cement implied that averagely a bag of cement produced 52-53 interlocking blocks. To obtain the right mix, the ratios change day by day and was variant with different days of production day of production.

Table 6.3b: Day 2 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	4	8	12	3	210	120
Mix 2	4	8	12	3	210	
Mix 3	4	8	12	4	210	
Mix 4	1	2	3	1	40	
TOTALS	13	25	39	11	670	120

BLOCKS PRODUCED = 407 INTERLOCKING BLOCKS

The activities of day 2 begins with curing of blocks produced on day one. This is done by adequate watering of the blocks, a process which is conducted twice daily, that is, every morning and evening to the blocks produced in the preceding day. As such, blocks produced on the same day are taking as green given the water absorption during the material mixing process, hence the watering of the same is commenced on the following day.

Table 6.3c: Day 3 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	2	4	6	2	70	210
Mix 2	2	4	6	2	70	
Mix 3	2	4	6	2	70	
TOTALS	6	12	18	6	210	210

BLOCKS PRODUCED = 382 INTERLOCKING BLOCKS

Table 6.3d: Day 4 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	3	6	10	3	60	150
Mix 2	3	6	10	3	70	
TOTALS						
	6	12	20	6	130	150

BLOCKS PRODUCED = 331 INTERLOCKING BLOCKS.

Table 6.3e: Day 5 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	4	6	10	3	150	260
Mix 2	4	6	10	3	150	
Mix 3	3	4	7	2	100	
TOTALS						
	11	14	17	8	250	260

BLOCKS PRODUCED = 459 INTERLOCKING BLOCKS

6.2.2.1.1.1 Table 6.3f: Day 6 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	4	6	10	3	80	200
Mix 2	3	5	7	2	80	
Mix 3	3	5	7	2	80	
TOTALS						
	10	16	24	7	240	200

BLOCKS PRODUCED = 483 INTERLOCKING BLOCKS.

Table 6.3g: Day 7 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	4	6	8	3	250	150
Mix 2	3	5	8	2		
Mix 3	3	5	8	2		
TOTALS						
	10	16	24	7	250	150

BLOCKS PRODUCED = 454 INTERLOCKING BLOCKS.

Table 6.3h: Day 8 Production

MIXES	Sand	Quarry Dust	Normal Soil	Cement	Water at production (L)	Water at curing (L)
Mix 1	4	3	7	2	70	
Mix 2	4	3	7	2	70	
TOTALS						
	8	6	14	4	210	

BLOCKS PRODUCED = 287 INTERLOCKING BLOCKS.

The interlocking block production project was completed successfully in April 2019. The table of total raw material summary is as follows:

Table 6.3i: Total Raw Materials Used for ISSB Production

Sand	Quarry Dust	Normal Soil	cement	Water at production (L)	Water at curing (L)
67	**105**	**161**	**51**	**2014**	**1090**
TOTAL RATIO – SOIL: CEMENT					
SOIL			**CEMENT**		
333			**51**		
6.529			**1**		
TOTAL RATIO –CEMENT: INTERLOCKING BLOCKS					
51			**2908**		
1			**57.019 = Approximately = 58**		

TOTAL BLOCKS PRODUCED OVERALLY= 2908 INTERLOCKING BLOCKS.

From the above analysis, it was deduced that within the research area, the ISSB processing involving a 50kg of cement with mixture ratio of 7 parts soil yielded about 58 blocks. The production cycle consumed 40 Litres of diesel (Sangori, et al., 2020). The findings of this study on the production of ISSB which established that 7% cement ratio produced approximately 58 blocks is close to the findings documented in Sangori (2012) which demonstrated that use of 7% cement ratio yields about 60 blocks.

The procedure included selection of suitable soil for quality blocks, identification of the right sand and quarry dust where applicable. A suitable wire mesh was sought to sieve both soil and sand materials for purposes of getting the right sizes / particles which readily mixes with cement during the material preparation and production processes. The process further involved proper machine servicing and maintenance to achieve the desired level of efficiency and longevity. ISSB production was preceded by levelling block stacking and curing site, a process which was followed by having tarpaulins / polythene paper laid down. The use of tarpaulins below and above the stacked blocks was necessary to avoid rapid moisture loss from the blocks as curing was done by way of watering and not firing. Block testing was conducted with different mix designs before full production was embarked on. The daily production always commenced with watering the previous day's blocks and a new line for green blocks was prepared in readiness for the stacking process.

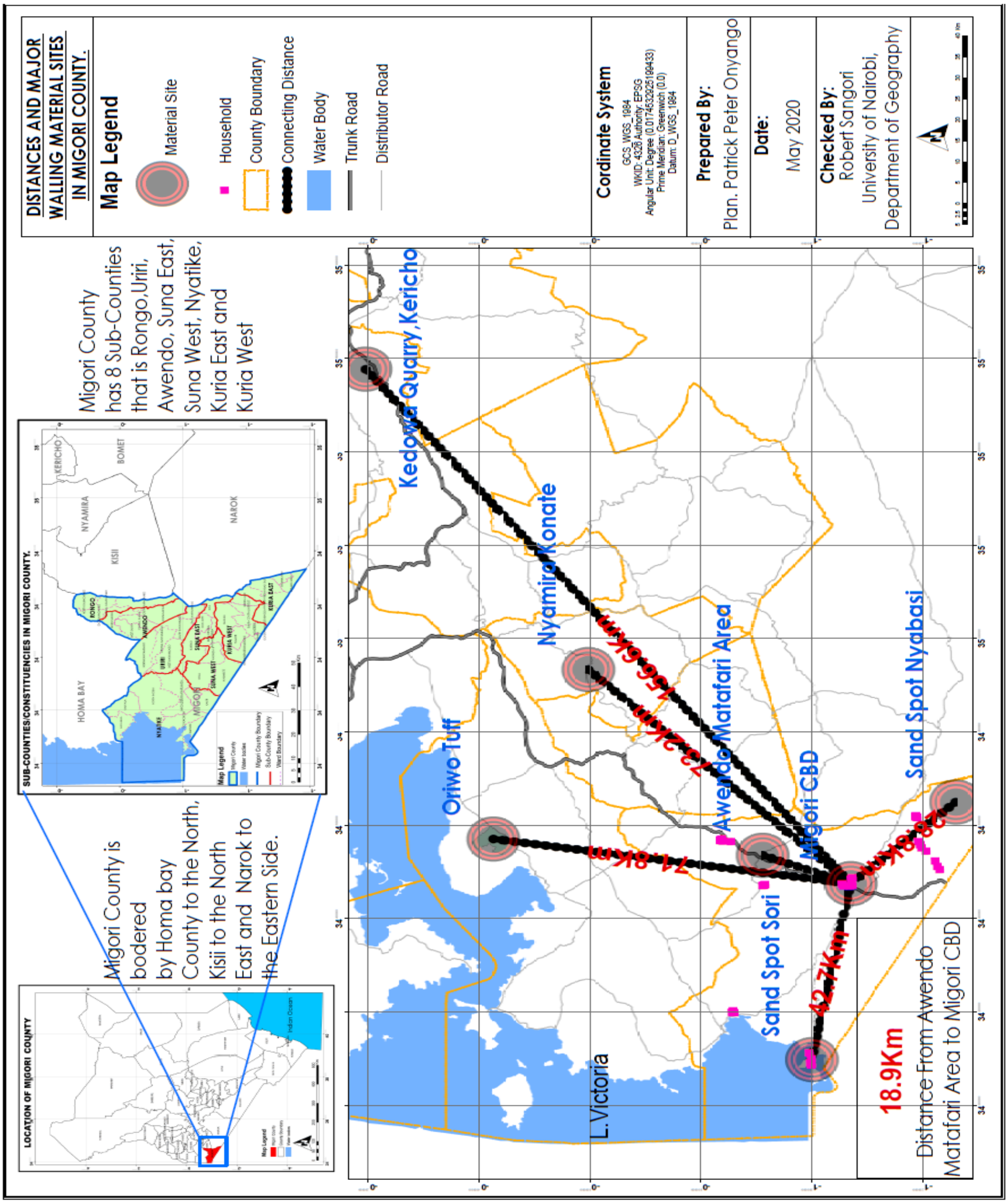
The analysis is comparable to a similar result tests demonstrated in Nakuru County in which the researcher earlier established that in one of the Hydraform-ISSBs production sites, the mix ratios for Cement: Sand: Soil was 1: 4: 7, which implied, One Wheelbarrow Portion of Cement: Four Wheelbarrow portions of Sand: Seven Wheelbarrow Portions of Soil. Each mixture comprising these proportions yielded an average of 60 blocks. In this case, wheelbarrow was adopted as a standard measure. The present study equally adopted the use of wheelbarrow as a standard measure at the ISSB experimental site in Kehancha.

Plate 6.1: Photos of ISSB Production Site at Kehancha Prison

Source Author: 2019

In order to get the embodied energy, the study estimated the hauling distance from material sourcing to construction sites by using GIS approach. This was attributed to the relationship between the distance and green gas emission of the material. The result from the distance analysis revealed that materials were sourced from various distance with higher GHG emission being associated with long distances. The resulting relationship is depicted in figure 6.2.

Figure 6.2: Migori town and location of building material sources.



Source: Researcher, 2020

The analysis further indicated that some of the building materials preferred by the locals were sourced from locations outside the study area. These included quarry stone which was mainly sourced from Oriwo Turf in Rachuonyo (74.8km), Kedowa in Kericho (166.6km) as well as some particular fired bricks of large sizes which were mainly sourced from Sironga in Nyamiwa County. Various reasons were advanced on the selective application of the preferred building materials including the perceived superiority, desired colour, ready availability and existing laws and regulations.

For instance, the preference of the quarry stones from Oriwo Turf is due to ready availability as well as variety of colour and quality of the quarry stones. The stone mining area is quite vast and comprises over 50 active quarrying sites. A visit to Ndarugo in Juja (Thika) which was by way of referencing encountered heavy machine operations that produces machine cut stones in mass, thus making access and collection process much faster. The site at Ndarugo had over 100 active quarrying sites. This particular site was however associated with high GHG emissions due to heavy machine operations to produce machine cut stones and the long distances covered in the transportation of the ready products to the construction sites.

6.2.3 Construction and Resource Efficiency

On-site production and application of ABMTs including the use of ISSBs is observed to be much faster thereby reducing the overall cost of construction. This process is demonstrated in the outlined on-site training programme in Appendix 1.L.

Table 6.4 outline the cost of production of ISSB taking into consideration all the input and processes. Production of ISSB entail two major phases: production and curing phase. The experimental design demonstrated that it would cost Kes. 83,540.00 to produce 3100 pieces of ISSB each weighing 12 kg. This would cost approximately Kes 27.00 per piece. The highest cost was noted on Cement products at Kshs. 38,500.00, which contributed 46% of the cost of production followed by labour cost at 30%. This implies that the major contributor to GHG emission in the production of ISSB is cement since it has a relatively higher GHG emission factor.

Table 6.4: Production Cost of ISSB (66.7M^2)

Phases	Parameters	Units	Quantity	Cost per Unit	Total Cost
Production phase	Soil	Tonnes	17.1	-	-
	Quarry dust	Tonnes	11.2	-	-
	Sand	Tonnes	7.1	1,000.00	7,100.00
	Water	Litres	2140	1.00	2,140.00
	Cement	Bags	55	700.00	38,500.00
	Diesel Fuel	Litres	43	94.00	4,042.00
	Labours (skilled)	Man days	10	1,000.00	10,000.00
	Labours (Non skilled)	Man days	50	300.00	15,000.00
	Productivity	Daily	582		
	Time	Days	5		
Curing Phase	Polythene roll	roll	2	-	-
	Grass	bales			-
	Water	Litres	1158	1.00	1,158.00
	Semi-skilled Labour	Man days	14	400.00	5,600.00
	Curing period	Days	7		
Total					**83,540.00**

Source: Researcher, 2020

The estimated cost provided is exclusive of cost associated with equipment which are considered as capital cost in nature as well as the cost of materials / inputs with re-use potential. Such equipment involves; Wheelbarrows, Jembes, Rake, buckets, sieve, spades, watering cans among others. The comparison of the cost of production of mortared and mortarless building technologies is provided in Appendix 1F.

6.2.4 Raw Materials and Application of Ready Products in Construction Process

Mortarless construction technologies are mainly applied within an on-site set up and are aided by portable production machines in most instances. There has been a number of Block making machines in use in Kenya which support the application of Stabilized Soil Blocks (SSBs) namely; CINVA-Ram Press, BREPAK Press, and more recently, the Hydraform Machine (HABRI, 2003; Samgori, 2012). The CINVA-Ram Press was one of the earliest machines for making Stabilised Soil Blocks (SSBs) which was developed in the 1950s and was capable of exerting pressure of upto 10KgN/M^2 (UNHabitat, 2009; Kintingu, 2009; Sangori, 2012). The Building Research Establishment (BRE) in the UK developed the BREPAK Press Machine in the late 1970s. Due to the hydraulic mechanism it incorporated, the BREPAK could exert high amount of pressure (almost five times the pressure of CINVA-Ram), and therefore the quality of stabilized blocks produced were quite high (Agevi, 1986). The report by HRDU (1987), indicated that these machines had been known to produce between 200-250 soil blocks per day, with a group of 5 labourers, while on construction process, one mason and a labourer could lay upto 150 blocks per day (i.e. 4.7 square metres). The blocks were measuring 290mm X 140mm X 125mm and weighed approximately 8kg (Donde, 1994).

The introduction of Hydraform-ISSBs machines into the market brought with it a lot of dynamism since it was capable of achieving mass production of blocks with single chamber machine having a daily maximum production of 1500 blocks and a double chamber machine having a capacity of 3000 blocks per day. The standard Hydraform blocks weighed between 8-12kgs. Table 6.5 shows the construction of ISSB application arising from this study.

Table 6.5: Construction Cost of ISSB (66.7M^2)

Parameters	**Units**	**Quantity**	**Cost per Unit**	**Total Cost**
Time (Days)	Days	4		
Skilled Labours (Man Days)	Man days	8	1,000.00	8,000.00
Non Skilled Labours (Man Days)	Man days	16	500.00	8,000.00
Sand (Tons)	Tons	2	1,000.00	2,000.00
Cement (50kg bags)	50 kg/bag	17	700.00	11,900.00
Water	100 Litres	10.2	100.00	1,020.00
Wastage (Pcs)	Pieces	0		-
Main Walling material	pcs	3100	27.00	83,700.00
Total Cost				**114,620.00**

Source: Researcher, 2020

The demo unit depicting the application of ISSB in the resource analysis is provided in plate 6.2 below.

Plate 6.2: ISSB Demo Unit at Kehancha Prison Experimental Design Site

Source: Researcher, 2020

In this study, the researcher produced 3100 ISSB to construct a house of plinth area measuring **66.7M²** with each ISSB weighing 12 kg. Table 6.5 summarises the major parameters used to demonstrate the resource factors and their related cost. The total cost of construction upto to the lintel level was computed as Kes. 114,620.00. Cost of ISSB used in construction derived from production phase was Kes. 83,700.00, and this constituted 73% of the construction cost followed by labour cost at 14% and cement cost at 10.3%. It took only 4 days to construct the building using ISSB upto the lintel level. This further demonstrates the faster construction process that is associated with some of the emerging construction technologies where ISSB falls. Other materials found in this category include prefabricated and precast construction methods.

6.3 Mortared Building Technologies

Mortared building technologies are represented by mortar and brick construction methods. It involves application of diverse construction materials notably; quarry stones, burnt bricks, and concrete blocks among others. This study focused on 2 mortared technologies as applied by the respondents namely; burnt bricks and quarry stone. The burnt bricks technology was analysed at the experimental design phase involving both production of blocks and walling using the resultant fired bricks while quarry stone was used as a case study for the analysis of resource efficiency at the construction stage.

In computing the cost of Production in BB, three major phases were considered, namely: production phase, curing phase and firing phase as summarized in Table 6.6. The resources used in the production of bricks were mainly soil, water, wood fuel and labour. The total cost of producing 4,500 pieces of BB was Kes. 22,300.00. The major cost component was wood fuel which cost Kes. 9,360.00 constituting 42% followed by combined labour Cost at 41%. The other cost constituting 7% was on water costing Kes. 3,840.00. The total duration of the production process took 49 days with curing taking the highest period (30 days). The longer construction periods noted in the use of this particular construction method is generally associated with additional cost both direct and indirect. For instance, the cost of labour in most instances will be relatively high as the man-hours increases.

Table 6.6: Production Cost of BB (66.7M^2)

Phases	Parameters	Units	Quantity	Cost per Unit	Total Cost (Kes)
Production phase	Soil	Tonnes	22.5	-	-
	Water	Litres	3600	1.00	3,600.00
	Labours (Non skilled)	Man days	14	350.00	4,900.00
	Productivity	Daily	700		
	Time	Days	7		
Curing Phase	Semi-skilled Labour	Man days	4	350.00	1,400.00
	Curing period	Days	30		
Firing of burnt bricks	Semi-skilled Labour	Man days	8	350.00	2,800.00
	Wood fuel/Logs	Kgs	1440	6.50	9,360.00
	Water	Litres	240	1.00	240.00
	Time	Days	12		
Total					**22,300.00**

Source: Researcher, 2020

In the construction phase, burnt bricks and quarry stones were to construct walls covering a floor area of 66.7M^2. The cost of constructing a quarry stone wall was computed to be Kes. 494,319.00 compared to BB at Kes. 236,350.00 indicating that quarry stone wall is twice more expensive compared to BB. The higher cost was attributed to the cost of the stones which cost Kes. 43.00 per piece compared to Kes. 10.00 for the bricks. In addition, quarry stones are labour intensive during construction with 65-man hour of skilled labour and 390 man hours of semiskilled labour compared to 42-man hour of skilled labour and 140-man hour for semi-skilled labour for the burnt bricks. Plates 6.3 depicts burnt bricks demonstration house used in the analysis of resource efficiency.

Plate 6.3: Burnt Bricks Demo Unit for Experimental Analysis

The comparison of resource utilization components for the study analysis involving BB and quarry stone technologies is contained in table 6.7.

Table 6.7: Construction Cost of BB (66.7M²) and Quarry Stone (66.7M²)

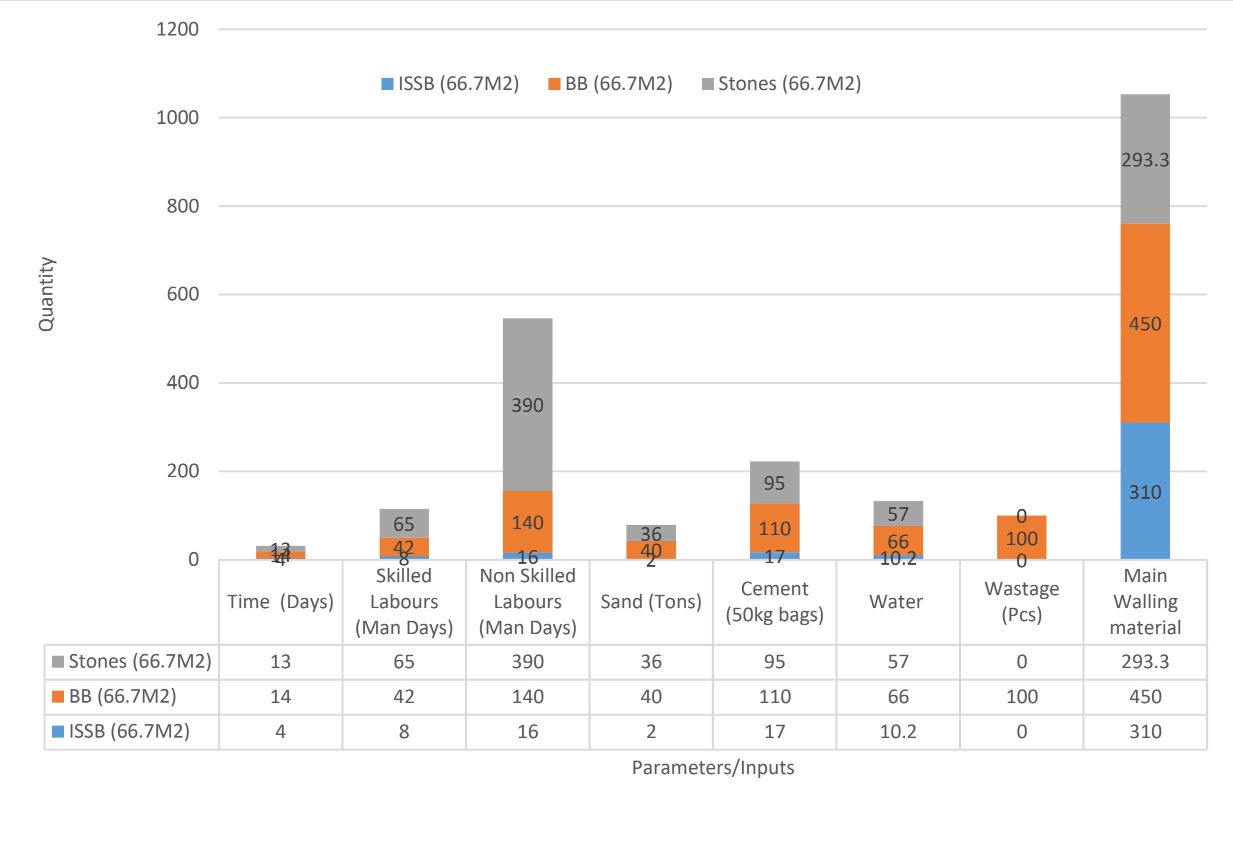
		BB (66.7M²)			**Quarry Stone (66.7M²)**		
Parameters	**Units**	**Quantity**	**Cost per Unit**	**Total Cost**	**Quantity**	**Cost per Unit (Kes.)**	**Total Cost (Kes.)**
Parameters		**BB (66.7 M2)**		**BB (66.7M2)**	**Stones (66.7M2)**		**Stones (66.7M2)**
Time (Days)	Days	14			13		
Skilled Labours (Man Days)	Man days	42	1,000.00	42,000.00	65	1000	65,000
Non Skilled Labours (Man Days)	Man days	140	500.00	70,000.00	390	500	195,000.00
Sand (Tons)	Tons	40	1,000.00	40,000.00	36	1000	36,000
Cement (50kg bags)	50 kg/bag	110	700.00	77,000.00	95	700	66,500
Water	100 Litres	66	100.00	6,600.00	57	100	5,700.00
Wastage (Pcs)	Pieces	100	7.50	750.00	0		0
Main Walling material	pcs	4500	10.00	45,000.00	2933	43	126,119
Total Cost				**236,350.00**			**494,319**
Cost per unit				**10**			**43**

Researcher, 2020

6.4 Comparison of Mortarless and Mortared Building Technologies and Climate Change

Comparison between ISSB and BB revealed fewer production duration for ISSB which takes about 12 days compared to burnt bricks which takes roughly 49 days for the process to be concluded. The % Difference in the production timelines of the 2 products is about 308.3% thereby providing a clear demonstration that ISSB is 3 times faster to produce.

Figure 6.3: Comparison of Quantity of Inputs used in the Construction using ISSB, BB and Quarry Stone

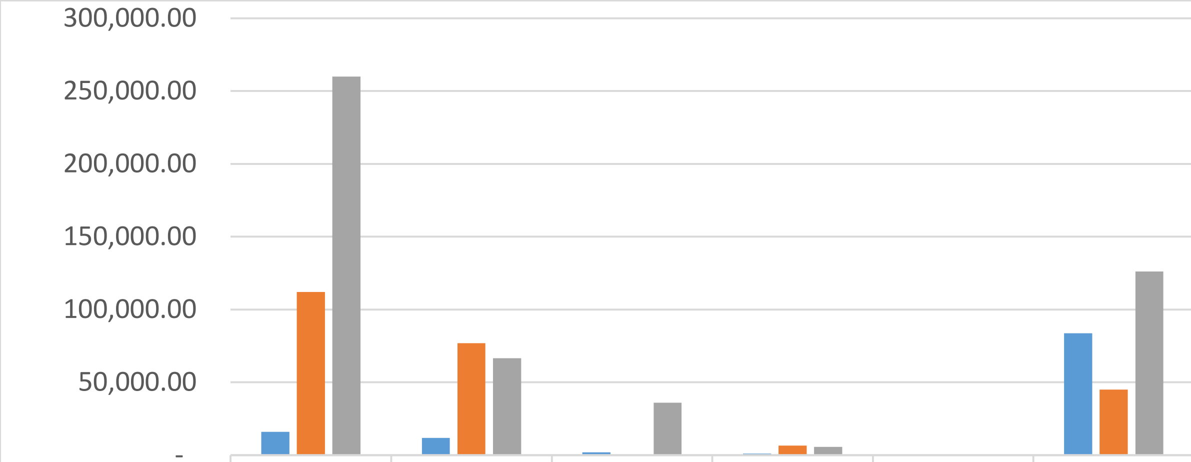


	Time (Days)	Skilled Labours (Man Days)	Non Skilled Labours (Man Days)	Sand (Tons)	Cement (50kg bags)	Water	Wastage (Pcs)	Main Walling material
Stones (66.7M2)	13	65	390	36	95	57	0	293.3
BB (66.7M2)	14	42	140	40	110	66	100	450
ISSB (66.7M2)	4	8	16	2	17	10.2	0	310

Source: Researcher, 2020

Figure 6.3 illustrates the major parameters used to compare the resources used in both mortared and Mortarless Technologies. In terms of the period of construction, ISSB took 4 days compared to 13 days and 14 days to construct stones and bricks respectively. It is therefore 4 times faster to constructs using ISSB compared to stones and BB. The labour required for constructing ISSB is much lower and is more than 5 times less compared to stones and bricks. In terms of sand, ISSB consumed 17 bags of cement in the construction of foundation and lintel compared to 110 bags and 95 bags for BB and stone construction respectively. The higher amount of cement would lead to higher GHG emission and consequently higher construction cost due to cost of pollution.

Figure 6.4: Comparison of Cost of Inputs in the Construction using ISSB, BB and Quarry Stone



	Labour Cost	Cement	Sand	Water	Wastages	Walling Materials
ISSB (Kshs)	16,000.00	11,900.00	2,000.00	1,020.00	-	83,700.00
BB (Kshs)	112,000.00	77,000.00	-	6,600.00	100.00	45,000.00
Stones (Kshs)	260,000.00	66,500.00	36,000.00	5,700.00	-	126,119.00

Source: Researcher, 2020

Similarly, the cost of inputs was computed and result illustrated in Figure 6.4. The highest costs were related to labour, followed by walling material and cement. ISSB was cheaper in terms of labour at Kes 16,000.00 followed by BB at Kes. 112,000.00 and Stones at Kes. 260,000.00. The same trend was replicated terms of cost of walling materials and cement with cost of ISSB cost ranging on the lower end compared to cost of stones and bricks.

The overall costs of technologies were compared by using ISSB and BB. The cost of production, construction and pollution was computed for comparative analysis. It was revealed that ISSB is more expensive to produce at Kes 83,540 compared to BB at Kes 22,300 while ISSB was cheaper to construct at 114,620.00 compared to BB at Kes 281,350.00. The cost of pollution was also computed by using a standard conversion procedure provided by Eco-costs 2017 system which provided the cost as 116 Euro per 1000kg of CO_2 emission (DUT, 2017; 2020). This translated into Kes. 14.00/Kg of CO_2.

The total embodied energy used in the construction of ISSB was 30,955.20 MJ compared to BB at 67,965.80 MJ while the equivalent CO_2 emission was 3302.88 MJ for ISSB and 7,802.91

MJ for BB. Using these figure to compute the cost of pollution resulted to ISSB causing harm equivalent to Kes. 246,051.00 while cost of pollution for BB being Kes. 416,792.00.

Figure 6.5 Comparison of Cost of Construction between ISSB and BB

Source: Researcher, 2020

In order to determine the resource efficiency and climate change mitigation levels associated with the utilization of mortarless and mortared building technologies, the study made comparison of embodied energy and CO_2e from technology use at construction phases as shown in Table 6.8. It was evidence that even though the production cost of ISSB seems to be higher compared to BB, the pollution cost associated with BB is much higher making the technology to be expensive in the long run. The emission associated with BB is almost 3 times higher compared to ISSB with the emission factor of ISSB being (0.087 Kg CO_2e/Kg) and that of BB recorded at (3.021 Kg CO_2e/Kg).

Table 6.8: Comparison of Embodied Energy and CO_2e from Technology Used

Parameters	ISSB		Bricks		% Difference	
	Per Kg	Total	Per Kg	Total	Per Kg	Total
Embodied Energy	0.811	30,955.20	3.021	67,965.80	272.5%	119.6%
Carbon Emission Equivalent	0.087	3302.88	0.347	7,802.91	298.6%	136.2%
Cost of Emission (Kshs./KgCO_2e) -14.5						
Cost of Emission (Euro/1000kg) -116						

Source: Modified from DUT (Eco-costs), 2017 Version1.6

The research used Paired Sample T-Test. This test compares two means of the two related objects of the related units and in this case the means of the comparable values of bricks and ISSB for the input resources consumed in the production of bricks and ISSB. The study Null Hypothesis was that; there was no difference in resource efficiency and mitigation levels between mortarless and mortared building technology states as follows:

H_0: There is no difference in resource efficiency and mitigation levels between Mortarless and mortared building technologies.

Null Hypothesis: H_0: $\mu 1 = \mu 2$ (the paired input resource values for bricks and ISSB are equal)

Research Hypothesis: H1: $\mu 1 \neq \mu 2$ (the paired input resource values for Bricks and ISSB are not equal)

The paired Sample T-test provided both the means of the values, the correlation and T-test values for comparison purposes as provided in Table 6.9, Table 6.10a and Table 6.10b respectively. At the construction level, the mean input of ISSB was 52.45 compared to 123.14 for bricks. There was a strong correlation between the input used in constructing ISSB and brick with a correlation of 0.969 with a P-value $0.001<0.05$. The t-statics for the inputs at the construction level showed that there is significant difference in the amount of input used in the construction of mortarless compared to motored building technologies since the p-value was 0.001 compared to an alpha value of 0.05

In term of input resources used in the application of bricks and ISSB, we reject the hypothesis and accept the research hypothesis stating that there was difference in resource efficiency and mitigation levels between Mortarless and mortared building technologies.

Table 6.9: Paired Sample Statistics of Inputs and Cost of Construction and Production phase

Construction Phase		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ISSB Input	52.457	7	113.7034	42.9758
	BB Input	123.143	7	150.5362	56.8973
Pair 2	ISSB Cost (Kes.)	16374.286	7	30009.7756	11342.6290
	BB Cost (Kes.)	40085.714	7	28906.4830	10925.6236
Production Phase		**Mean**	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	ISSB Input	402.157	7	794.6985	300.3678
	BB Input	625.357	7	1336.2988	505.0735
Pair 2	ISSB Cost (Kes.)	3248.571	7	5583.7127	2110.4450
	BB Cost (Kes.)	1414.286	7	2038.3233	770.4138

Source: Researcher, 2020

By following the sample approach, values where compared for cost the input materials which results indicating that there was no significant difference between the costs employed in the construction of bricks compared to ISSB since the p-value was 0. 142 which was greater than the α value of 0.005. The research therefore failed to reject the hypothesis in terms of cost of construction.

Table 6.10a: Paired Samples Correlations of Inputs and Cost of Construction and Production phase

Construction Phase		N	Correlation	Sig.
Pair 1	ISSB Input & BB Input	7	.969	.000
Pair 2	ISSB Cost (Kes.) & BB Cost (Kes.)	7	.206	.658
Production Phase		**N**	**Correlation**	**Sig.**
Pair 1	ISSB Input & BB Input	7	.997	.000
Pair 2	ISSB Cost (Kes.) & BB Cost (Kes.)	7	.833	.020

Source: Researcher, 2020

At the production level the study revealed that there was a strong relationship between the inputs used in the production of ISSB compared to BB since with a correlation coefficient of 0.997 with the sample reflected in the cost of the inputs. However, the difference in application of inputs and their respective cost was not significant given the p-values of 0.322 and 0.276 respectively. The study therefore, failed to reject the hypothesis at the production level and ascertain that there was there was no difference in resource efficiency and mitigation levels between Mortarless and mortared building technologies. This was associated with the fact that the social cost of pollution was not factored in the analysis.

Table 6.10b: Paired Sample Test of Inputs and Cost of Construction and Production phase

Construction Phase	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
1Pair ISSB Input - BB Input	-70.6857	49.0974	18.55	-116.09	-25.27	-3.809	6	.009
2 Pair. ISSB Cost (Kes.) - BB Cost (Kes.)	-23711.4286	37137.6123	14036.69	-58057.99	10635.13	-1.689	6	.142
Production Phase								
1 Pair ISSB Input - BB Input	-223.2000	547.5330	206.9480	-729.5836	283.1836	-1.079	6	.322
2 Pair ISSB Cost (Kes.) - BB Cost (Kes.)	1834.2857	4046.1787	1529.3118	-1907.8054	5576.3769	1.199	6	.276

Source: Researcher, 2020

Further investigation was done using the embodied energy, greenhouse gas and the social cost associated with the construction of mortarless and mortared building technologies. The input cost of labour, cement, sand, walling material and water was analysed and their input cost and social cost of pollution aggregated. The cost of production was ignored since it was factored as inputs for the walling materials. The hypothesis to be tested was stated as follows:

Null Hypothesis: H_0: $\mu 1 = \mu 2$ (the paired input cost of resource during construction for bricks and ISSB are equal)

Research Hypothesis: H1: $\mu 1 \neq \mu 2$ (the paired input cost of resource during construction for bricks and ISSB are not equal)

The cost of construction and social cost of pollution was compared using Paired T-test and results presented in Table 6.11a-c as shown below. The results show that the mean cost of ISSB was Kes. 29,142 compared to bricks at Kes. 77,566. Further analysis using correlation indicated that there was a positive relationship between the cost of ISSB and bricks given the correlation of 0.755. However, the association was not significant at 95% confident level given that the p-value of 0.08 was higher than the critical alpha value of 0.05. However, at 92% confident level, the association is considered to be significant.

Table 6.11a: Paired Samples Statistics for Cost of using ISSB and Brick

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	ISSB	29142.3017	6	51499.49998	21024.58283
	Bricks	77566.5800	6	60003.35096	24496.26545

Source: Researcher, 2020

Table 6.11b: Paired Samples Correlations for Cost of using ISSB and Brick

		N	Correlation	Sig.
Pair 1	ISSB & Bricks	6	.755	.083

Source: Researcher, 2020

The pared sample t-statistics revealed a t-value of 2.978 indicating that there was significant difference at 95% confident level since the p-value (0.031) was lower than the alpha value of 0.05. In conclusion, the study rejected the null hypothesis that there was no difference in resource efficiency and mitigation levels between Mortarless and mortared building technologies. The research objective was therefore upheld since there was enough evidence to ascertain that resource efficiency and climate change mitigation levels are associated with utilization of mortarless and mortared building technologies. Therefore, building technologies used in Migori County have a significant effect on climate change.

Table 6.11c: Paired Samples Test for Cost of using ISSB and Brick

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Pair 1 ISSB - Bricks	-48424.27833	39828.90794	16260.08358	-90222.15382	-6626.40285	-2.978	5	.031

Source: Researcher, 2020

7 ENERGY EFFICIENCY AND GREENHOUSE GAS EMISSION

7.1 Introduction

The research findings addressed objectives four of the study which focused on establishing the relationship between energy efficiency levels of building materials and Greenhouse Gas Emission (GHG). The research hypothesis that was tested and validated by this study was as expressed below:

H_O: Building technologies used in Migori County have no effect on climate change.

7.2 Building Technologies and Climate Change

The study set to establish the nature of relationship in the application of building technologies and climate change. Under Paris Agreement (COP 21) of 2015, all parties to the agreement (184 countries) were bound to submit NDCs, aggregate progress on mitigation, adaptation, and commitment to review means of implementation every 5 years. UNFCCC (1992) strategic goal is to stabilize atmospheric concentrations of greenhouse gases (GHGs), by avoiding dangerous anthropogenic interference with the climate systems. Just like the Kyoto protocol and its call for the DCs and Countries in transition to a market economy, to achieve qualified emissions reduction targets for a basket of six GHGs, Kenya is fast approaching the league of such Countries given her entry into the bracket of lower-middle income status together with the likes of Bangaledesh, Mynmar and Tajikistan among others (World Bank, 2015). Buildings and energy consumption of a Nation and the significance of embodied energy of building materials towards sustainable architecture. Recognition of of environmental issues since the first energy crisis of 1970s and having it firmly embedded in the development agenda.

With increasing significance of building industry towards the energy consumption of a Nation, built environment professionals including environmentalists are concerned of the solutions to minimize energy consumtion in building processes and environmental pollution prevention (Barbaros Bulvari). Storey and Baird, 1990; noted that most modern city buildings' design possesses a lifespan of 50-60 years and at times most of such buildings are subjected to major reconstruction, thereby doubling or trippling their embodied energy levels. Farinola, 1999: provides five main components of energy requirement over a building lifetime notably; Energy embodied at intial construction stages; Energy requirement towards its operations including heating, cooling, ventilation, lighting, power among others; Energy embodied in the regular maintenance and periodic refurbishment of the building; Energy consumption during demolitions and disposal stages of buildings; Energy savings due to recycling.

Choice of materials and design principles in buildings are significant but remains largely unrecognized as having greater impact on energy efficiency aspects.Tucker, 2000: provides that CO_2 emissions are significantly correlated with energy consumed in manufacturing materials with 0.098 tonnes emitted per gigajoule of embodied energy. Some reprocessing of building materials may use more energy, for instance, the involvement of long distances. Robison, 1999: noted the importation of stones for cladding is associated with double the embodied energy of the same stone which are subjected to local quarrying.

The embodied energy is recognized as one of the measures of the environmental impact of the construction in any locality and the effectiveness of the recycling processes, particularly, the carbon dioxide emissions. Environmental issues that relates to the built environment have been on the agenda since early 1970s when the first energy crisis was experienced. In the analysis of the role of buildings in energy consumption of a Nations, CIRAVOGLU (2005) indicated that concrete structural systems and brick envelope serves as the most energy intensive design preferences in building sector in Turkey. The study by CIRAVOGLU notes the advantages of adopting appropriate selection in design projects along with passive designs solutions among other sustainable building practices. Further, Turker (2000) emphasized the significance of EE and details that energy embodied in existing building stock in Australia amounts to about 10 years of the total energy consumption for the entire nation. In the current practice, the desire to make buildings, especially, those of dwelling nature more energy efficient often results in higher embodied energy thus increasing the ration even further.

7.3 Relationship between Dominant Building Materials and Climate Change

The purpose of the study was to determine the contribution of building materials and technologies in climate change mitigation and adaptation processes. This was achieved by determining the dominant walling materials adopted in Migori country and relating the embodied energy and its contribution to climate change through greenhouse gas emission. In order to determine the relationship between the Embodied energy and GHG emission of the materials for walling material in Migori, Regression Analysis was done using SPSS and trend analysis in Microsoft Excel. This was achieved using the nine dominant building material used in the study area. The descriptive statistic Table 7.1a shows the mean values of GHGe and EE_{cm} of the dominant materials indicating that the mean embodied energy coefficient was 1.375 MJ/Kg while the Equivalent CO_2 emission was 0.1893 Kg.

Regression analysis was conducted to determine the relationship between embodied energy and greenhouse gas emission based on the material used in Migori County. The regression equation is given in this format for one independent and one dependent variable

Hypothesis was also tested based on the regression values obtained.

$Y=\beta_o + \beta_1 X + €$: Where Y= GHG and X = Embodied Energy, β_o = Constant+ β_1= coefficient of Embodied Energy and € = error term

H0: Building technologies used in Migori County have no effect on climate change

Null Hypothesis $H_0 : \beta_1 = 0$ (There is no association between EE and GHG)

Research Hypothesis $H_1 : \beta_1 \neq 0$ (There is an association between EE and GHG)

Table 7.1a:Descriptive Statistics of Embodied Energy Coefficient and Equivalent GHGe

Descriptive Statistics

	Mean	Std. Deviation	N
Equivalent CO2e/Kg	.189333	.2651155	9
Embodied Energy Coefficient (MJ/KG)	1.374667	1.4872982	9

Source: Researcher, 2020

Table 7.1b shows the coefficients of the regression line derived from the model. The table states that the expected GHG e is equal to 0.173* Embodied Energy – 0.049.
Based on the analysis, the Regression equation was:

$Y= 0.1733X - 0.0488$ (R^2 =0.9451)

or $GHG = 0.1733EE_{cm} - 0.049$

Where; Y=GHG =Greenhouse gas emission per kg of material

$X= EE_{cm} =$ Embodied Energy per Kg of Material

Table 7.1b: Model Coefficients of Walling Materials

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-.049	.031		-1.578	.159
	Embodied Energy Coefficient (MJ/KG)	.173	.016	.972	10.984	.000

Source: Researcher, 2020

Table 7.1c indicates the ANOVA table used for testing whether the model can be significantly be used for prediction. The Regression values provides the variation that are due to the model while the residual provides variation that are due to other factors beyond the model of variable under study. The F- statistics is a ratio that compares the variation due to model and the variation not accounted by the model and it critical value is noted by comparing the p-value and the alpha values at 95% level of significant. In this case the p-value was 0.00 showing that the model is significant can be used for prediction. It shows that there is a relationship between the GHG and embodied energy of the walling materials.

Table 7.1c: ANOVA on Dominant Materials

ANOVA						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.531	1	.531	120.652	.000[a]
	Residual	.031	7	.004		
	Total	.562	8			
a. Predictors: (Constant), Embodied Energy Coefficient (MJ/KG)						
b. Dependent Variable: Equivalent CO2e/Kg						

The model in Table 7.2 was used to test the strength of the relationship of the two variable under study. The values of R show the correlation between embodied energy and GHG was calculated at 0.972 indicating a strong association between the variables. Its large value of 0.92 indicates a strong relationship. R squared (R^2 =0.945) indicates that 94.5% of the Greenhouse gas emitted is explained by the embodied energy of a materials and this indicate a near perfect relationship between the GHG Emission and embodied energy of the walling materials used in the study area. It further demonstrates the need to minimize the embodied energy of the walling materials or the need to adopt walling materials with minimized embodied energy in order to reduce the greenhouse gas emission.

Table 7.2: Model Summary of Embodied Energy Coefficient and Equivalent GHGe

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.972a	0.945	0.937	0.0663692

a. Predictors: (Constant), Embodied Energy Coefficient (MJ/KG)
b. Dependent Variable: Equivalent CO_2e/Kg

In order to further demonstrate the fitness of model and its use for prediction, normality test was carried out using a histogram and P-P plots of the residuals. A histogram or P-P plot of the residuals helps in checking the assumption of normality of the error term. Further, for the assumption of normality, the P-P plots for the residuals should follow 45-degree line. In this study both the Histogram and P-P plot observed the normality assumptions and provided in Figure 7.1 and Figure 7.2.

Figure 7.1: Histogram of Residuals of Dominant Walling Materials

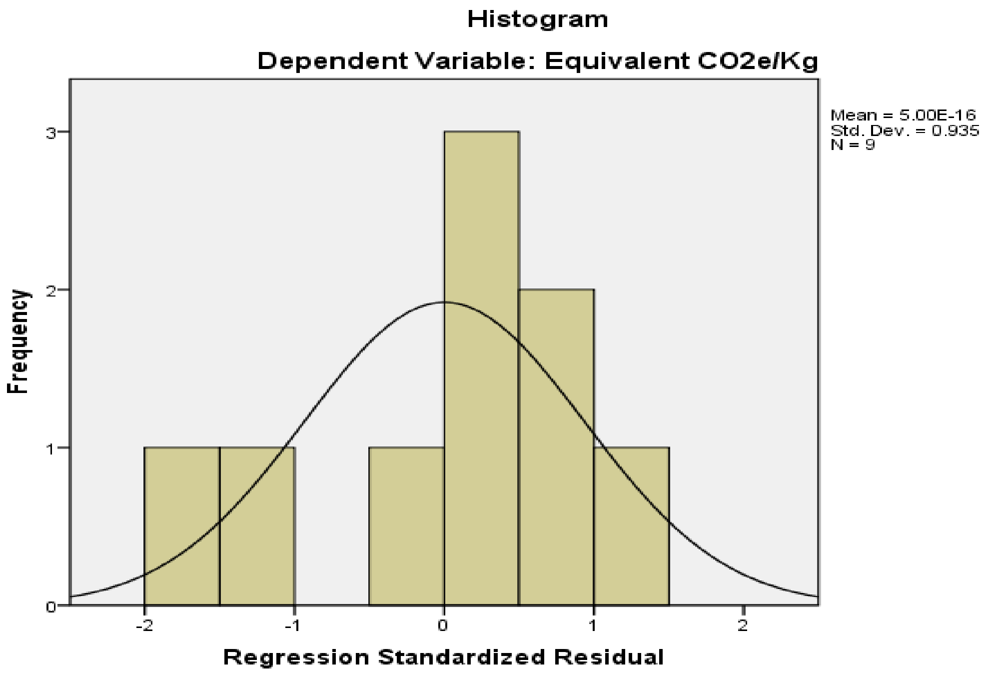


Figure 7.2 Normal P-P Plot of Regression Standardized Residuals of Dominant Walling Materials

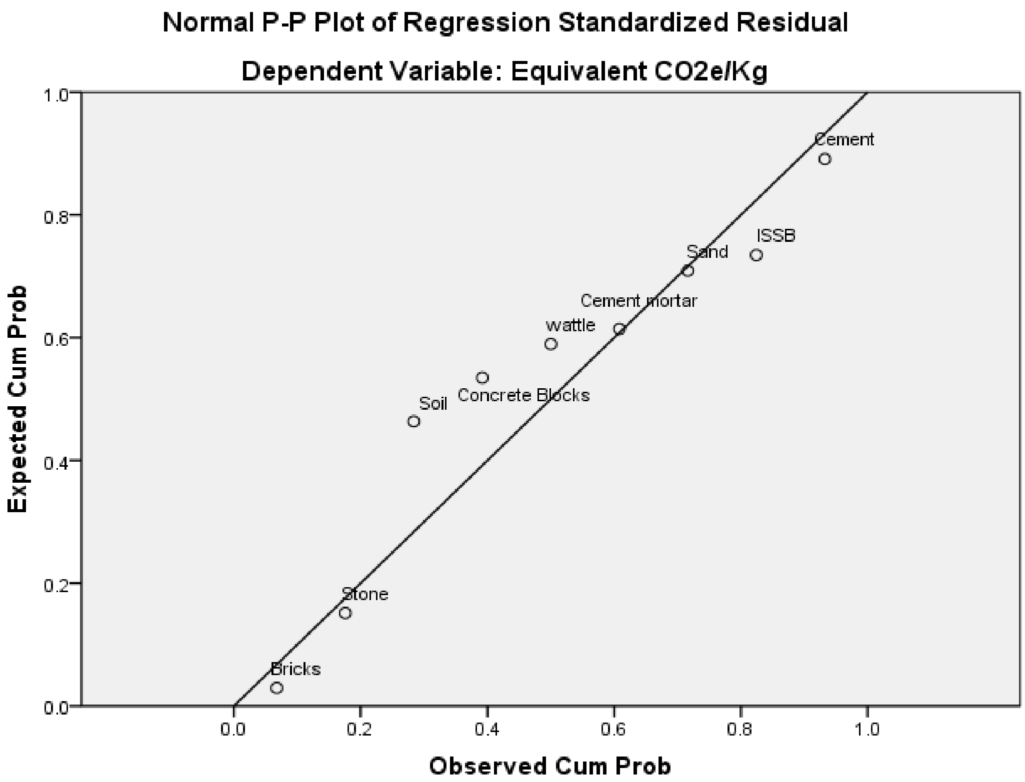
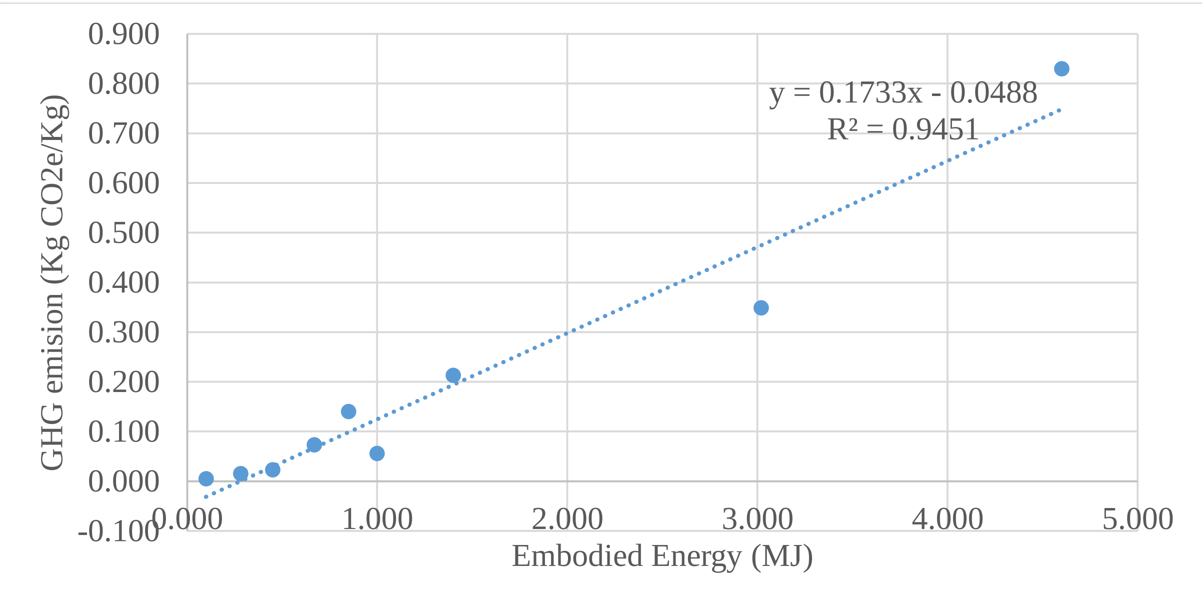


Figure 7.3 indicates the scatter plot of GHG and embodied energy and the linear trend line equation showing the best line of fit. The graph further demonstrates linear relationship and the proof for the study to carry out regression analysis.

Figure 7.3: Regression Analysis of Greenhouse Gas Emission with Embodied Energy



Source: Researcher, 2020

Table 7.4: Standard Embodied Energy Coefficient and GHG equivalent

Material	**Embodied Energy Coefficient (MJ/KG)**	**Equivalent CO_2e/Kg**	**Remarks**
Stone	1	0.056	Literature
Soil	0.45	0.023	Literature
Bricks	3.02	0.349	Calculated
Concrete Blocks	0.67	0.073	Literature
Iron Sheets	39	2.51	Literature
Cement	4.6	0.83	Literature
Sand	0.1	0.005	Literature
Timber	8.5	0.46	Literature
wattle	0.2816	0.0153	EE -Literature CO_2e -Calculated
ISSB	0.887	**0.089**	Calculated
Cement mortar (1:3)	1.4	0.213	Literature
Other Materials			Literature
Water	0.2		Literature
Polythene	83.1	1.94	Literature
Wood	17	1.7233	Literature
Diesel Fuel	42	2.68	EE -Literature CO_2e -Calculated
bricks	**3**	**0.22**	Literature
ISSB	0.85	0.14	Literature
Petrol	44	2.31	EE -Literature CO_2e -Calculated

Source: Researcher, 2020

Table 7.4 shows the standard Embodied energy coefficient and the equivalent greenhouse gas emission for the various walling materials adopted in Migori County. The table was used to carryout regression analysis used in developing the relationship between the GHG and EE.

The analysis indicates that the $\beta_1 \neq 0$ and that the ANOVA p-value is less than the alpha value ($p< \alpha$; $0.001<0.05$), hence we reject the null hypothesis and asserts that there is a strong relationship between Building materials in terms of embodied energy and climate change.

7.4 Regression Analysis of the Walling Materials used in Migori County

The study further demonstrated the relationship between the building technologies used based on the walling materials and the climate change by using the sample data collected during the study. Table 7.5 indicates the information generated based on the sample data from the 356 household. The information indicates the percentage of usage of the walling materials and the equivalent embodied energy for the sample and extrapolated embodied energy based on the national census data in 2009 and 2019. It was worth noting that in 2009, Migori County had 166,500 household number which increased marginally to 238,133 household resulting into an increase of energy requirement for housing purposes. The study demonstrates that the building material consuming much energy was bricks at 55.7%. This further revealed that most of the energy is consumed in low energy efficient building materials while more efficient building technologies such as ISSB consumed only 3.6%.

Table 7.5 Embodied Energy of Walling Materials used in Migori

Type of Walling Materials	No. of H/H	% HH	2019 H/H Census	2009 HH-Census	Embodied Energy Coefficient (MJ/KG)	EE per HH (MJ)	EE for sample (MJ)	EE in 2009	EE 2019	EE%
Stone	27	7.6%	18,061	12,627.81	1	22.6	609.2	284897.4	407468.3	3.8%
Soil	46	12.9 %	30,770	21,514.04	0.45	14.8	680.2	318114.5	454976.3	4.2%
Bricks	102	28.7 %	68,229	47,705.06	2.1283	87.7	8946.7	4184357.7	5984586.5	55.7%
Concrete Blocks	11	3.1%	7,358	5,144.66	0.67	59.0	648.6	303329.3	433830.2	4.0%
Iron Sheets	7	2.0%	4,682	3,273.88	39	362.8	2539.9	1187886.9	1698949.4	15.8%
Cement	67	18.8 %	44,817	31,335.67	5.32	21.3	1426.8	667320.8	954421.0	8.9%
Sand	157	44.1 %	105,019	73,428.37	0.1	3.4	532.4	249022.7	356159.3	3.3%
Timber	4	1.1%	2,676	1,870.79	8.5	15.3	61.3	28650.9	40977.3	0.4%
Wattle	63	17.7 %	42,142	29,464.89	0.2816	0.5	33.5	15678.0	22423.1	0.2%
ISSB	8	2.2%	5,351	3,741.57	0.887	72.2	577.3	270015.6	386183.9	3.6%
Total						**659.56**	**16,055.86**	**7,509,273.69**	**10,739,975.20**	**100.0 %**

Source: Author, 2020

The equivalent greenhouse gas generated by energy consumed during the production and used of the walling material was also computed and presented in Table 7.6. From the sample of 356 household 16,056 MJ of embodied energy were consumed in the walling materials generating a CO_2 equivalent of 1,475 tonnes. This further translated into 690,027 tonnes in 2009 and 986,896 tonnes in 2019 based on the projections using census data. The increase in greenhouse gas emission could be attributed to the population and GDP increase over the same period. The housing requirement is expected to increase over the coming period leading increased effect on climate change.

Table 7.6: Greenhouse Gas Emission of Walling Materials used in Migori

Type of Walling Materials	No. of H/H	% HH	2019 H/H Census	2009 HH-Census	Equivalent CO2e/Kg	Kg CO2e per HH	CO2e for Sample (Kg)	Co2e in 2009	Co2e in 2019	Co2e% tage
Stone	27	7.6%	18,061	12,627.81	0.056	1,263.42	34,112.40	15,954,254.49	22,818,225.14	2.3%
Soil	46	12.9%	30,770	21,514.04	0.023	755.75	34,764.39	16,259,185.68	23,254,346.33	2.4%
Bricks	102	28.7%	68,229	47,705.06	0.2046	8,432.13	860,077.02	402,255,123.12	575,316,632.03	58.3%
Concrete Blocks	11	3.1%	7,358	5,144.66	0.073	6,424.00	70,664.00	33,049,314.61	47,268,062.67	4.8%
Iron Sheets	7	2.0%	4,682	3,273.88	2.51	23,351.88	163,463.19	76,451,182.44	109,342,639.21	11.1%
Cement	67	18.8%	44,817	31,335.67	0.83	3,322.48	222,606.00	104,112,075.84	148,904,029.77	15.1%
Sand	157	44.1%	105,019	73,428.37	0.005	169.57	26,622.25	12,451,136.59	17,807,967.02	1.8%
Timber	4	1.1%	2,676	1,870.79	0.46	828.81	3,315.22	1,550,517.22	2,217,593.50	0.2%
Wattle	63	17.7%	42,142	29,464.89	0.0153	28.91	1,821.31	851,821.48	1,218,299.13	0.1%
ISSB	8	2.2%	5,351	3,741.57	**0.089**	7,241.04	57,928.32	27,092,880.00	38,749,001.76	3.9%
Total						**51,817.98**	**1,475,374.10**	**690,027,491**	**986,896,796**	**100.0%**

Source: Researcher, 2020

Further demonstration of the effects of building technologies on climate change was done using regression analysis of the above data to generate predictable model showing the relationship between EE and GHG emission. Table 7.7 shows the coefficients of the regression line of the sampled data. It states that the expected GHG is equal to 95.888* Embodied Energy – 6418.632. If embodied energy of a walling materials is 10,000 GJ, the predicted Greenhouse Gas emission would be 95.888 * 10,000 – 6418.63 =. 952,461 Gg

Table 7.7: Coefficients of sampled data

Coefficients						
Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	-6418.632	16499.424		-.389	.707
	Embodied Energy	95.888	5.487	.987	17.474	.000
a. Dependent Variable: GHG Emission						

Source: Researcher, 2020

The ANOVA test result presented in table 7.8 demonstrates the acceptability levels of the model with regard to the statistical front. It is noted that the regression row provides information on the extent of variation as accounted by the model. Further, the residual row in this case, details the statistical information regarding the extent of variation that is excluded from the model accountability dimensions. The scenario depicted in this study provide clear indication of the difference that exists, between the regression and residual sums of squares, hence the study arrives at a conclusion of the existence of a bigger percentage of variation in GHG emission levels being explained by the model.

It is further observed that there exists a significant value with regard to the F test, where the F statistics was recorded at below 0.05, thus implying that the variation arising from the model has not occurred by chance.

Table 7.8: ANOVA of the sampled data

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	5.942E11	1	5.942E11	305.341	.000[a]
	Residual	1.557E10	8	1.946E9		
	Total	6.098E11	9			
a. Predictors: (Constant), Embodied Energy						
b. Dependent Variable: GHG Emission						

Source: Researcher, 2020

While the ANOVA table is a useful test of the model's ability, the model Table 7.9 directly address the strength of that relationship between the model and the dependent variable.

Table 7.9: Model Summary of sampled data

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.987[a]	0.974	0.971	44114.04433	0.974	305.341	1	8	.000	3.157

a. Predictors: (Constant), Embodied Energy

b. Dependent Variable: GHG Emission

Source: Researcher, 2020

R, shows the correlation between the embodied energy (input variable) and model- greenhouse gas emission (predictor variable). There was a higher correlation of 0.987 showing strong linear association between the material adopted in the building technologies and climate change in terms of CO_2 emission. Further, R Square of 0.974 shows that about 97.4% of the variation in GHGe is explained by the model. In addition to R, the model is also compared by the use of standard error of the estimates and the standard deviation of the dependent variable. In this case the standard error was lower than the standard deviation showing that, it is better to use the model than the common descriptive statistics for prediction. Table7.10 demonstrates the residual statistics of the sample data.

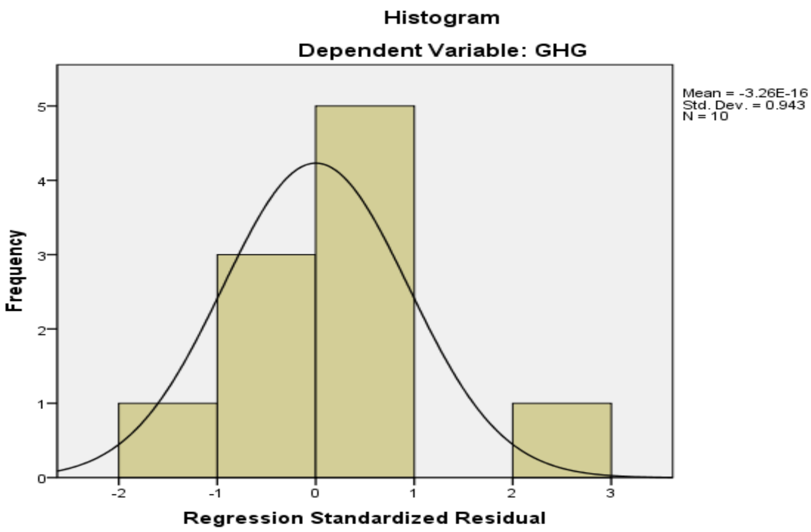
Table 7.10:Residual Statistics of Sampled Data

Residuals Statistics					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	-3206.4004	851458.2500	147537.4100	2.56950E5	10
Residual	-73662.89063	92212.32031	.00000	41591.11985	10
Std. Predicted Value	-.587	2.740	.000	1.000	10
Std. Residual	-1.670	2.090	.000	.943	10
a. Dependent Variable: GHG Emission					

Source: Researcher, 2020

The study also did analysis of the residual in order to states for normality and this was done by using both the histogram and P-P plots. The residual values are used to compare the error terms of both the dependent and independent variables and if the distribution is normal then the model is fit for prediction. Figure 7.4 shows that the histogram is normally distributed indicating that the sample data is normal thereby fitting our assumption for normality.

Figure 7.4: Histogram Normality Test graph



The P-P plotted residuals should follow the 45-degree line. Neither the histogram nor the P-P plot indicates that the normality assumption is violated hence the model developed by the study is suitable for prediction.

Figure 7.5: Normal P-P Plot of Regression for Sampled data

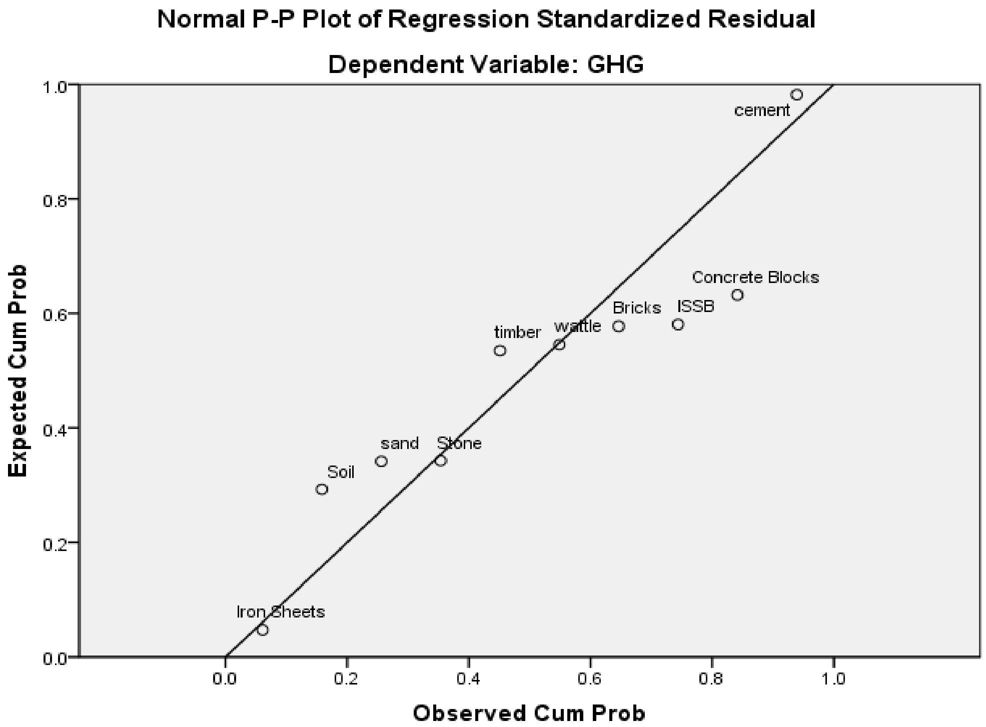
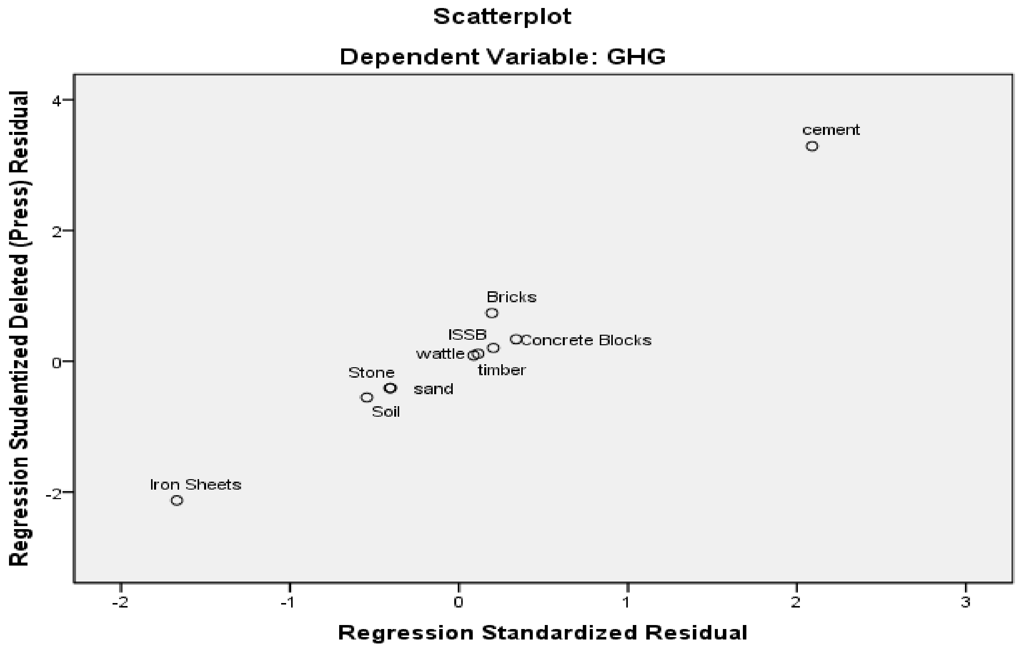


Figure 7.6: Scatter Plot of GHG Emission Regression



The study also employed the null hypothesis to the study sample data using the approach in the previous section. The analysis indicates that the $\beta_1 \neq 0$ and that the ANOVA p-value is less than the alpha value ($p < \alpha$; $0.001 < 0.05$), hence we rejected the null hypothesis and asserts that there is a strong relationship between Building materials in terms of embodied energy and climate change based on household sampled data.

7.5 National Projection of Built Environment Climate Change Effects Based on Study Area

The world population continues to increase rapidly and that has affected the ecology due to human economic activities. In 1800, the world population was at 1 billion and this has since increased to 7.8 billion in 2020. Population experts project the population to be at 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100. According to GoK (1975), increasing population adds to threats posed by climate change which continue to put pressure on the already limited environmental resources such as land resources of forests, cropland and water. In this study, the household sample was used to facilitate the projections for countywide population and household data using the procedure as outlined below;'

Based on the proportionality and using the available projection for Kenyan population for years 2030, 2050 and 2100, the Migori Population projections were obtained as indicated in Table 7.11. Projections for household were aided by;

i. Taking 2019 census data as a baseline
ii. Calculated the proportion of Migori as a percentage of national population
iii. Using the calculated proportion to make projections for 2030, 2050 and 2100 population for Migori County
iv. Making household projections for years 2030, 2050 and 2100 using 4.7 as household size for Migori. This was noted to be above the National household size of 3.9 (Census, 2019)

The year 1800 household projection used a household size of 6.5. This figure is supported by research conducted by GoK and the Netherlands (1975) which provided household size for Migori at an average of 6.5.

In order to understand the County (Migori) and National level (Kenya) overall housing requirement resultant effects on climate change, the area sample statistics was used to derive the county and national household data. Table 7.11 shows the world population in billions and the projected household numbers in millions.

7.5.1.1.1.1 Table 7.11: National and Study Area Population Estimates and Projected Households

SN	Year	Kenya		Study Area (Migori)	
		Population (Million)	Household Number (Million)	Population	Household Number
1	1800	2.57	0.3	60,278	9,274
2	2019	47.6	12	1,116,436	238,133
3	2030	66.4	17	1,557,381	331,358
4	2050	91.6	23.5	2,148,436	457,114
5	2100	125.4	32	2,941,199	625,787

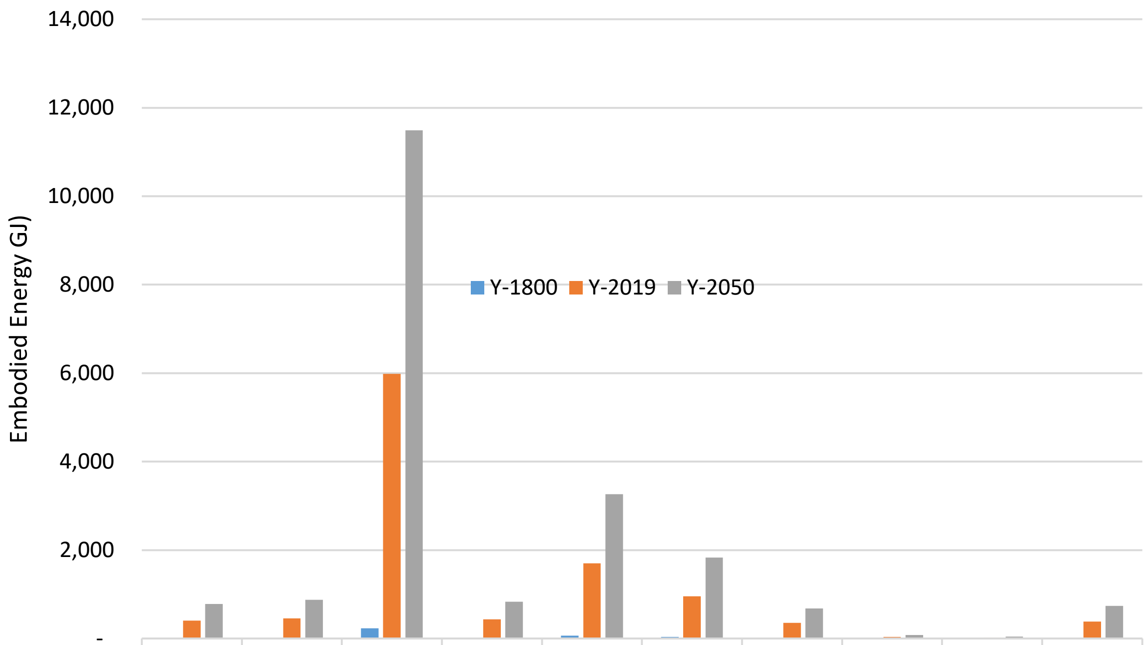
Source: Researcher 2020

The household number was employed to project the usage of walling materials based on the proportions obtained in the study areas in Table 7.5 and Table 7.6. Embodied Energy was then computed obtaining the product of mean household requirement of embodied energy and the projected national household numbers for the particular walling materials. Figure 7.7a and 7.7b illustrate the embodied energy projected for the years 1800, 2019 and 2050 of the various walling materials. The study demonstrated that less efficient building technologies continues to dominate the housing sector in the study area as well as nationally with bricks leading over the three years at 233 GJ in 1800, 5,985 GJ in 2019 and 11,488 GJ in 2050 in the study area. The same was reflected at the national level which recorded higher figures for burnt bricks at 7,176 GJ, 306,730 GJ and 590,263 GJ for the years 1800, 2019 and 2050 respectively if the current environment of Migori is to prevail nationally. Other materials with larger embodied energy over the same periods includes iron sheets, cement, concrete blocks and quarry stones. The study further demonstrates that energy efficient technologies such as ISSB continue to attract low embodied energy due to its low adoption in the local environment coupled with low energy requirement during its production and application.

The above situation where production of bricks has continued to employ rudimentary methods with resultant negative impacts on the surrounding environment need to change. Key institutions notable the National Government through the State Department for Housing and Urban Development, Kenya Building Research Centre (KBRC), National Construction

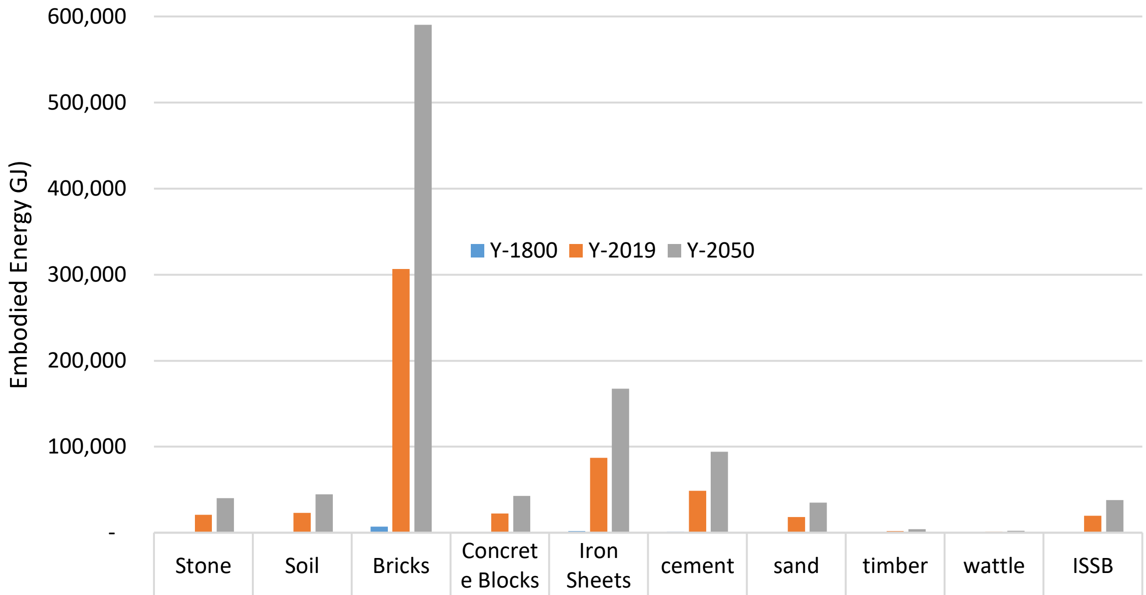
Authority (NCA), the Kenya Industrial Research Development Institute (KIRDI), Kenya, Lake Basin Development Authority, Industrial Estate (KIE) as well as other International Agencies notably UN-Habitat and UNEP among others should enhance collaboration and partnerships in research and development towards the realization of Environmentally-Friendly brick kilns across the Country. Achieving this noble course is key towards lowering of the above energy and GHG emission projections for the period the year 2050.

Figure 7.7a: Projected Embodied Energy of Walling Materials by Selected Years in Migori



	Stone	Soil	Bricks	Concret e Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	16	18	233	17	66	37	14	2	1	15
Y-2019	407	455	5,985	434	1,699	954	356	41	22	386
Y-2050	782	873	11,488	833	3,261	1,832	684	79	43	741

Figure 7.7b: Projected Embodied Energy of Walling Materials by Selected Years in Kenya

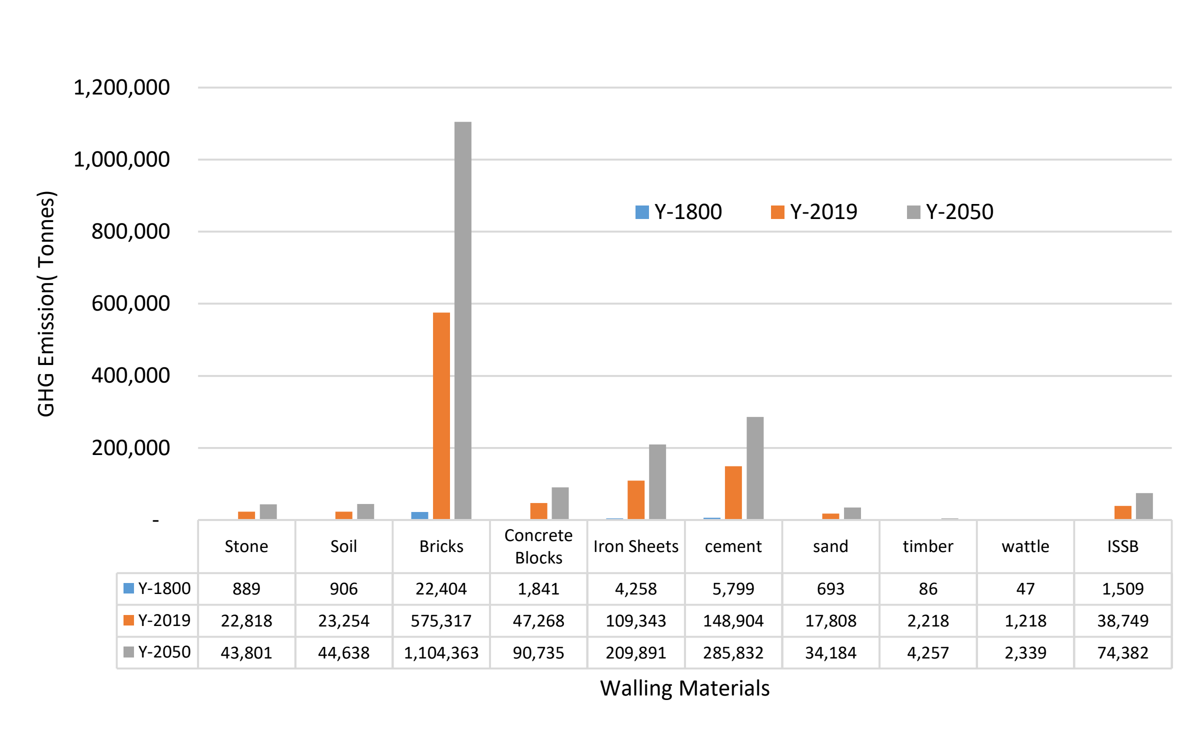


	Stone	Soil	Bricks	Concrete Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	489	546	7,176	520	2,037	1,144	427	49	27	463
Y-2019	20,884	23,319	306,730	22,235	87,077	48,917	18,254	2,100	1,149	19,793
Y-2050	40,189	44,875	590,263	42,789	167,568	94,135	35,128	4,042	2,212	38,090

Source: Researcher, 2020

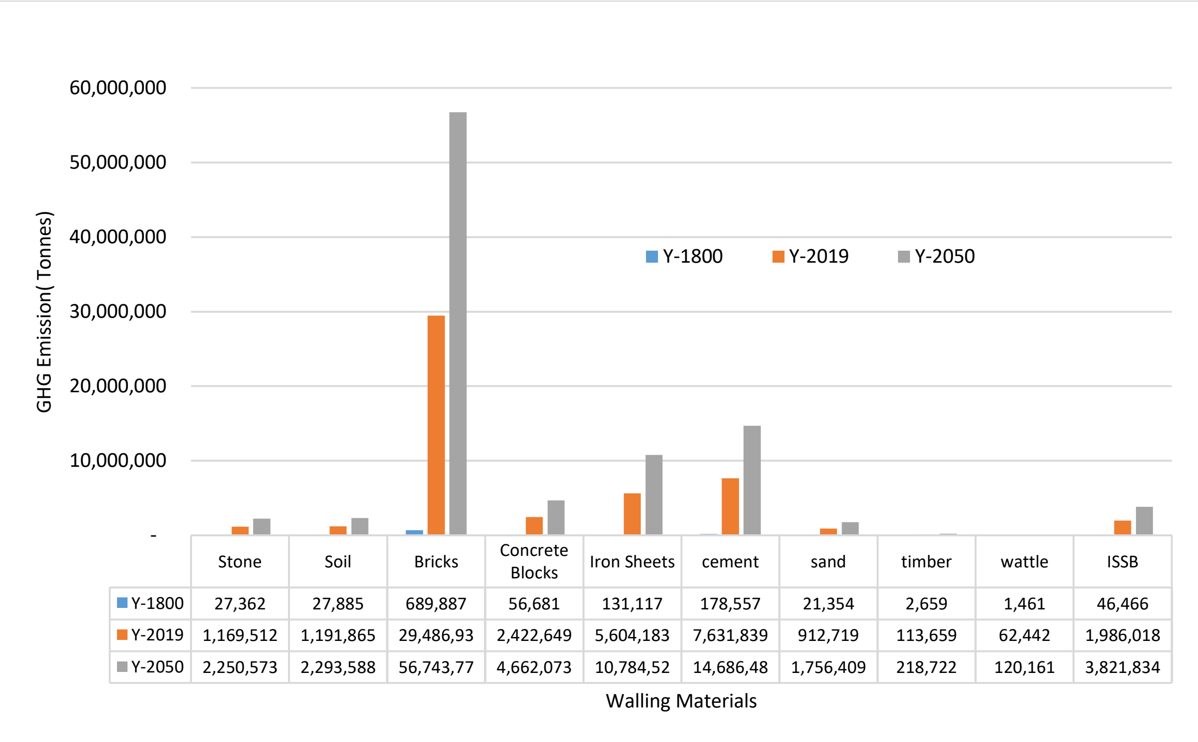
The equivalent greenhouse gas emission on the same study period was projected and results presented in Figure 7.8a and 7.8b. It was important to note that the graphical profile of greenhouse gas emission followed the same pattern as that of embodied energy as a further demonstration that there is strong relationship between the two aspects of climate change. The CO_2 emission associated with the walling materials shows a direct relationship since bricks attracted higher values of CO_2 emission at 22,404 tons, 575,317 tons and 1,104,363 tons for the study area and 689,887 tons, 29,486,939 tons and 56,743,773 tons for the national projections for the years 1800, 2019 and 2050 respectively. The second major pollutant was projected to be cement with emission of 7,631,839 tons in 2019 followed by iron sheet at 5,504,183 tons at the national level. The emission from the use of timber and wattle were comparatively negligible since their application as building materials was either low or attracts low embodied energy. Similarly, energy efficient building technologies such as ISSB attracted low greenhouse gas emission with 1,986,018 tons in 2019 and projected emission of 3,821,834 tons in 2050.

Figure 7.8a: Projected County Greenhouse Gas Emission of Walling materials of Selected Years in Migori



	Stone	Soil	Bricks	Concrete Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	889	906	22,404	1,841	4,258	5,799	693	86	47	1,509
Y-2019	22,818	23,254	575,317	47,268	109,343	148,904	17,808	2,218	1,218	38,749
Y-2050	43,801	44,638	1,104,363	90,735	209,891	285,832	34,184	4,257	2,339	74,382

Figure 7.8b: Projected National Greenhouse Gas Emission of Walling materials of Selected Years in Kenya



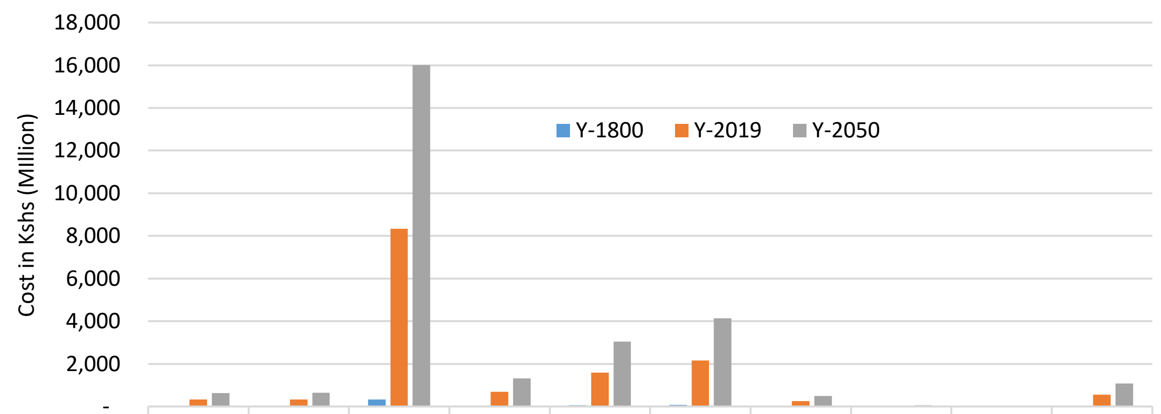
	Stone	Soil	Bricks	Concrete Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	27,362	27,885	689,887	56,681	131,117	178,557	21,354	2,659	1,461	46,466
Y-2019	1,169,512	1,191,865	29,486,93	2,422,649	5,604,183	7,631,839	912,719	113,659	62,442	1,986,018
Y-2050	2,250,573	2,293,588	56,743,77	4,662,073	10,784,52	14,686,48	1,756,409	218,722	120,161	3,821,834

Source: Researcher, 2020

The global effect of climate change includes the devastating impact on the environment. The adverse impacts ranges from extreme weather conditions both in terms of intensity and severity that comprises flooding and storms, epidemics, rise in sea levels, increase food insecurity and many other disasters. The impact of climate change can be computed in terms what it cost to business, governments and taxpayers in terms of billions of dollars due to increase in healthcare cost, destruction to property and inflation due to increase in food prices among others.

The cost of carbon emission to the environment entails the computation of economic harm from the negative effects which is normally stated in currency value of the total damages from emitting one ton or one kg of carbon dioxide into the atmosphere. The current cost of carbon is over $50 per ton in today's dollars. Further figures indicate that the cost of carbon emission per tonne of carbon is £113 which can be translated into Kes. 14,500 per tonne or Kes. 14.5 per kg of carbon dioxide emitted (Eco-costs, 2017).

Figure 7.9a: Projected Cost of County Greenhouse Gas Emission of Walling Materials of Selected Years in Migori

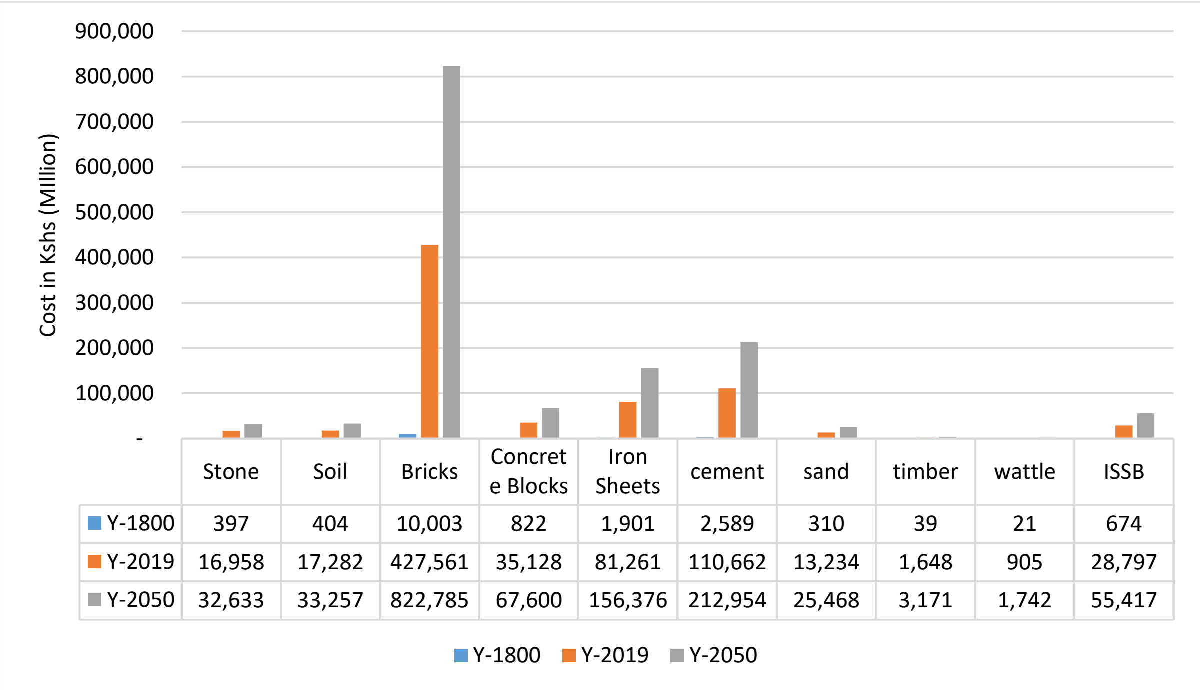


	Stone	Soil	Bricks	Concret e Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	13	13	325	27	62	84	10	1	1	22
Y-2019	331	337	8,342	685	1,585	2,159	258	32	18	562
Y-2050	635	647	16,013	1,316	3,043	4,145	496	62	34	1,079

Source: Author; 2020

The study used these figures to compute the social cost of carbon as a demonstration of the impact of energy building technologies on climate change. Figure 7.9a and 7.9b show the study area and national projection of the social cost of carbon segregated based on the walling material for the projected three years. The study revealed that the highest social cost was related to dominant building technology such as bricks with a cost of 8,342 million in 2019 and projected cost of 16,013 million in 2050 compared to the national projection of 425,561 million and 822,785 million for 2019 and 2050 respectively. The second highest social cost was in the use of cement with the projected national cost of 110,662 million in 2019 and projected cost of 212,954 million in 2050.

Figure 7.9b: Projected Cost of National Greenhouse Gas Emission of Walling Materials of Selected Years in Kenya



	Stone	Soil	Bricks	Concret e Blocks	Iron Sheets	cement	sand	timber	wattle	ISSB
Y-1800	397	404	10,003	822	1,901	2,589	310	39	21	674
Y-2019	16,958	17,282	427,561	35,128	81,261	110,662	13,234	1,648	905	28,797
Y-2050	32,633	33,257	822,785	67,600	156,376	212,954	25,468	3,171	1,742	55,417

Source: Researcher, 2020

Based on the study area and national figures generated for the 5 years under consideration, data was generated for each year (1800, 2019, 2030, 2050 and 2100) related to the walling materials, embodied energy, greenhouse gas emission and social cost of emission as indicated in appendix I (1E1 and 1E2). Regression analysis was then conducted on the data to determine the strength of relationship between the building technologies and impact of climate change in terms of greenhouse gas emission. Table 7.10a shows the descriptive statistics of national projection of embodied energy and GHGe. The mean of embodied energy was 76,813 GJ and CO_2 emission was 7,058,367Gg but due to levels of variability demonstrated by big values of standard deviation, it was not considered as the best measure or predictor of the GHGe.

Table 7.10a: Descriptive Statistics of National Projection of GHGe

Descriptive Statistics			
	Mean	Std. Deviation	N
GHG	7058367.86	14795460.56	50
Embodied Energy	76813.14	153138.14	50

Source: Researcher, 2020

Table 7.10b shows the coefficients of the regression line of the projected national data. It demonstrates that the expected GHG is equal to 95.481* Embodied Energy – 275,828.452.

Thus the projected liner regression equation is given as:

$$Y = 95.481X - 275{,}828.452 + €$$

$$GHG = 95.481 * \text{Embodied Energy} - 275{,}828.452$$

The analysis further demonstrates that the coefficient of embodied energy was significant since the p-value provided (p=0.00) was less than 0.05 at 95% significant level hence reliable in predicting GHGe.

Table 7.10b: Model Coefficients of National Projection of GHGe

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-275828.452	362062.894		-.762	.450
	Embodied Energy	95.481	2.130	0.988	44.818	.000
a. Dependent Variable: GHG						

Source: Researcher, 2020

The ANOVA presented in Table 7.10c was used to check whether the model derived from the study was statistically acceptable. The Regression row displays larger figures compared to residual rows indicating that the variation accounted for by the model is much higher than that not accounted by the model. This is an indication that a bigger percentage the variation in GHG is explained by the model. The significance value of the F statistic is less than 0.05 ($P \leq 0.00 \leq 0.05$) which means that the variation explained by the model is not due to chance by impact of building technologies based on the building materials.

Table 7.10c: ANOVA of National Projection of GHGe

ANOVA[b]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1.048E16	1	1.048E16	2008.635	.000[a]
	Residual	2.503E14	48	5.215E12		
	Total	1.073E16	49			

a. Predictors: (Constant), Embodied Energy

b. Dependent Variable: GHG

Source: Researcher, 2020

Table 7.10d directly address the strength of that relationship between the model and the dependent variable. R, shows the correlation between the embodied energy and model-predicted values of greenhouse gas emission. The large value of 0.988 that there is a strong association between the building material adopted and climate change in terms of CO_2 emission. R Square of 0.977shows that about 97.7% the variation in GHGe is explained by the model making the model to be a perfect predictor of climate change in the building sector.

Table 7.10d Model Summary of National Projection of GHGe

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.988[a]	.977	.976	2.28375E6

a. Predictors: (Constant), Embodied energy
b. Dependent Variable: GHG
Source: Researcher, 2020

The acceptability of any model is based on its ability to align to the assumption of normality. This was demonstrated by the use of histogram and P-P plot on of Regression Standardized

Residual as illustrated in Figure 7.11a and 7.11b. Further, for the assumption of normality the -P plotted residuals should follow the 45-degree line which the histogram should have a normal graph configuration. In this study neither the histogram nor the P-P plot indicates that the normality assumption is violated hence the model is acceptable for prediction of GHGe.

Figure 7.11a: Histogram of Normality Test of GHG National projection model

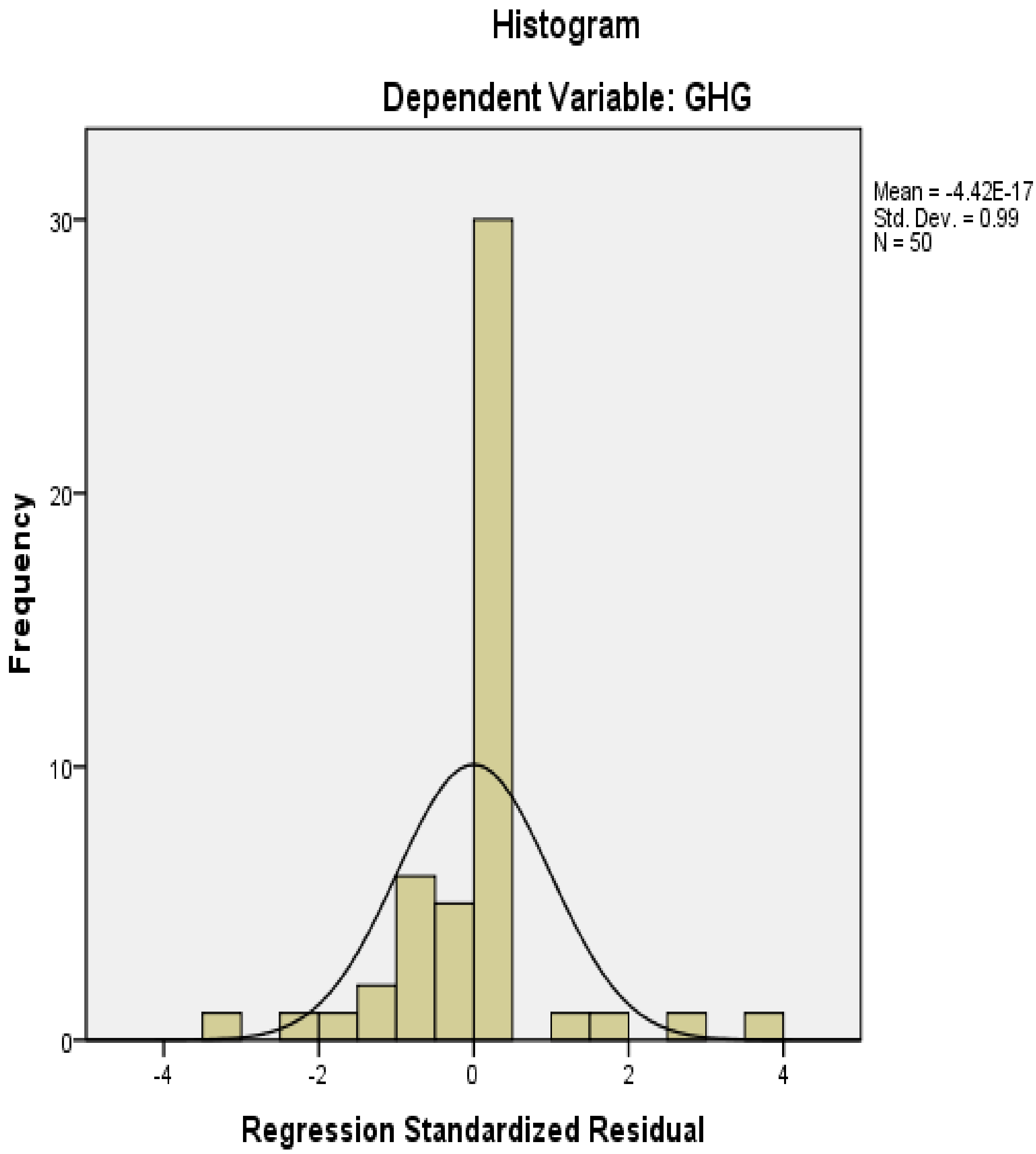
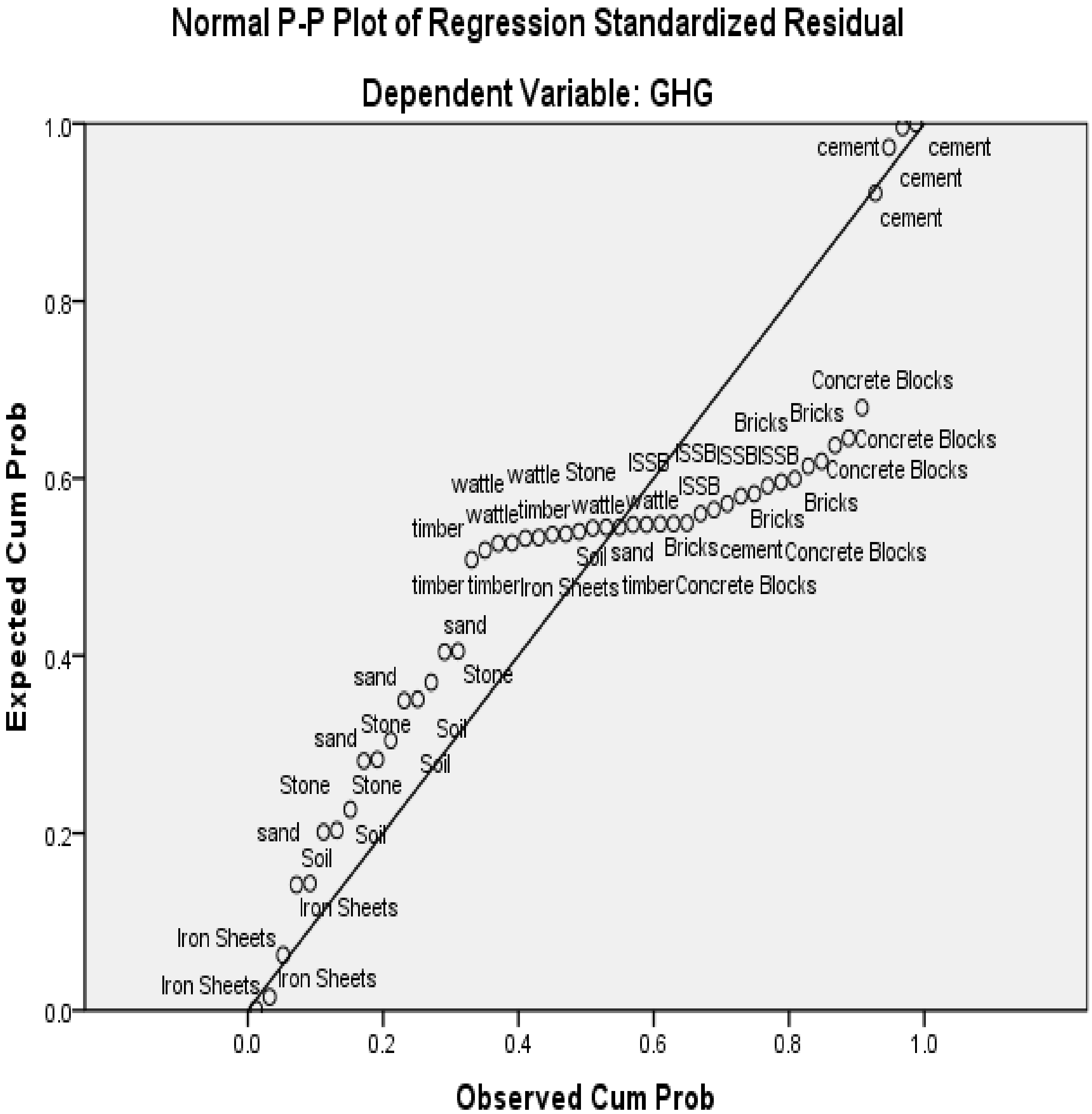


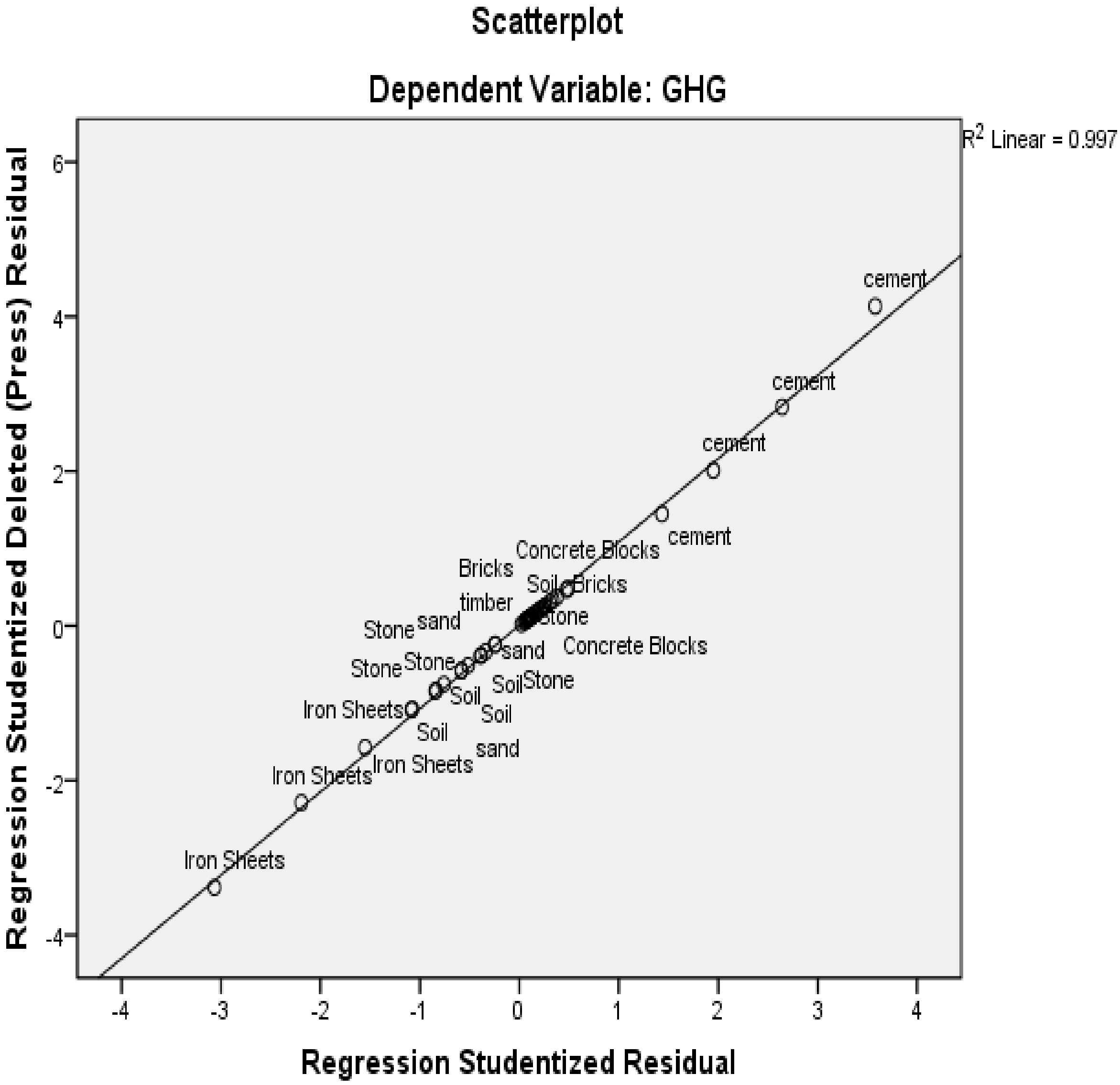
Figure 7.11b: Normal P-P Plot of Regression Standardized Residual of GHGe National Projection Model



Source: Author, 2020

The scatter plot was further used to reveal that linearity assumption that is essential for the use of regression analysis was met. Figure 7.12 shows that the graph is linear and that R square was 0.997 indicating a near perfect linear relationship between the independent and the dependent variables.

Figure 7.12: Scatter plot of GHGe



Source: Author, 2020

The assumption for normality and linearity were met in this study hence the fitness for the model for future prediction. The study also employed the null hypothesis to the study projected global data using the approach in the previous section. The analysis indicates that the $\beta_1 \neq 0$ and that the ANOVA p-value is less than the alpha value ($p< \alpha$; $0.001<0.05$), hence we reject the null hypothesis and asserts that there is a strong relationship between Building materials in terms of embodied energy and climate change.

8 BUILDING APPROVAL PROCESSES AND ADOPTION OF SUSTAINABLE TECHNOLOGIES

8.1 Introduction

The research findings addressed objectives five of the study which focused on suitability of County building approval processes in relation to policies and regulations that promotes use of selected building technologies including appropriate and other emerging materials and technologies towards built environment sustainability. The research hypothesis that was tested and validated by this study was as expressed below:

H_O: County building approval processes are effective in promoting selected environmentally-friendly building technologies.

8.2 Suitability of Building Approval Processes

The adoption and implementation of suitable policies and regulations is key towards integration and application of sustainable building practices in the built environment. The metadata developed by UN-Habitat on SDG indicators towards ensuring resilience and sustainability of cities and human settlements calls for actions that increases the number of settlements adopting and implementing inclusive and integrated policies. Such Policies and Plans support the integration of resources efficiency, mitigation and adaptation to climate change (UN-Habitat, 2018) within the built environment. Further, the NCCAP (2018-2022) for Kenya prioritizes the realization of low carbon climate resilient development with a view to achieving Kenya's NDC under COP21 (2015) where Kenya committed to GHG emission reductions of 30% by 2030.

Kenya further committed to move away from the "Business As Usual" Scenario, and adopt more proactive approach with an aim of mainstreaming the climate change adaptation into planning processes as well as implementation of adaptation actions. The key climate risks identified by the NCCAP include environmental degradation including loss of forest cover, high level of water scarcity and mismanagement of water resources, insecure land tenure and land fragmentation, as well as population growth and migration to urban areas. The Government of Kenya further provides priority climate change actions which encourages integration of climate-resilient solid waste management and promoting the development of climate resilient buildings and settlements including urban areas under the Health, Sanitation and Human settlement sector.

It is however noted that the key challenge facing the wide spread use of low-cost construction technologies at present is the extent of compliance with current norms in building standards as well as the ability to realize reasonable shelter and comfort (Kuchena and Ushiri, 2009; Sangori, 2020). In Kenya, the building and construction sector is set to be transformed once the Draft National Building Code (2020) under the NCA (No. 41 of 2011) Act is approved. The envisaged code provides for integration of emerging building technologies which are energy and resource efficient.

It is noted that the current building code (1968) is out of touch with the current construction trends as it emphasizes on the application of mortar and brick construction technology while limited flexibility on the adoption of sustainable building materials and technologies that includes passive building designs, energy and resource efficiency, and renewable energy technologies among others. Various planning initiatives which included: the 1926 Mombasa Municipal Council Plan; 1948 Nairobi Master Plan; Swynerton Plan of 1955; and Mombasa Municipal Council Master Plan of 1962 were institutionalized through the 1931 Town and Country Ordinance, (Kimani and Musungu, 2010).

8.3 Building Approval Requirement

The building approval process is guided by various laws and regulations including: Physical and Land Use Planning (PLUPA) Act of 2019, Urban Area and Cities Act of 2011 (amendment 2019), EMCA (1999; Revised 2015) among others. Approvals for building plans began in the late 1980s after the first town Part Development Plan (PDP, 1980). Most plans were approved by individual county council officers and at this point no records were kept. In 2008, Migori district development plan 2008-2012 was drafted and this included the former Migori, Rongo and Kuria Districts. These PDPs were initially prepared with invaluable inputs from various development stakeholders in the respective current sub-counties.

The procedure for building plan approval as documented by the study is as follows:

i. The developer/client visits the county physical planning department in Lands offices and presents the plan to confirm the intention to develop.
ii. The physical planner receives the plan and processes an Application for development permission (PPA 1 Form) and issues it to the client.
iii. The physical planners then verify if all the building regulation are put into consideration, ranging from the floor area against the plot area. In this case the plot

coverage is verified if it complies with the specific zonal ordinance of the proposed development area. The planner then verifies the provided verses the allowable setback and frontage limits.

iv. The planner then proceeds to the actual ground to confirm if the above stated conditions/standard are met and that the plan fits on the ground.

v. Once the above have been verified and ascertained, the planner then requests the developer to present the land ownership documents of the plot to be developed to confirm if the developer is the genuine owner of the land for proposed development, in this case the accepted documents are: Tittle deed, plot card, allotment letter, lease certificate, and the current land search of the plot.

vi. The planner then drafts a field report either recommending, objecting or deferring the approval of the plan. If recommended for approval, the developer is advised on the plan approval amounts to bank and obtain a receipts for the same.

vii. Once the money is banked and receipts processed, the physical planner then forwards the plans alongside, the report to the approval committee. In this case, key departments which are directly involved are three namely; Public Works, Physical Planning and Public Health.

viii. The committee then sits to approve, rejects or defers the development application request of the plan according to the physical planner’s recommendations.

ix. Once approved, rejected or deferred, the developer is issued with PPA 2 document/certificate either confirming to him/her that the plan has been approved, rejected or deferred.

x. Once approved the developer commences development and the subsequent task is left to the supervision team. (Development control, NCA, NEMA, and Building inspectors).

The research was set to establish the status of building plans for the period 2008-2018 in terms of the building plans presented for approval, the number approved, the duration taken to obtain the approval, the number of rejected plans and reasons for rejections.

The study established that most of the records related to the building approval processes were missing as there were no proper systems put in place. It was therefore had to get the data dating back to three decades which could have supported the objective of this study regarding trend analysis. Further, the only available data as established by the study related to the period commencing 2012 to date. It was further established that most records of the previous years were lost as they were done manually as opposed to the current record keeping which demonstrates best practises. The study established the status of building plans approved by authorities in Migori County for the period 1979-2019 as illustrated in Table 8.1a.

Table 8.1a:Building Approval Status for Migori County from 1979-2019

Period	1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019	Total
Number of Building Approved	-	-	-	-	-	-	-	294	294

Source: Migori County Building Approval Register, 2019

During the transition to the county governments in 2012, the original records and the plans which were in the offices were disposed and new plans storage picked up in 2014. For instance, Public Works in particular did not major on record keeping as they were generally mandated to undertake supervisory duties of the approved plans from lands department. Most houses currently being developed uses bricks and concrete blocks for construction. Table 8.1b demonstrates the status of building plan processed within as at 2019.

Table 8.1b: Sample of Building Approval Status for February, 2019

Sub County	Plot No	Description	No. Of Units	Floor Area
Kuria East	-	Commercial	10	2456.01
Suna West	20560	Residential	6	3051.11
Suna East	1363	Church	9	3562.01
Rongo	1078	Commercial	10	496.615
Suna East	1905	Commercial	8	769.21
Suna East	5661	Residential	8	277.2
Suna East	15470	Residential	7	172.8
Suna West	4868	Commercial	14	1029.12
Sori	8177	Commercial	13	473.18
Sori	4494	Commercial	11	550.12
Suna East	12795	Residential	5	138.7
Suna East	337	Commercial	8	698.01
Rongo	-	School	100	1550.67
Rongo	11366	Commercial	8	439.2
Rongo	76931	Commercial	12	671.01
Suna West	432	Residential	15	1520.11
Rongo	11310	Commercial	10	720.1
Kuria East	-	Commercial	9	421.2
Suna East	15705	Residential	12	381.07
Suna East	-	School	3	1012.62
Suna East	-	Commercial	6	2015.71
Suna East	63 B	Commercial	10	430.9
			294	

Source: Migori County Building Approval Register, 2019

5.6.2: Effectiveness of Buiding Approval Process

The study evaluated County building approval processes and it's effective in promoting selected environmentally-friendly building technologies. In order for a building to be approved by the local authorities, the house owners have a set of requirement that need to be adhered to such as building plan, valid title deed and compliance to the county bylaws on building. The responded were requested to state whether they were aware of the building approval requirement. The results revealed that 83% of the household were aware of these requirement compared to 17% who were not aware. Further cross tabulation by ward indicated that 87.8% of household in urban were aware of the approval process compared to 78.6% in the rural setup. Similarly, 12.2% of the household in urban setup were not aware of the approval process compared to 21.4% in the rural setup. The study therefore concluded that most of the household population know the approval requirement more so in urban areas. About 83% of the respondents were aware of the existence of building approval requirements while 17% were not aware of such requirements. Table 8.2 provide more details.

Table 8.2: Awareness of Building Approval Requirements Cross tabulation with Nature of Ward

			Awareness level		Total
			Yes	No	
Nature of Your Ward	Urban	Count	165	23	188
		% within Nature of Your Ward	87.8%	12.2%	100.0%
	Rural	Count	132	36	168
		% within Nature of Your Ward	78.6%	21.4%	100.0%
Total		Count	297	59	356
		% within Nature of Your Ward	83.4%	16.6%	100.0%

The study set out to find out the proportion of the household that subjected their building plan to the local authorities for approval process. It was revealed that out of the sample population 49.7% presented their plan for appvoval while 3.7% did not. About 46.6% did not present their building plan for approval since they were not aware of the approval requirement or we not having a building plan. This can be associated with the fact that about 30% of the houses were not permanet or made of mud and wattle which could not be approved.

Table 8.3: Building Plan subjected to the Local Authority / County Government for Approval

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	177	49.7	49.7	49.7
	No	13	3.7	3.7	53.4
	No Building Plan	166	46.6	46.6	100.0
	Total	356	100.0	100.0	

Source: Researcher, 2020

It was to the interest of the study to find out the proportion of the plan presented and approved by the local authorities. Table 8.3 indicates that 91% of the plan presented for approval were approved representing 45.2% of the household under study. Only 9% of the plan presented were not approved due to lack of conformity to the approval requirement.

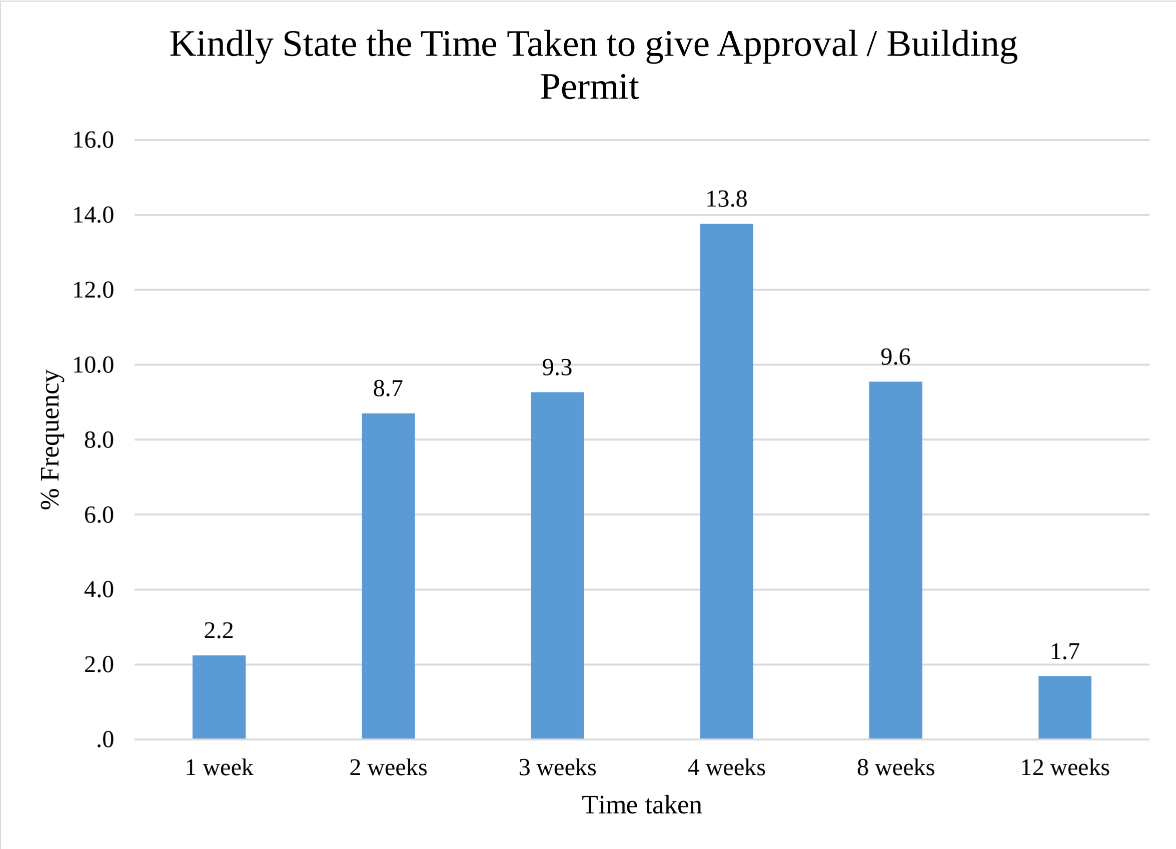
Table 8.4: Proportion of Plan Approved

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	161	45.2	91.0	91.0
	No	16	4.5	9.0	100.0
	Total	177	49.7	100.0	
Missing	Not Applicable	179	50.3		
Total		356	100.0		

Source: Researcher, 2020

The study further determines the period it took the authorities to approve the building plan as a way of determining their effectiveness. The study revealed that it takes a minimum of one week and a maximum of 12 weeks to approve the building plan. 13.8% of the plan were approved at 4 weeks while 9.6% of the plan were approved at 8 weeks. On average, it takes five weeks to approve the building plan by the local authorities. It was however noted that responses pertaining to the aspects of building plans approval were cautiously provided by the respondents as some initially had the fear that the assignment could be related to an investigation regarding the compliance with the existing regulations on building approvals and safety standards. Figure 8.1 depicts the time taken to issue development permission.

Figure 8.1: Time taken to give Approval/Building Permit

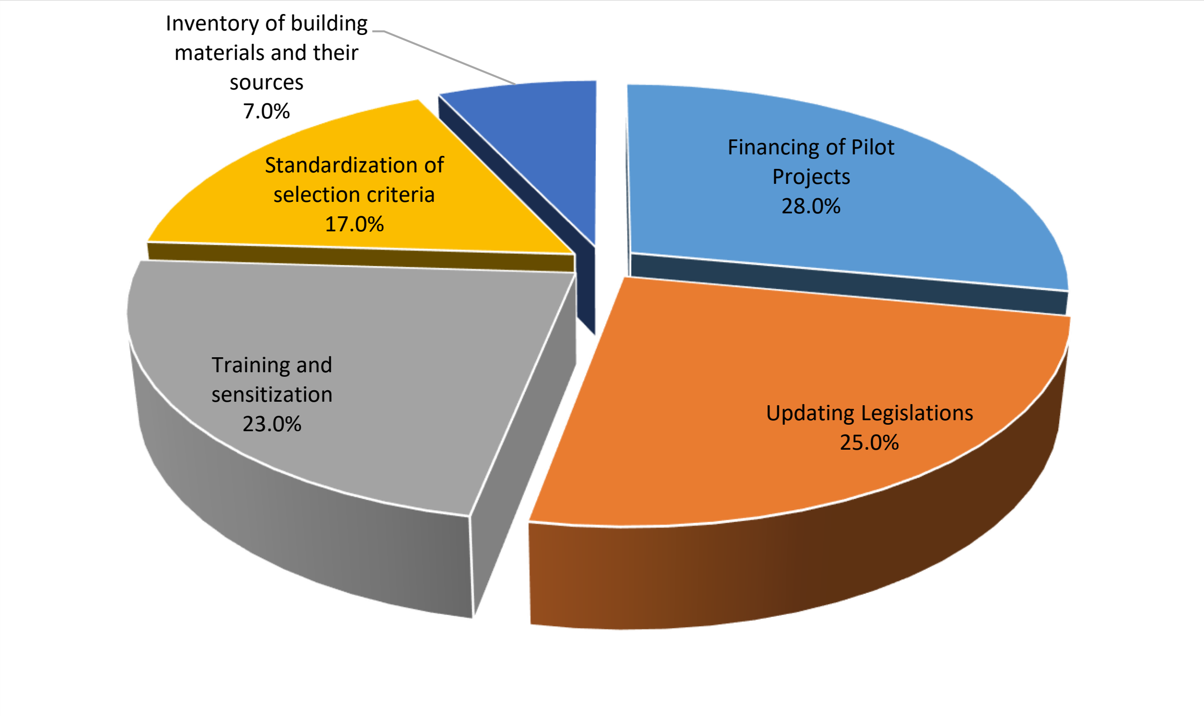


Source: Author, 2020

8.4 Policies and Regulatory Frameworks

The component of the research targeted the experts in the building and construction sector which the aim of establishing the extent to which the existing laws and regulations support the adoption of the energy efficient technologies and material. It was noted that about 77.4% of the experts did not believe that the existing policies and regulations as currently spelt can promote the using of emerging energy efficient technologies. The main reasons provided was that the regulations have never been updated since the formulation of the existing building code (1968), hence the need to conclude revision of the regulation and the Draft Built Environment Bill (2015). The proposed actions are necessary since there is no proper Act of Parliament to anchor the National Building Regulations. Figure 8.2 shows policy and regulatory framework gaps.

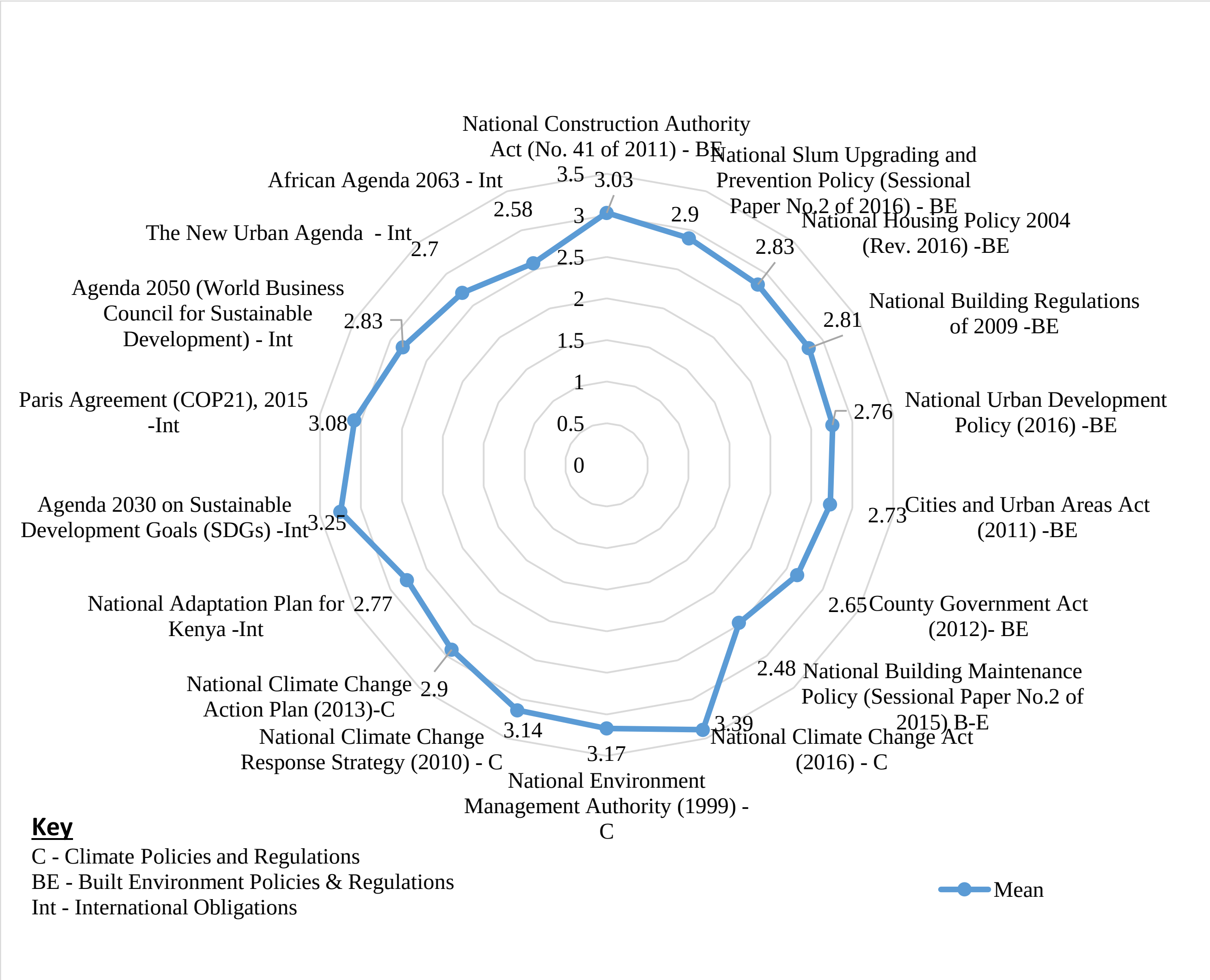
Figure 8.2 Gaps in policy and regulatory frameworks



Source: Author, 2020

The study further evaluated the existing policy and regulatory framework in order to determine their impact in promoting the energy efficient building technologies. The radar graph illustrated in Figure 8.3 provides an overview of the impact of these regulation in a mean scale of 0 to 4 where 0 signifies no impact and 4 signifies high impact. The policy and regulatory frameworks were group into three categories for comparison purposes notably; Climate Change related Policies, International Obligations which have been domesticated in Kenya as well as the built environment related policies. The climate change related policies and regulations considered in this analysis were four and had the highest averaged mean score 3.15. The level of result attained in this particular are indicates that these categories of policies and regulations has the greatest impact in promoting energy efficient building technologies. This was closely followed by various international obligations / tools which had an average mean score of 2.87. Finally, the impacts of the built environment related policies and regulations followed closely at third position with an average mean score of 2.77.

Figure 8.3: Radar Graph of Potential Impact on Policies and Regulatory Frameworks



Source: Author, 2020

The study provided respondents who rated the impacts on various policies and regulations in relation to the climate change, built environment interactions and international obligations. However, a number of respondents failed to rate these regulations due to lack of awareness of their existence. For instance, 16.1% of the respondents had no knowledge of the impacts by international obligations. On the hand, about 12.9% of the respondents played ignorance on the impacts due to climate change while 9.7% were found to be ignorant as pertains to the impacts posed by built environment policies and regulations.

The study is a replica of an earlier study undertaken by Kimani and Musungu (2010) who in their paper noted the gap in the application of appropriate building materials and technologies in Kenya. The extent of low uptake of emerging technologies was attributed to a number of factors as corroborated in the study findings by Sangori (2012). Some of the factors put forward included but not limited to the following aspects;

i. Negative cultural perception among the users,

ii. Inadequate trained personnel in the application of emerging building technologies,

iii. Inadequate funding to cater for the initial capital cost due to resistance from the financial sectors as a result of ignorance on their operations,

iv. Inappropriate dissemination methods due to lack of capacity among implementing partners,

v. Ineffective legislations on use of appropriate technologies as the current legislative framework mainly promotes conventional building technologies,

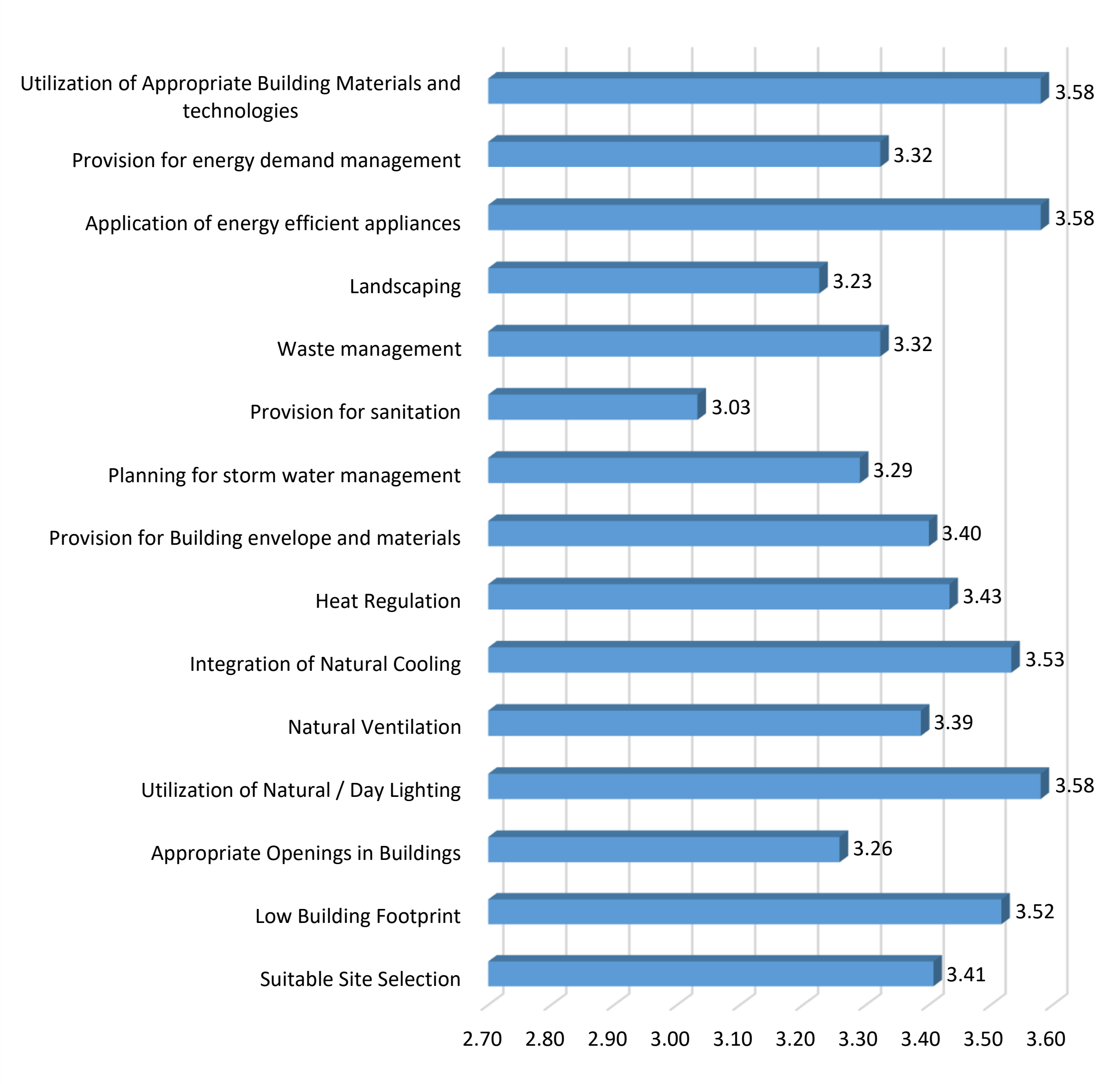
vi. Lack of adequate research and technology development due to limited capacities and support by the existing research institutions in Kenya, and

vii. Inadequate government support to research institutions.

8.5 Uptake of Building Materials Sustainability Selection Criteria Techniques

The selection criteria techniques has key rating features or tools that make them suitable for adoption due to their impact in making the resultant building energy efficient and easy to adapt. These features were shared with the expert in the building industry for rating purposes. The mean rating for all the features were at 3.39 indicating that most of the features of the selection criteria techniques has a significant impact on the suitability of the criteria techniques. The result indicates that the highest impact was related to utilization of natural lighting with a score of 3.58. The same score was obtained in the features related to utilization of appropriate building materials and technologies and application of energy efficient appliances. The least score was established to be on the provision of sanitation at 3.03 followed by landscaping as indicated in Figure 8.4.

Figure 8.4: Features of Sustainable Building Selection Criteria Techniques



Source: Modified from Sangori, 2019

In order to assess the effectiveness of the various tools used in the assessment of building materials and technologies sustainability, the research used a scale of 1-4 where 1- signifies not effective and 4 – very effective. The study assessed 14 tools and demonstrated that the overall level of effectiveness stood at approximately 2.34 reflecting 58.4 % rate of effectiveness. The highest rating of effectiveness was recorded on Edge Green Building with a mean score of 2.84. This was followed by LEED certification at 2.73, Green Star certification which stood at 2.71 while the LCA rating system was at 2.58. The study further established that about eight tools scored below the average score with BREEAM and Curb Tool scoring a lower effectiveness rate of 2.00 and 2.08 respectively as indicated in Table 8.5.

Table 8.5: Adoption of Sustainable Building Selection Tools

SN	Building material and technology sustainability selection techniques	N	Mean
1.	EDGE Green Building Certification System	19	2.84
2.	Leadership in Energy & Environmental Design (LEED)	26	2.73
3.	Green Star Rating System	24	2.71
4.	Life Cycle Assessment (LCA)	24	2.58
5.	Environmental Preference Method (EPM)	23	2.39
6.	Multi-Criteria Analysis (MCA)	22	2.36
7.	Building for Environmental and Economic Sustainability (BEES)	24	2.25
8.	GreenMark Rating System	20	2.20
9.	Environmental Product Declaration (EPD)	21	2.19
10.	Building Environment Assessment Tool (BEAT 2001)	17	2.18
11.	ATHENATM Impact Estimator for Buildings	18	2.11
12.	Building Environmental Performance Assessment Criteria (BEPAC)	23	2.09
13.	CURB Tool	12	2.08
14.	British Research Establishment (BRE) Environmental Assessment Method (BREEAM)	17	2.00

Source: Author, 2020

The study also noted that higher ratings were recorded on criteria with higher awareness rate. As a demonstration, 48.4% of the experts and 67.7% of the respondents were aware of the existence of CURB and EDGE tools respectively.

The above tools have been adopted in the assessment of various buildings in Kenya with about 12 buildings having been successfully certified in Kenya while 32 of similar buildings were registered for certification process as at the year 2019. Table 8.6 depicts the some of the buildings earmarked for certification in Kenya and the type of certification tool for application in the identified buildings.

Table 8.6 Buildings Registered for Certification in Kenya by 2019

S/No	Building	Type of Certification Tool
1.	Garden city Mall	LEED
2.	Garden City residential unit	GreenStar
3.	Britam Towers	EDGE
4.	Africa Logistic Properties located in Tatu City	EDGE
5.	Lumen Square	LEED
6.	Dunhil Towers	GreenStar
7.	Wrigleys Factory in Machakos	LEED
8.	Strathmore Business School	LEED
9.	EATON Place	LEED

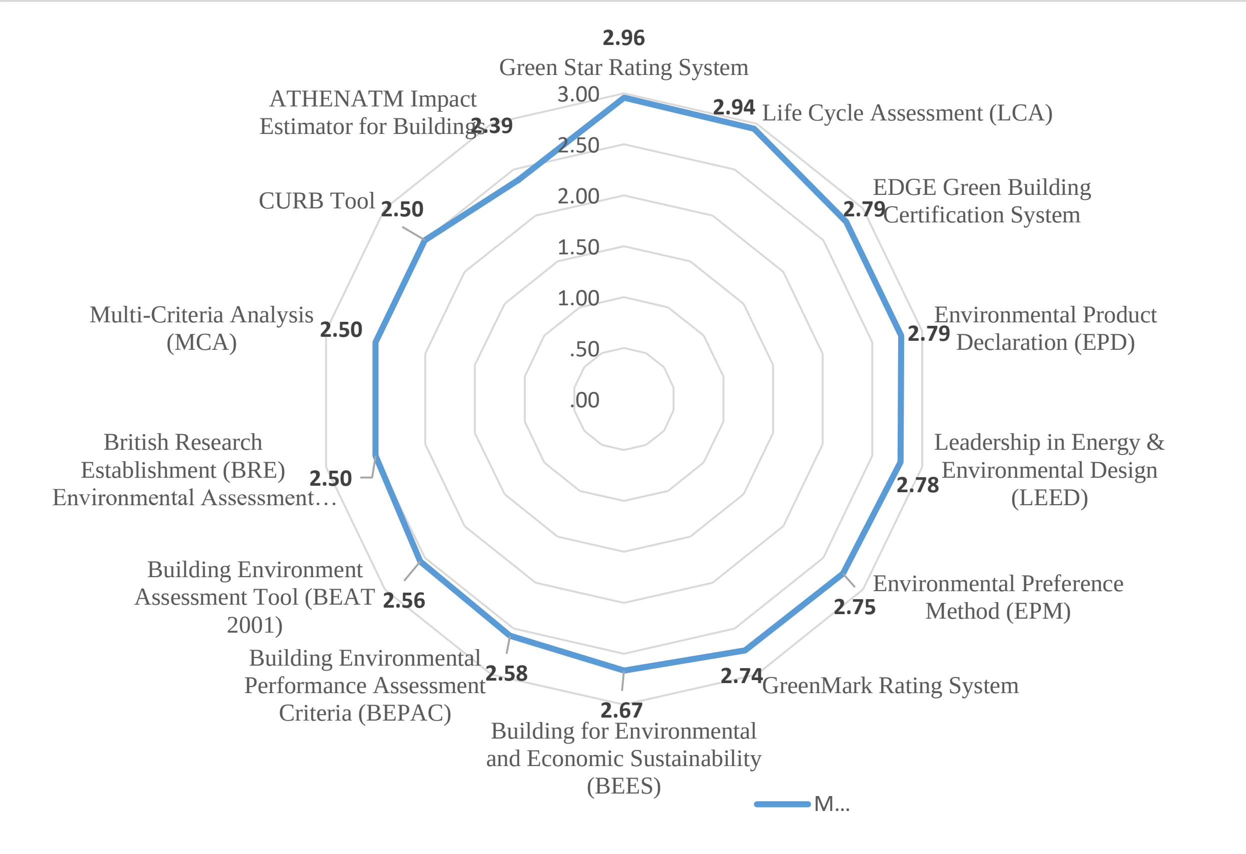
Source: Author, 2020

A visit to UN-Habitat and subsequent interviews detailed that UNEP and UN-Habitat new complex in Nairobi exhibits excellent green building strategies in its design and installation with a solar rooftop of 550kwp. Building demonstrates a best practice as a pioneer in integration of solar energy where 65% of the energy generated cover the demand of the building and the remaining 35 % in excess is fed into the national grid (Sangori, 2020). It is however observed that the complex has never attempted to be subjected to certification despite its comparative advantage of hosting the UN work station in third World Country. This scenario depicts the challenge demonstrated by most public buildings as certification is currently market driven.

8.6 Effectiveness of Building Materials Sustainability Selection Criteria Techniques

The Criteria Techniques determines the type of building materials to be put in use and this applies differently depending on the regional reach such as global, regional, national or local levels. The study sought to determine the effectiveness of these criteria techniques in Kenyan context. The overall effectiveness of all the evaluated criteria was at 2.67 out of a total mean of 4.00 signifying moderate effectiveness. All the Criteria Techniques were at moderate level with Green Star Rating System leading with a score of 2.96 followed by Life Cycle Assessment at 2.94 and EDGE Green Building Certification System at 2.79. The criterion with the least effectiveness was ATHENA™ impact Estimator for Buildings with a mean score of 2.39 followed by CURB Tool at 2.50. This is demonstrated in Figure 8.5

Figure 8.5: Effectiveness of building materials and technology sustainable selection techniques/tools



Source: Author, 2020

The study established that the low level of effectiveness in the application of building material and technologies sustainable selection techniques which stood at 2.67 was attributed to inadequate knowledge in the existence of such tools / techniques given that over 30% of the respondents had no knowledge on the application of the tools. A similar study by Herda and Sangori (2017) pointed out the need bridge the knowledge gap in adoption of building materials sustainability selection criteria techniques. This in effect would aide nurturing of environmentally-labelled products for wider usage in the market.

9 CONCLUSION AND RECOMMENDATION

9.1 Introduction

The chapter presents a summary of the study. It has factored in findings from the literature review, household survey that targeted the project owners, Key informant on policy implementation that involved key County Staff on relevant data sought, general key informant that targeted experts in the built environment both the within the study area and beyond by way of referencing, as well as experimental design on mortared and mortarless construction technologies. The conclusion made in this chapter provides synthesis of the research findings to the study objectives.

The recommendations presented suggests policy directions to be embraced by relevant authorities in the built environment and future research which have emerged as a result of the findings of this study.

The study explored the energy efficiency of building technologies in order to determine its contribution towards climate change mitigation and adaptation processes in Kenya. The energy efficiency of building technologies was evaluated by determining the embodied energy of the building material while the climate change was determined by assessing the greenhouse gas emission in terms of CO_2 emissions. The study was conducted in Migori County and received response of 356 from households, 31 general key informants and 5 public institution key informants.

The key Departments under the public institutions key informant that deals with built environment related policy implementation in Migori County included; Lands and Physical Planning, Survey, Housing, Kenya National Bureau of Statistics (KNBS) and Public Works.

The main data collection tool for the survey was questionnaire and interview guide while experimental design targeted one building material considered to be energy efficient (ISSB) and another building material considered to have low energy efficient (bricks).

9.2 Summary of Research

This research has satisfied the purpose and objectives outlined in the introduction chapter of this report. The study assessed the application of dominant building materials, building technologies, energy expenditure and emission of carbon dioxide equivalent in addition to the existing policies and regulations to promote the use of energy efficient technologies. The findings were adequate in providing actual data on measurement of embodied energy as an index of modelling the carbon sequestration levels which is useful for formulation of climate change mitigation strategies.

9.2.1 Dominant Building Materials and their Embodied Energy Levels

The first research objective was to identify the dominant building materials applied in housing development and establish their embodied energy levels. The study determined the dominant building materials in study areas using household sample data. The exploratory tools were used to determine the dominant building materials in terms of the modal materials and the individual variation form the modal materials. The Chi-Square Test statistics generated through SPPS provided Chi-Square values and significant level and were interpreted to understand the dominants building materials. The resultant dominants walling materials with higher frequencies were later subjected to further analysis related to embodied energy and Carbon dioxide equivalent generated during their extraction, transportation and construction.

The major walling materials was identified to be bricks at 39% followed by mud at 32% and concrete at 17.7%. Mud is not an approved walling materials since the products from mud is not permanent and used by the local for building traditional houses due to low income levels. The study therefore, identified the major approved walling material in the study area to be bricks and concrete with embodied energy as 3.0 MJ/kg and 0.670 MJ/Kg respectively. Further, the total Embodied energy from the sampled household was 12,611,100 MJ for bricks and concrete to be 648,560.00 while the embodied energy for ISSB was calculated to be 553,248.00 MJ and Iron Sheet to be 2,539,866 MJ. More over the research therefore rejected the null hypothesis and accepted the research hypothesis by concluding that environmentally sound building materials, technologies and designs are not predominantly applied in meeting the building demand levels of Migori County. This was demonstrated by commonly walling material being bricks and concrete blocks as opposed to ISSB, precast or prefabricated materials.

9.2.2 Extent of Application of Energy Efficient Building Technologies

The second research objective was to establish the extent of application of energy efficient building technologies. The preliminary phase involved the use of exploratory data analysis tools to measure the extent of adoption between the rural and urban wards. The analysis was done using single sample t-test within the factors and using Kruskal-Wallis H Test ($\alpha = 0.05$) between factors as depicted in the equation. The literature review noted that building materials production, transportation and construction related activities are responsible for 2.2% of the life cycle and that the primary energy consumption manufacturing processes accounts for about 80% of industrial energy consumption with an equivalent energy related carbon emissions. . Study findings demonstrates low application levels of energy efficient building technologies, particularly the Interlocking Stabilized Soil Blocks (ISSB), prefabricated and precast construction methods. The main building technology adopted in the study area was Mortar and Bricks or Concrete constituting 65.2% followed by Mud and Wattle at 30.1% while the energy efficient building technologies such as ISSB, Prefabrication and Precast constituted 2.2%, 2.2% and 0.3% respectively. The overall percentage of energy efficient building technology stands at 4.7% compared to 65.2%. The study therefore rejected the null hypothesis that there were high proportion of respondents adopting energy efficient technologies in the study area and concluded that the adoption technologies adopted in the study area are difference across the household and that low energy efficient technologies are commonly used in the study area. Analysis by the type of ward revealed a significant difference in the adoption technologies in rural and urban set up. This was further confirmed by a lower leading to the rejection of null hypothesis and affirming that the application of energy efficient technologies in Migori County was further dependant on the type of wards.

9.2.3 Resource Efficiency and Climate Change Mitigation Levels associated with Mortarless and Mortared Building Technologies

The third study objective was to determine resource efficiency and climate change mitigation levels associated with utilization of mortarless and mortared building technologies. The study compared the resource requirements in producing unit block of ISSB and BB respectively and in constructing $1m^2$ of a wall using ISSB and BB. The efficiency levels were measured in terms of raw materials (sand, cement, soil, water, fuel), embodied energy, GHGe, labour per man-day and time for construction up to lintel level and social cost of pollution. The analysis of building technology efficiency levels involves comparison of the input – output processes in the material utilization which considered energy efficiency of building materials at the initial stages based on the limitation of this study.

Comparison between ISSB and BB revealed fewer production duration for ISSB which takes about 12 days compared to burnt bricks which takes roughly 49 days for the process to be concluded. The % difference in the production timelines of the 2 products is about 308.3% thereby providing a clear demonstration that ISSB is 3 times faster to produce. In terms of the period of construction, ISSB took 4 days compared to 13 days and 14 days to construct stones and bricks respectively. It is therefore 4 times faster to constructs using ISSB compared to stones and BB. The labour required for constructing ISSB is much lower and is more than 5 times less compared to stones and bricks. The highest costs were related to labour, followed by walling material and cement. ISSB was cheaper in terms of labour at Kes. 16,000.00 followed by BB at Kes. 112,000.00 and Stones at Kes. 260,000.00. The same trend was replicated terms of cost of walling materials and cement with cost of ISSB cost ranging on the lower end compared to cost of stones and bricks.

It was revealed that ISSB is more expensive to produce at Kes. 83,540 compared to BB at Kes. 22,300 while ISSB was cheaper to construct at 114,620.00 compared to BB at Kes. 281,350.00. The total embodied energy used in the construction of ISSB was 30,955.20 MJ compared to BB at 67,965.80 MJ while the equivalent CO_2 emission was 3302.88 MJ for ISSB and 7,802.91 MJ for BB. The cost of pollution by adopting ISSB was causing harm equivalent to Kes. 246,051.00 while cost of pollution for BB was Kes. 416,792. In term of input resources used in the application of bricks and ISSB, we rejected the hypothesis and accept the research hypothesis stating that there was difference in resource efficiency and mitigation levels between Mortarless and mortared building technologies before considering the social cost of pollution.

At the production level the input used did not show any significant difference level in the application of technologies, same for the cost of input at the construction level and production level. However, by factoring the social cost of pollution for every input used in the production of ISSB and bricks, the hypothesis was rejected and the research concluded that there was enough evidence to ascertain that resource efficiency and climate change mitigation levels are associated with utilization of mortarless and mortared building technologies. This research confirms that ISSB has a major comparative advantage in mitigating against the social cost of climate change to the environment and society. Therefore, building technologies used in Migori County have a significant effect on climate change.

9.2.4 Relationship between Energy Efficiency Level of Building Materials and Climate Change

The forth research objective was to establish the relationship between energy efficiency levels of building materials and climate change. The study adopted the linear regression analysis to determine the relationship between energy efficiency levels of building materials and climate change. The linear regression model was useful in establishing relationship between the dependent variable (GHGe) and independent variable (embodied energy) since energy efficiency level is a function of embodied energy and greenhouse gas emission is a function of climate change. The resultant model regression equation is used to predict the outcome of climate change with a relatively small amount of error compared to descriptive statistics. The study employed least squares method inbuilt in SPSS to determine the line of best fit for the data used to establish the relationship between the two variables as a further test for normality. The literature affirms that the cost associated with the effects of climate change is felt in the built environment and that innovative adaptive ways are sought for the adverse contributions from the built environment sector towards climate change to be minimized.

The findings revealed that there was a relationship between the embodied energy of walling of a materials GHG Emission. It further demonstrates the need to minimize the embodied energy of the walling materials or the need to adopt walling materials with minimized embodied energy in order to reduce the greenhouse gas emission. The projection of the study at the national level demonstrated that less efficient building technologies continues to dominate the housing sector with bricks leading over the three years at 7,176 GJ in 1800, 306,730 GJ in 2019 and 590,263 GJ in 2050 if the current environment of Migori is to prevail nationally. Other materials with larger embodied energy over the same periods includes iron sheets, cement and concrete blocks. The study further demonstrates that energy efficient technologies such as ISSB continue to attract low embodied energy due to its low adaptation in the local environment coupled with low energy requirement during its production and application.

9.2.5 Suitability of County Building Approval Processes to Promote Selected Building Technologies

The fifth research objective was to analyse the suitability of County building approval processes to promote selected building technologies. The study assessed the systems and structure of the county and national government department in promoting environmentally friendly building technologies by examining the building plan approval process. The knowledge of the project owners in terms of approval requirement was generally high. The level of knowledge was however on the energy efficient building technologies.

The literature available revealed lack of records related to the approval process in the last 30 years as envisage by the study. It was revealed that 83% of the household were aware of the building approval requirement with more awareness recorded in urban setup (87.8%) compared to rural setup (78.6%). Further, the current policies and regulations does not adequately support the emerging building material and related technologies which are energy efficient. The study established that most of the records related to the building approval processes were missing as there were no proper systems put in place. It was therefore not possible to obtain the data dating back to three decades as envisaged by the study in order to support the objective of this study regarding trend analysis.

The study did not found out any policy or activities geared towards promoting energy efficient building technologies in the approval process and that the traditional approval is still practiced. The study established that the building approval process in Migori County is solely manual in the present form and application with no clear back-up systems.

9.3 Conclusions of the Study

The housing sector continues to grow due to increasing demand for the housing services as population increases. This leads to major challenges related to climate change as a results of unsustainable exploitation of ecosystem resources namely soil, water and forest / tree cover among others thereby resulting into imbalance in carbon sequestration levels. This phenomenon in turn affects the stability of atmospheric carbon (CO_2) which is one of the GHG used in this study as a proxy to climate change. Through experimental design, the study revealed that the building materials extraction, manufacture, transportation, and construction consume significant amount of energy and emit greenhouse gas into the atmosphere and that the level of emission of greenhouse gas is dependent on the building technologies adopted.

The study revealed that the dominant walling materials in the study areas was bricks followed by mud and concrete blocks. These materials are associated with large amount of embodied energy during extraction, transportation, manufacture and construction hence considered to be less energy efficient building technologies due to high amount of associated greenhouse gas emission. Moreover, there was low application energy efficient technologies such as ISSB, prefabricated and precast material due to its low adaptation in the local environment since they were associated with advance technology.

The study compared the application of the mortarless and mortared technology through experimental design by using ISSB and bricks and concluded that there was a significant difference in resource efficiency and mitigation levels between the two technologies. The mortared technology was associated with large amount of embodied energy and equivalent greenhouse gas emission which impact negatively on human life due to high social cost of pollution. Therefore, building technologies used in the developing countries such as Kenya have a significant effect on climate change.

The study concludes that there is a strong relationship between the embodied energy of walling of a materials and GHG emission. It also demonstrates the need to minimize the embodied energy of the walling materials or the need to adopt walling materials with minimized embodied energy in order to reduce the greenhouse gas emission. The study is instrumental towards improving measurements of embodied energy in building materials.

The housing sector in Kenya consumes large amount of embodied energy leading to the increase of social cost of pollution and this require a consorted effort in terms of policy to promote efficient energy technologies. The study revealed that there was minimal knowledge on the application of energy efficient technologies and that the approval process does not promote the use of energy efficient technologies due to lack of policy to spearhead the initiative.

9.4 Recommendations of the Study

9.4.1 Recommendation for Policy Review and Implementation

Based on the study findings, the study recommends the use of energy efficient technologies in the manufacture of bricks since its adoption will continue to increase. This can be done by promoting energy efficient kiln in Kenya.

The adoption of mortarless technology is still low and the study recommends the promotion of mortarless technologies such as ISSB, prefabs and precast in order to minimize on the greenhouse gas emission. This can be done by creation of more demonstration sites within the country. As revealed by the research, education and awareness level in the adoption of building materials and technologies are related hence both government and private sector players in the built environment sustainable development processes should avail more resources towards enhance capacity building and awareness creation among building technology users.

Kenya does not have building codes that are relevant to energy efficiency and worse still, there are no guidelines to assist the construction industry on how to contribute to reduction of carbon discharge in the atmosphere, a proposition that negates achievement of the COP21 commitments regarding the relationship between buildings and climate change. Kenya should develop a building codes that promote energy efficient technology.

The study revealed that there was no regulation or policy in the building approval process to promote the use of high energy efficient technology. We recommend that the National and the County government should develop a policy that promote the appropriate building technologies which are energy efficient.

The study further recommends that the County Government of Migori considers digitization of the building approval processes towards effective record management and ease of access to information which is presently inadequate.

9.4.2 Recommendation for further Research

The study did not examine the full life cycle of the building materials and how it impacts on the climate change. The study recommends a comprehensive study examining the full life cycle of the building materials (extraction, processing, transportation, construction, operations, refurbishment/ maintenance and demolition, reuse/disposal

The study proposes a study on trend analysis for the past 40 years from 1979 to date, the 4-year cycle of 10-year interval between each cycles to establish the actual impact of building materials arising from the demand necessitated by the increasing population and shelter provision needs. This was not adequately achieved in this study due to missing data in the selected study area both at the county level and at the Kenya National Bureau of statistics since documentation of the building material usage was inadequate as proper records were not available. This situation calls for improvement of the data management at the County level especially the need for establishment of County Data centres including fully operational Urban Observatories.

There is also need to do a quantitative study on the social cost of pollution as a results of greenhouse gas emission in African Context since the study revealed that the difference is resource efficiency are dependent on the social cost of pollution.

Further Research is needed on the use of energy efficient kiln in the manufacture of burnt brick in Kenya and the rest of the developing world which mainly rely on burnt bricks in meeting the building material needs.

Further research dedicated to impacts of building technologies on climate change in the context developing countries.

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APPENDICES:

Appendix I: More Tables of Study Results

1. A: Embodied Energy of ISSB analysis at 5% Cement

Phases	Parameters	Units	Quantity	**EE transport (MJ)**	**EE for Processing**	**Total EE (MJ)**	**Embodied Energy Coefficient (MJ/kg)**	**Fuel Consumed (Litres) - Diesel**
Production	Soil	Kg	17468.57	0.00	7860.86	7860.86	0.45	0.00
	Quarry dust	Kg	11441.40	1008.00	1910.71	2918.71	0.167	24.00
	Sand	Kg	7253.03	2100.00	725.30	2825.30	0.10	50.00
	Water	Litres	2140.00	840.00	428.00	1268.00	0.20	20.00
	Cement	Kg	1987.00	252.00	9140.20	9392.20	4.60	6.00
	Diesel Fuel	Litres	43.00	0.00	1806.00	1806.00	42.00	0.00
Curing Phase	Polythene roll (2 rolls)	kg	46.00	0.00	3822.60	3822.60	83.10	0.00
	Water	Litres	1158.00	420.00	231.60	651.60	0.20	10.00
	Total		**38150.00**	**4,620.00**	**25,925.27**	**30,545.27**		**110.00**

Soil		17468.57	
Quarry dust		11441.40	
Sand		7253.03	
Cement		1987	
Total		**38,150.00**	KG
	Embodied Energy	**0.801**	MJ/KG

1. B: Embodied Energy of ISSB analysis at 10% Cement

Phases	Parameters	Units	Quantity	EE transport (MJ)	EE for Processing	Total EE (MJ)	Embodied Energy Coefficient (MJ/kg)	Fuel Consumed (Litres) - Diesel
Production	Soil	Kg	16547.15	0.00	7446.22	7446.22	0.45	0.00
	Quarry dust	Kg	10837.90	1008.00	1809.93	2817.93	0.167	24.00
	Sand	Kg	6870.45	2100.00	687.05	2787.05	0.10	50.00
	Water	Litres	2140.00	840.00	428.00	1268.00	0.20	20.00
	Cement	Kg	3894.50	252.00	17914.70	18166.70	4.60	6.00
	Diesel Fuel	Litres	43.00	0.00	1806.00	1806.00	42.00	0.00
Curing Phase	Polythene roll (2 rolls)	kg	46.00	0.00	3822.60	3822.60	83.10	0.00
	Water	Litres	1158.00	420.00	231.60	651.60	0.20	10.00
	Total		**38150.00**	**4,620.00**	**34,146.09**	**38,766.09**		**110.00**

Soil		16547.15	
Quarry dust		10837.90	
Sand		6870.45	
Cement		3894.5	
Total		**38,150.00**	KG
	Embodied Energy	**1.016**	MJ/KG

1. C: CO2e of ISSB analysis at 5% Cement

Phases	Parameters	Units	Quantity	Processing - CO_2 (Kg)	Transportation - CO_2 (Kg)	Total CO2 (Kg)	$KgCO_2e/kg$	Fuel consumed (Litres) - diesel transport
Production	Soil	Kg	17468.57	401.78	0.00	401.78	0.023	0.00
	Quarry dust	Kg	11441.40	263.15	0.00	263.15	0.023	0.00
	Sand Production	Kg	7253.03	36.27	0.00	36.27	0.005	0.00
	Sand Transportation	Kg	0.00	0.00	134.00	134.00	0.000	50.00
	Water - Transport	Litres	2140.00	0.00	53.60	53.60	0.000	20.00
	Cement	Kg	1987.00	1649.21	16.08	1665.29	0.830	6.00
	Diesel Fuel	Litres	43.00	115.24	0.00	115.24	2.680	0.00
Curing Phase	Polythene roll (2 rolls)	kg	46.00	89.24	0.00	89.24	1.940	0.00
	Water - Transport	Litres	1158.00	0.00	26.80	26.80	0.000	10.00
	Total		**38150**	**2,554.88**	**230.48**	**2,785.36**		**86.00**
	Total blocks	**3100**						
	1 block	0.90	KgCo2e/ block	0.090	KgCo2e/Kg (10kg)			
				0.067	KgCo2e/Kg (12kg)			
				0.073	KgCo2e/Kg			

1. D: CO2e of ISSB analysis at 10% Cement

Phases	Parameters	Units	Quantity	Processing -CO_2 (Kg)	Transportation -CO_2 (Kg)	Total CO2 (Kg)	$KgCO_2e$ /kg	Fuel consumed (Litres) - diesel transport
Production	Soil	Kg	16547.15	380.58	0.00	380.58	0.023	0.00
	Quarry dust	Kg	10837.90	249.27	0.00	249.27	0.023	0.00
	Sand Production	Kg	6870.45	34.35	0.00	34.35	0.005	0.00
	Sand Transportation	Kg	0.00	0.00	134.00	134.00	0.000	50.00
	Water - Transport	Litres	2140.00	0.00	53.60	53.60	0.000	20.00
	Cement	Kg	3894.50	3232.44	16.08	3248.52	0.830	6.00
	Diesel Fuel	Litres	43.00	115.24	0.00	115.24	2.680	0.00
Curing Phase	Polythene roll (2 rolls)	kg	46.00	89.24	0.00	89.24	1.940	0.00
	Water - Transport	Litres	1158.00	0.00	26.80	26.80	0.000	10.00
	Total		**38150**	**4,101.12**	**230.48**	**4,331.60**		**86.00**
	Total blocks	**3100**						
	1 block	1.40	KgCo2e/block	0.140	KgCo2e/Kg (10kg)			
				0.107	KgCo2e/Kg (12kg)			
				0.114	KgCo2e/Kg			

1: E1: National Projection of Embodied Energy, GHG emission and Cost of Emission based on Study Location

SN	Year	Material	Embodied Energy (GJ)	GHG Emission(Gg)	Cost of Emission (Kshs Million)
1	1800	Stone	489	27,362	397
2	1800	Soil	546	27,885	404
3	1800	Bricks	7,176	689,887	10,003
4	1800	Concrete Blocks	520	56,681	822
5	1800	Iron Sheets	2,037	131,117	1,901
6	1800	cement	1,144	178,557	2,589
7	1800	sand	427	21,354	310
8	1800	timber	49	2,659	39
9	1800	wattle	27	1,461	21
10	1800	ISSB	463	46,466	674
11	2020	Stone	20,884	1,169,512	16,958
12	2020	Soil	23,319	1,191,865	17,282
13	2020	Bricks	306,730	29,486,939	427,561
14	2020	Concrete Blocks	22,235	2,422,649	35,128
15	2020	Iron Sheets	87,077	5,604,183	81,261
16	2020	cement	48,917	7,631,839	110,662
17	2020	sand	18,254	912,719	13,234
18	2020	timber	2,100	113,659	1,648
19	2020	wattle	1,149	62,442	905
20	2020	ISSB	19,793	1,986,018	28,797
21	2030	Stone	29,132	1,631,420	23,656
22	2030	Soil	32,529	1,662,601	24,108
23	2030	Bricks	427,876	41,133,041	596,429
24	2030	Concrete Blocks	31,017	3,379,494	49,003
25	2030	Iron Sheets	121,469	7,817,600	113,355
26	2030	cement	68,238	10,646,095	154,368
27	2030	sand	25,464	1,273,205	18,461
28	2030	timber	2,930	158,550	2,299
29	2030	wattle	1,603	87,104	1,263
30	2030	ISSB	27,611	2,770,412	40,171
31	2050	Stone	40,189	2,250,573	32,633
32	2050	Soil	44,875	2,293,588	33,257
33	2050	Bricks	590,263	56,743,773	822,785
34	2050	Concrete Blocks	42,789	4,662,073	67,600
35	2050	Iron Sheets	167,568	10,784,520	156,376
36	2050	cement	94,135	14,686,481	212,954
37	2050	sand	35,128	1,756,409	25,468
38	2050	timber	4,042	218,722	3,171

SN	Year	Material	Embodied Energy (GJ)	GHG Emission(Gg)	Cost of Emission (Kshs Million)
39	2050	wattle	2,212	120,161	1,742
40	2050	ISSB	38,090	3,821,834	55,417
41	2100	Stone	55,018	3,081,025	44,675
42	2100	Soil	61,433	3,139,912	45,529
43	2100	Bricks	808,067	77,681,978	1,126,389
44	2100	Concrete Blocks	58,578	6,382,358	92,544
45	2100	Iron Sheets	229,400	14,763,961	214,077
46	2100	cement	128,870	20,105,728	291,533
47	2100	sand	48,090	2,404,516	34,865
48	2100	timber	5,533	299,430	4,342
49	2100	wattle	3,028	164,501	2,385
50	2100	ISSB	52,144	5,232,074	75,865

1: E2: Migori County Projection of Embodied Energy, GHG emission and Cost of Emission based on Study Location

SN	Year	Material	Embodied Energy (GJ)	GHG Emission(Gg)	Cost of Emission (Kshs Million)
1	1800	Stone	16	889	13
2	1800	Soil	18	906	13
3	1800	Bricks	233	22,404	325
4	1800	Concrete Blocks	17	1,841	27
5	1800	Iron Sheets	66	4,258	62
6	1800	cement	37	5,799	84
7	1800	sand	14	693	10
8	1800	timber	2	86	1
9	1800	wattle	1	47	1
10	1800	ISSB	15	1,509	22
11	2019	Stone	407	22,818	331
12	2019	Soil	455	23,254	337
13	2019	Bricks	5,985	575,317	8,342
14	2019	Concrete Blocks	434	47,268	685
15	2019	Iron Sheets	1,699	109,343	1,585
16	2019	cement	954	148,904	2,159
17	2019	sand	356	17,808	258
18	2019	timber	41	2,218	32
19	2019	wattle	22	1,218	18
20	2019	ISSB	386	38,749	562
21	2030	Stone	567	31,751	460

SN	Year	Material	Embodied Energy (GJ)	GHG Emission(Gg)	Cost of Emission (Kshs Million)
22	2030	Soil	633	32,358	469
23	2030	Bricks	8,327	800,543	11,608
24	2030	Concrete Blocks	604	65,773	954
25	2030	Iron Sheets	2,364	152,148	2,206
26	2030	cement	1,328	207,197	3,004
27	2030	sand	496	24,779	359
28	2030	timber	57	3,086	45
29	2030	wattle	31	1,695	25
30	2030	ISSB	537	53,919	782
31	2050	Stone	782	43,801	635
32	2050	Soil	873	44,638	647
33	2050	Bricks	11,488	1,104,363	16,013
34	2050	Concrete Blocks	833	90,735	1,316
35	2050	Iron Sheets	3,261	209,891	3,043
36	2050	cement	1,832	285,832	4,145
37	2050	sand	684	34,184	496
38	2050	timber	79	4,257	62
39	2050	wattle	43	2,339	34
40	2050	ISSB	741	74,382	1,079
41	2100	Stone	1,071	59,964	869
42	2100	Soil	1,196	61,110	886
43	2100	Bricks	15,727	1,511,868	21,922
44	2100	Concrete Blocks	1,140	124,215	1,801
45	2100	Iron Sheets	4,465	287,340	4,166
46	2100	cement	2,508	391,303	5,674
47	2100	sand	936	46,797	679
48	2100	timber	108	5,828	85
49	2100	wattle	59	3,202	46
50	2100	ISSB	1,015	101,828	1,477

1. F: Comparison of the Cost of Production of Mortared and Mortarless Building Technologies

Parameters	ISSB (66.7 M2)	BB (66.7 M2)	% Difference in Inputs	ISSB Cost (Kes.)	BB Cost (Kes.)	ISSB		Bricks					
Time (Days)	4	14	10	0	0	EE for ISSB (MJ)	GHG Emission (Kg)	EE (MJ)	GHG Emission (Kg)	ISSB Cost of Emission (Kes.)	Bricks Cost of Emission (Kes.)	ISSB Total Cost (Kes.)	Bricks Total Cost (Kes.)
Skilled Labours (Man Days)	8	42	34	8000	42000							8000	42000
Non Skilled Labours (Man Days)	16	140	124	8000	70000							8000	70000
Sand (Tons)	2	40	38	2000	40000	200	10	4000	200	145	2900	2145	42900
Cement (50kg bags)	17	110	93	11900	77000	3910	705.5	25300	4565	10229.75	66192.5	22129.75	143192.5
Water	1020	6600	5580	1020	6600	632.4	27.336	4224	176.88	396.372	2564.76	1416.372	9164.76
Main Walling material	3100	4500	140	83700	45000	30955.2	3411.22	67965.8	7802.912	49462.69	113142.224	133162.69	158142.224

1. G 1: Dominant Building Materials by Nature of Ward

S/NO	Dominant Walling Materials	**Urban**		**Rural**		**Total**	
		Count	% within Wards	Count	% within Wards	Count	% within Wards
1.	Stone	17	9.0%	6	3.6%	23	6.5%
2.	Mud	41	21.8%	74	44.0%	115	32.3%
3.	Bricks	85	45.2%	54	32.1%	139	39.0%
4.	Timber	0	0.0%	4	2.4%	4	1.1%
5.	Interlocking Stabilized Soil Blocks (ISSBs)	4	2.1%	4	2.4%	8	2.2%
6.	Concrete Blocks	40	21.3%	23	13.7%	63	17.7%
7.	Iron Sheets	1	.5%	3	1.8%	4	1.1%

Total	188	100.0%	168	100.0%	356	100.0%

1. G 2: Data on Building Materials by Ward

			Walling Materials								
			Stone	Mud	Bricks	Timber	ISSBs	Concrete Blocks	Iron Sheets	Others	Total
Ward	Nyabasi East (Kegonga)	Count	0	5	3	1	0	0	1	0	10
		Percent	0.0%	50.0%	30.0%	10.0%	0.0%	0.0%	10.0%	0.0%	100.0%
	Ntimaru West	Count	1	7	9	0	0	2	0	0	19
		Percent	5.3%	36.8%	47.4%	0.0%	0.0%	10.5%	0.0%	0.0%	100.0%
	Isbania	Count	0	6	5	0	0	3	0	0	14
		Percent	0.0%	42.9%	35.7%	0.0%	0.0%	21.4%	0.0%	0.0%	100.0%
	Bukira East	Count	1	6	14	0	0	4	0	0	25
		Percent	4.0%	24.0%	56.0%	0.0%	0.0%	16.0%	0.0%	0.0%	100.0%
	Central Kamagambo	Count	0	5	7	0	0	3	1	1	17
		Percent	0.0%	29.4%	41.2%	0.0%	0.0%	17.6%	5.9%	5.9%	100.0%
	North Kamagambo	Count	0	13	7	0	0	0	0	0	20
		Percent	0.0%	65.0%	35.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Central Sakwa	Count	1	0	13	0	1	4	0	0	19
		Percent	5.3%	0.0%	68.4%	0.0%	5.3%	21.1%	0.0%	0.0%	100.0%
	North East Sakwa	Count	1	13	7	2	0	3	0	0	26
		Percent	3.8%	50.0%	26.9%	7.7%	0.0%	11.5%	0.0%	0.0%	100.0%
	Central Suna	Count	4	2	8	0	0	6	0	0	20
		Percent	20.0%	10.0%	40.0%	0.0%	0.0%	30.0%	0.0%	0.0%	100.0%
	Kakrao	Count	0	4	5	0	0	16	0	0	25
		Percent	0.0%	16.0%	20.0%	0.0%	0.0%	64.0%	0.0%	0.0%	100.0%
	Ragana-Oruba	Count	1	12	9	0	0	4	0	0	26
		Percent	3.8%	46.2%	34.6%	0.0%	0.0%	15.4%	0.0%	0.0%	100.0%
	Wasweta II	Count	0	4	7	0	1	4	0	0	16
		Percent	0.0%	25.0%	43.8%	0.0%	6.3%	25.0%	0.0%	0.0%	100.0%
	Central Kanyamkago	Count	6	2	14	0	1	9	0	0	32
		Percent	18.8%	6.3%	43.8%	0.0%	3.1%	28.1%	0.0%	0.0%	100.0%
	North Kanyamkago	Count	0	8	8	0	0	0	0	0	16
		Percent	0.0%	50.0%	50.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%
	Muhuru	Count	2	2	9	0	1	7	0	0	21
		Percent	9.5%	9.5%	42.9%	0.0%	4.8%	33.3%	0.0%	0.0%	100.0%
	Kanyasa	Count	4	16	7	0	1	0	2	0	30
		Percent	13.3%	53.3%	23.3%	0.0%	3.3%	0.0%	6.7%	0.0%	100.0%
	Ikerege	Count	2	8	7	1	0	1	1	0	20
		Percent	10.0%	40.0%	35.0%	5.0%	0.0%	5.0%	5.0%	0.0%	100.0%
Total		Count	23	113	139	4	5	66	5	1	356
		Percent	6.5%	31.7%	39.0%	1.1%	1.4%	18.5%	1.4%	0.3%	100.0%

1. H: EE and CO2e of Building Materials used in the Study

Walling Material	**Embodied Energy Coefficient (MJ/KG)**	**Equivalent CO2e/Kg**	Remarks
Stone	1	0.056	
Soil	0.45	0.023	
Bricks	3.00	0.22	
Concrete Blocks	0.67	0.073	
Iron Sheets	39	2.51	
cement	4.6	0.83	
sand	0.1	0.005	
timber	8.5	0.46	
wattle	0.2661	0.01442	
ISSB	0.85	**0.14**	
Cement mortar (1:3)	1.4	0.213	
Other Materials			
Water	0.2		
Polythene	83.1	1.94	
Wood	17	1.7233	
Diesel Fuel	42	2.68	
bricks	**3**	**0.22**	
ISSB	0.85	0.14	
Petrol	44	2.31	

1. J: Items for ISSB Production and Construction

S/NO	TOOL	APPLICATION
1.	Wheelbarrow	Measuring proportions of soil, sand and cement Carrying / transportation of materials
2.	First-Aid-Kit	Stores first – aid – equipments
3.	Toolbox	Storage of hydraform tools
4.	Spade	Mixing of proportions of sand, soil and cement Loading of materials at the site
5.	Shovel	Used to break the ground or digging trenches
6.	Water level / horse pipe	Used in determining level
7.	Block brush	Used for cleaning of blocks

S/NO	TOOL	APPLICATION
8.	Wood float trowel	Used in plastering and floor finishing
9.	Factory broom	Used in sweeping the floor
10.	40mm steel scraper	Used while shaving blocks
11.	Large trowel	Used for plastering
12.	Small trowel	Used for finishing
13.	4 pound hammer	Used with block cutter machine
14.	2 pound hammer	Hammering and removing of nails
15.	Rubber hammer	Used in joining of blocks during construction work
16.	1.0m and 300mm spirit level	Used in levelling of coarses
17.	Metal square	Used in lining of corners
18.	Steel float	Used in plastering or floor finishing
19.	Corner steel float	Used in plastering or moulding of corners
20.	30m tape measure	Used for taking various measurements at the site
21.	5m tape measure	Used for taking measurements
22.	Wire cutter	Used for cutting binding wire
23.	Pliers	Used for cutting binding wires
24.	Builder’s line	Help to guide when setting trend (foundation)
25.	Brick hammer	Help in breaking stones
26.	Paint bush	Used for various painting requirements at the site
27.	Line holders bobbins	Used in aligning the coarse
28.	Steel chisel	Shaping of blocks or walls
29.	Block cutter	Used for cutting blocks in Hydraform
30.	Jerry can for diesel (20-25 L)	Used for carrying and storing diesel
31.	Watering can	Used for watering the mix and blocks during block making and curing respectively
32.	10 L Bucket	Used for carrying water at the site
33.	Steel bolster chisel	Cutting and shaping of blocks

S/NO	TOOL	APPLICATION
34.	Gauge rod (1m x 30mm)	Used in measurement
35.	Wood profiles (38 x 38mm, 152 x 38mm)	Determines size of foundation
36.	Plastic roll	Used for covering blocks
37.	Sieve: 8-10mm, Mesh in Metal Frame of 2m x 1m wide with stand	Used for sieving of soil

1. **K: On-site ISSBs production Tools and Equipment**

S/NO.	Tool / Equipment	Application
1.	Wheel barrow	Measuring proportions of raw materials (Soil, Sand and Cement), and transportation of materials
2.	First-Aid Kit	Stores First-Aid equipment
3.	Toolbox	Storage of machine tools, especially for the hydraulic machines
4.	Spade	Mixing of proportions of raw materials (Soil, Sand and cement), and loading of materials at excavation and material preparation site
5.	Block brush	Cleaning of blocks (Wet and Dry Blocks)
6.	Watering can	Watering the mix and blocks during block making and curing respectively
7.	10 Litre Bucket	Loading ready mix into the block production chamber
8.	Plastic roll (Polythene)	Used for covering wet blocks
9.	8-10mm Mesh in metal frame measuring 2m x 1m with stand	Sieving of raw materials (soil and sand, etc.) for any impurities.
10.	Jembe / Hoe	Levelling of block production, laying and curing sites

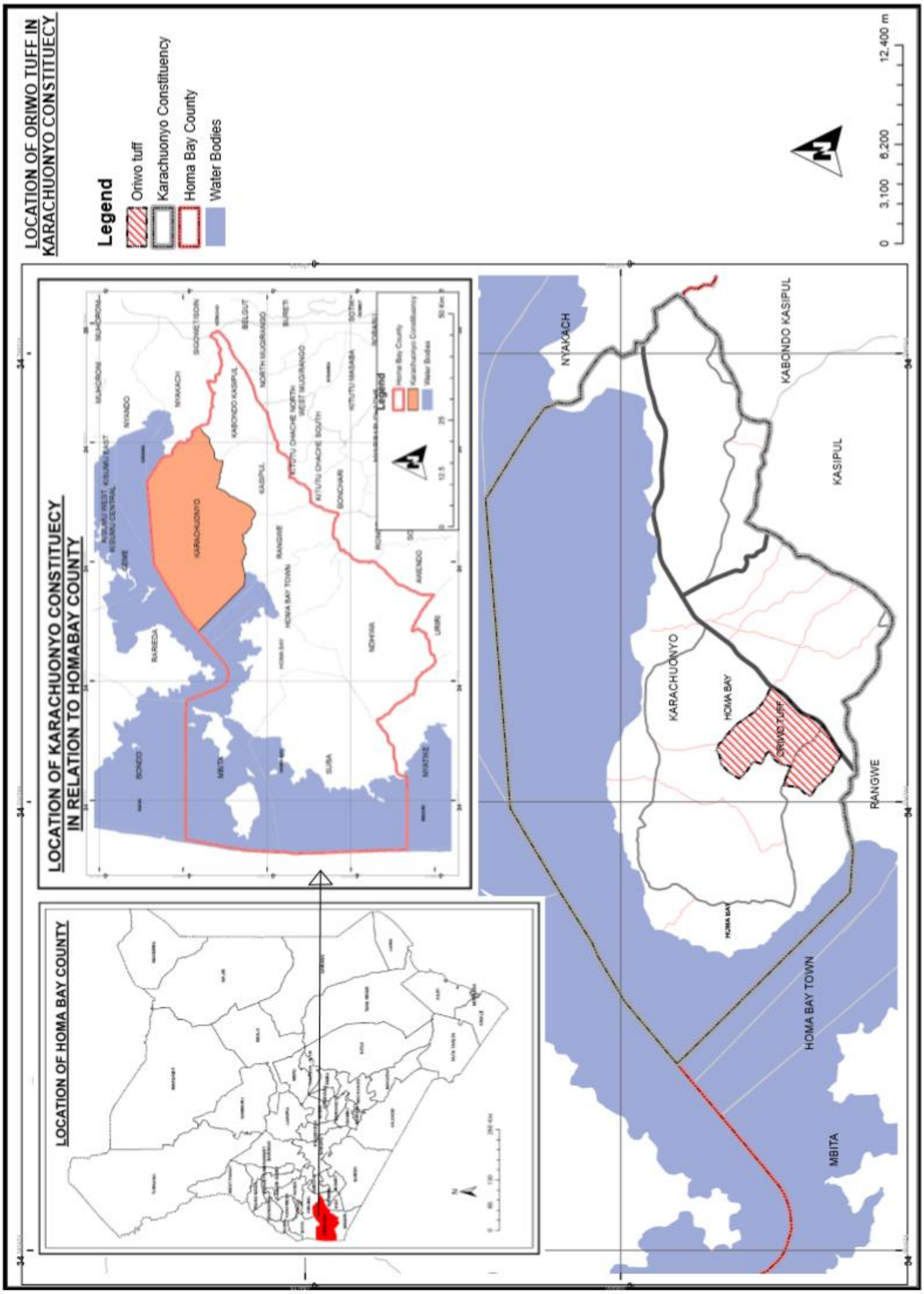
1. **L: On-site training programme**

Day	Activity
Day 1	i. Selecting the perfect soil for block making ii. Getting river sand to on-site training location where applicable iii. Getting the right mesh for the sieve and get soil ready (get the maximum soil sieved) iv. Setting up the production site for maximum capacity and easy access v. Getting the curing site levelled and get tarpaulins laid down on ground (if the curing is done on soil to prevent water loss)

	vi.	Before starting machine, run through the safety around machine
	vii.	Making test blocks, with different mix designs and marking them for testing (take notes of the different mixes)
Day 2	i.	Get to site early for watering (curing) of blocks
	ii.	Prepare new line for green blocks while some are watering the blocks
	iii.	If no mixer, get the mixes going while the other members of team are doing the other tasks
	iv.	Start machine for block production
	v.	Put date on the line and note the quantity at the end of the day
	vi.	Make sure there is a small foundation / slab made for construction training
Day 3 and 4	i.	Make sure the blocks are watered correctly
	ii.	Start getting tools and equipment ready for the construction training
	iii.	On day 4, get the masons ready for the next day construction training (2 or 3 Maximum)
	iv.	The rest is the same as day 2
Day 5, 6, 7 and 8	i.	Makes sure blocks are watered correctly
	ii.	On day 5 test some blocks taken for testing and mark results (if needed adjust the mix design)
	iii.	Teach the masons about lintels preparations; get the carpenter to make boxes for the poring of the lintels
	iv.	Start the construction training
	v.	Teach them to put a block level on sand before going on real construction
	vi.	Show corners, T-junction, cross-over section before going to a real construction
	vii.	Teach them to build between profiles
Day 9 and 10	i.	Make sure the blocks are watered correctly
	ii.	Lay the lintels at frame height on mortar
	iii.	Show the ring beam construction with brick force or mesh
	iv.	Show the finishes (patching of block, pointing and plastering)
	v.	Conclude the training with the owner of machine (give block price, M^2 price of wall)
End of Training		

Appendix II: Additional Maps

2A: Map Depicting Position of Oriwo Turf in Homa Bay County



Appendix III: Inventory of Carbon and Energy and Heating Values

3.A: Inventory of Carbon and Energy (ICE)

Material	Energy MJ per kg	Carbon kg CO_2 per kg	Density kg /m^3
Aggregate	0.083	0.0048	2240
Concrete (1:1.5:3)	1.11	0.159	2400
Bricks (common)	3	0.24	1700
Concrete block (Medium density)	0.67	0.073	1450
Aerated block	3.5	0.3	750
Limestone block	0.85		2180
Marble	2	0.116	2500
Cement mortar (1:3)	1.33	0.208	
Steel (general, av. recycled content)	20.1	1.37	7800
Stainless steel	56.7	6.15	7850
Timber (general, excludes sequestration)	8.5	0.46	480–720
Expanded Polystyrene insulation	88.6	2.55	15–30
Polyurethane insulation (rigid foam)	101.5	3.48	30
Mineral fibre roofing tile	37	2.7	1850
Slate	0.1–1.0	0.006–0.058	1600
Clay tile	6.5	0.45	1900
Aluminium (general &incl 33% recycled)	155	8.24	2700
Bitumen (general)	51	0.38–0.43	
Medium-density fibreboard	11	0.72	680–760
Plywood	15	1.07	540–700
Glass	15	0.85	2500
PVC (general)	77.2	2.41	1380
Terrazzo tiles	1.4	0.12	1750
Ceramic tiles	12	0.74	2000
Vitrified clay pipe (DN 500)	7.9	0.52	
Paint - Water-borne	59	2.12	
Paint - Solvent-borne	97	3.13	

3.B: Heat Values of Various Fuel Products

Fuel types	**Heat value**
Hydrogen (H_2)	120-142 MJ/kg
Methane (CH_4)	50-55 MJ/kg
Methanol (CH_3OH)	22.7 MJ/kg
Dimethyl ether - DME (CH_3OCH_3)	29 MJ/kg
Petrol/gasoline	44-46 MJ/kg
Diesel fuel	42-46 MJ/kg
Crude oil	42-47 MJ/kg
Liquefied petroleum gas (LPG)	46-51 MJ/kg
Natural gas	42-55 MJ/kg
Hard black coal (IEA definition)	>23.9 MJ/kg
Hard black coal (Australia & Canada)	c. 25 MJ/kg
Sub-bituminous coal (IEA definition)	17.4-23.9 MJ/kg
Sub-bituminous coal (Australia & Canada)	c. 18 MJ/kg
Lignite/brown coal (IEA definition)	<17.4 MJ/kg
Lignite/brown coal (Australia, electricity)	c. 10 MJ/kg
Firewood (dry)	16 MJ/kg
Natural uranium, in LWR (normal reactor)	500 GJ/kg
Natural uranium, in LWR with U & Pu recycle	650 GJ/kg
Natural uranium, in FNR	28,000 GJ/kg
Uranium enriched to 3.5%, in LWR	3900 GJ/kg

Source: World Nuclear Association, 2018

Appendix IV: Study Instruments

4.A: Field Research Questionnaire for Household

Questionnaire No:-------------------------

Project Location Coordinates: X--------

Y-------

FIELD RESEARCH QUESTIONNAIRE FOR HOUSEHOLD RESPONDENTS:

ENERGY EFFICIENCY OF BUILDING TECHNOLOGIES AND CLIMATE CHANGE: A CASE STUDY OF CARBON SEQUESTRATION IN MIGORI COUNTY.

Dear Sir / Madam,

My Name is **Robert Sangori**. I am a student at the Department of Geography and Environmental Studies, the University of Nairobi. I am currently conducting a Thesis Research leading to award of PhD in the field of Environmental Planning and Management. The research targets households' / project owners. The households' / projects owners' questionnaires are administered to the individual household heads in order to establish the dominant building materials, sources, production processes and the energy requirement. Your participation is of great significance to this study and as such, you are kindly requested to voluntarily participate in this important exercise by answering some few questions relating to the subject matter. The ***information provided will be confidential and strictly used for the purpose of this research only***. Please feel free to respond to the set of questions enumerated below as may be appropriate.

Section A: Personal Data

1. Name of the sub-county you come from?

1. Rongo	[ ]	5. Awendo	[ ]
2. Suna East	[ ]	6. Suna West	[ ]
3. Uriri	[ ]	7. Nyatike	[ ]
4. Kuria West	[ ]	8. Kuria East	[ ]

2. Ward? ---

3. Nature of Your Ward? 1. Urban [ ] 2. Rural [ ]

4. Gender? 1. Male [ ] 2. Female [ ]

5 Age? ---

6 Respondent Category? 1. Individual [ ] 2. Organization [ ]
3. Professional [ ]

7 Occupation / Profession? ---
----

8 Highest level of education attained? --

Section B: Current Scenario in Building Materials Application and the State of Environment

9. Kindly state your view on the conditions of the local environment (***general conditions of the environment, population density, rainfall pattern, state of rivers, forest cover, common trees, condition of soil, disease prevalence, dominant crops, state of crop yields/harvest etc***)?--
----
----

10. In what Capacity have you interacted with the Building Materials?

1. Unskilled labourer [ ] 2. Local Mason [ ] 3. Home / Project Owner [ ]
4. Material Supplier [ ] 5. Manufacturer [ ]

11. If home / project owner in No.10 above, kindly state the project type?

1. Residential House [ ] 2. Commercial Building [ ] 3. Educational [ ]
4. Others [Specify]---
----

12. If 1 in No. 11 above, please state the walling materials used in building your house?

1. Stone [ ] 2. Mud [ ] 3. Bricks [ ] 4. Timber [ ]
5. Interlocking blocks [ ], 6. Concrete blocks [ ] 7. Iron Sheets [ ]
8. Others Specify---

13. Kindly estimate the area in square Metres of your house / project?

----

14. Based on your choice of answer in question 12, kindly state where you sourced the walling materials used in the construction of your house?

1. On-Site Production [ ] 2. Sourced from a Quarry [ ]

3. Purchased from a hardware [ ] 4. Local Traders [ ]

5. Others, (Specify)---
----

15. With reference to answers provided in no. 14 above, coordinates of all local sites taken with assistance of GPS equipment are as provided tabulated below;

Project Category	Source Area of Walling Materials	Ward	Longitudes	Latitudes	Approx. Distance (Km)

16. For your choice of answer in question 12 please provide the quantities in tonnage of the materials used in constructing your house/project?

Type of Walling Materials	Quantity	Size (Dimension)	Tonnage/ Volume	Units of measurement

Section C: Energy Consumption and Carbon Emission

17. For on-site production, kindly state the methods of production?

1. Human Labour [ ] 2. Machinery [ ]

18. Please state the number of workers involved in the production process? ---------------------
----

19. If machinery were used, kindly state the type of machinery involved?

1. Manual/hand press [ ] 2. Fuel Operated [ ] 3. Electric [ ]

20. If fuel operated, please provide the type of fuel used?

1. Diesel [ ] 2. Petrol [ ]

21. Please estimate the amount of fuel used in the entire process of material production either in Litres or Kg---

22. If you adopted local production, kindly enumerate the raw materials extracted/sourced from the local environment? --

----

23. For each answer provided in no. 22 above, please indicate the estimated amount of the raw materials used in KG or M^3---

----

24. In case of local production, kindly state the number of days taken for the production of total walling materials for your house--

----

25. Please state the mode of transportation of the building materials used?------------------------

----

26. For each transportation mode used above, kindly provide the number of trips made in the whole process? --

----

27. Kindly estimate the average distance covered in transporting the walling materials for your house from source to the construction site (***where applicable***) --------------------------------

----

Section D: Building Technology Selection and Regulations

28. Kindly outline the type of construction technology used in your project?

1. Mortar and Brick [ ] 2. Prefabrication [ ] 3. Precast [ ]
4. Interlocking System [ ] 5. Mud and Wattle [ ]
6. Others, (Specify)--

----

29. Please provide reasons for the choice of the building technology used? ----------------------

----

30. Kindly state if you are aware of any building approval requirements?

1. Yes [ ] 2. No [ ]

31. Please state whether your building plan was submitted to the local authority / county government for approval?

1. Yes [ ] 2. No [ ] 3. No Building Plan [ ]
4. Don't Know [ ]

32. In case you submitted your building plan to the approving authorities, please state if the plan was approved?

1. Yes [ ] 2. No [ ]

33. If approved, kindly state the time taken to give approval/building permit?

----

34. If not approved, kindly state the reasons given?

Section E: Building Technology and Climate Change

The following quiz examines the relationship between buildings as forms of human settlements and climate change:

35. From history and knowledge available, kindly state the time/period when people first settled in this locality / Ward?

----

36. Before majority of people settled in this ward, do you have an idea of the state of the environment?

1. Yes [ ] 2. No [ ] 3. Don't Know [ ]

If the answer in no.36 above is Yes, proceed to the questions that follow below;

37. Please describe the state of rainfall in the area?---

----

38. Kindly Describe the intensity of rainfall? --

----

39. Please describe the state of rivers / streams? ---

----

40. Please state whether residents experienced severe water shortages? --------------------------

----

41. Kindly state the conditions of vegetation? ---

----

42. Kindly mention the types of trees which were dominant in the area? -------------------------

----

43. Please state whether such trees were associated with rainfall attraction in the area? --------

----

44. How were disease prevalence and which were the common ailments?------------------------

----

45. Kindly state the prevailing soil conditions (Cambisols, Planosols, Vertisols, Regosols, Ferrolsols or simply; sandy-loam soils, black cotton soils, red volcanic soils, clay soils etc)? -
----

46. Given the conditions of the soils, kindly state how crop yields / harvest were? -------------
----

47. Please describe the state of the food security in the area?---------------------------------------
----

48. kindly outline the dominant crops grown in the area? ---

Section F: Building Technologies and the State of Environment

The quiz that follows focuses on the state of human settlements in relation to quiz 36 above.

49. Kindy describe the state of environment at the time?---
----

50. Kindly state the type of walling materials used by residents in this locality?-----------------
----

51. Kindly outline sources of walling materials used?--
----

52. Please state methods used in sourcing and processing of the walling materials? -------------
----

53. If local extraction was applied, kindly describe the extraction methods used? ---------------
----

54. Please enumerate the energy sources used in manufacturing / production of walling materials? ---
----

55. Kindly estimate the distance covered in the transportation of materials from extraction points to the project sites? ---
----

56. Kindly describe the modes of transportation used by locals in getting the walling materials to project / construction sites?---
----

57 Please suggest ways you can utilize the local building materials and technologies without negatively affecting the environment under the following categories.

a) Extraction of raw materials for building: ---

----

b) Productions/ Processing of building materials: --

----

c) Transportation of the materials: --

----

d) Construction--

Thank for your participation

<u>FOR OFFICIAL USE ONLY:</u>

Name of Enumerator ---

Date of data collection ---

Respondent number: ---

Geospatial Location: N: ----------------------E: --------------------------H: ---------------------

Name of location--

4.B: Public Institutions Key Informant Questionnaire

Questionnaire No:-----------------------------

Project Location Coordinates: X--------

Y-------

FIELD RESEARCH QUESTIONNAIRE: **KEY INFORMANT RESPONDENTS**

ENERGY EFFICIENCY OF BUILDING TECHNOLOGIES AND CLIMATE CHANGE: A CASE STUDY OF CARBON SEQUESTRATION IN MIGORI COUNTY.

Dear Sir / Madam,

My Name is **Robert Sangori**. I am a student at the Department of Geography and Environmental Studies, the University of Nairobi. I am currently conducting a Thesis Research leading to award of PhD in the field of Environmental Planning and Management. The research targets key informants with experience in Building Materials and Construction Technologies. The key informant categories also include: policy makers, implementers, researchers and entrepreneurs to establish the dominant building technologies, their energy requirement and associated greenhouse gas emission (CO_2) requirement, as well as possible effects on carbon sequestration and climate change conditions. Your participation is of great significance to this study and as such, you are kindly requested to voluntarily participate in this important exercise by answering some few questions relating to the subject matter. The ***information provided will be confidential and strictly used for the purpose of this research only***. Please feel free to respond to the set of questions enumerated below as may be appropriate.

SECTION A: PROFILE OF RESPONDENT

1 Gender of the respondent: 1. Male [ ] 2. Female [ ]

1 Respondent Category? 1. Individual [ ] 2. Organization [ ]
3. Professional [ ]

3 Occupation / Profession of the respondent?---
----

4 Highest level of education attained ---

SECTION B: ENERGY EFFICIENCY OF BUILDING TECHNOLOGIES AND CLIMATE CHANGE

Questions in that follows relates to information sought from professionals regarding growth in the building and housing sector, building approval processes for the period 1979-2019 with focus on building designs, approval processes, the type of walling materials and enabling regulations in place. Target respondents are Officials from the Ministry of Transport, Infrastructure, Housing, Urban Development and Public Works; County Government Officials and Kenya National Bureau of Statistics (KNBS).

5. Are building permits issued for both rural and urban wards in this locality?

1. Yes [ ] 2. No [ ] 3. Don't Know [ ]

6. If answer is 2 in no.5 above, please state reasons--

----

7. If answer is 1 in no.5 above, how many building designs have been submitted and approved based on the building permits issued within the focus period in the selected wards? *Figures for total number of buildings received for approval to be represented by (R) while actual approvals to be represented by (A).*

S/No.	Ward	**Status of Building Approvals / Period**															
		1979-1984		**1984-1989**		**1989-1994**		**1994-1999**		**1999-2004**		**2004-2009**		**2009-2014**		**2014-2019**	
		R	A	R	A	R	A	R	A	R	A	R	A	R	A	R	A
1.	Nyabasi East (Kegonga)																
2.	Gokeharaka/ Getambwega																
3.	Isbania																
4.	Masaba																
5.	Central Kamagambo																

6.	North Kamagambo																
7.	Central Sakwa																
8.	West Sakwa																
9.	Central Suna																
10.	Kakrao																
11.	Ragana-Oruba																
12.	Wasweta II																
13.	Central Kanyamkago																
14.	South Kanyamkago																
15.	Muhuru																
16.	Got Kochola																

8. Based on the number of building approvals determined in no.7 above, could you specify the type of dominant walling materials prevalence in each ward per year by ticking correctly in boxes for each year in the table below?

Ward	**Category of Walling Materials**	**Walling Materials Prevalent in Each Ward / Period**							
		1979-1984	**1984-1989**	**1989-1994**	**1994-1999**	**1999-2004**	**2004-2009**	**2009-2014**	**2014-2019**
Nyabasi East (Kegonga)									
Gokeharaka/ Getambwega									

Ward	Category of Walling Materials	Walling Materials Prevalent in Each Ward / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Isbania									
Masaba									
Central Kamagambo									
North Kamagambo									
Central Sakwa									
West Sakwa									

Ward	Category of Walling Materials	Walling Materials Prevalent in Each Ward / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Central Suna									
Kakrao									
Ragana-Oruba									
Wasweta II									
Central Kanyamkago									

Ward	Category of Walling Materials	Walling Materials Prevalent in Each Ward / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
South Kanyamkago									
Muhuru									
Got Kochola									

9. Given the Dominant Walling Materials in each Ward per year as outlined in No.8 above, could you detail the Quantity of such materials in tonnes?

Ward	Category of Walling Materials	Quantity of Walling Materials Prevalent in Each Ward /Tons / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Nyabasi East (Kegonga)									
Gokeharaka/ Getambwega									

Ward	Category of Walling Materials	Quantity of Walling Materials Prevalent in Each Ward /Tons / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Isbania									
Masaba									
Central Kamagambo									
North Kamagambo									
Central Sakwa									
West Sakwa									

Ward	**Category of Walling Materials**	**Quantity of Walling Materials Prevalent in Each Ward /Tons / Period**							
		1979-1984	**1984-1989**	**1989-1994**	**1994-1999**	**1999-2004**	**2004-2009**	**2009-2014**	**2014-2019**
Central Suna									
Kakrao									
Ragana-Oruba									
Wasweta II									
Central Kanyamkago									

Ward	Category of Walling Materials	Quantity of Walling Materials Prevalent in Each Ward /Tons / Period							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
South Kanyamkago									
Muhuru									
Got Kochola									

10. Based on the answers provided in no.9 above on quantities of building / walling materials applied in walling needs in each Ward per Year, kindly estimate embodied energy of each building materials category by applying the ***Formulae for Estimating Embodied Energy as described in the methodology.***

Ward	Category of Walling Materials	Embodied Energy of Identified Walling Materials in Each Ward (MJ/Ton / Year)							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Nyabasi East (Kegonga)									

Ward	Category of Walling Materials	Embodied Energy of Identified Walling Materials in Each Ward (MJ/Ton / Year)							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Gokeharaka/ Getambwega									
Isbania									
Masaba									
Central Kamagambo									
North Kamagambo									

Ward	Category of Walling Materials	Embodied Energy of Identified Walling Materials in Each Ward (MJ/Ton / Year)							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Central Sakwa									
West Sakwa									
Central Suna									
Kakrao									
Ragana-Oruba									
Wasweta II									

Ward	Category of Walling Materials	Embodied Energy of Identified Walling Materials in Each Ward (MJ/Ton / Year)							
		1979-1984	1984-1989	1989-1994	1994-1999	1999-2004	2004-2009	2009-2014	2014-2019
Central Kanyamkago									
South Kanyamkago									
Muhuru									
Got Kochola									

11. Based on the embodied energy levels of selected building materials as highlighted in no.10 above, kindly estimate the equivalent greenhouse gas emissions (GHGe) of each building / walling materials categories by Ward per year.

Ward	**Category of Walling Materials**	**Greenhouse Gas Emission Equivalent for Each Building Material Category ($C0_{2e}$)**							
		1979-1984	**1984-1989**	**1989-1994**	**1994-1999**	**1999-2004**	**2004-2009**	**2009-2014**	**2014-2019**
Nyabasi East (Kegonga)									
Gokeharaka/ Getambwega									
Isbania									
Masaba									
Central Kamagambo									
North Kamagambo									

Ward	**Category of Walling Materials**	**Greenhouse Gas Emission Equivalent for Each Building Material Category ($C0_{2e}$)**							
		1979-1984	**1984-1989**	**1989-1994**	**1994-1999**	**1999-2004**	**2004-2009**	**2009-2014**	**2014-2019**
Central Sakwa									
West Sakwa									
Central Suna									
Kakrao									
Ragana-Oruba									
Wasweta II									

Ward	**Category of Walling Materials**	**Greenhouse Gas Emission Equivalent for Each Building Material Category ($C0_{2e}$)**							
		1979-1984	**1984-1989**	**1989-1994**	**1994-1999**	**1999-2004**	**2004-2009**	**2009-2014**	**2014-2019**
Central Kanyamkago									
South Kanyamkago									
Muhuru									
Got Kochola									

The questions that follows focuses on information that relates to energy and resource efficiency of buildings in relation to climate change debate and related policy framework. It targets all selected professionals within the building and housing sector.

12. Kenya has developed climate various policies in response to adverse climate change effects experienced in the past decade. In your opinion please rate the impact of the policy instruments provided below considering a likert scale of 1-4 where; 1 – Implies No Impact; 2-Small Impact; 3-Moderate Impact; 4-High Impact; and 5-Don't Know.

Rate the level of Potential Impact on Promoting Resource Efficiency and Climate Change Mitigation with the following Policy and Regulatory frameworks in Kenya.	**No Impact**	**Small Impact**	**Moderate Impact**	**High Impact**	**Don't Know**
1.1 National Climate Change Act (2016)	**1**	**2**	**3**	**4**	**5**
1.2 National Environment Management Authority (1999)					
1.3 National Climate Change Response Strategy (2010)					
1.5 National Climate Change Action Plan (2013)					
1.6 National Adaptation Plan for Kenya					
1.7 National Housing Policy 2004 (Rev. 2018)					
1.8 National Urban Development Policy (2016)					
1.9 National Slum Upgrading and Prevention Policy (Sessional Paper No.2 of 2016)					
1.10 National Building Maintenance Policy (Sessional Paper No.2 of 2015)					
1.11 Cities and Urban Areas Act (2011)					
National Building Regulations of 2009					
1.12 County Government Act (2012)					
National Construction Authority Act (No. 41 of 2011)					
1.13 Agenda 2030 on Sustainable Development Goals (SDGs)					
1.14 Paris Agreement (COP21), 2015					
1.15 The New Urban Agenda					
1.16 Agenda 2050 (World Business Council for Sustainable Development)					
1.17 African Agenda 2063					

13. Kindly rate the impacts of Sustainable Building Designs including integration of energy Efficiency and Appropriate Building Materials and technologies on Climate Change mitigation in a score rating of 1-4 ***where***;

1 – No Impact; 2-Small Impact; 3-Moderate Impact; 4-High Impact; and 5-Don't Know.

Rate the level of Potential Impact on Promoting Resource Efficiency and Climate Change with the following design aspects	**No Impact**	**Small Impact**	**Moderate Impact**	**High Impact**	**Don't Know**
1.1 Suitable Site Selection	1	2	3	4	5
1.2 Low Building Footprint					
1.3 Appropriate Openings in Buildings					
1.4 Utilization of Natural / Day Lighting					
1.5 Natural Ventilation					
1.6 Integration of Natural Cooling					
1.7 Heat Regulation					
1.8 Provision for Building envelope and materials					
1.9 Planning for storm water management					
1.10 Provision for sanitation					
1.11 Waste management					
1.12 Landscaping					
1.13 Application of energy efficient appliances					
1.14 Provision for energy demand management					
1.15 Utilization of Appropriate Building Materials and technologies					

14. Please provide a rating score on the following aspects of decision hierarchy for selecting sustainable walling materials.

Rate the level of Potential Impact on climate change from the following aspects of decision hierarchy for selecting sustainable materials	No Impact	Small Impact	Moderate Impact	High Impact	Don’t Know
1.1 Life Cycle Cost with focus on initial cost	1	2	3	4	5
1.2 Waste Minimization involving environmental sound disposal and 3Rs (reduce, recycle and reuse)					
1.3 Performance Capability with focus energy saving, thermal insulation and durability					
1.4 Resource Efficiency including aspects of raw materials extraction, embodied energy, amount of likely wastages and environmental impact during harvest					
1.5 Environmental Impact elements notably; environmental regulatory compliance, ozone depletion, pollution and air quality					
1.6 Social Benefit with focus on labour availability, aesthetics, utilization of local materials, health and safety.					

15 Kindly state your level of agreement with the following statement on building technologies and environmental sustainability by applying a score rating of 1-5, ***where***, 1 implies – 1 – Don’t Agree, 2- Slightly Agree, 3 – Agree, and 4- Strongly Agree, 5-Don’t Know

Rating levels of Agreement with statements of building technologies and environmental sustainability	**Don’t Agree**	**Slightly Agree**	**Agree**	**Strongly Agree**	**Don’t Know**
	1	**2**	**3**	**4**	**5**
1.1 Carbon Sequestration is the long term storage of carbon by the natural systems (water, soils, vegetation & geological strata)					
1.2 Ecosystems of soil, water and vegetation (forest cover) serve as ultimate Carbon Sequestration Medium					
1.3 A healthy ecosystem significantly contributes to climate regulation through natural systems like photosynthesis.					

Rating levels of Agreement with statements of building technologies and environmental sustainability	**Don't Agree**	**Slightly Agree**	**Agree**	**Strongly Agree**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.4 Unsustainable human/anthropogenic actions likely to compromise the resilience of many ecosystems in the cause of the 21st Century					
1.5 Building Industry is responsible for high levels of pollutions resulting from the energy consumed during raw materials extraction, processing and transportation					
1.6 specific embodied energy data is lacking for most local walling products					

16 Please rate the effectiveness of the various tools used in the assessment of building materials and technologies sustainability by applying a rating score of 1-5, where: 1-Not effective, 2- Moderate, 3 – Effective, 4 - Very Effective and 5- Don't Know

Rating the Effectiveness of Building Materials and Technologies Sustainability Assessment Tools.	**Not Effective**	**Moderate**	**Effective**	**Very Effective**	**Don't Know**
	1	2	3	4	5
1.1 Life Cycle Assessment (LCA)					
1.2 Multi-Criteria Analysis (MCA)					
1.3 Environmental Preference Method (EPM)					
1.4 Environmental Product Declaration (EPD)					
1.5 Leadership in Energy & Environmental Design (LEED)					
1.6 Building for Environmental and Economic Sustainability (BEES)					
1.7 Building Environmental Performance Assessment Criteria (BEPAC)					
1.8 British Research Establishment (BRE) Environmental Assessment Method (BREEAM)					
1.9 ATHENA™ Impact Estimator for Buildings					
1.10 Building Environment Assessment Tool (BEAT 2001)					
1.11 Green Star Rating System					
1.12 GreenMark Rating System					
1.13 EDGE Green Building Certification System					
1.14 CURB Tool					

17 Please provide some recommendations to enhance carbon sequestration levels climate change mitigation---
----

Thank for your participation

<u>FOR OFFICIAL USE ONLY:</u>

Name of Enumerator --

Date of data collection --

Respondent number: ---

Geospatial Location: N: ----------------------E: ---------------------------H: ---------------------

Name of location--

4.C: General Key Informant Questionnaire

Questionnaire No:-----------------------------

FIELD RESEARCH QUESTIONNAIRE: GENERAL KEY INFORMANT RESPONDENTS CATEGORY.
ENERGY EFFICIENCY OF BUILDING TECHNOLOGIES AND CLIMATE CHANGE: A CASE STUDY OF CARBON SEQUESTRATION IN MIGORI COUNTY.

Dear Sir / Madam,

My Name is **Robert Sangori**. I am a student at the Department of Geography and Environmental Studies, the University of Nairobi. I am currently conducting a Thesis Research leading to award of PhD in the field of Environmental Planning and Management. This field research instrument targets key informants with experience in Building Materials, Construction Technologies and Housing Development Processes in relation to sustainability selection criteria techniques/tools and climate change at national and county levels. It is specifically administered to policy makers and implementers, researchers and entrepreneurs to establish extent of uptake of built environment sustainability selection criteria techniques/tools, best practices in utilization of building materials and technology, their energy requirement and associated greenhouse gas emission (CO_2), as well as possible effects on carbon sequestration and environmental sustainability. Your participation is of great significance to this study and as such, you are kindly requested to voluntarily participate in this important exercise by answering some few questions relating to the subject matter. The ***information provided will be confidential and strictly used for the purpose of this research only***. Please feel free to respond to the set of questions enumerated below as may be appropriate.

SECTION A: PROFILE OF RESPONDENT

1 Gender of the respondent: 1. Male [ ] 2. Female [ ]

1 Respondent Category? 1. Individual [ ] 2. Organization [ ]
3. Professional [ ]

3 Occupation / Profession of the respondent?--
----

4 Highest level of education attained --

The questions that follows focuses on information that relates to energy and resource efficiency of buildings in relation to climate change debate and related policy framework.

5. Sessional Paper No. 3 of 2004 on National Housing Policy of Kenya (Revised 2018) provides for promotion of emerging / appropriate building materials and technologies towards affordable housing and environmental sustainability. Kindly state emerging / appropriate building materials and technologies which are available at the national and local levels.

i. National level--

----

ii. County Level--

----

iii. Sub-County Level---

----

iv. Ward Level--

----

6. Please state whether existing regulations adequately support the adoption of emerging / appropriate building materials and technologies at the National and County level.

1. Yes [ ] 2. No [ ] 3. Don’t Know [ ]

7. If No. kindly provide suggestions on what needs to be done--------------------------------------
----

----

8. Kenya has developed various policies in response to adverse climate change effects experienced in the past decade. In your opinion please rate the impact of the policy instruments provided below considering a likert scale of 1-4 where; 1 –No Impact; 2-Small Impact; 3-Moderate Impact; 4-High Impact and 5– Don't Know

Rate the level of Potential Impact on Promoting Resource Efficiency and Climate Change Mitigation with the following Policy and Regulatory frameworks in Kenya.	**No Impact**	**Small Impact**	**Moderate Impact**	**High Impact**	**Don't Know**
1.1 National Climate Change Act (2016)	**1**	**2**	**3**	**4**	**5**
1.2 National Environment Management Authority (1999)					
1.3 National Climate Change Response Strategy (2010)					
1.5 National Climate Change Action Plan (2013)					
1.6 National Adaptation Plan for Kenya					
1.7 National Housing Policy 2004 (Rev. 2018)					
1.8 National Urban Development Policy (2016)					
1.9 National Slum Upgrading and Prevention Policy (Sessional Paper No.2 of 2016)					
1.10 National Building Maintenance Policy (Sessional Paper No.2 of 2015)					
1.11 Cities and Urban Areas Act (2011)					
National Building Regulations of 2009					
1.12 County Government Act (2012)					
National Construction Authority Act (No. 41 of 2011)					
1.13 Agenda 2030 on Sustainable Development Goals (SDGs)					
1.14 Paris Agreement (COP21), 2015					
1.15 The New Urban Agenda					
1.16 Agenda 2050 (World Business Council for Sustainable Development)					
1.17 African Agenda 2063					

9. Kindly rate the impacts of Sustainable Building Designs including integration of energy Efficiency and Appropriate Building Materials and technologies on Climate Change mitigation in a score rating of 1-4 ***where***;

1 – No Impact; 2-Small Impact; 3-Moderate Impact; 4-High Impact; and 5-Don't Know.

Rate the level of Potential Impact on Promoting Resource Efficiency and Climate Change with the following design aspects	**No Impact**	**Small Impact**	**Moderate Impact**	**High Impact**	**Don't Know**
1.1 Suitable Site Selection	1	2	3	4	5
1.2 Low Building Footprint					
1.3 Appropriate Openings in Buildings					
1.4 Utilization of Natural / Day Lighting					
1.5 Natural Ventilation					
1.6 Integration of Natural Cooling					
1.7 Heat Regulation					
1.8 Provision for Building envelope and materials					
1.9 Planning for storm water management					
1.10 Provision for sanitation					
1.11 Waste management					
1.12 Landscaping					
1.13 Application of energy efficient appliances					
1.14 Provision for energy demand management					
1.15 Utilization of Appropriate Building Materials and technologies					

10. Please provide a rating score on the following aspects of decision hierarchy for selecting sustainable walling materials.

Rate the level of Potential Impact on climate change from the following aspects of decision hierarchy for selecting sustainable materials	No Impact	Small Impact	Moderate Impact	High Impact	Don't Know
1.1 Life Cycle Cost with focus on initial cost	1	2	3	4	5
1.2 Waste Minimization involving environmental sound disposal and 3Rs (reduce, recycle and reuse)					
1.3 Performance Capability with focus on energy saving, thermal insulation and durability					
1.4 Resource Efficiency including aspects of raw materials extraction, embodied energy, amount of likely wastages and environmental impact during harvest					
1.5 Environmental Impact elements notably; environmental regulatory compliance, ozone depletion, pollution and air quality					
1.6 Social Benefit with focus on labour availability, aesthetics, utilization of local materials, health and safety.					

11. Kindly state your level of agreement with the following statement on building technologies and environmental sustainability by applying a score rating of 1-5, ***where***, 1 implies - Don't Agree, 2- Slightly Agree, 3 – Agree, 4- Strongly Agree and 5- Don't Know

Rating levels of Agreement with statements of building technologies and environmental sustainability	**Don't Agree**	**Slightly Agree**	**Agree**	**Strongly Agree**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.1 Carbon Sequestration is the long term storage of carbon by the natural systems (water, soils, vegetation & geological strata)					
1.2 Ecosystems of soil, water and vegetation (forest cover) serve as ultimate Carbon Sequestration Medium					
1.3 A healthy ecosystem significantly contributes to climate regulation through natural systems like photosynthesis.					

Rating levels of Agreement with statements of building technologies and environmental sustainability	**Don't Agree**	**Slightly Agree**	**Agree**	**Strongly Agree**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.4 Unsustainable human/anthropogenic actions are likely to compromise the resilience of many ecosystems in the cause of the 21st Century					
1.5 Building Industry is responsible for high levels of pollutions resulting from the energy consumed during raw materials extraction, processing and transportation					
1.6 specific embodied energy data is lacking for most local walling products					

12. Please rank the uptake of the outlined building materials sustainability selection techniques / tools by adopting a ranking scale of 1-4, where, 1- Zero Uptake, 2- Low Uptake, 3 – Moderate Uptake, 4- High Uptake and 5- Don't Know

Ranking of the Uptake of Building Materials and Technology Sustainability Selection Techniques / Tools	**Zero Uptake**	**Low Uptake**	**Moderate Uptake**	**High Uptake**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.1 Life Cycle Assessment (LCA)					
1.2 Multi-Criteria Analysis (MCA)					
1.3 Environmental Preference Method (EPM)					
1.4 Environmental Product Declaration (EPD)					
1.5 Leadership in Energy & Environmental Design (LEED)					
1.6 Building for Environmental and Economic Sustainability (BEES)					
1.7 Building Environmental Performance Assessment Criteria (BEPAC)					
1.8 British Research Establishment (BRE) Environmental Assessment Method (BREEAM)					
1.9 ATHENA™ Impact Estimator for Buildings					

Ranking of the Uptake of Building Materials and Technology Sustainability Selection Techniques / Tools	**Zero Uptake**	**Low Uptake**	**Moderate Uptake**	**High Uptake**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.10 Building Environment Assessment Tool (BEAT 2001)					
1.11 Green Star Rating System					
1.12 GreenMark Rating System					
1.13 EDGE Green Building Certification System					
1.14 CURB Tool					

13. Please rate the effectiveness of the various tools used in the assessment of building materials and technologies sustainability by applying a rating score of 1-5, where, 1 – Not effective, 2- Moderate, 3 – Effective, 5- Very Effective and 5-Don't Know

Rating the Effectiveness of Building Materials and Technologies Sustainability Assessment Tools.	**Not Effective**	**Moderate**	**Effective**	**Very Effective**	**Don't Know**
	1	**2**	**3**	**4**	**5**
1.1 Life Cycle Assessment (LCA)					
1.2 Multi-Criteria Analysis (MCA)					
1.3 Environmental Preference Method (EPM)					
1.4 Environmental Product Declaration (EPD)					
1.5 Leadership in Energy & Environmental Design (LEED)					
1.6 Building for Environmental and Economic Sustainability (BEES)					
1.7 Building Environmental Performance Assessment Criteria (BEPAC)					
1.8 British Research Establishment (BRE) Environmental Assessment Method (BREEAM)					
1.9 ATHENA™ Impact Estimator for Buildings					
1.10 Building Environment Assessment Tool (BEAT 2001)					
1.11 Green Star Rating System					
1.12 GreenMark Rating System					
1.13 EDGE Green Building Certification System					
1.14 CURB Tool					

14. What action should be taken to enhance uptake of building technologies sustainability selection criteria techniques / tools by:

a) National Government --

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b) County Government ---

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c) Private Sector Institutions --

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15. Please provide some recommendations to enhance carbon sequestration levels and climate change mitigation--
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Thank for your participation

<u>FOR OFFICIAL USE ONLY:</u>

Name of Enumerator ---

Date of data collection --

Respondent number: ---